 YMP/CM-0011

U.S. DEPARTMENT OF ENERGY

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YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

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SITE CHARACTERIZATION PROGRAM BASELINE

REVISION 1

VOLUME 3 OF 5

MARCH 1991

UNITED STATES DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Document No. YMP/CM-0011
Revision 1
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Date 4/5/91
WBS No. 1.2.3
QA Level Yes

PROJECT BASELINE DOCUMENT

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROGRAM BASELINE (SCPB) VOLUME 3

CHANGES TO THIS DOCUMENT REQUIRE PREPARATION AND APPROVAL OF A CHANGE REQUEST IN ACCORDANCE WITH PROJECT AP-3.3Q

UNITED STATES DEPARTMENT OF ENERGY
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT OFFICE

Y-AD-057
9/90

YUCCA MOUNTAIN PROJECT
CHANGE DIRECTIVE (CD)

1 CR No. 91/052
Page 1 of 2

SECTION I. IDENTIFICATION

Title of Change:

Submittal of the "Site Characterization Program Baseline, Rev. 1," for CCB Control

3 Change Classification:
☐ Class 1 ☐ Class 3
☒ Class 2

SECTION II. DISPOSITION

4 CR Disposition:
☐ Approved ☐ Disapproved
☒ Approved with Conditions

5 Conditions: *(if applicable)*

The next revision of this document should incorporate the following items:

1. The term "Exploratory Shaft Facility" should be replaced by "Exploratory Studies Facility" throughout the document.

2. The term "repository" should be replaced by "potential repository" throughout the document.

(See Change Documentation Continuation Page ___)

.mplementation Direction: *(if applicable)*

1. This Change Request (CR) is approved for CCB Baselining as the "Site Characterization Program Baseline, Revision 1," and is assigned Controlled Document number YMP/CM-0011.

2. The Director, Regulatory and Site Evaluation Division is responsible for ensuring the above listed conditions are incorporated into the next revision of Document YMP/CM-0011.

(See Change Documentation Continuation Page 2)

SECTION III. CONCURRENCE

7 Quality Assurance Organization Concurrence

Name: D. G. Horton (print) Org.: PQA (print)
Signature: N Valdura for DG Horton Date: 3/28/91

8 Disposition Authority

Name: M. B. Blanchard (print) Title: CCB Chrprsn (print)
Signature: Robert H. Fortin For Maxwell Blanchard Date: 3/28/91

9 Effective Date: 3/28/91

5 Implementation Direction (continued)

3. The CCB Secretary shall ensure that the Cover Page and the Title Page for Document YMP/CM-0011, Revision 1, are prepared.

4. The Document Originator shall provide a Print Ready Copy of YMP/CM-0011, Revision 1, to the CCB Secretary. The Document Number and Revision Number will be identified on each page of the Publication Ready Document, YMP/CM-0011.

5. The CCB Secretary shall ensure that YMP/CM-0011, Revision 1, is prepared in accordance with this Change Directive (CD). The CCB Secretary shall ensure the Document Change Notice (DCN), indicating changes made in the document, is prepared. The DCN will be attached to the front of the Print Ready Copy of the document. The CCB Secretary shall also prepare a Controlled Document Issuance Authorization (CDIA) to transmit this CD, the DCN, and YMP/CM-0011, Revision 1, to the Project Document Control Center (DCC) in accordance with AP-1.5Q.

6. Per AP-3.3Q, each TPO and Project Office Division Director will complete an Affected Document Notice (ADN) as notification of completion of implementation planning for this CD.

7. The CCB Secretary shall ensure that the Configuration Information System (CIS) and the CCB Register are updated to reflect Revision 1 to YMP/CM-0011.

8. Any changes to document YMP/CM-0011, Revision 1, will require submittal of a CR to the Project CCB.

9. Upon release of YMP/CM-0011, Revision 1, all Project Participants will be required to use YMP/CM-0011, Revision 1, in performing duties applicable to this document.

Y-AD-059
9/90

YUCCA MOUNTAIN PROJECT
DOCUMENT CHANGE NOTICE (DCN) RECORD

1 Document Title:

Site Characterization Program Baseline

2 Document Number:
YMP/CM-0011

The document identified in Blocks 1 and 2 has been changed. The changed pages attached to this DCN are identified in Block 7 opposite the latest DCN number in Block 3. The original issue of this document as modified by all applicable DCN's constitutes the current version of the document identified in Blocks 1 and 2.

3 DCN NO.	4 CR NO.	5 DOCUMENT Rev./ICN #	6 CR TITLE	7 AFFECTED PAGES	CHANGE	ADD	DELETE	8 DATE
001	91/052	Rev. 1	Submit SCPB, Rev. 1 for CCB Control (complete revision of information related to ESF design)	All	X			4/5/91

Department of Energy
Yucca Mountain Site Characterization
Project Office
P. O. Box 98608
Las Vegas, NV 89193-8608

WBS 1.2.9
QA: N/A

MAR 20 1991

Distribution

RENAMING OF EXPLORATORY SHAFT EFFORT

As a consequence of the instructions from Dr. John W. Bartlett, Director of the Office of Civilian Radioactive Waste Management, on February 12, 1991, about the redirection of Yucca Mountain Site Characterization Project efforts associated with the Exploratory Shaft Facility design effort, it has become apparent that retaining the name of Exploratory Shaft would be somewhat misleading when the current design studies are focusing upon ramps, and a shaft is only being considered as a possible backup.

Therefore, after considerable discussion with many parties about selecting a new name, I have concluded that the most appropriate approach for now is to change the name of Exploratory Shaft Facility (ESF) to Exploratory Studies Facility (ESF). As you can observe, the acronym remains the same but "Shaft" becomes "Studies."

For all future communication, I request that you use this new name for this very important facility. We do not plan on modifying any completed documents or sending out errata sheets. I do request that all new communications within the U.S. Department of Energy's program now refer to this facility as the Exploratory Studies Facility. I thank you for your cooperation.

Carl P. Gertz
Project Manager

YMP:MBB-2814

YMP-5

Distribution—Memorandum dated

MAR 20 1991

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 YMP/CM-0011, Rev. 1

The numbering scheme used in this table of contents reflects that the numbering of the Site Characterization Plan has been preserved to maintain consistency among related documents. Sections 8.5 and 8.6 have been intentionally excluded.

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8.3.1.13 Overview of offsite installations and operations program: Description of the offsite installations and operations required by performance and design issues

Summary of performance and design requirements for offsite installations and operations information

This program provides the technical data required to support the resolution of the following performance and design issues:

Performance or design issue	Short title	SCP section
2.1	Radiological exposures to public--normal conditions	8.3.5.3
2.2	Worker radiological safety--normal conditions	8.3.5.4
2.3	Accidental radiological releases	8.3.5.5
2.5	Higher level finding--preclosure radiological safety	8.3.5.6
2.7	Repository design criteria for radiological safety	8.3.2.3

Approach to satisfy performance and design requirements

The data base presented in the environmental assessment (DOE, 1986b) describes the nearby offsite installations and operations that could potentially affect repository operations. Further information required to support resolution of design and performance issues related to radiological safety includes the following:

1. An evaluation of offsite accident initiators, their probabilities and potential impacts to support Issues 2.3 and 2.5.

2. An assessment of routine releases from nuclear operations to support Issues 2.1, 2.2, and 2.5.

3. An assessment of the onsite impact of nonrepository-related routine and potential accidental releases of radioactive material to support Item 1 and to support resolution of Issues 2.3 and 2.5.

4. The collection of agricultural and cultural data to support the calculation of the dose to the public from releases at the Yucca Mountain site and to support resolution of Issues 2.1 and 2.3.

Interrelationships of offsite installations and operations investigations

The first investigation developed for this program addresses the requirement to document the presence of all nearby industrial, transportation, and military installations and operations, both nuclear and nonnuclear (Investigation 8.3.1.13.1). The second investigation requires an evaluation of the potential impacts of those nearby installations and operations (Investigation 8.3.1.13.2).

The investigations identified for nearby industrial, transportation, and military installations and operations (both nuclear and nonnuclear) consist of identifying the near-site operations, nuclear fuel cycle facilities, and nuclear facilities not associated with the nuclear fuel cycle in the area. Once these operations have been identified, the impacts of those facilities will be assessed. The planned activities for assessing impacts consist of evaluating (1) near-site operations, (2) nuclear fuel cycle facilities, (3) nuclear facilities not associated with the nuclear fuel cycle, and (4) nuclear testing induced ground motion.

Certain agricultural and cultural data are necessary for assessing radionuclide dose to the public. This information will not be collected as part of this program because this type of data is not considered part of site characterization activities as defined in the Nuclear Waste Policy Act (NWPA, 1983). However, these data are an essential component of the program of calculating doses to the public through the ingestion dose pathway and will be presented as part of the environmental program planning process within the Yucca Mountain Project. Specific information on these data is addressed in the Radiological Monitoring Plan.

Schedule information for Site Program 8.3.1.13 (offsite installation) is presented in Section 8.3.1.13.3.

8.3.1.13.1 Investigation: Determination of nearby industrial, transportation, and military installations and operations (nuclear and nonnuclear)

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The preliminary data currently available are contained in Sections 3.4.1, 3.4.7, 3.5, 3.6.1, 3.6.3, 5.3, and 6.2.1.5 of the Yucca Mountain environmental assessment (DOE, 1986b). Data for this investigation will be collected according to a transportation studies plan, a preliminary site characterization radiological monitoring plan, and a radiological monitoring plan, which are currently being developed.

Parameters

The parameters for this investigation are

1. A list of all nearby DOE, industrial, transportation, and military operations.

2. The scope and frequency of the operations in Item 1.

3. Distance to all operations listed in item 1.

4. Estimates of potential radiological releases from the operations listed in item 1.

5. Meteorological parameters (from Program 8.3.1.12).

Purpose and objectives of the investigation

The data and parameters list includes those items considered important to assess impacts from nearby DOE, industrial, transportation, and military operations. These parameters will be included in performance strategies as presented in the performance and design issues and ultimately used to address preclosure radiological safety aspects of the site.

Technical rationale for the investigation

The data collected will be used to (1) estimate the probability and magnitude of exposures caused by abnormal events and (2) estimate the magnitude of any routine radiological releases from offsite nuclear operations to determine that these releases, when combined with the release from Yucca Mountain, will be within allowable limits (40 CFR 191.03(a)). This investigation consists of three activities collecting similar data types. The activities are separated because of the differences in how the data will be collected.

The following activities will identify all current DOE, industrial, transportation, and military operations and such operations projected for the future in the Yucca Mountain area. This data will be used to provide the data base for the evaluations described in Section 8.3.1.13.2.1.

8.3.1.13.1.1 Activity: Identify near-site activities

Objectives

The objective of this activity is to identify and describe all DOE, industrial, commercial, transportation, and military operations within 8 km of the Yucca Mountain site. In addition, significant operations outside this area that could impact the site will also be evaluated. This will not include offsite radioactive materials transportation since this operation will be addressed by the Division of Systems Integration and the environmental program planning efforts of the Yucca Mountain Project. For the environmental impact statement, offsite transportation will be considered in evaluating the impact of the repository facility.

Parameters

The parameters of this activity are the description of (1) all industrial operations, (2) flight operations, (3) commercial operations, and (4) DOE operations within 8 km of the Yucca Mountain site. A radius of 8 km was chosen because of the high concentration of activities within this area. The Nevada Test Site (NTS) operations will be addressed separately under Activity 8.3.1.13.1.3.

Description

A review of military flight operations in the area is being conducted and will be documented. A list of all existing and projected commercial operations in the area will be compiled. This will include a review of all public domain land use permits in the area for mining and other operations. In addition, the DOE management will be contacted to determine NTS operations near the site. Windshield survey observations from a motor vehicle of the local area will be conducted to complete the compilation of this list. In addition, information obtained from state agencies and other sources will be used to project future operations and determine if any of those operations could have an adverse impact on repository site operations. Activity 8.3.1.13.2.1 contains further details on the evaluation of near-site activities.

8.3.1.13.1.2 Activity: Characterize nuclear fuel cycle facilities in the area

Objectives

The objective of this activity is to identify all nuclear fuel cycle facilities within 80 km of the Yucca Mountain site or within Nevada areas adjacent to Las Vegas.

Parameters

The parameters for this activity are

1. A list of all nuclear fuel cycle facilities within the specified area.

2. The data base to predict magnitudes of projected normal and accidental releases of radioactivity.

Description

The regional NRC office and the State organizations with similar responsibilities will be contacted to identify any nuclear fuel cycle facilities. The routine yearly release of radioactive material from all such facilities will be available because these values are required for routine reports to the NRC and State agencies. Also, potential accidental releases from the facilities will be obtained from safety evaluations of those facilities. The

radiological environmental data from Yucca Mountain will be used to identify sources of the material in addition to amounts of past releases, consistent with the limitations imposed by the need to maintain national security measures.

8.3.1.13.1.3 Activity: Characterize all nuclear facilities not associated with the nuclear fuel cycle near the Yucca Mountain site

Objectives

The objective of this activity is to characterize the impacts of all radiological operations at facilities within 80 km of the Yucca Mountain site that are not part of the nuclear fuel cycle. The basis for using an 80 km radius for this activity is documented in Section 4.3.2 of the radiological monitoring plan. Because of the potential for classified information being associated with the identification of NTS operations, radionuclide concentrations in the existing environment of the Yucca Mountain area will be assumed to bound the cumulative effects of past radiological operations in the area. Attempts will be made to make corrections for global fallout and natural sources.

Parameters

For the existing environment at Yucca Mountain, radionuclide concentration and radiation levels will be assessed in (but not limited to)

1. Air (particulate form), concentration.
2. Air (gaseous form).
3. Ambient exposure rate.
4. Soil.
5. Surface water.
6. Sediments.
7. Biota.

In addition, the NTS environmental monitoring reports (produced yearly by various organizations) and any other available data will be reviewed to assess the impacts of past releases at the Yucca Mountain site and in the City of Las Vegas.

Description

All data collection will be conducted in a manner consistent with applicable regulatory guides, DOE guidance documents, and industry practices. Specific examples can be found in the Preliminary Site Characterization Radiological Monitoring Plan (SAIC, 1986b), which addresses data collection before the initiation of significant site characterization activities. The requirements for this activity are the radiological environmental monitoring and sampling equipment and services procured consistent with the studies identified. The equipment and services required include

1. Air sampling equipment.
2. Soil and water sampling equipment.
3. Ambient radiation monitoring equipment and services.
4. Laboratory analysis of air, soil, and water samples.

The radiological environmental data from Yucca Mountain will be used to identify sources of the material in addition to amounts of past releases, consistent with the limitations imposed by the need to maintain appropriate national security measures.

8.3.1.13.2 Investigation: Potential impacts of nearby installations and operations

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The preliminary data used in this activity are in Sections 3.4.1, 3.4.7, 3.5, 3.6.1, 3.6.3, 5.3, and 6.2.1.5 of the Yucca Mountain environmental assessment (DOE,1986b). Information not currently available will be collected by the activities for Investigation 8.3.1.13.1. This investigation is addressed by activities described in the Yucca Mountain Project transportation studies efforts, the Preliminary Site Characterization Radiological Monitoring Plan (SAIC, 1986b), and by the Project Radiological Monitoring Plan (DOE, 1987c).

Parameters

The parameters for this investigation are as follows:

1. A list of all accidents initiated by offsite operations that must be considered in the repository safety analyses.

2. An assessment of the potential impacts of those events on the basis of data from Investigation 8.3.1.13.1.

3. Estimates of potential exposures of the public to radiation and radioactive material from all nuclear fuel cycle activities in the area.

4. Projected radioactive airborne concentrations for existing and projected conditions at the site.

5. Other factors contributing to onsite occupational or offsite exposure.

Purpose and objectives of investigation

The information collected from Investigation 8.3.1.13.1 will be used to conduct impact assessments as a result of accidents involving any nearby installations and operations. Those accidents include radiological and nonradiological events that may have an impact on site operations. The

information collected will also be used to assess compliance with 40 CFR 191.03 and to resolve Issue 2.5 (Section 8.3.5.6) for routine releases, which addresses compliance with 40 CFR 191.03, 10 CFR Part 20, and 10 CFR Part 60. The results of these assessments will provide data and analyses for use in determining the preclosure radiological safety aspects of the site as outlined in the performance and designs issues of Key Issue 2 (preclosure radiological safety).

Technical rationale for investigation

The data on potential offsite accident initiators will be used to determine if further performance analyses (Issue 2.3, Section 8.3.5.5) are required. If so, the accident data will be used to assess preclosure system performance relative to the regulations cited in Key Issue 2.

The exposure from other nuclear fuel cycle operations covered by 40 CFR Part 190 are required to assess compliance with 40 CFR 191.03(a). The limits specified are the total for all nuclear fuel cycle operations.

The surrounding facilities will be evaluated to determine the effects they could have on potential repository operations and to determine the ability of the repository to complete its mission while in compliance with the regulations cited in Key Issue 2. The surrounding facilities could, under rare circumstances, force evacuation of the facility or limit the ability of the facility to detect and thus respond to abnormal events. This type of circumstance can thus act as an accident initiator (Issue 2.3, Section 8.3.5.5). In addition, any radiation exposure received by workers while at the site, independent of its sources, affects the ability of the facility to comply with applicable radiation standards for occupational exposure (Issue 2.2, Section 8.3.5.4).

The following activities will evaluate all operations identified in Investigation 8.3.1.13.1 and assess their impact on compliance with Key Issue 2. These data will be used to provide the data base for evaluation of operations that could have an impact on Yucca Mountain repository operations and to support the resolution of Issues 2.1, 2.2, 2.3, and 2.5.

8.3.1.13.2.1 Activity: Evaluate near-site activities

Objectives

The objective of this activity is to review all commercial, DOE, DOD, and transportation operations within 8km of the site; identify those operations that could act as accident initiators; and quantify their probability and magnitude. This activity will reduce the list of activities gathered in Activity 8.3.1.13.1.1 to those that could act as accident initiators, thus generating accident scenarios for analysis in the resolution of Issues 2.3 and 2.5.

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Parameters

The parameters for this activity are

1. A list of all operations within 8 km of the Yucca Mountain site.

2. A description of the operations that have the potential to act as accident initiators for the site.

3. The probability and magnitude of events with potential to initiate accidents.

Description

Flight operations in the area are being reviewed and will be documented in a report to be issued. The list of all existing and projected operations in the area collected for Investigation 8.3.1.13.1 will be reviewed by experts to determine if any operations may adversely impact site activities. The primary considerations will include the following:

1. Could this operation lead to a breach of the confinement barriers of the waste handling facilities at Yucca Mountain?

2. Could this operation require evacuation of the Yucca Mountain site or endanger site employees?

3. Could this operation cause the loss of offsite services (electrical, telephone, transportation access, etc.)?

4. Could this operation cause a disruption of the flow of waste into the site?

Any such operation will be investigated and the probability and magnitude estimated on the basis of actual technical data on flight operations and the information from Activity 8.3.1.13.1.1. This data will then be used to support the analyses associated with Issues 2.3 and 2.5 and will be documented in a report on offsite impacts.

8.3.1.13.2.2 Activity: Evaluation of the impact of nuclear fuel cycle operations near the Yucca Mountain site and Las Vegas

Objectives

The objective of this activity is to project the impact of all nuclear fuel cycle operations within 80 km of the Yucca Mountain site.

Parameters

The parameters of this activity are

1. A list of all nuclear fuel cycle operations within the specified area and the magnitude of their routine and projected accident releases estimated from Investigation 8.3.1.13.1.

2. Estimates of probabilities and magnitudes of any projected releases.

Description

All nuclear fuel cycle operations within 80 km of the site will be reviewed. The routine yearly releases of radioactive material from all such facilities will be determined from safety documentation. In addition, the probability and magnitude of potential accidents at the facilities will be determined based on past technical reports and safety analyses documentation. The primary considerations will be to

1. Assess the magnitude of the routine releases of radioactive material from these facilities to determine their contribution to the nuclear fuel cycle facilities release limits (Issues 2.1 and 2.2 discussed in Section 8.3.5) specified in 40 CFR 191.03(a), if any.

2. Provide the basis for determining if the radioactive releases by these nuclear fuel cycle operations could obscure the detection of routine and accidental releases from a Yucca Mountain facility (Issues 2.1, 2.2, and 2.3).

3. Provide the basis for determining if the operation could require evacuation of the Yucca Mountain site (Issue 2.3) or expose workers to significant levels of radiation (Issues 2.2 and 2.3), which may endanger the workers or impact compliance with the exposure limits in 10 CFR Part 20.

All models and computer programs used in these evaluations will be consistent with those used in resolving Issues 2.1, 2.2, and 2.3.

8.3.1.13.2.3 Activity: Evaluate the impact of all nuclear facilities not associated with the nuclear fuel cycle near the Yucca Mountain site

Objectives

The objective of this activity is to use the data from Activity 8.3.1.13.1.3 to project airborne concentrations. The probability of such concentrations resulting from operations within 80 km of the Yucca Mountain site will then be estimated and used to predict the potential for exposure of individuals in Las Vegas, Nevada.

The primary considerations in evaluating the results for this operation will be the same as items 2 and 3 under the objective for Activity 8.3.1.13.2.2.

Parameters

The parameters of this activity include the projected airborne radionuclide concentrations and the probabilities of such concentrations for the operations impacting the site.

Description

The routine yearly releases of radioactive material from all such facilities and the existing concentrations at the Yucca Mountain site will be determined. The probability and magnitude of potential accidents will be determined, including the probability and magnitude of release near the Yucca Mountain site. The cumulative effects of past radiological operations in the area will be used to estimate the impacts and probabilities of such operations in the future.

This activity will include (1) the evaluation of resuspension of radionuclides from past operations at the Nevada Test Site (NTS) and the subsequent deposition at the site and (2) the extrapolation of NTS environmental data to Yucca Mountain using standard modeling techniques. All models and computer programs used in these evaluations will be consistent with those used in the resolution of Issues 2.1, 2.2, and 2.3.

8.3.1.13.2.4 Activity: Evaluate the impact of ground motion from nuclear testing activities at the Nevada Test Site

This activity is addressed in the resolution of Investigation 8.3.1.17.3.

8.3.1.14 Overview of the surface characteristics program: Description of the surface characteristics required by the performance and design issues

Summary of performance and design requirements for surface characteristics information

The surface characteristics program reflects requirements from the DOE, the NRC, and the EPA that the surface facilities, including openings to the underground, must ensure public health and safety, are technically feasible, and have reasonable costs. This program investigates two areas pertinent to preclosure design and performance issues:

1. Topography (Investigation 8.3.1.14.1).
2. Soil and rock conditions (Investigation 8.3.1.14.2).

A logic diagram showing what design and performance issues and what characterization programs require surface characteristics information is presented in Figure 8.3.1.14-1. A more detailed interlinking of design and performance issue parameters with characterization program parameters is presented in Table 8.3.1.14-1. Table 8.3.1.14-1 is organized around column 4, characterization parameters, as the "key" column. The parameter listed in this column "feeds" characterization data to the design and performance parameters listed in column 3. Conversely, the resolution of the performance or design issues and their corresponding parameters listed in column 3 requires data input from the characterization parameter specified in column 4. To reduce duplication in Table 8.3.1.14-1, each characterization parameter is only presented once, in column 4. For each characterization parameter presented in column 4, there can be one or more performance or design parameters, listed in column 3, that require this characterization parameter data. Column 2 indicates which sections in the SCP require the performance or design parameters presented in column 3, and column 1 identifies which issues and programs initiate a need for the performance or design parameters listed in column 3.

The design- and performance-issue parameters in Table 8.3.1.14-1 are determined by the site surface system element (1.1.1) requirements described in Section 8.3.2 (Table 8.3.2.5-1). These design and performance parameters determine what characterization parameters will be needed. The characterization parameters with their expected ranges, confidence levels, and required activities are also presented in Table 8.3.1.14-1.

The issues and site programs related to the surface characteristics program, along with their SCP section number, are as follows (the relationships are discussed in the paragraphs following the list):

Issue or program	Short title
1.8	NRC siting criteria (Section 8.3.5.17)
1.9	Higher level findings--postclosure (Section 8.3.5.18)

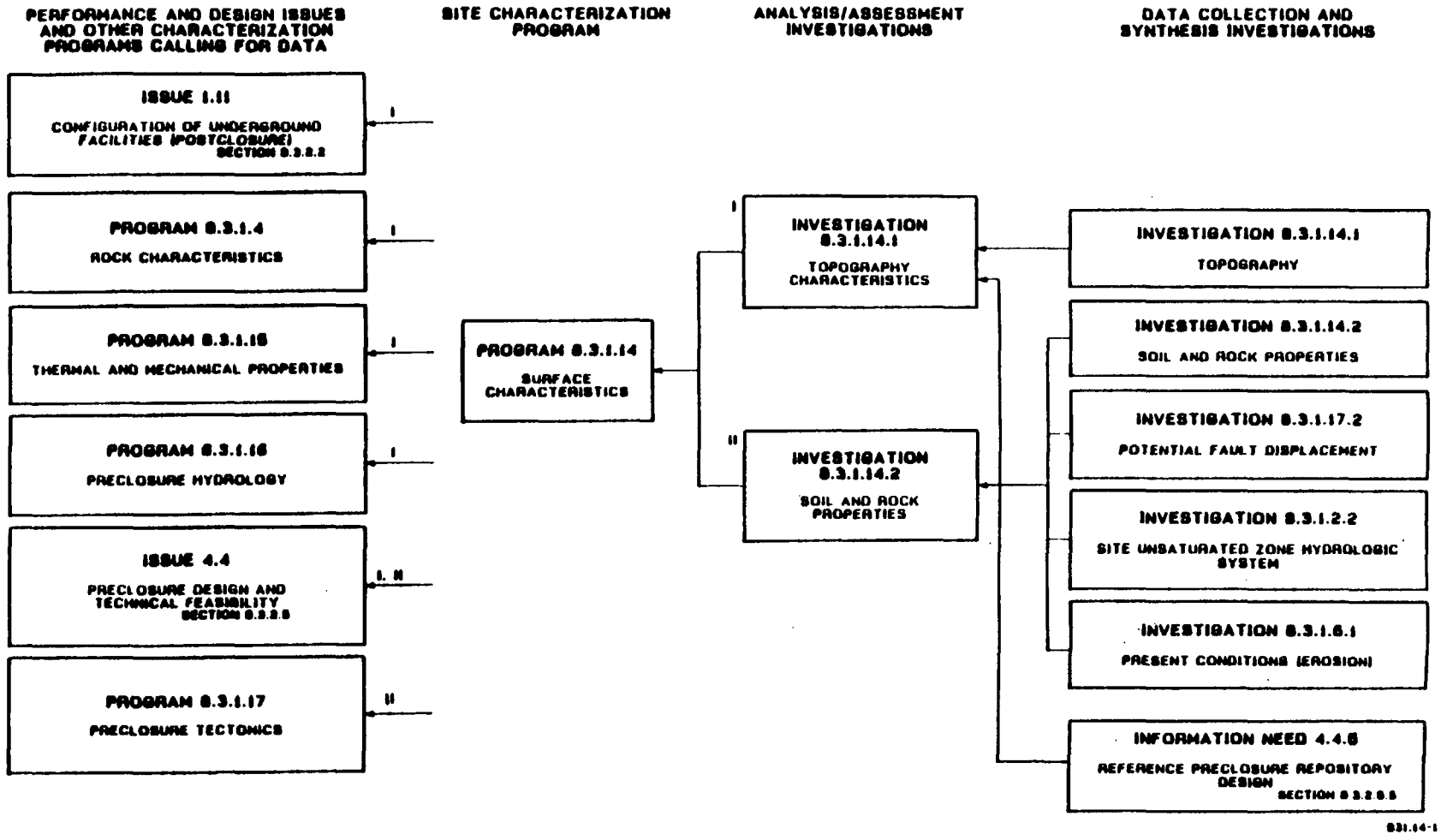

Figure 8.3.1.14-1. Logic diagram for Program 8.3.1.14, surface characteristics. Roman numerals indicate data flow.

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 1 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			GEOMETRICAL PARAMETERS				
1.11 4.4 8.3.1.4 8.3.1.15 8.3.1.16	8.3.2.2.1 8.3.2.2.3 8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.4.3 8.3.1.15.3 8.3.1.16.1	Surface topography at facility locations (1-m contour interval)	Surface topography at facility locations (1-m contour interval)	20-ft contour interval topographic map (see Figure 4-3 of the SCP-CDR (SNL, 1987))	Medium	Medium	No further studies are planned. Topographical measurements have been made and topographic maps are forthcoming.
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Allowable foundation bearing capacity in soil Allowable foundation bearing capacity in rock Active and passive soil pressures on a wall Active and passive rock pressures on a wall Factor of safety of slope (soil) Factor of safety of slope (rock)					
4.4 8.3.1.16	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.16.1	Surface topography of access routes (2-m contour intervals)	Surface topography of access routes (2-m contour intervals)	20-ft contour interval topographic map (see Figures 4-2 and 4-3 of the SCP-CDR (SNL, 1987))	Medium	Medium	No further studies are planned. Topographical measurements have been made and topographic maps are forthcoming.

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 2 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			GEOMETRICAL PARAMETERS (continued)				
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Factor of safety of slope (soil)					
		Factor of safety of slope (rock)					
			SOIL PARAMETERS				
		Allowable foundation bearing capacity in soil	Alluvial stratigraphy Layering Thickness Geometry	General stratigraphic description. Top 0.3 to 0.7 m is loose fine-grained sandy soil overlying approximately 2 m of material that is partly to wholly cemented with calcite (caliche). Below the caliche layer is an 10 to 50 m thick layer of dense sandy gravel alluvial material which overlies the ashflow tuff bedrock (Section 6.1.2.1.2)	Low	Medium	8.3.1.14.2.1.1, 8.3.1.14.2.1.2, 8.3.1.14.2.1.3, 8.3.1.14.3.3
		Active and passive soil pressure on a wall					
		Factor of safety of slope (soil)					
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Soil-structure interaction for foundation[e]					
8.3.1.17	8.3.1.17.3	Soil-structure interaction for retaining wall[e]					
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Magnitude of time dependent settlement in soils below earthfills[d]					
		Magnitude of swell in subgrade soils[d]					
		Magnitude of soil collapse[d]					
		Soil liquefaction potential[d]					
		Identification of any fault within 100 m of facilities important to safety (FITS) with greater than 1 chance in 100 of producing more tha 5 cm of surface displacement in 100 yr	Alluvial faulting (the study for this characterization parameter is developed in Section 8.3.1.17.4.2 (preclosure tectonics) location orientation	See Section 8.3.1.17.4.2 in preclosure tectonics	Low	High	See Study 8.3.1.17.4.2, (location and recency of faulting near prospective surface facilities)

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 3 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			SOIL PARAMETERS (continued)				
		Allowable foundation bearing capacity in soil	Soil classification vs. depth				
			Soil gradation	GP-GM[c]	Low	Medium	8.3.1.14.2.2.1
		Active and passive soil pressure on a wall	Atterberg limits[d]	From preliminary investigations, no cohesive soils have been found	Low	Medium	
		Factor of safety of slope (soil)					
		Soil-structure interaction for foundation[b]					
		Soil-structure interaction for retaining wall[b]					
		Magnitude of time dependent settlement in soils below earthfills[d]					
		Magnitude of swell in subgrade soils[d]					
		Magnitude of soil collapse[d]					
		Soil liquefaction potential[d]					
		Allowable foundation bearing in soil	Physical properties vs. capacity depth				8.3.1.14.2.2.1, 8.3.1.14.2.3.1
			In situ density	101-112 pcf	Low	Medium	
		Active and passive soil pressure on a wall	Relative density	Not available	Low	Medium	
			Moisture content	7.2%	Low	Medium	
		Factor of safety of slope (soil)	Percent saturation	47.3%	Low	Medium	
			Specific gravity	2.43	Low	Medium	
		Soil-structure interaction for foundation[a]					
		Soil-structure interaction for retaining wall[a]					
		Magnitude of time dependent settlement in soils below earthfills[d]					

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 4 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			SOIL PARAMETERS (continued)				
		Magnitude of swell in subgrade soils[d]					
		Magnitude of soil collapse[d]					
		Soil liquefaction potential[d]					
		Allowable foundation bearing capacity in soil	Compaction characteristics				
		Active and passive soil pressure on a wall	Compaction curves for potential fill material including maximum dry density (γ_d) and optimum water content	γ_d (max) = 108-114 pcf Optimum water content = 12-15%	Low Low	Medium Medium	8.3.1.14.2.2.1
		Magnitude of soil collapse[d]					
			Mechanical and dynamic properties vs. depth for undisturbed and recompacted soils				
4.4 8.3.1.17	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.17.3	Allowable foundation bearing capacity in soil Soil structure interaction for foundation[e]	Young's modulus (static and dynamic)	10,000-20,000 psi (static) (Ho et al., (1986) 192,000 psi (dynamic calculated from Vp)	Low	Medium	8.3.1.14.2.2.2, 8.3.1.14.3.2, 8.3.1.14.2.3.3
		Soil structure interaction for retaining wall[e] Soil liquefaction potential[d]	Poisson's ratio (static and dynamic)	0.3-0.35 (static) (Ho et al., 1986) 0.286 (dynamic) (Neal, 1986)	Low	Medium	8.3.1.14.2.2.2, 8.3.1.14.2.3.3

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 5 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			SOIL PARAMETERS (continued)				
		Soil structure interaction for foundation[e] Soil-structure interaction for retaining wall[e] Soil liquefaction potential[d]	Compressive wave velocity (Vp) and shear wave velocity (Vs) (these parameters will be used to calculate the dynamic elastic characterization parameters: Young's modulus, shear modulus, and Poisson's ratio).	Vp = 3,300 ft/sec (Neal, 1986) Vs = 1,800 ft/sec (Neal, 1986)	Medium	High	8.3.1.14.2.3.3
			Shear modulus (static and dynamic)	3,700-7,700 psi (static-calculated) 74,100 psi (dynamic-calculated from Vs)	Low	Medium	8.3.1.14.2.3.3
			Damping	Not available	Low	Medium	8.3.1.14.2.3.3
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Allowable foundation bearing capacity in soil Active and passive soil pressure on a wall Factor of safety of slope (soil) Soil-structure interaction for foundation[e] Soil-structure interaction for retaining wall[e]	Mohr-Coulomb strength parameters in terms of cohesion (c) and angle of friction (ϕ)	c = 500 psf (cemented) ϕ = 33 to 37°	Low	High	8.3.1.14.2.2.2
		Allowable foundation bearing capacity in soil	Plate load bearing pressure vs. settlement	Not available	Low	Medium	

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 6 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			CONTINGENT SOIL PARAMETERS				
			The following characterization parameters are contingent parameters (see footnote d)				
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Soil-structure interaction for foundation[c]	Other strength parameters such as Drucker-Prager, etc. (if required)[d]	Not available	Low	Medium	8.3.1.14.2.2.2
8.3.1.17	8.3.1.17.3	Soil-structure interaction	Bulk modulus and constrained modulus[d]	Not available	Low	Medium	8.3.1.14.2.2.2
		Soil liquefaction potential[d]	Strength and stress-deformation characteristics under dynamic load conditions evaluated as a function of stress rate, confinement stress, initial static stress level, magnitude of pulsating stress, number of stress cycles, and frequency of loading[d]	Not available	Low	Medium	8.3.1.14.2.2.2
			Dynamic shear modulus as a function of strain and confinement stress[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Damping as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Shear wave velocities as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Deformation modulus in terms of stress-strain characteristics and confinement stress conditions[d]	Not available	Low	High	8.3.1.14.2.2.2

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 7 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			CONTINGENT SOIL PARAMETERS (continued)				
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Soil liquefaction potential[d]	Liquefaction parameters: cyclic shearing stress ratio, cyclic deformation, and pore-pressure response (this information will not be needed if there are no perched water bodies near the ground surface)[d]	Not available	Low	Medium	8.3.1.14.2.2.2
		Allowable foundation bearing capacity in soil Soil-structure interaction for foundation[e] Soil-structure interaction for retaining wall[e]	Modulus of subgrade reaction from plate load test (static and dynamic)[d]	200-300 pci	Low	Medium	8.3.1.14.2.3.2
		Allowable foundation bearing capacity in soil Magnitude and rate of time dependent settlement below earthfills[d]	Compression and swell index (for saturated clayey soils if they are encountered)	Not available	Low	Medium	8.3.1.14.2.2.2
		Magnitude of swell in subgrade soils below roads[d]	Coefficient of consolidation (for saturated clayey soils if they are encountered)[d]	Not available	Low	Medium	8.3.1.14.2.2.2
		Allowable foundation bearing capacity in soil Magnitude of soil collapse below surface facilities (foundations, earthfills, and roads) due to saturation and/or loading[d]	Collapse potential (for relative dry low density soils)[d]	Not available	Low	Medium	8.3.1.14.2.2.2

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 8 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			OTHER SOIL PARAMETERS				
		Favorable hydraulic induced soil erosion characteristics	Erosion potential	<13 m/100 yr of scour around bridge piers <5 m/100 yr of bed erosion <1 m/100 yr of sheet erosion	Low	Medium	8.3.1.6.1.1.2, 8.3.1.6.1.1.3
		Favorable infiltration/runoff ratio	Infiltration/runoff ratio	See Section 8.3.1.12 (meteorology) and 8.3.1.2 (geohydrology)	Low	Medium to high	See Section 8.3.1.12 (meteorology) and 8.3.1.2 (geohydrology)
			ROCK PARAMETERS				
4.4 8.3.1.17	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.17.3	Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Factor of safety of slope (rock) Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Rock stratigraphy Rock type Layering Thickness Geometry	See Figure 6-6 in the SCP and Figures 5 and 7 in Neal (1986)	Low	Medium	8.3.1.14.2.1.1, 8.3.1.14.2.1.2, 8.3.1.14.2.1.3, 8.3.1.14.2.3.3
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Factor of safety of slope (rock)	Rock structure Quantitative description of faults Location Orientation Aperture Type of infilling Moisture and/or seepage conditions Waviness and roughness	Not available	Low	High	8.3.1.14.2.1.2, 8.3.1.14.2.1.3, 8.3.1.14.2.3.1

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 9 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			ROCK PARAMETERS (continued)				
			Quantitative description of joints Number of joint sets Spacing of joints for each set Orientation of each joint set Type of infilling if any Moisture and/or seepage conditions Waviness and roughness Persistence Drill core (total core recovery, discontinuity, frequency, and rock quality designation (RQD))	Not available			
		Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Rock-structure interaction for foundation[e] Rock-structure interaction for retaining wall[e]	Rock mass classification Rock mass rating (RMR)[f] Tunneling quality index (Q)[f]	Not available	Low	Medium	8.3.1.14.2.3.1
		Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Factor of safety of slope (rock) Rock-structure interaction for foundation[e] Rock-structure interaction for retaining wall[e]	Physical properties vs. depth Density (dry)	2.23 gm/cc or 139 lb/ft^3	Low	Medium	8.3.1.14.2.2.1
			Percent saturation	67% < 23%	Low	Medium	
			Porosity	11% < 4%	Low	Medium	
			Specific gravity	2.51 < 0.04	Low	Medium	
			Mechanical and dynamic properties				

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 10 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			ROCK PARAMETERS (continued)				
		Allowable foundation bearing capacity in rock Rock-structure interaction for foundation[e]	Plate load bearing pressure vs. settlement	Not available	Low	Medium	8.3.1.14.2.3.2
		Magnitude of soil collapse below surface facilities[d]					
		Allowable foundation bearing capacity in rock Factor of safety of slope (rock) Rock-structure interaction for foundation[e] Rock-structure interaction for retaining wall[e]	Peak and residual failure envelopes derived from uniaxial and triaxial compression tests	c (peak) = 26.0 ±10.13 MPa (range) ϕ (peak) = 44.7° ±0.20° (range) Tensile strength = 9.3 MPa Unconfined compressive strength = 120 ± 82 MPa (range)	Low	High	8.3.1.14.2.2.2
		Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Factor of safety of slope (rock)	Discontinuity shear strength in terms of c and ϕ	c = 0.1 MPa < 0.1 (range) ϕ = 28.4 (range: 11.3° - 38.7°	Medium	High	8.3.1.14.2.2.2
4.4 8.3.1.17	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.17.3	Allowable foundation bearing capacity in rock Rock-structure interaction for foundation[e] Rock-structure interaction for retaining wall[e]	Young's modulus (static and dynamic	20.0 GPa ± 5.55 (range) - static rock mass (SCP, Chapter 6) 2.94 GPa (calculated from in situ Vp)	Low	Medium	8.3.1.14.2.2.2, 8.3.1.14.2.3.2, 8.3.1.14.2.3.3
			Poisson's ratio	0.24 (laboratory-static) (SCP, Chapter 6) 0.319 (in situ calculated from Vp and Vs) (Neal, 1986)	Low	Medium	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
		Rock-structure interaction for foundation[e] Rock-structure interaction for retaining wall[e]	Shear modulus (static and dynamic)	8.1 GPa ± 2.2 (range) - static rock mass 1.1 GPa (calculated from in situ Vs)	Low	Medium	8.3.1.14.2.2.2, 8.3.1.14.2.3.3

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 11 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			ROCK PARAMETERS (continued)				
		Rock-structure interaction for foundation[e] Rock-structure interaction for retaining wall[e]	Compressive wave velocities vs. depth	Vp = 7,500 - 9,000 ft/sec (laboratory) (Neal, 1986)	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
				Vp = 4,500 ft/sec (in situ) (Neal, 1986)	Low	High	
			Shear wave velocities vs. depth (the compressive and shear wave velocities will be used to calculate the dynamic elastic characterization parameters: Young's modulus, shear modulus, and Poisson's ratio)	Vs = 4,390 - 5,790 ft/sec (laboratory-calculated)	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
				Vs = 2,320 ft/sec (in situ-calculated)	Low	High	
			Damping vs. depth	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			CONTINGENT ROCK PARAMETERS				
			The following characterization parameters are contingent parameters (see footnote(d))				
		Rock-structure interaction for foundation[e] Rock-structure interaction for retaining wall[e]	Shear wave velocities as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Dynamic shear modulus as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Damping as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3

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Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 12 of 12)

Footnotes

[a]This table is organized around column 4, characterization parameters, as the "key" column. The parameter listed in this column "feeds" characterization data to the design and performance parameters listed in column 3, performance or design parameters. Conversely, the resolution of the performance or design issues listed in column 3 requires data input from the characterization parameter specified in column 4 (key column).

[b]See Table 8.3.2.5-1 for complete description of performance and design parameter.

[c]If the alluvium or rock adjacent to the foundation has shear velocities greater than 3,500 ft/sec, then a soil structure interaction analysis will probably not be necessary.

[d]The need for these design and performance parameters or characterization parameters are contingent on the soil and rock conditions encountered, function or design requirements of the surface facilities, types of foundations selected, and the sophistication or type of analyses used in the design or performance studies. However, based on the sites preliminary surface soil and rock data and the type of foundations which are recommended in the SCP-CDR (SNL, 1987), the paramters are currently not needed.

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

[f]RMR = rock mass rating from CSIR (South African Council for Scientific and Industrial Research) Geomechanics Classification; Q = NGI (Norwegian Geotechnical Institute) tunneling quality index.

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Issue or program	Short title
1.11	Configuration of underground facilities--postclosure (Section 8.3.4.2)
4.4	Preclosure design and technical feasibility (Section 8.3.2.5)
8.3.1.4	Rock characteristics
8.3.1.12	Meteorology program
8.3.1.15	Thermal and mechanical properties program
8.3.1.16	Preclosure hydrology
8.3.1.17	Preclosure tectonics

Surface characteristic information such as topographic contours will be required for locating and designing repository surface facilities (Issue 4.4), establishing repository costs, and determining probable flood levels at potential surface facility locations (Section 8.3.1.16). Topographic contour maps are necessary for locating shaft and ramp entrances above potential flood levels and for locating sensitive structures such as waste handling facilities.

Surface topographic characteristics will also be required for certain underground design and performance studies. Topographic contour maps will be used to determine the usable repository horizon area while maintaining the required amount of overburden (Issues 1.8 and 1.9). The topographic data from Investigation 8.3.1.14.1 will actually be provided to Issue 1.11 to determine if the repository has an adequate amount of overburden to resolve Issues 1.8 and 1.9. Also, in situ stresses will be influenced, in part, by local topography (Sections 8.3.1.4 and 8.3.1.15).

The surface characteristics of the alluvial soil and rock at or near the surface impact the location and design of the surface facilities (Issue 4.4) and their costs. This is especially applicable to sensitive structures, such as the waste-handling facilities, which may experience earthquake loading (Section 8.3.1.17). The soil and rock conditions of the site for static-loading conditions will influence the selection of the surface facility location in addition to its foundation design.

The performance issue under Key Issue 4 specifies that the higher level findings required by 10 CFR Part 960 be supported for (1) the qualifying condition on the preclosure system guideline for ease and cost of construction on the basis of reasonably available technology and (2) the qualifying condition on the technical guideline for surface characteristics. Section 8.3.5.7 (Issue 4.1) discusses the higher level findings.

Approach to satisfy performance and design requirements

Surface-characterization information must be obtained and evaluated to determine whether it will support the preclosure higher level findings for preclosure radiological safety and the ease and cost of siting, construction, operation, and closure of the repository. The approach to determining whether the information about surface characteristics and conditions is adequate to resolve the performance and design issues is an iterative process. Close collaboration between engineering and geotechnical participants is needed to allow timely development of the repository design.

The major elements defining the surface characteristics include topography and soil and bedrock properties. Site surface characteristics data will be used to design surface structures and their foundations for buildings, shaft and ramp portals, roads, drainage systems, and flood control structures. These designs will also consider dynamic loading conditions caused by earthquakes and man-induced explosions.

The information required for any of the surface characteristics investigations will be initiated by the site surface system element 1.1.1 (site surface) requirements described in Section 8.3.2.5. To satisfy these requirements, the appropriate design and performance parameters must be obtained. A listing of these design and performance parameters and their corresponding characterization program parameters was previously presented in Table 8.3.1.14-1. To determine these characterization program parameters, studies and activities have been developed to provide the appropriate data. A list of characterization parameters and their corresponding studies and activities is also presented in Table 8.3.1.14-1.

A summary of the information required for the soil and rock property investigation (8.3.1.14.2) is provided in the logic diagram in Figure 8.3.1.14-2. This figure illustrates the information required by the soil and rock investigation and what studies and activities are needed to provide this information. A similar logic diagram was not developed for the other investigation in Program 8.3.1.14. The topography investigation (8.3.1.14.1) needs no further data acquisition activities since adequate contour maps have already been developed.

The site requirements discussed for this program and its associated investigations will be in conformance with applicable local, State of Nevada, and Federal codes and standards referring to natural hazard and foundation stability, such as those requirements specified in DOE Order 6430.1 (DOE, 1983a).

Interrelationships of surface characteristics investigations

There are no interrelationships between the investigations within the surface characteristics program. The investigations within this program only have interrelationships with issues and programs outside this program. The connections between the surface characteristics program and the performance and design issues or other characterization programs calling for data from this program have already been presented in Figure 8.3.1.14-1. This same figure also shows what investigations or information needs supply data to this program.

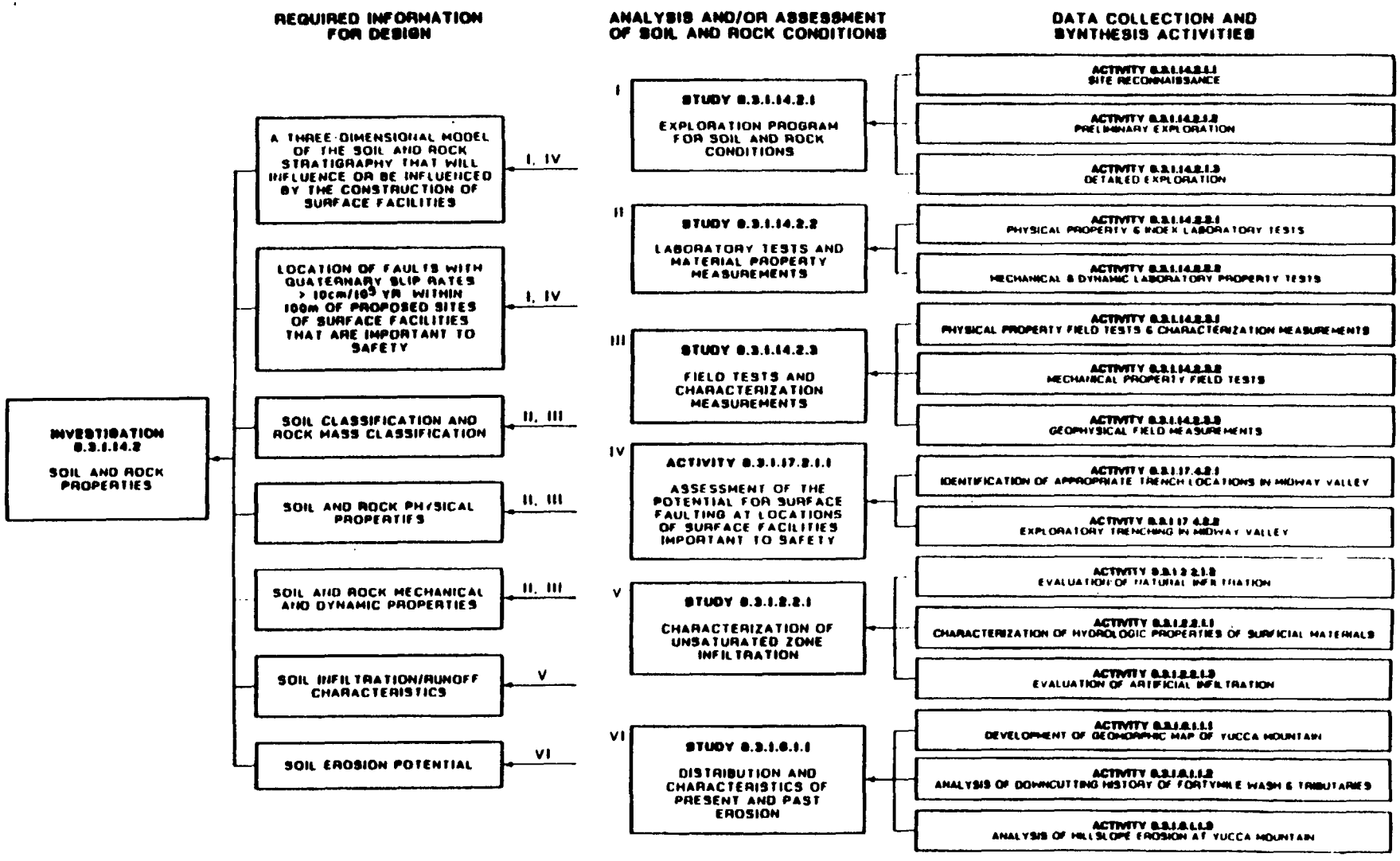

Figure 8.3.1.14-2. Logic diagram for Investigation 8.3.1.14.2, soil and rock properties

To provide a more detailed description of these interrelationships, two additional tables have been prepared. The investigations and information needs that require parameters from this program are provided in Table 8.3.1.14-2. This table also indicates why the data are needed and recommends general types of studies to obtain the data. Table 8.3.1.14-3 describes the investigations, information needs, and the associated data that will be required by this program.

Summary of studies

No studies are needed or planned for Investigation 8.3.1.14.1 (topography) because the requirements for this investigation have been satisfied.

The recommended studies to address the requirements of Investigation 8.3.1.14.2 (soil and rock properties) consist of an exploratory program, laboratory testing program, and a field testing and measurement program. The exploratory program will use various methods to investigate and characterize the subsurface soil and rock strata beneath the reference conceptual site. The laboratory test program will test undisturbed samples (minimal disturbance) obtained from the exploratory program to determine the soil or rock physical and mechanical material properties. The results from the field test and measurement program will further enhance the characterization of the subsurface conditions that may influence or impact surface facilities performance and design.

8.3.1.14.1 Investigation: Studies to provide the topographic characteristics of potential locations of surface facilities

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The topographic characteristics of the potential surface facility locations can best be illustrated with topographic contour maps. Topographic contour maps of the Yucca Mountain vicinity have been developed for use in the geologic, hydrologic, and climatologic site characterization studies described in this plan; numerous examples are presented as base maps in Chapters 1, 3, 5, and in Section 6.1.2.1.1 (topography and terrain) in Chapter 6. More detailed contour maps of the topography of potential repository surface facilities have been developed; examples are included in Section 6.2.4 (design of surface facilities).

Parameters

The following parameter has been measured or calculated as a result of site studies performed as part of this investigation: Ground-surface elevation as a function of geographic position at Yucca Mountain and vicinity.

Table 8.3.1.14-2. Investigations and information needs that require parameters from the surface characteristics program (page 1 of 4)

Issue, investigation, or information need calling for data	Parameter	Why data needed	Type of study or analysis needed to develop parameter
		INVESTIGATION 8.3.1.14.1 (TOPOGRAPHY)	
2.3.1 Credible repository accidents (Section 8.3.5.5.1)	Topographic contour maps	Determine if accidents from potential slope instabilities and flooding are credible	Topographic survey of the site
2.7.1 Radiological protection (Section 8.3.2.3.1)	Topographic contour maps	Evaluate the potential for slope instabilities and flooding	Topographic survey of site
4.1 Determine if site meets qualifying conditions of the technical guidelines (Section 8.3.5.7)	Topographic contour maps	Determine ease and cost of siting, construction, operation, and closure	Topographic survey of the site
4.2.1 Site performance information needed for design (Section 8.3.2.4.1)	Topographic contour maps	Evaluate the potential for slope instabilities and flooding that may be a hazard to personnel	Topographic survey of the site
4.4.1 Site and performance assessment information needed for design (Section 8.3.2.5.1)	Topographic contour maps	Evaluate feasibility and cost effective technologies for construction and operation on topography of proposed site	Topographic survey of the site

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Table 8.3.1.14-2. Investigations and information needs that require parameters from the surface characteristics program (page 2 of 4)

Issue, investigation, or information need calling for data	Parameter	Why data needed	Type of study or analysis needed to develop parameter
INVESTIGATION 8.3.1.14.1 (TOPOGRAPHY) (continued)			
8.3.1.16.1 Flood recurrence intervals and levels at surface facility locations	Topographic contour maps	Flood magnitudes and levels will be used in performance assessment and surface facility design studies	Topographic survey of the site
1.11 Site characterization information needed for design to determine if the repository configurations satisfy Issues 1.9 (Section 8.3.5.18) and 1.8 (Section 8.3.5.17).	Isopach maps of overburden thickness above repository horizon	Determine if the favorable 300-m overburden depth is satisfied in 10 CFR 60.122(b)(5). Determine if site is disqualified based on minimum 200-m overburden depth in 10 CFR 960.4-2-5(d)	Topographic survey of the site
8.3.1.15.2 and 8.3.1.4.3 Spatial distribution of ambient stress conditions and three-dimensional rock characteristics model	Topographic contour maps and ground surface elevation cross sections	Determine in situ stress at depth considering surface topography variations	Topographic survey of the site
8.3.1.6.1 Present location and rates of erosion	Topographic contour map	Use topographic contours to assist evaluating rates of erosion	Topographic survey of the site

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Table 8.3.1.14-2. Investigations and information needs that require parameters from the surface characteristics program (page 3 of 4)

Issue, investigation, or information need calling for data	Parameter	Why data needed	Type of study or analysis needed to develop parameter
	INVESTIGATION 8.3.1.14.1 (TOPOGRAPHY) (continued)		
2.3.1 Credible repository accidents (Section 8.3.5.5.1)	Physical and mechanical (static and dynamic) properties of soil and bedrock, alluvium bedrock contact, and layering	Evaluate the potential hazards from earthquakes and slope instabilities to structures and systems important to safety (60.131 (b) (1))	Standard laboratory and field static and dynamic tests
2.7.1 Radiological protection (Section 8.3.2.3.1)	Physical and mechanical (static and dynamic) properties of soil and bedrock, alluvium bedrock contact, and layering	Evaluate the potential hazards from earthquakes and slope instabilities to structures and systems important to safety (60.131 (b) (1))	Standard laboratory and field static and dynamic tests

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Table 8.3.1.14-2. Investigations and information needs that require parameters from the surface characteristics program (page 4 of 4)

Issue, investigation, or information need calling for data	Parameter	Why data needed	Type of study or analysis needed to develop parameter
INVESTIGATION 8.3.1.14.2 (SOIL AND ROCK PROPERTIES) (continued)			
4.2.1 Site performance information needed for design (Section 8.3.2.4.1)	Physical and mechanical (static and dynamic) properties of soil and bedrock, alluvium bedrock contact, and layering	To evaluate the potential hazards from earthquakes and slope instabilities to personnel	Evaluate ground-motion response due to earthquakes and conduct a static and dynamic analysis of proposed foundations and slopes
4.4.1 Site and performance information needed for design (Section 8.3.2.5.1)	Physical and mechanical (static and dynamic) properties of soil and bedrock, alluvium bedrock contact, and layering	Do technologies exist for cost effective surface construction on the site's soil and bedrock	Standard laboratory and field static and dynamic tests
8.3.1.17.3 Vibratory ground motion at site from potential man-made or natural seismic-induced events	Alluvium and bedrock stratigraphy and their compressive and shear wave velocities	Evaluate ground motion response due to seismic event for siting and designing surface facilities	Drilling, surface and borehole geophysical testing and laboratory tests to determine stratigraphy and wave velocities

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Table 8.3.1.14-3. Investigations or information needs supplying data to the surface characteristics program

Surface characteristics investigation	Information needs and investigations providing data	Data needed by this program
8.3.1.14.1, topography	4.4.5, reference preclosure repository design (Section 8.3.2.5.5)	Location of proposed surface facilities and roads
8.3.1.14.2, soil and rock properties	4.4.5, reference preclosure repository design (Section 8.3.2.5.5)	Location of proposed surface facilities and roads
	8.3.1.17.2, fault displacement	Fault locations
	8.3.1.2.2, site unsaturated zone hydrologic system	Infiltration and run-off characteristics
	8.3.1.6.1, present locations and rates of surface erosion	Soil erosion potential

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Purpose and objectives of the investigation

The purpose of this investigation was to evaluate the surface topographic elevation and relief at the potential surface facility locations to provide a basis for evaluating (1) the surface drainage, flood levels, and erosion characteristics in the vicinity of Yucca Mountain, (2) the cut-and-fill requirements for the design and engineering of the repository surface facilities, and (3) the stability of natural slopes and cut slopes. Topographic maps will be used in locating surface facilities, roads, and railways.

A knowledge of the surface topographic characteristics of the site will also be required for certain underground design and performance studies. The site's topography will have an influence on the underground design and the site's performance in terms of determining the usable area in the repository horizon while maintaining the required amount of overburden. A favorable site condition will exist if an overburden depth of 300 m is maintained above the repository horizon (10 CFR 60.122(b)(5)). The site will be disqualified if a minimum overburden depth of 200 m is not maintained (10 CFR 960.4-2-5(d)).

Another underground design parameter that is influenced by surface topography is in situ stress. In situ stresses are a result of three stress conditions: gravitational induced stress due to the weight of overburden, residual stress due to energy stored in the rock during the geologic past, and tectonic stress produced by current tectonic forces affecting the region. Bauer et al. (1985) evaluated the effect of Yucca Mountain's topography on gravitational induced horizontal stresses. Their study found that the surface topography will influence the horizontal stress field at the repository horizon.

The surface topographic information resulting from this investigation will contribute to data needs in the following design issues and characterization programs:

Issue or program	Subject
8.3.1.16	Preclosure hydrology. Topographic contours will be used to determine flood level.
4.4	Preclosure design and technical feasibility (Section 8.3.2.5). Topographic contours will be used in the design and therefore influence the technical feasibility of the technologies required for repository construction, operation, closure, and decommissioning.

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Issue or program	Subject
1.11	Configuration of underground facilities (postclosure) (Section 8.3.2.2). Topographic contours will be used to determine if the site has less than 200 m of overburden, which would result in disqualification (Section 8.3.5.18). Topographic contours will also be used to determine if the site is favorable with a minimum overburden depth of 300 m (Section 8.3.5.17).
8.3.1.4	Rock characteristics. Topographic contours will be used to determine in situ stress at depth considering surface topography variations.
8.3.1.15	Thermal and mechanical properties. Topographic contours will be used to determine in situ stress at depth considering surface topography variations.

To control map compilation, a total of 623 control points were generated from 50 original ground-targeted points. Field surveys of the targeted points were contracted to a private survey firm. Elevation precision of targeted points is about 0.3 m (1 ft), and the size of the target about 0.6 m (2 ft), producing 80-micrometer images on photographs.

Aerial photographs of the Yucca Mountain region were taken in two phases. Phase 1 photography covered an area 10 by 14 km. Phase 2 photography covered an area 11 by 15 km, from 160°22′30" to 160°30′00" longitude and from 36°48′ to 36°56′ latitude. Photographs were taken by a 6-in. lens camera at a flight height of 1,140 m above the terrain; the photographic scale is 1:7,500.

Photogrammetric analysis included production of additional control points using analytical photogrammetric methods and map compilation on stereo plots. A total of 623 control points were produced from 179 aerial photographs. Control maps were compiled at a scale of 1:5,000 with a contour interval of 1 to 2 m; each map covers an area 3 by 3 km, and has a precision of 10 cm on the ground.

Digital topographic data were collected from the contour maps. Three-dimensional modeling of the Yucca Mountain geology will be made by combining digital topographic and image data Section 8.3.1.15.1). Topographic maps of appropriate portions of the Yucca Mountain area were compiled by Wu (1985) at 1 and 2 m contour intervals.

Technical rationale for the investigation

The requirements for this investigation have been satisfied. No further studies, tests, or analyses are planned.

8.3.1.14.2 Investigation: Studies to provide soil and rock properties of potential locations of surface facilities

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
2.7.3	Geoengineering properties of surface materials
6.1.2.1.2	Near surface soil and rock
6.2.4	Design of surface facilities

As discussed in Sections 6.1.2.1.2 and 6.2.4, limited preliminary field investigations (boring and test pits) and laboratory tests have been performed to estimate the soil properties and depth-to-rock. The results of these investigations suggest that the foundation soil or rock has adequate physical and mechanical characteristics for supporting the facility buildings and that ground motion amplification is not expected to be a problem. However, these investigations were only preliminary and the engineering properties were conservatively estimated using empirical correlations with soil classification methods. Therefore, further investigations are necessary to confirm these preliminary estimates.

Parameters

The characterization parameters that will be measured or calculated as a result of the site studies planned as part of this investigation were previously presented in Table 8.3.1.14-1. These data requirements are summarized in the following list:

1. Alluvial and rock stratigraphy and structure.

2. Soil and rock classification vs. depth.

3. Physical properties vs. depth.

4. Mechanical and dynamic properties vs. depth.

5. Compaction characteristics of soil.

6. Infiltration-runoff characteristics of soils and rock at surface (Investigations 8.3.1.2.2 and 8.3.1.6.1).

7. Erosion potential of undisturbed soil, cut slopes, and engineered fill slopes (Investigation 8.3.1.6.1).

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Data similar to that described in the summarized list of data requirements will be obtained in two other investigations and one study:

Investigation or study	Subject
8.3.1.4.2	Geologic framework of the Yucca Mountain site
8.3.1.17.4	Preclosure tectonics data collection and analysis
8.3.1.5.1.4	Analysis of the paleoenvironmental history of the Yucca Mountain region

Because the objectives of these other investigations and studies are not always the same as that of the soil and rock investigation, differences may exist in the methods or techniques used to obtain the data. These differences may result in an incompatibility between the soil and rock investigation and the data from the previously described investigations and study. However, in the instances where the data are compatible, every effort will be made to coordinate the soil and rock investigation with similar data-gathering activities in the other investigations and studies.

Purpose and objectives of the investigation

The characteristics of the soil and rock at or near the surface will primarily influence the selection of the surface facilities locations and their design. The soil and rock conditions, as well as topographic relief, influence the specific locations selected for surface buildings, shaft and ramp entrances, and road and rail lines. They also provide information on infiltration-runoff characteristics and erosion potential so that the site drainage and erosion control systems can be designed when the facility design has been completed.

The most direct application of the soil and rock characterization activities will be to provide the necessary data to design surface structure foundations and retaining walls, evaluate the soil-structure interaction (response) due to earthquake loading conditions, and evaluate any potential slope instability conditions. Foundation designs will be necessary for various types of structures, including buildings, shaft hoist frames, and ramp portals.

The foundation design will consist of determining what type, size, and configuration of foundation would be most compatible with the soil or rock conditions, expected loads, function of structure, and design requirements. A determination of the allowable bearing load or pressure of the soil or rock will be a key factor in the foundation design analysis.

After the buildings, foundation, and superstructure have been designed for static-loading conditions, the soil or rock-structure interaction must be evaluated for earthquake loading conditions. In this instance, the number of

stories and stiffness of the superstructure will affect the soil-structure response, but even more important will be the subsurface soil and rock conditions. Factors such as the thickness and inclination of an alluvial wedge, the seismic impedance contrast between the alluvium and bedrock, and the seismic absorptivity of the alluvium can all significantly contribute to ground motion response and therefore affect the interaction between the soil and structure.

The characterization of the soil and rock conditions will also be needed for evaluating any potential slope instabilities. Slope stability will be evaluated for road or rail line cuts, ramp portal entrances, and any potential unstable cut or natural slope near a surface facility.

The primary design issue that will be influenced by the soil and rock conditions is Issue 4.4 (Section 8.3.2.5). This issue addresses whether available technologies exist to construct, operate, close, and decommission the repository.

Technical rationale for the investigation

The soil and rock properties investigation has been developed into three studies. These studies are further subdivided into activities. The studies and activities for the soil and rock investigation are as follows:

Study	Activity	Subject
8.3.1.14.2.1		Exploration program
	8.3.1.14.2.1.1	Site reconnaissance
	8.3.1.14.2.1.2	Preliminary exploration
	8.3.1.14.2.1.3	Detailed exploration
8.3.1.14.2.2		Laboratory test and material property measurements
	8.3.1.14.2.2.1	Physical property and index laboratory tests
	8.3.1.14.2.2.2	Mechanical and dynamic laboratory property tests
8.3.1.14.2.3		Field tests and characterization measurements
	8.3.1.14.2.3.1	Physical property and field tests and characterization measurements
	8.3.1.14.2.3.2	Mechanical property field tests
	8.3.1.14.2.3.3	Geophysical field measurements

The data obtained from this investigation will be primarily used in the resolution of Issue 4.4 (Section 8.3.2.5). As described earlier, and presented in the logic diagram for this program (Figure 8.3.1.14-1), Design Issue 4.4 addresses whether construction, operation, closure, and decommissioning technologies are adequately established to resolve performance issues.

The main objective of the soil and rock investigation is to provide these design issues with the necessary geotechnical information to help locate the surface facilities, conduct foundation design analyses, evaluate soil-structure interactions, and if necessary, evaluate potentially unstable slopes. A secondary objective will be to provide these design issues with hydraulic-related soil information for evaluating erosion potential and infiltration-runoff characteristics. However, this hydraulic-related soil information will be contributed by Studies 8.3.1.2.2.1 and 8.3.1.6.1.1, which are outside this investigation. Other outside information contributing to this investigation will be from Activities 8.3.1.17.2.1.1, 8.3.1.17.4.2.1, and 8.3.1.17.4.2.2. These activities will provide information on surface fault locations that will be used in the surface facility siting process. The contribution from these outside activities to the soil and rock investigation, and ultimately the relevant design issues, is illustrated in Figures 8.3.1.14-1 and 8.3.1.14-2.

A generalized outline of the geotechnical information required for design is also presented in Figure 8.3.1.14-2 with the corresponding studies and activities that will provide this information. A list of the characterization parameters that will be developed from these studies and activities and provide the necessary geotechnical information required for the design process is presented in Table 8.3.1.14-1. Also provided in this table are the studies and activities associated with each of these characterization parameters.

The characterization parameters will be used to develop the design parameters as illustrated in Table 8.3.1.14-1. This is a key interlink since the design process is an iterative process between the surface facility design requirements (functions) and the soil and rock conditions. The surface facility design requirements and soil and rock conditions must both be considered when determining where to locate a surface facility, what type of foundation would be most appropriate, and evaluating the soil-structure interaction and the potential for unstable slope conditions. A preliminary evaluation of the site and a preconceptual design will determine more specifically what design parameters will be needed for further design activities and therefore what characterization parameters will be required to develop these design parameters. The interlink between the design parameters and the surface facility design requirements (functions) is presented in Section 8.3.2.5 (technical feasibility).

The recommended studies and their corresponding activities were listed previously in this section. These studies include (1) exploration program, (2) laboratory tests and material property measurements, and (3) field tests and characterization measurements.

The exploration program will evaluate all existing data (maps, aerial photographs, etc.), obtain representative samples from boreholes or trenches, and conduct geophysical surveys. Laboratory testing will be conducted on representative samples to determine the physical, mechanical, and dynamic properties of the soil and rock. Field tests will also be conducted on the soil and rock to better establish their physical, mechanical, and dynamic properties. Classification and characterization measurements and evaluations will be conducted on the soil and rock in both the laboratory and field.

The geotechnical exploratory program and its associated laboratory and field test programs will focus on the area east of Exile Hill for characterizing the foundation conditions for the central surface facilities area. Exploratory characterization activities will also be conducted in the areas of the ramp portals and shafts. Additional foundation geotechnical exploration activities will be conducted at the bridge site over Fortymile Wash.

8.3.1.14.2.1 Study: Exploration program

The objectives of this study are to conduct an exploration program for characterization of the soil and rock conditions that will influence or be influenced by the construction of the surface facilities. The exploration program study will consist of three activities: (1) site reconnaissance, (2) preliminary exploration, and (3) detailed exploration. This study will evaluate all existing data and determine what additional and appropriate data will be needed to adequately address all design issues and characterization programs requesting data from this investigation (Figure 8.3.1.14-1). On the basis of these data needs and the expected soil and rock conditions at the site, an optimum exploration program will be developed and implemented to obtain this data using such methods as drilling, trenching, sampling, sounding, and geophysical surveys. The selection of the appropriate methods will be dependent on the specific requirements of each data need and the soil or rock conditions that are encountered.

Samples obtained from drilling or trenching will be used in the laboratory testing activities described in Study 8.3.1.14.2.2. Laboratory and field test results and the other geotechnical information developed during this study will contribute to the development of the geotechnical design parameters presented in Table 8.3.1.14-1, which in turn will be used to address Design Issue 4.4 (Section 8.3.2.5).

8.3.1.14.2.1.1 Activity: Site reconnaissance

Objectives

The objectives of this activity are to review existing site information and conduct a field reconnaissance for the purpose of establishing a preliminary exploration program to include subsurface drilling, test pits, trench-

ing, and geophysical methods. Data from this activity will contribute to the development of the geotechnical parameters in Table 8.3.1.14-1 and to the resolution of Design Issue 4.4 (Section 8.3.2.5).

Parameters

The following data are required to fulfill the objectives of this activity:

1. Existing topographic (Investigation 8.3.1.14.1), soil, and geologic maps.

2. Existing subsurface drilling, trenching, and geophysical information.

3. Existing geologic and geotechnical reports.

4. Aerial photographs.

5. Onsite visual reconnaissance.

Some preliminary site reconnaissance and data-gathering activities have already been completed in the Midway Valley-Yucca Mountain area. Four test pits were excavated in the alluvium at potential surface repository facility sites. These sites are located along the western edge of Midway Valley and the eastern edge of Yucca Mountain as illustrated in Figure 8.3.1.14-3. These exploratory activities were conducted to evaluate the conditions of the natural alluvial soils that are expected to support the foundations of the potential surface facility sites. Data collected from these activities include densities, moisture content, specific gravity, gradation analysis, and moisture-dry density compaction relationships (Ho et al., 1986).

Boreholes have also been drilled in the Midway Valley-Exile Hill area as illustrated in Figures 8.3.1.14-3 and 8.3.1.14-4. These boreholes were used to better define the geologic stratigraphy and structure of the preferred reference conceptual site (Figures 8.3.1.14-4, 8.3.1.14-5, 8.3.1.14-6, and 8.3.1.14-7) and to obtain preliminary physical property and wave velocity data from the alluvium and Tiva Canyon cap rock. These borehole data, plus seismic reflection and refraction surface survey data, were used to determine that the wedge angle between the alluvium and bedrock was low and that the seismic impedance contrast between the alluvium and Tiva Canyon cap rock was small. Both of these characteristics are important from the standpoint of evaluating potential seismic-induced ground motion. It was determined that neither the small wedge angle between the alluvium and bedrock nor the low seismic impedance contrast between the alluvium and bedrock would significantly amplify incoming seismic-induced ground motion (Neal, 1986).

Description

This activity will collect and evaluate all existing geotechnical and air photographic information that exists for the reference conceptual site east of Exile Hill, around shaft and ramp portals, at the tuff pile site, and at other locations associated with surface facilities, such as roads, bridges, and flood protection facilities (e.g., embankments, channels, and

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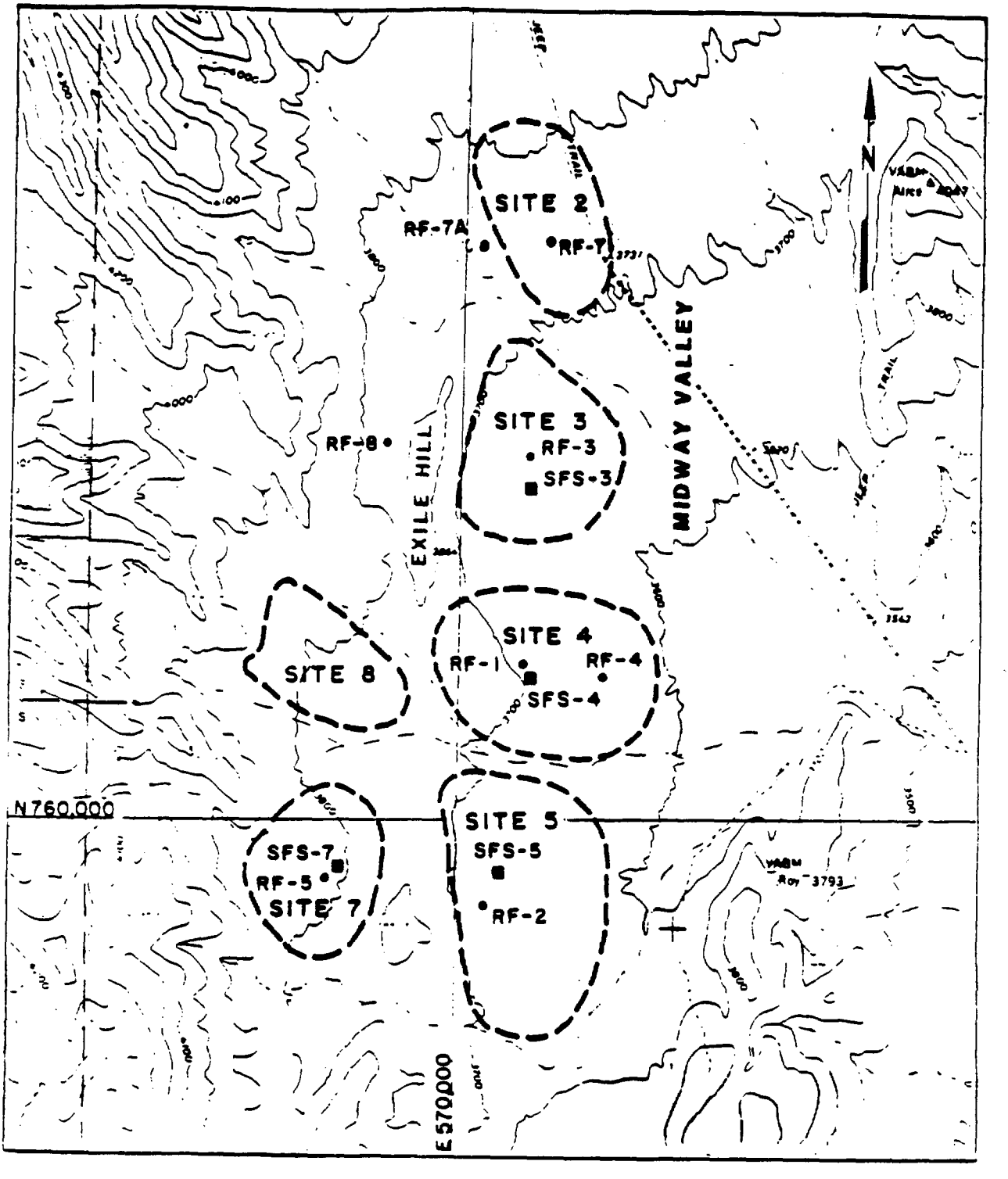

KEY

■ SFS TEST PITS

• RF BORINGS

0 2500 5000 FEET

0 750 1500 METERS

Figure 8.3.1.14-3. Location of surface test pits in alluvium Modified from Ho et al (1986)

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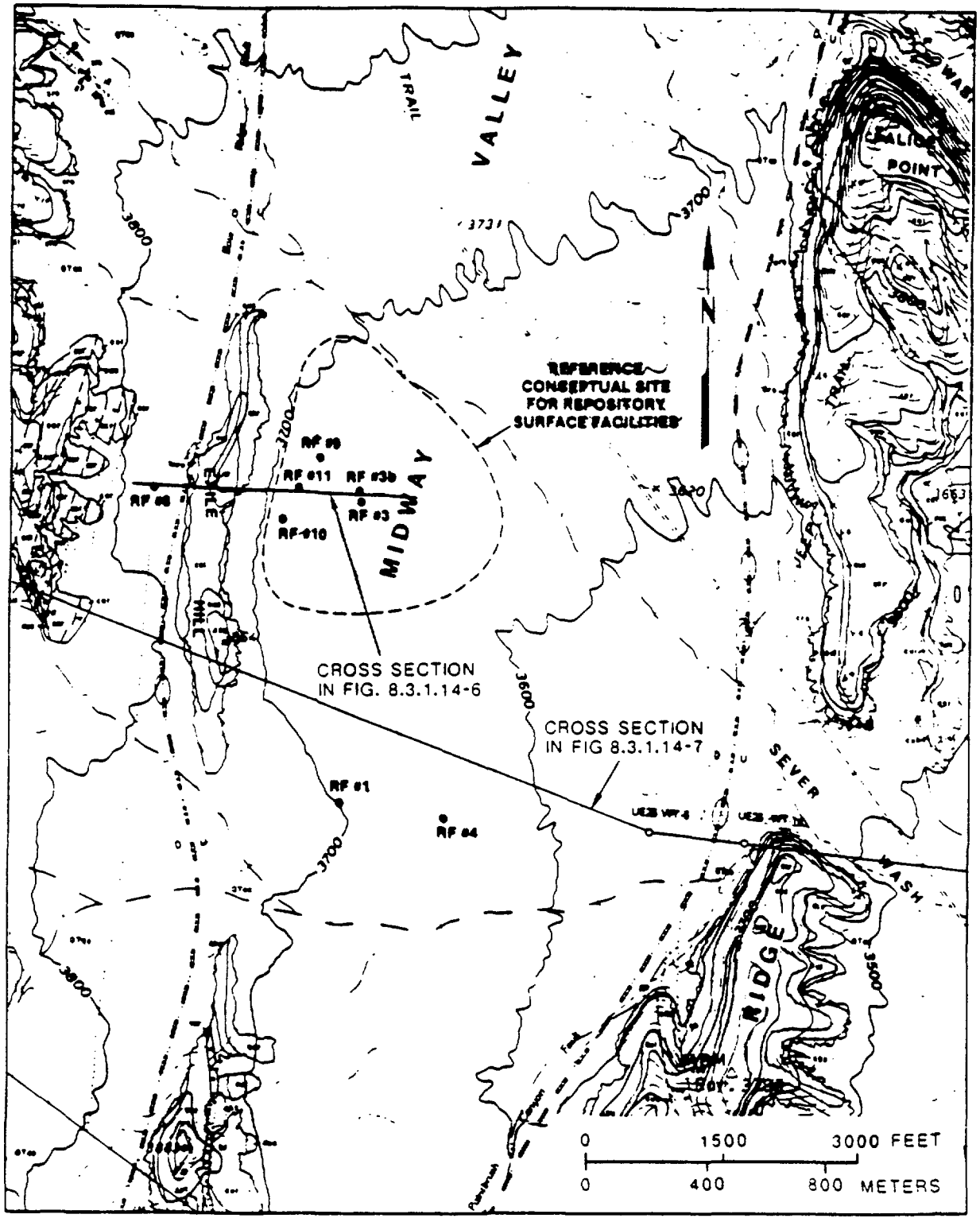

Figure 8.3.1.14-4. Map of the surface geology and faults in the vicinity of Exile Hill (Unit definitions are given on Figures 8.3.1.14-6 and 8.3.1.14-7.) Modified from Scott and Bonk (1984)

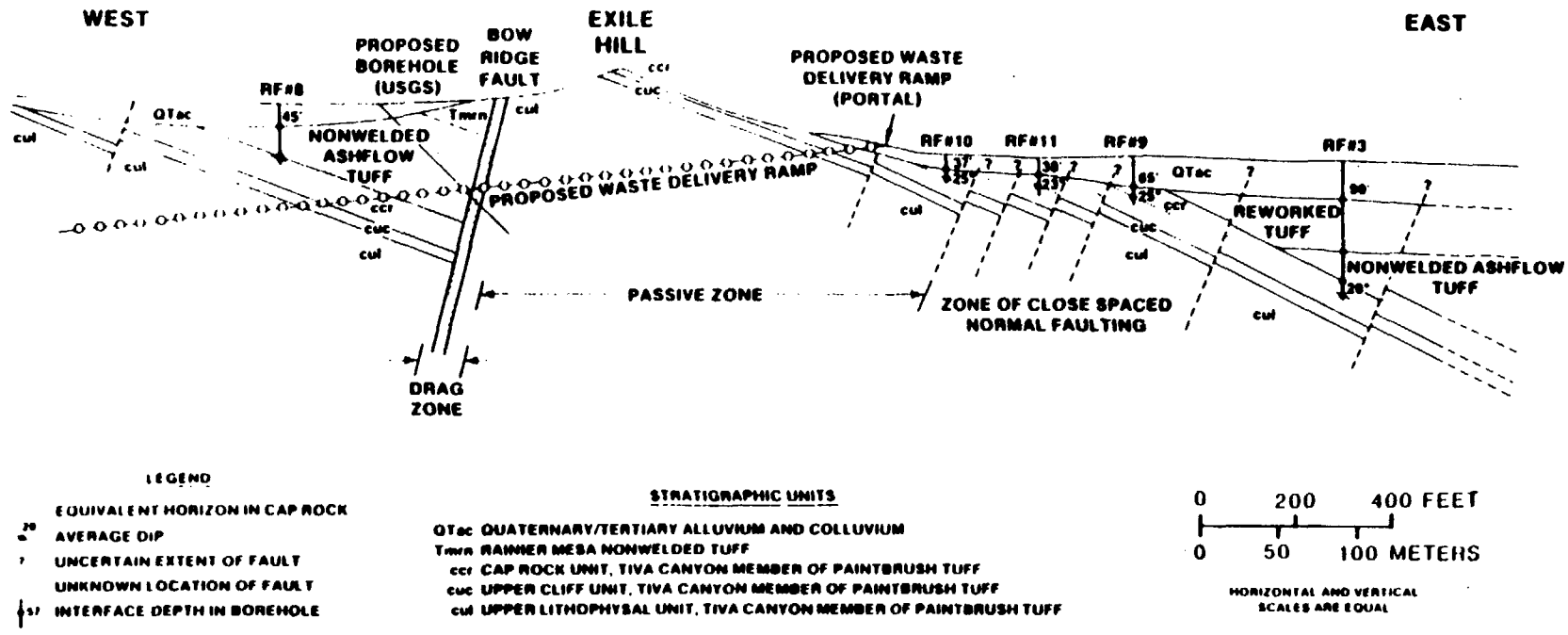

Figure 8.3.1.14-5. Cross section of the geologic structure through Exile Hill and the reference conceptual site based on surface mapping and borehole data (See Figure 8.3.1.14-5 for the location of the section.) Modified from Scott and Bonk (1984).

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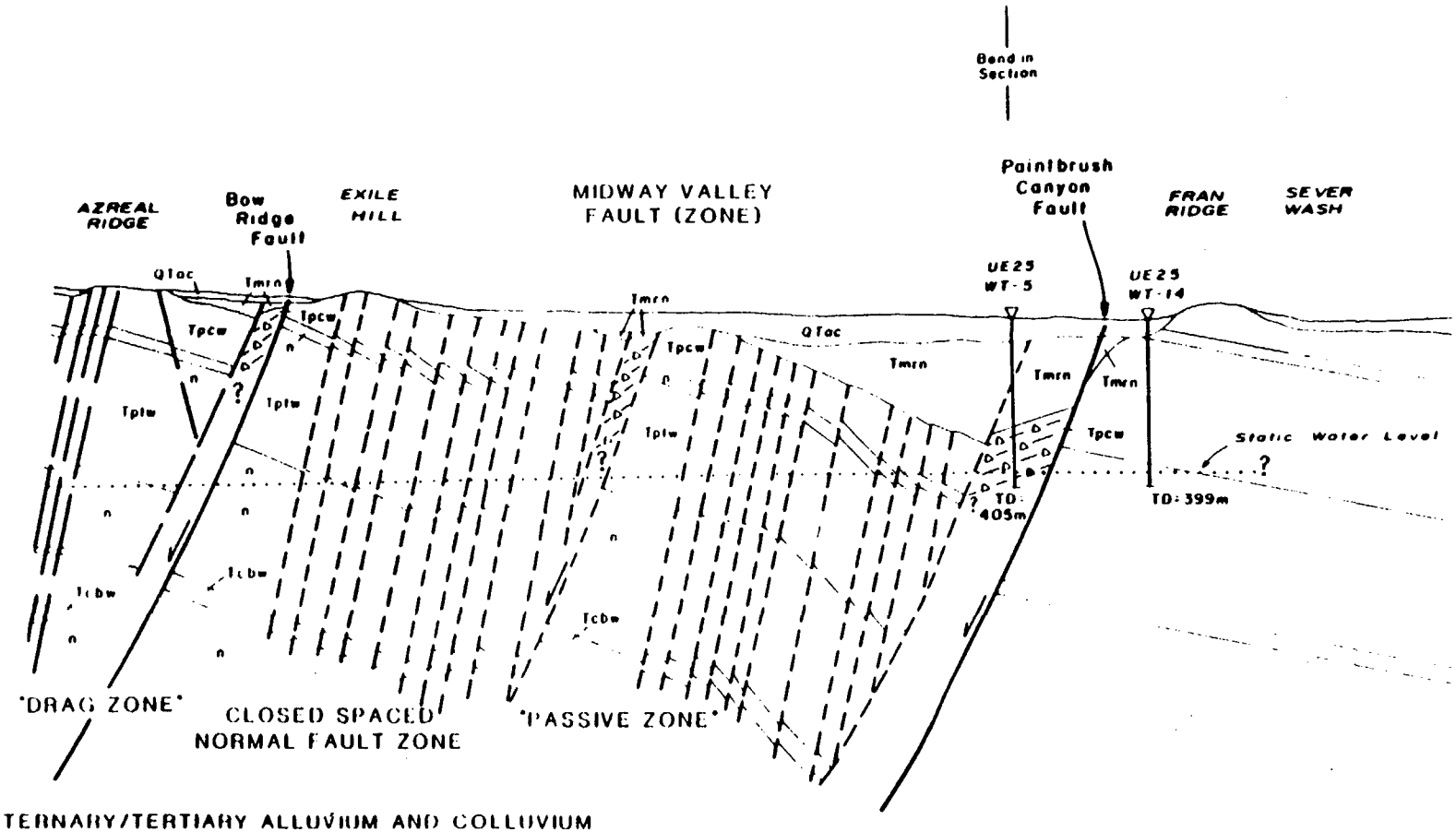

QTac QUATERNARY/TERTIARY ALLUVIUM AND COLLUVIUM
Tmrn RAINIER MESA MEMBER OF TIMBER MOUNTAIN TUFF, NONWELDED
Tpcw TIVA CANYON MEMBER OF PAINTBRUSH TUFF, WELDED
n NONWELDED TUFF
Tptw TOPOPAH SPRING MEMBER OF PAINTBRUSH TUFF, WELDED
Tcbw BULLFROG MEMBER OF CRATER FLAT TUFF, WELDED
TD TOTAL DEPTH

Figure 8.3.1.14 6. Conceptual cross section of the geologic structure south of the reference conceptual site for repository surface facilities (See Figure 8 3 1 14 5 for the location of the section) Modified from Scott and Bonk (1984)

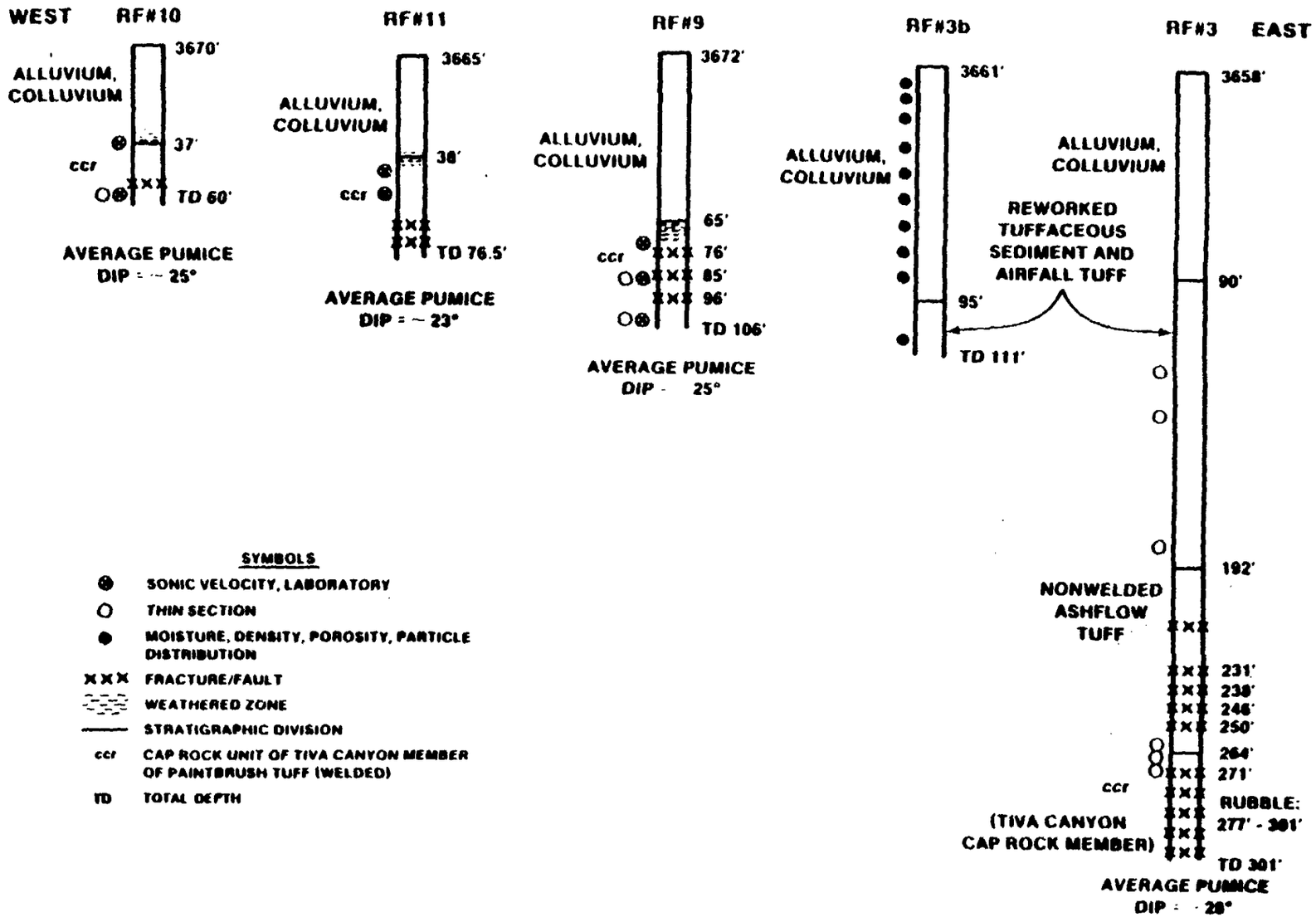

Figure 8.3.1.14-7. Summary of boreholes UE-25 RF #10, 11, 9, 3b, and 3 showing major stratigraphic units and features. (See Figure 8.3.1.14-5 for the locations of the boreholes.) To convert feet to meters, multiply by 0.3048. Modified from Scott and Bonk (1984).

culverts). This information will be used in conjunction with an onsite visual reconnaissance to develop an optimum subsurface drilling, trenching, and geophysical survey program.

The previously described site reconnaissance information will be used to develop a preliminary exploration program plan. This plan will identify the type, location, spacing, and depth of subsurface borings, test pits, and trenches. The preliminary exploration program plan will also identify the method and location of recommended geophysical surveys. Recommendations for subsurface boring location, spacing, and depth are given in Hvorslev (1949), and U.S. Army EM 1110-1-1804.

8.3.1.14.2.1.2 Activity: Preliminary exploration

Objectives

The primary objective of the preliminary explorations is to obtain sufficient subsurface data to identify or verify the types, locations, and principal dimensions of all major surface structures comprising the proposed project. Preliminary designs based on these explorations will be suitable for economic and technical feasibility reports and project planning reports. The depth, thickness, and areal extent of all major soil and rock strata that will influence or be influenced by the construction of the surface facilities must be established in reasonable detail. In addition, disturbed and undisturbed samples must be obtained for laboratory testing to provide a basic knowledge of the engineering properties of the various strata.

Parameters

The following data are required to fulfill the objectives of this activity:

1. Depth, thickness, and areal extent of all major soil and rock strata that will be within the zone of stress influence of surface facility loads or that may influence the soil-structure interaction response of the surface facilities under dynamic loading conditions.

2. Identification of existence of significant geologic structures.

3. Representative disturbed and undisturbed samples (undisturbed sampling will be very difficult in a nonsaturated cohesionless soil with cobbles).

4. Identification and classification of soil and rock types encountered.

5. Blow count or penetration resistance with depth in soils (sounding methods).

6. Schmidt impact hammer data for rock.

7. Preliminary determination of physical, mechanical, and dynamic properties developed from empirical methods related to material classifications, blow count or penetration resistance, Schmidt impact hammer data, and geophysical surveys and borehole logging.

Description

Field methods such as sounding, drilling, trenching, and test pits will be used in conjunction with geophysical methods to characterize the depth, thickness, and areal extent of all soil and rock strata that will be within the zone of stress influence of surface facility loads or that may influence the soil-structure interaction response of the surface facilities under dynamic loading conditions. These same methods can also be used to identify significant geologic structures such as faults in the vicinity of critical surface facilities. However, trenching will be the most reliable method for identifying faults in the alluvium at the site. The results of previous preliminary exploration activities (Ho et al., 1986) that were used to develop a conceptual design will be used in conjunction with the results of the exploration program described in this activity to develop an advanced conceptual design and provide the basis for developing a detailed exploration program.

Representative disturbed samples and undisturbed samples (if possible) of the soil and rock will be obtained from the drilling, trenching, and test pit activities for identification, classification, and laboratory testing of physical, mechanical, and dynamic properties. Undisturbed sampling of the unsaturated and cohesionless silty gravels or poorly graded gravels with cobbles at the site (Ho et al., 1986) will be difficult if not impossible.

Preliminary evaluations of the physical, mechanical, and dynamic soil properties of the site will be developed from empirical methods related to material classifications, blow count of penetration resistance, Schmidt impact hammer data, and geophysical surveys and borehole logging. Sounding methods such as the Standard Penetration Test (SPT) (ASTM, 1984b), the Dutch cone penetration resistance (ASTM, 1984a) the Becker penetration resistance (Harder and Seed, 1986) can be used to estimate the physical or mechanical properties of soil. Established empirical relationships can be used to correlate the soil classification and blow count or penetration resistance data to density, Young's modulus, or friction angle (Winterkorn and Fang, 1975). It is recommended that the Becker penetration resistance method be used for coarse gravels that are anticipated at the site. The use of sounding methods such as the SPT blow count or the Dutch cone penetration resistance in coarse gravels may provide unreliable data. If finer grained soil conditions are encountered, then it is recommended to use the SPT blow count method or the Dutch cone penetration resistance method.

Field methods can also be used to provide preliminary estimates of the mechanical rock properties of the site. The point load test (Broch and Franklin, 1972) is commonly used on rock core to estimate its unconfined compressive strength. The Schmidt impact hammer can also be used on rock core or surface outcrops to estimate unconfined compressive strength (ISRM, 1981). These are both very fast, inexpensive, but not necessarily reliable field methods.

Surface and borehole geophysical methods will be used to evaluate the dynamic and physical properties of the subsurface strata. The use of geophysical borehole logging will only be considered below the depth of the trenches or test pits. It will be used to correlate strata between boreholes and provide very approximate values for density, moisture content, porosity, wave velocities, and estimates of the degree of fracturing in rock.

The need for seismic geophysical methods is more apparent. Geophysical methods such as seismic refraction, cross-hole seismic, and up/downhole seismic are recommended for determining the compressive and shear wave velocities of the subsurface strata. The wave velocities will then be used to calculate the dynamic elastic parameters of the subsurface soil and rock. These field parameters are expected to be more reliable than the same parameters measured in the laboratory.

8.3.1.14.2.1.3 Activity: Detailed exploration

Objectives

The objective of the detailed exploration activity is to fill in any gaps in the previous preliminary exploration activity and to make such additional explorations that are necessary to define adequately the subsurface conditions. When the subsurface information from the preliminary and detailed exploration activities are combined, the resulting information must be adequate for preparation of bidding plans and specifications for construction.

Parameters

The detailed exploration will conduct activities to improve on the understanding and confidence of the parameters and data identified in the preliminary exploration activity. The soil or rock conditions encountered during the preliminary exploration activities will determine which parameters will require further investigations during the detailed exploration activities or which contingent parameters will require characterization. The results of the preliminary exploration activities may indicate that certain parameters will not require further characterization.

Description

This activity will be an extension of the preliminary exploration program to better define a three-dimensional model or view of subsurface conditions that will influence or be influenced by the construction of surface facilities. Additional boreholes will be drilled or trenches dug at locations planned for critical surface structures or where subsurface conditions are not adequately understood or are highly varied.

In this activity the precise location of each surface facility has been set, and additional borings are made so that an adequate number of borings are located at each surface facility site. During the preliminary exploration, soil or rock conditions may have been encountered that will require

different or modified detailed exploration methods. Otherwise, the type of exploration methods used in this activity will be similar to the methods used in the preliminary exploration activity.

Attempts may be made to obtain undisturbed samples; however, the undisturbed sampling of a dry cohesionless soil with cobbles may be difficult if not impossible. The presence of cobbles will require larger samples so that the characteristics of the soil mass will not be overshadowed by the presence of cobbles.

Due to the probable difficulty that will be encountered when attempting to obtain undisturbed samples, it may be necessary to obtain disturbed samples and recompact these samples to the in situ density before testing. The testing of recompacted soil has two disadvantages. The first consideration is that any effects of cementing or fabric will be destroyed by disturbing the sample. The second consideration is that some potential collapse characteristics of the soil sample, if present, may be lost due to the disturbance.

8.3.1.14.2.2 Study: Laboratory tests and material property measurements

The objective of this study is to conduct laboratory tests and material property measurements on representative samples of soil and rock. These tests and measurements are intended to determine physical, mechanical, and dynamic properties. Additional tests and measurements will be conducted on soils to determine index properties and moisture-density compaction curves for potential fill material. Geotechnical information from this study will contribute to the development of the geotechnical design parameters presented in Table 8.3.1.14-1, which in turn will be used to address Design Issue 4.4 (Section 8.3.2.5).

8.3.1.14.2.2.1 Activity: Physical property and index laboratory tests

Objectives

The objective of this activity is to measure the soil or rock weight and volume components using physical property tests. Soils can be further characterized by index tests such as gradation analysis and Atterberg limits testing. The physical and index property test results are used to classify soils and rocks, to group soils and rocks in major strata, and to extrapolate results from a restricted number of mechanical and dynamic properties tests to determine properties of other similar materials. Empirical methods can also be used to relate the physical properties and soil or rock classifications to engineering parameters.

Parameters

The following soil and rock parameters will be collected, evaluated, or both to fulfill the objectives of this activity.

1. Soil parameters

   a. Density.

   b. Specific gravity.

   c. Moisture content.

   d. Soil classification.

      i. Gradation analysis.

      ii. Atterberg limits (this parameter will only be determined if cohesive soils are encountered).

   e. Moisture-density compaction curves for potential fill material.

   f. Relative density (cohesionless soils).

2. Rock parameters

   a. Density.
   b. Moisture content.
   c. Porosity.
   d. Specific gravity.

Description

A representative number of samples will be tested so that the variations in physical and index properties throughout the reference conceptual site will be adequately characterized. The laboratory soils tests can be conducted on disturbed samples except for the density and porosity tests. These two soil tests will require undisturbed samples. Because of the difficulty in obtaining an undisturbed sample from a dry cohesionless soil with cobbles, soil densities will have to be determined in situ using either field density test methods, or empirical correlations with sounding methods such as the Standard Penetration Test (SPT) blow count data (Winterkorn and Fang, 1975) or Becker penetration resistance data (Harder and Seed, 1986).

Because of the very coarse nature of the soil, it may not be possible to use the Standard Proctor or Modified Proctor compaction methods to develop the moisture-dry density compaction curve relationships of the soil. For gravelly soils, up to 3-in. maximum size, it is recommended that the U.S. Bureau of Reclamations E-38 procedure be used to develop compaction curves.

8.3.1.14.2.2.2 Activity: Mechanical and dynamic laboratory property tests

Objectives

The objective of this activity is to measure in the laboratory the static and dynamic deformation and strength characteristics of soil and rock

samples obtained from the exploratory program. The results of this testing will be used to evaluate bearing capacity, earth pressures, shear strength parameters, slope stability, settlement and swelling potentials, and the dynamic characteristics of the soil and rock. This geotechnical information will be used for locating and designing buildings, foundations, retaining walls, backfills, roads, and slopes. Results from this activity will be the major contributor for developing the geotechnical design parameters presented in Table 8.3.1.14-1.

Parameters

The data and parameters listed in this section will be collected, evaluated, or both, to fulfill the objectives of the activity.

1. Required static load derived parameters.

   a. Mohr-Coulomb strength criteria parameters for soils (cohesion and angle of friction). The type of strength testing will depend on the type of soil, stress history, new stress state, and rate of loading.

   b. Peak and residual failure envelopes for rocks.

   c. Young's modulus.

   d. Poisson's ratio.

   e. Shear modulus.

   f. Rock discontinuity shear strength parameters in terms of cohesion and angle of friction.

   g. Plate load pressure versus settlement.

2. Contingent static load derived parameters.

   a. Collapse potential (for relatively dry, low-density soils).

   b. Coefficient of consolidation (for saturated, clayey soils).

   c. Compression and swell index (for saturated, clayey soils).

   d. Other failure criteria parameters such as Drucker-Prager or Hoek and Brown.

   e. Deformation modulus of soils in terms of stress-strain characteristics and confinement stress conditions.

   f. Bulk modulus and constrained modulus of soils.

3. Required dynamic load derived parameters.

   a. Compressive wave velocities versus depth.

   b. Shear wave velocities versus depth.

   c. Damping versus depth.

4. Contingent dynamic load derived parameters.

   a. Strength and stress-deformation characteristics of soil under dynamic load conditions evaluated as a function of stress rates, confinement stress, initial static stress level, magnitude of pulsating stress, number of stress cycles, and frequency of loading.

   b. Dynamic shear modulus as a function of strain and confinement stress.

   c. Damping as a function of strain.

   d. Shear wave velocities as a function of strain.

   e. Liquefaction parameters--cyclic shearing stress ratio, cyclic deformation, and pore-pressure response (applicable for soils with perched-water tables near the surface).

The need for any contingent parameters will be determined by the soil or rock conditions encountered, the function or design requirements of the surface facilities, the types of foundations selected, and the type or sophistication of the analyses that are selected for the design or performance studies. On the basis of the known site conditions and the design presented in the SCP-CDR (SNL, 1987), these contingent parameters are not presently required. The contingent parameters will be characterized if unexpected soil and rock conditions are encountered, or if more sophisticated constitutive models are required or used in the soil or rock-structure interaction numerical codes.

Description

Standard laboratory tests for geotechnical engineering practice will be performed. Testing will be conducted on undisturbed or recompacted samples taken from soil and rock strata that will influence or is influenced by surface facility construction. Selection of sample location, depth, and type of test will be influenced by the surface structure function, loads (static or dynamic), and foundation depths and widths. Testing will also be conducted on all soils to be used for engineered fills. These soils must be compacted to the appropriate dry density and moisture content before conducting laboratory tests to determine their mechanical and dynamic properties.

The static strength and deformability of cohesionless soils will be determined in the laboratory from the results of triaxial compression tests and direct shear tests. The results of this testing will be used to confirm or validate the mechanical parameters determined in the field using empirical

correlations with soil classification, density, and blow count data. Additionally, plate load bearing tests may be used if spread footings are recommended for the design. Unconfined compressive tests can also be conducted if cohesive soils are encountered.

The type of test or method selected to determine the settlement characteristics of the soil will depend on whether the soil is cohesionless or cohesive. The immediate settlement characteristics of a cohesionless soil will be determined by an analytical method developed by Schmertmann (1970) based on the results of Standard Penetration blow count data or Dutch cone penetration resistance data. The time-dependent settlement characteristics of a saturated cohesive soil will be developed from the results of one-dimensional consolidation tests, however, saturated cohesive soils are not expected to be encountered.

The strength and deformability of rock will be determined in the laboratory from the results of triaxial compression tests, unconfined compression tests, and Brazilian tensile tests. The strength parameters will be in the form of peak and residual strength envelopes. These parameters will be used to evaluate the allowable foundation bearing pressure of the rock (Goodman, 1980).

The direct shear testing method can be used in the laboratory to measure the mechanical properties of the rock discontinuities. The discontinuity strength parameters will be used in the stability evaluation of rock slopes and will contribute to the evaluation of the allowable bearing pressure for a foundation, especially for foundations on sloping topography.

The velocity characteristics of the propagation of elastic waves through soil and rock can be determined in the laboratory using resonant methods. High- and low-frequency ultrasonic pulse techniques can also be used for rock. The resulting velocities from these tests can then be used to determine the elastic deformation parameters of the soil or rock. Elastic deformation parameters derived from laboratory resonant test methods will only be used to confirm or validate the elastic deformation parameters derived from field geophysical seismic methods. However, the material damping characteristics of the soil or rock will be determined in the laboratory using resonant test methods.

Determination of the dynamic compression and shear moduli will depend primarily on field geophysical seismic methods, such as, cross hole and up/downhole measurement techniques. Using these techniques, the maximum dynamic shear modulus (low-strain) can be obtained. The nonlinearity of soil can be considered by reducing the shear modulus with strain based on correlations developed by Seed et al. (1984). It is also recommended that the relationship developed by Seed et al. (1984) be adopted to determine the maximum shear modulus of soil as a function of a density related factor, K_2, obtainable from the field measured shear wave velocities) and the mean effective confining stress. A method for reducing the shear modulus of rock as a function of strain is addressed by Schnabel et al. (1971).

The determination of the strength and stress-deformation characteristics of soils under dynamic load conditions evaluated as a function of stress level, magnitude of pulsating stress, number of stress cycles, and frequency

of loading can only be determined in the laboratory using a cyclic loaded triaxial compression test. However, because of the difficulty in obtaining undisturbed samples of the coarse cohesionless soils at the site and the resulting unreliable nature of these samples or recompacted samples, it is recommended that the cyclic loaded triaxial compression test not be conducted if sufficient confidence can be acquired in the previously described field and empirical methods for determining the dynamic mechanical characteristics of the soil. Certain conditions may develop that will either require or produce more of a need for cyclic loaded triaxial test data. These conditions would include a lack of confidence in the previously described field and empirical methods, therefore, requiring the cyclic loaded triaxial test as a means of confirming or validating the parameters developed from the field and empirical methods. In addition, this test would provide the design engineer with more information to better assess the dynamic characteristics of the soil (assuming the data are not totally invalidated due to sample disturbance or questionable testing procedures). The need and validity of the cyclic loaded triaxial test may increase if other soil conditions are encountered such as saturated soils or finer grained soils. Other conditions that may require the implementation of cyclic loaded triaxial test methods are the use of more sophisticated constitutive models in the soil structure interaction numerical codes.

8.3.1.14.2.3 Study: Field tests and characterization measurements

The objective of this study is to conduct field tests and characterization measurements. These field tests are intended to determine the in situ physical, mechanical, and dynamic properties of the soil and rock. Characterization measurements will be conducted on the rock for the purpose of classifying the rock and quantitatively describing the rock structure. Geophysical field measurements will help develop a three-dimensional model of the subsurface soil and rock strata in addition to determining their dynamic properties. Geotechnical information from this study will contribute to the development of the geotechnical design parameters presented in Table 8.3.1.14-1, which in turn will be used to address Design Issue 4.4 (Section 8.3.2.5).

8.3.1.14.2.3.1 Activity: Physical property field tests and characterization measurements

Objectives

The objectives of this activity are to classify and describe the soil and rock conditions in the field and to determine their physical properties. The results of these tests and measurements will be used to develop preliminary estimates of the engineering characteristics of the soils and rocks. In addition, these properties and measurements will aid in the grouping of oils and rocks into stratigraphic units and the extrapolation of results from a restricted number of mechanical and dynamic properties tests to zones of soil and rock with similar material properties.

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Parameters

The data and parameters that will be evaluated, collected, or both, to fulfill the objectives of this activity are as follows:

1. Soil

   a. Density.

   b. Relative density (from standard penetration blow count data on cohesionless soils).

2. Rocks

   a. Rock mass classification.

      i. Q-Norwegian Geotechnical Institute (NGI) Tunneling Quality Index.

      ii. RMR--rock mass rating from South African Council for Scientific and Industrial Research (CSIR) Geomechanics Classification.

   b. Rock structure.

      i. Quantitative description of faults.

         (a) Location.
         (b) Orientation.
         (c) Aperture.
         (d) Type of infilling.
         (e) Moisture and seepage conditions.
         (f) Waviness and roughness.

      ii. Quantitative description of joints.

         (a) Number of joint sets.

         (b) Spacing of joints for each set.

         (c) Orientation of each joint set.

         (d) Type of infilling if any.

         (e) Moisture and seepage conditions.

         (f) Waviness and roughness.

         (g) Persistence.

         (h) Drill core (total core recovery, discontinuity frequency, and rock quality designation (RQD)).

Description

Standard geotechnical engineering field tests and characterization activities will be conducted. A representative number of tests and characterization activities will be conducted throughout the reference conceptual site so that variations in physical properties and characteristics will be adequately understood.

Soils density in the field can be determined by any one of the four different methods described in the following "Methods and technical procedures" section. However, the sand-cone method is the most commonly used method for measuring density in the field. Estimates of relative density in cohesionless soils can be made empirically from Standard Penetration Test (SPT) blow count data. However, SPT blow count data are invalid for the coarse grained gravels found during the previous exploratory activities of the site (Ho et al., 1986). Therefore, the Becker penetration resistance method will be used to obtain blow count data in the coarse gravels and then correlated with equivalent SPT blow count data (Harder and Seed, 1986).

Rock mass classification data will be developed from two commonly used methods. The first method is called the tunneling quality index (Q) method and was developed by the Norwegian Geotechnical Institute, while the second method is referred to as the rock mass rating (RMR) method and was developed by the South African Council for Scientific and Industrial Research. Rock mass classification data can be used to provide preliminary estimates of rock strength and deformation characteristics. However, its primary purpose is to evaluate the stability and required support or reinforcement for subsurface excavations. This characterization data can contribute to locating and designing surface facilities such as ramp portals and shaft collars.

Rock mass discontinuities will be quantitatively described using methods recommended by the International Society for Rock Mechanics Commission on Standardization of Laboratory and Field Tests. These data will be used in conjunction with the rock mass classification data to evaluate the stability of any potentially hazardous rock slopes and to contribute to a better understanding of the engineering characteristics of the rock mass.

8.3.1.14.2.3.2 Activity: Mechanical property field tests

Objectives

The objective of this activity is to measure the deformation and strength characteristics of in situ soil and rock conditions. The results of this testing will be used to evaluate bearing capacity, earth pressures, settlement and swelling potentials, slope stability, and the dynamic response of soil and rock for the design of foundations, retaining walls, backfills, roads, and slopes.

Parameters

The data and parameters that will be collected, evaluated, or both, to fulfill the objective of this activity are listed in this section.

1. Required parameters for soil (these parameters will be developed from empirical relationships using the following possible data: Dutch cone penetration resistance, Standard Penetration Test (SPT) blow count, Becker penetration resistance, relative density and soil classification or gradation).

   a. Indirect estimates of Mohr-Coulomb shear strength parameters.

   b. Indirect estimates of stiffness or Young's modulus for use in evaluating immediate settlement (compression).

2. Contingent parameters for soil.

   a. Plate load bearing pressure versus settlement (this will be applicable if spread footings are considered in the design).

   b. Modulus of subgrade reaction from plate load test (static or dynamic).

   c. Pile load versus settlement (presently piles are not considered in the SCP-CDR (SNL, 1987)).

3. Required parameters for rock (these parameters will be developed from empirical relationships using rock mass classification data).

   a. Indirect estimates of strength.

   b. Indirect estimates of stiffness or Young's modulus.

4. Contingent parameters for rock.

   a. Plate load bearing pressure vs. settlement (on the surface or down a borehole).

   b. In situ direct shear test to measure the peak and residual shear strength of rock discontinuities.

The need for any contingent parameters will be determined by the soil or rock conditions encountered, the function or design requirements of the surface facilities, the types of foundations selected, and the type or sophistication of the analyses that are selected for the design or performance studies. On the basis of the known site conditions and the design presented in the SCP-CDR (SNL, 1987), these contingent parameters are not presently required. The contingent parameters will be characterized if unexpected soil and rock conditions are encountered, or if more sophisticated constitutive models are required or used in the soil or rock-structure interaction numerical codes.

Description

Standard field tests for geotechnical engineering practice will be conducted. Testing will be conducted only on soil and rock strata that will influence or be influenced by construction at the reference conceptual site. The type of test, location of test, and depth of test are dependent on

factors like surface facility function, loads, type and depth of footings, and subsurface soil or rock conditions. If plate bearing or pile loading tests are conducted, they will be located in the immediate vicinity and in the same soil or rock strata as that of the proposed spread footing or pile. In addition, the confinement and moisture conditions of the test and the proposed foundation will also be similar. The results of these in situ loading tests will be extrapolated to estimate the bearing capacity or potential settlement of the larger proposed foundations. However, the in situ loading tests can be extrapolated only if properties of the soil or rock are uniform both laterally and with depth, otherwise potential deep-seated settlement resulting from the entire foundation loading will not be recognized from the results of the in situ loading test.

Indirect in situ methods can be used to estimate strength and stiffness in soils. The two most common methods are the Standard Penetration Test and the Dutch Cone Test. Both of these in situ methods are penetration resistance methods with the Standard Penetration Test applying an impact load and the Dutch Cone applying a continuous load. Another method has recently been developed called the Becker penetration resistance (Harder and Seed, 1986). It is recommended that this method be used in the gravelly soils at the site.

Preliminary estimates of rock mass strength and deformability will be made from empirical relationships with rock mass classification data. Hoek and Brown (1980) have attempted to relate Q and RMR rock mass classification values to failure criteria parameters they developed, which in turn can be related to Mohr-Coulomb failure criteria parameters. Rock mass deformation modulus was also empirically related to rock mass classification values by Bieniawski (1978).

The peak and residual strength of rock discontinuities will be evaluated in the field using in situ direct shear testing methods. This type of test will only be conducted if the site reconnaissance or preliminary exploration activities identify unfavorably oriented discontinuities in a potentially unstable rock slope that could result in a hazard to a critical safety-related structure like the waste handling facility.

8.3.1.14.2.3.3 Activity: Geophysical field measurements

Objectives

Geophysical methods will be used to measure in situ soil and rock properties, profile the alluvium-bedrock contact, locate discontinuities or other structural abnormalities, and determine the depth, thickness, and lateral extent of soil and rock stratigraphic units. These geophysical activities will be integrated with other geophysical studies discussed in Section 8.3.1.4.2.1.6. Geophysical methods provide a rapid and economical means of obtaining subsurface information and supplementing other facets of the exploration program. Geophysical measurements can be used to help set up detailed exploration programs (e.g., location, number, and depth of subsurface borings, trenches, and test pits), in addition to providing input for the evaluation of ground motion response and soil-structure interaction caused by earthquakes or underground nuclear events.

Developing an understanding of the seismic response of the ground surface and its interaction with surface facilities is important for siting and designing earthquake-resistant structures. To develop this understanding, it is necessary to first identify the principal parameters that will control the seismic response of the ground surface. These parameters are the depth of the alluvium, the angle between the ground surface and the bedrock-alluvium interface, the seismic impedance contrast between the alluvium and bedrock, and the seismic absorptivity of the alluvium (Harmsen and Harding, 1981; Ohtsuke and Harumi, 1983; King and Tucker, 1984). These parameters will be used in addressing the repository design Issue 4.4 (Section 8.3.2.5) and for the preclosure tectonics investigation (Section 8.3.1.17.3) that evaluates ground motion caused by man-made or natural seismic events.

Parameters

The following data and parameters will be evaluated, collected, or both, to fulfill the objectives of this activity.

The measured or collected data for this activity are

1. Shear-wave velocities (three-dimensional model).
2. Compression-wave velocities (three-dimensional model).
3. Density (three-dimensional model).
4. Porosity.

The evaluated data for this activity are

1. Dynamic Young's modulus.

2. Dynamic shear modulus.

3. Dynamic Poisson's ratio.

4. Damping.

5. Alluvium-bedrock contact depth and angle between the surface and the bedrock-alluvium interface.

6. Seismic impedance contrast between the alluvium and bedrock.

7. Location of changes in physical properties which may indicate a geologic discontinuity.

8. Three-dimensional model of the soil and rock strata.

Description

Sufficient surface and borehole geophysical measurements will be conducted at the reference conceptual site and its vicinity such that three-dimensional models can be developed showing the subsurface geometry of the soil and rock strata and their corresponding dynamic material properties. Dynamic properties such as shear-wave and compression-wave velocities will be determined for alluvial material and bedrock beneath the reference conceptual site for the repository surface facilities and throughout Midway Valley, to a

depth of 10 to 20 m below the alluvium-bedrock contract. Information on subsurface seismic-wave transmission properties (velocities, densities, and damping) of the site is required by the preclosure tectonics investigation (Section 8.3.1.17.3) of potential ground motion caused by manmade or natural seismic events. If it is determined that a soil-structure or rock-structure interaction analysis will be required for facilities important to safety (e.g., waste handling building), then the shear-wave and compression-wave velocities will also be needed to determine the dynamic compression and shear moduli, and Poisson's ratio of the subsurface strata beneath the facilities important to safety.

Geophysical measurement methods can be categorized as either surface or borehole methods. Surface methods that will be applicable to this site and provide the required information consist of seismic refraction and possibly electrical resistivity. Borehole methods will consist of seismic and logging techniques. Borehole seismic methods include cross-hole seismic, up-hole seismic, and down-hole seismic techniques. Borehole logging techniques include neutron logging, gamma-gamma density logging, electrical logging, and acoustic or sonic logging.

Shallow seismic refraction methods can be used to determine depth of bedrock or the depth of a stratum with a substantially higher wave velocity. These methods are generally limited to depths of 1,000 ft (300 m) or less. Seismic refraction methods are most useful at sites where wave velocities in successive layers become greater with depth. For depths greater than 1,000 ft (300 m) seismic reflection methods will be used.

Various methods can be used to produce a seismic energy source. These methods can be categorized as impulse or steady-state seismic sources. The most common of these is the impulse method using small charges as the energy source. Mechanically generated energy impulses have also been successfully used to generate seismic waves.

The use of steady-state or continuous vibration provides another seismic energy source technique for characterizing the dynamic properties of the subsurface strata. This technique has certain advantages for characterizing the dynamic properties of soil and rock. All the various energy source techniques can be used to measure wave velocities, but the continuous vibration technique provides another method to better quantify properties such as the natural period of vibration, damping characteristics, and the dynamic modulus of subgrade reaction. The compressive and shear wave velocities can be used to infer the type of subsurface strata, its depth, and its thickness, and will be used in the considerations for siting and designing earthquake-resistant surface structures and foundations. The natural period of vibration is an important factor in the design of foundations subject to induced vibrations. Preliminary estimates of the allowable bearing capacity of soils can be made on the basis of empirical correlations (e.g., Terzaghi, 1943) with shear wave velocities or the natural period of vibration. Caution should be taken when using these empirical correlations especially in cases of exploration outside the region for which the correlations have been made.

For shallow geophysical exploration, electrical resistivity methods can be used to help determine the horizontal extents and depths of subsurface strata. These shallow methods are effective within the top 100 ft (30 m) of subsurface strata. The effectiveness of these methods is influenced by the moisture content and salinity of the pore water within the soil and rock. The very low moisture content of the soils at the site may limit its effectiveness. Electrical methods can be used for deeper geophysical exploration, however, they require greater energy sources and greater electrode spacing.

The cross-hole seismic method can be used to measure compressional and shear-wave velocities and damping characteristics of the subsurface strata. This method appears to be the best method for measuring in situ dynamic soil moduli (Woods, 1978). This method also allows for the measurement of velocity as a function of strain. Other advantages include the ability to identify and characterize lower velocity strata located below higher velocity strata. The disadvantage of this method is that it is more costly, requiring two or more boreholes that must be surveyed for vertical deviations. Considering the higher costs, the seismic refraction method may be preferred unless there is a need for strain-dependent velocities or the site is found to have lower velocity strata below higher velocity strata (e.g., a highly cemented layer of soil (caliche) above an uncemented or lightly cemented soil).

Up-hole and down-hole seismic methods can also be used to measure compressional and shear-wave velocities. This method is cheaper than the cross-hole seismic method because it requires only one borehole. The disadvantage is that the properties of individual layers are determined with less certainty with this method because it measures average properties between the source and the recorder.

Geophysical borehole logging will provide estimates of physical properties of the soil and rocks in addition to correlating strata between boreholes and locating strata transitions or contacts. Gamma-gamma logs will provide estimates of the bulk density of the subsurface stratas. If used in combination with neutron and acoustic logs, gamma-gamma logs will indicate the presence and degree of fracturing in crystalline rock. Neutron logs can be used to correlate strata between boreholes and to approximate water content. When used in combination with the gamma-ray log, the neutron log provides a means for identifying lithologies and estimating porosity. Acoustic or sonic logs will be used to measure wave velocities and estimate porosity. The attenuation characteristics of compressional and shear waves may be correlated with the mechanical properties and degree of fracturing and fissuring of the formation.

For correlating strata between boreholes, data from electric logs (electrical resistivity, spontaneous potential, and natural gamma) provide a means for correlation. Data from other geophysical logs will supplement the data from electric logs and will increase the confidence in correlating the strata.

8.3.1.15 Overview of thermal and mechanical rock properties program: Description of thermal and mechanical rock properties required by the performance and design issues

Summary of performance and design requirements for thermal and mechanical rock properties information

This program provides all site information needed on thermal and mechanical rock properties and on ambient stress and temperature conditions. The issues specifically requesting information from this characterization program are summarized in the following table. Other issues utilizing this information are indirectly supported by this characterization program (e.g., 1.4, 1.7, 2.4, etc.)

Data required	Issue	Short title	SCP section
Thermal properties of host rock for analyses related to waste package design	1.10	Waste package characteristics (postclosure)	8.3.4.2
Thermal/mechanical properties of the rock for repository design and in situ stress and temperature conditions for initial and boundary conditions for design calculations	1.11	Configuration of underground facilities (postclosure)	8.3.2.2
	1.12	Seal characteristics	8.3.3.2
	4.4	Preclosure design and technical feasibility	8.3.2.5
Thermal properties of rock for disturbed zone analysis	1.6	Ground-water travel time	8.3.5.12
Bulk properties and radon emanation rate for radiologic safety analysis	2.7	Repository design criteria for radiological safety	8.3.2.3
	2.2	Worker radiological safety (normal conditions)	8.3.5.4

Table 8.3.1.15-1 summarizes the required rock characteristics information and outlines the tie to this section's site characterization activities, which describe how the data will be obtained. The parameters to be measured may be different from those requested in the table. The reasons for

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 1 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.6 (8.3.5.12)	Bulk density	Rock mass; primary area	NS	NS	NS	NS	NS	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	NS
1.10 (8.3.4.2)	Bulk density	Rock mass; primary area	TSw2	$\bar{x} \pm 0.1\,\bar{x}$	Medium	2.26 - 2.33 g/cm³	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	TSw2
2.2 (8.3.5.4)	Bulk density	Rock mass; primary area	TSw2	NS	High	2.26 - 2.33 g/cm³	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	TSw2
2.7 (8.3.2.3)	Bulk density	Rock mass; primary area	TSw2	(f)	Medium to high	2.26 - 2.33 g/cm³	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	TSw2
1.6 (8.3.5.12)	Thermal conductivity	Rock mass; primary area	NS	NS	NS	NS	NS	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1	(g)	NS
								Thermal conductivity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
1.10 (8.3.4.2)	Thermal conductivity	Intact rock; primary area	TSw2	$\bar{x} \pm 0.1\bar{x}$	Medium	NS	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw2
	Thermal conductivity	Rock mass; primary area	TSw2	$\bar{x} \pm 0.1\bar{x}$	Medium	NS	Low to medium	Thermal conductivity	Rock mass	8.3.1.15.1.7.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
1.11 (8.3.2.2)	Thermal conductivity	Rock mass; primary area and extensions	TSw2	$\bar{x} \pm 0.2\bar{x}$	High	See Table 6-16	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw2
								Thermal conductivity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-16	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw1
								Thermal conductivity	Rock mass	8.3.1.15.1.6.1	ESF	TSw1

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 2 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)			TSw3, CHn1	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-16	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw3, CHn1
			Units above TSw1, CHn2	$\bar{x} \pm 0.2\bar{x}$	Low	See Table 6-16	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	(h)
1.12 (8.3.3.2)	Thermal conductivity	Rock mass; primary area	TSw2, CHn1	NS	Medium	NS	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw2, CHn1
								Thermal conductivity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
4.4 (8.3.2.5)	Thermal conductivity	Rock mass; primary area	TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw2
								Thermal conductivity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw1
								Thermal conductivity	Rock mass	8.3.1.15.1.6.1	ESF	TSw1
	Thermal conductivity	Rock mass; primary area	Ground surface to base of TSw2	$\bar{x} \pm 0.2\bar{x}$	Low	$\bar{x}$	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	Alluvium, TCw, PTn, TSw1, TSw2
								Thermal conductivity	Rock mass	8.3.1.15.1.6.1 8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw1, TSw2

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 3 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.6 (8.3.5.12)	Heat capacity	Rock mass; primary area	NS	NS	NS	NS	NS	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	NS
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
1.10 (8.3.4.2)	Heat capacity	Intact rock; primary area	TSw2	$\bar{x} \pm 0.2\,\bar{x}$	Medium	$\bar{x}$	Low to Medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw2
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	(g)	TSw2
1.11 (8.3.2.2)	Heat capacity	Rock mass; primary area and extensions	TSw2	$\bar{x} \pm 0.1\bar{x}$	High	See Table 6-16	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw2
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	(g)	TSw2
			TSw1	$\bar{x} \pm 0.1\bar{x}$	Medium	See Table 6-16	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw1
								Heat capacity	Rock mass	8.3.1.15.1.6.1	ESF	TSw1
			TSw3, CMn1	$\bar{x} \pm 0.1\bar{x}$	Medium	See Table 6-16	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw3 CMn1
			All units above TSw1, CMn2	$\bar{x} \pm 0.1\bar{x}$	Low	See Table 6-16	Low	Heat capacity of solids, grain density, porosity	Intact Rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	(f)
1.12 (8.3.3.2)	Heat capacity	Rock mass; primary area	TSw2, CMn1	NS	Medium	NS	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw2, CMn1
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 4 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
4.4 (8.3.2.5)	Heat capacity	Rock mass; primary area	TSw2	$\bar{x} \pm 0.1\bar{x}$	Medium	$\bar{x}$	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw2
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.1\bar{x}$	Medium	$\bar{x}$	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw1
								Heat capacity	Rock mass	8.3.1.15.1.6.1	ESF	TSw1
	Heat capacity	Rock mass; primary area	Ground surface to base of TSw2	$\bar{x} \pm 0.1\bar{x}$	Low	$\bar{x}$	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	Alluvium, TCw, PTn, TSw1, TSw2
								Heat capacity	Rock mass	8.3.1.15.1.6.1 8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5		TSw1, TSw2
1.6 (8.3.5.12)	Coefficient of thermal expansion	Rock mass; primary area	NS	NS	NS	NS	NS	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	NS
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.4 8.3.1.15.1.6.5	ESF	TSw2
1.11 (8.3.2.2)	Coefficient of thermal expansion	Rock mass; primary area and extensions	TSw2	$\bar{x} \pm 0.15\bar{x}$	High	See Table 6-16	Medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw2
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.4 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-16	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw1
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.1	ESF	TSw1

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 5 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)			TSw3, CHn1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-16	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw3, CHn1
			All units above TSw1, CHn2	$\bar{x} \pm 0.15\bar{x}$	Low	See Table 6-16	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	(h)
1.12 (8.3.3.2)	Coefficient of thermal expansion	Rock mass; primary area	TSw2, CHn1	NS	Medium	NS	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw2, CHn1
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.4 8.3.1.15.1.6.5	ESF	TSw2
4.4 (8.3.2.5)	Coefficient of thermal expansion	Rock mass; primary area	TSw2	$\bar{x} \pm 0.15\bar{x}$	Medium	$\bar{x}$	Medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw2
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.4 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.15\bar{x}$	Medium	$\bar{x}$	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw1
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.1	ESF	TSw1
1.11 (8.3.2.2)	Elastic properties											
	Young's modulus	Intact rock; primary area and extensions	TSw2	$\bar{x} \pm 0.15\bar{x}$	High	See Table 6-12	Medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
			TSw1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-12	Medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1
			TSw3, CHn1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-12	Low	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw3, CHn1
			All units above TSw1, CHn2	$\bar{x} \pm 0.15\bar{x}$	Low	See Table 6-12	Low to medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	(h)

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 6 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)	Deformation modulus	Rock mass; primary area and extensions	TSw2	$\bar{x} \pm 0.15\bar{x}$	High	See Table 6-14	Low	Young's modulus, fracture stiffness	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2 8.3.1.15.1.3.2	(g)	TSw2
								Deformation modulus	Rock mass	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2
			TSw1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-14	Low	Young's modulus fracture stiffnesses	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw1
								Deformation modulus	Rock mass	8.3.1.15.1.7.1	ESF	TSw1
			TSw3, CHn1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-14	Low	Young's modulus, fracture stiffness	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw3, CHn1
			All units above TSw1, CHn2	$\bar{x} \pm 0.15\bar{x}$	Low	See Table 6-14	Low	Young's modulus, fracture stiffness	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	(h)
	Poisson's ratio	Intact rock; primary area and extensions	TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Medium	Poisson's ratio	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
			All units other than TSw2	$\bar{x} \pm 0.2\bar{x}$	Low	See Table 6-12	Low to medium	Poisson's ratio	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	(h)
4.4 (8.3.2.5)	Elastic properties											
	Young's modulus	Intact rock; primary area	TSw2	29-33 GPa	Medium	31 GPa	Medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
			TSw1	Nonlithophysal: 12-54 GPa	Medium	Nonlithophysal: 19-44 GPa	Medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 7 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
4.4 (8.3.2.5) (continued)				Lithophysal: 14-17 GPa	Medium	Lithophysal: 15.5 GPa	Low	Young's modulus				
	Deformation modulus	Rock mass; primary area	TSw2	11-19 GPa	Medium	11-19 GPa	Low	Young's modulus, fracture stiffnesses	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw2
								Deformation modulus	Rock mass	8.3.1.15.1.6.3 8.3.1.15.1.7.1 8.3.1.15.2.1.2	ESF	TSw2
			TSw1	Nonlithophysal: 12-20 GPa	Medium	Nonlithophysal: 12-20 GPa	Low	Young's modulus, fracture stiffnesses	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw1
				Lithophysal: 4-11 GPa	Medium	Lithophysal: 4-11 GPa	Low					
								Deformation modulus	Rock mass	8.3.1.15.1.3.1	ESF	TSw1
	Poisson's ratio	Intact rock; primary area	TSw2	0.19-0.29	Medium	0.19-0.29	Medium	Poisson's ratio	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1
			TSw1	Nonlithophysal: 0.20-0.30 GPa	Low	Nonlithophysal: 0.20-0.30 GPa	Low to medium	Poisson's ratio	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1
				Lithophysal: 0.13-0.19	Low	Lithophysal: 0.13-0.19	Low					
1.11 (8.3.2.2)	Compressive strength	Intact rock; primary area and extensions	TSw2	$\bar{x} \pm 0.2\bar{x}$	High	See Table 6-12	Medium	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
	Compressive strength	Intact rock; primary area and extensions	TSw1	$\bar{x} \pm 0.2\bar{x}$	High	See Table 6-12	Medium	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1
	Cohesion and angle of internal friction	Intact rock; primary area and extensions	Units above TSw1 and below TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Low to medium	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	(h)

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 8 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)	Unconfined compressive strength	Intact rock; primary area and extensions	Units above TSw1 and below TSw2	$\bar{x} \pm 0.15\bar{x}$	Low	See Table 6-12	Low to medium	Unconfined compressive strength	Intact rock	8.3.1.15.1.3.1	(g)	(f)
1.12 (8.3.3.2)	Unconfined compressive strength	Rock mass; shaft and ramp locations	TCw	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Low	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TCw
	Unconfined compressive strength	Rock mass; primary area	CHn1	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Low	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	CHn1
	Unconfined compressive strength	Rock mass; primary area	TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Low	Unconfined compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
4.4 (8.3.2.5)	Compressive strength	Intact rock; primary area	TSw1, TSw2	TSw1, nonlithophysal: 54-207 MPa	Medium	67-172 MPa	Medium	Unconfined compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1, TSw2
				TSw1, lithophysal: 13-19 MPa	Medium	16 MPa	Medium	Compressive strength				
				TSw2: 121-175 MPa	Medium	148 MPa	Medium	Unconfined compressive strength				
	Unconfined compressive strength	Intact rock; primary area	TCw, PTn	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low to medium	Unconfined compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TCw, PTn
	Cohesion and angle of internal friction	Intact rock; primary area	TCw, PTn	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low to medium	Compressive strength	Intact rock	8.3.1.15.1.13.1 8.3.1.15.1.3.2	(g)	TCw, PTn, TSw1, TSw2

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 9 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2)	Mechanical properties of fractures											
	Cohesion and coefficient of friction	Fractures; primary area and extensions	Units above TSw1 and below TSw2	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-13	Low	Shear stress at onset of slip	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	(h)
	Large-scale-joint strength	Fractures; primary area	TSw1, TSw2	$\bar{x} \pm 0.2\bar{x}$	High	NS	Low	Shear stress at onset of slip	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw1, TSw2
	Normal and shear stiffnesses	Fractures; primary area and extensions	TSw2	See Table 6-13	Medium	NS	Low	Normal and shear stiffnesses	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw2
			TSw1, TSw3, CHn1	See Table 6-13	Low	NS	Low	Normal and shear stiffnesses	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	(h)
4.4 (8.3.2.5)	Mechanical properties of fractures											
	Cohesion and coefficient of friction	Fractures; primary area	TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low	Shear stress at onset of slip	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw2
	Normal and shear stiffnesses	Fractures; primary area	TSw2	NS	Medium	NS	Low	Normal and shear stiffnesses	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw2
2.2 (8.3.5.4)	Radon emanation rate	Rock mass; primary area	TSw2	NS	High	0.48 pCi/m²s	Low	Radon emanation rate	Rock mass	8.3.1.15.1.6.2	ESF	TSw2
2.7 (8.3.2.3)	Radon emanation rate	Rock mass; primary area	TSw2	(f)	High	0.48 pCi/m²s	Low	Radon emanation rate	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.8.4	ESF	TSw2
4.4 (8.3.2.5)	Radon emanation rate	Rock mass; primary area	TSw2	(f)	Medium	NS	Low	Radon emanation rate	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.8.4	ESF	TSw2
1.11 (8.3.2.2)	Empirical design parameters											
	Joint wall compressive strength	Fracture surfaces; primary area	TSw2	See Table 6-15	Medium	NS	Low	Joint wall compressive strength	Fracture surfaces	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 10 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)			TSw1, TSw3, CHn1	See Table 6-15	Low	NS	Low	Joint wall compressive strength	Fracture surfaces	NS	(g)	(h)
	Joint roughness coefficient	Fracture surfaces; primary area	TSw2	See Table 6-15	Medium	NS	Low	Joint roughness coefficient	Fracture surfaces	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2
			TSw1, TSw3, CHn1	See Table 6-15	Low	NS	Low	Joint wall compressive strength	Fracture surfaces	NS	(g)	(h)
4.4 (8.3.2.5)	Empirical design parameters											
	Joint wall compressive strength	Fracture surfaces; primary area	TSw2	See Table 6-15	Medium	NS	Low	Joint wall compressive strength	Fracture surfaces	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2
	Joint roughness coefficient	Fracture surfaces; primary area	TSw2	See Table 6-15	Medium	NS	Low	Joint roughness coefficient	Fracture surfaces	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2
1.11 (8.3.2.2)	In situ stress state[i]											
	σ_v	Rock mass; primary area and extensions	Ground surface to water table	±1 MPa	Medium	(ρgh)[j]	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	Alluvium, TCw, PTn, TSw1, TSw2, TSw3, CHn1, CHn2
	σ_h, σ_H	Rock mass; primary area and extensions	Ground surface to water table	±2 MPa	Medium	NS	Low	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1	(g)	TSw2
1.12 (8.3.3.2)	In situ stress state											
	σ_v	Rock mass; primary area	TCw, TSw2, CHn1	±MPa	Low	4-10 MPa	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	Alluvium, TC2, PTn, TSw1, TSw2, TSw3, CHn1

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 11 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.12 (8.3.3.2) (continued)	σ_h, σ_H	Rock mass; primary area	TCw, TSw2, CHnl	±2 MPa	Low	σ_h/σ_v, σ_H/σ_v = 0.3-1.0	Low	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TCw, TSw2, CHnl
4.4 (8.3.2.5)	In situ stress state											
	σ_v	Rock mass; primary area	TSw2	300 m depth: 6.3-7.7 MPa	Medium	(6.3-7.7 MPa)	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	Alluvium, TCw, PTn, TSw1, TSw2,
	σ_h/σ_v	Rock mass; primary area	TSw2	0.3-0.8	Medium	0.3-0.8	Low	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TSw2
	σ_H/σ_v	Rock mass; primary area	TSw2	0.3-1.0	Medium	0.3-1.0	Low	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TSw2
	Bearing of σ_h	Rock mass; primary area	TSw2	N.45°W-N.65°W	Medium	N.45°W-N.65°W	Medium	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TSw2
	Bearing of σ_H	Rock mass; primary area	TSw2	N.25°E-N.40°E	Medium	N.25°E-N.40°E	Medium	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TSw2
1.6 (8.3.5.12)	Initial temperatures	Rock mass; primary area	TSw2	NS	NS	NS	NS	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2
1.10 (8.3.4.2)	Initial temperatures	Rock mass; primary area	TSw2	±3°C	Medium	23-25°C	Medium	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2
1.11 (8.3.2.2)	Initial temperatures	Rock mass; primary area and extensions	TSw2	±3°C	Medium	23-26°C	Medium	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2 and above
4.4 (8.3.2.5)	Initial temperatures	Rock mass; primary area	TSw2	23-25°C	Medium	23-25°C	Medium	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2

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Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 12 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
4.4 (8.3.2.5) (continued)	Initial temperatures	Rock mass; primary area	TSw2	±2C	Medium	Present values ±2C	Medium	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2
	Initial temperatures	Rock mass; primary area	Ground surface to base of TSw2	±2C	Medium	Present values ±2C		Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	Alluvium TCw, PTn, TSw1, TSw2

[a]This table summarizes requirements of both preclosure and postclosure issues.

[b]Definitions of the primary area and extensions are provided in Chapter 6, Figure 6-87.

[c]The thermal/mechanical stratigraphy at Yucca Mountain is shown in Figure 2-5 of Chapter 2. CHn = Calico Hills nonwelded unit; PTn = Paintbrush nonwelded unit; TCw = Tiva Canyon welded unit; TSw = Topopah Spring welded unit; and NS = not specified.

[d]The manner in which tentative goals and levels of confidence are used in planning the characterization program is discussed in the investigation for Section 8.3.1.15.1.

[e]$\bar{x}$ = mean value of existing sample group.

[f]Tentative goal is that a prescribed percentage (related to the needed confidence) of the data falls within the given interval. Failure to meet the goal will result in a need to reevaluate the existing design.

[g]Spatial locations will be a combination of new boreholes (location to be determined; see Investigation 8.3.1.4.1 for discussion) and the exploratory shaft and associated underground excavations; ESF = exploratory shaft facility.

[h]Stratigraphic locations will be in the units specified as required by pertinent issues if measurements need to be made. For many parameters for which the required confidence level is low, existing data will be sufficient to satisfy the requirements.

[i]σ_v = vertical in situ stress; σ_h = minimum horizontal in situ stress; σ_H = maximum horizontal in situ stress.

[j]ρgh indicates the product of density (ρ), gravitational acceleration (g), and height of overlying column of rock (h).

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the differences and the techniques to be used to produce required data from measured data are described in later portions of Section 8.3.1.15. In addition, amplified discussions of the reasons for the selection of testing techniques are provided in a number of study plans to be written in support of the SCP. In some instances, a preferred test technique is to be prototyped before use in site characterization. If prototyping indicates that a preferred technique will not produce satisfactory results, an alternative technique will be selected.

The stratigraphic locations in Table 8.3.1.15-1 are thermal/mechanical units rather than formal stratigraphic units. This approach has been taken because the repository design process uses the thermal/mechanical units as the stratigraphic framework for analysis. The relationship between formal stratigraphic units and thermal/mechanical units is provided in Figure 2-5 in the introduction to Chapter 2.

In addition to the parameter requirements listed in Table 8.3.1.15-1, several additional requirements from design issues affect the characterization program described in this section. Data on the multidimensional deformations that may result from repository-induced stresses will be obtained from the Yucca Mountain heated block experiment (Activity 8.3.1.15.1.6.3). In addition, information on opening stability and ground support systems, required by Issue 4.2 (Section 8.3.2.4) will be obtained as part of Activities 8.3.1.15.1.5.2, 8.3.1.15.1.5.3, and 8.3.1.15.1.6.5, and Study 8.3.1.15.1.8.

Figure 8.3.1.15-1 shows the ties between the investigation for acquisition of data on thermal and mechanical rock properties (Investigation 8.3.1.15.1) and performance assessment and design issues. Detailed logic diagrams are presented in Figure 8.3.1.15-2 (bulk, thermal, and mechanical properties) and Figure 8.3.1.15-3 (ambient stress and temperature conditions) as a supplement to the details in Table 8.3.1.15-1. These detailed diagrams show the studies and activities planned to provide the site data required by the performance and design issues.

Approach to satisfy performance and design requirements

The performance allocation process as described in Section 8.2 requires the definition of performance goals for design and performance assessment issues. These performance goals then are used to define the data necessary to address the issues. The necessary data are specified by the parameters contained in the equations, analyses, relationships, etc. being considered for evaluating whether the performance goals are met. The required thermal and mechanical data are listed in Table 8.3.1.15-1. The characterization goals in the table are quantitative estimates of the maximum variability in a parameter that can be tolerated without necessitating a change in the existing design. Required confidence levels are a measure of how important it is that the specified limits are met. The characterization goals and confidence levels reflect the sensitivity of a performance measure to variations in the parameter (Appendix N of SNL, 1987). When more than one issue requires a given parameter at the same location, the requirement that poses the greatest constraint will be used in planning site studies and activities to obtain values for the parameter. As site characterization proceeds, some proportion of the site data values may be found to fall

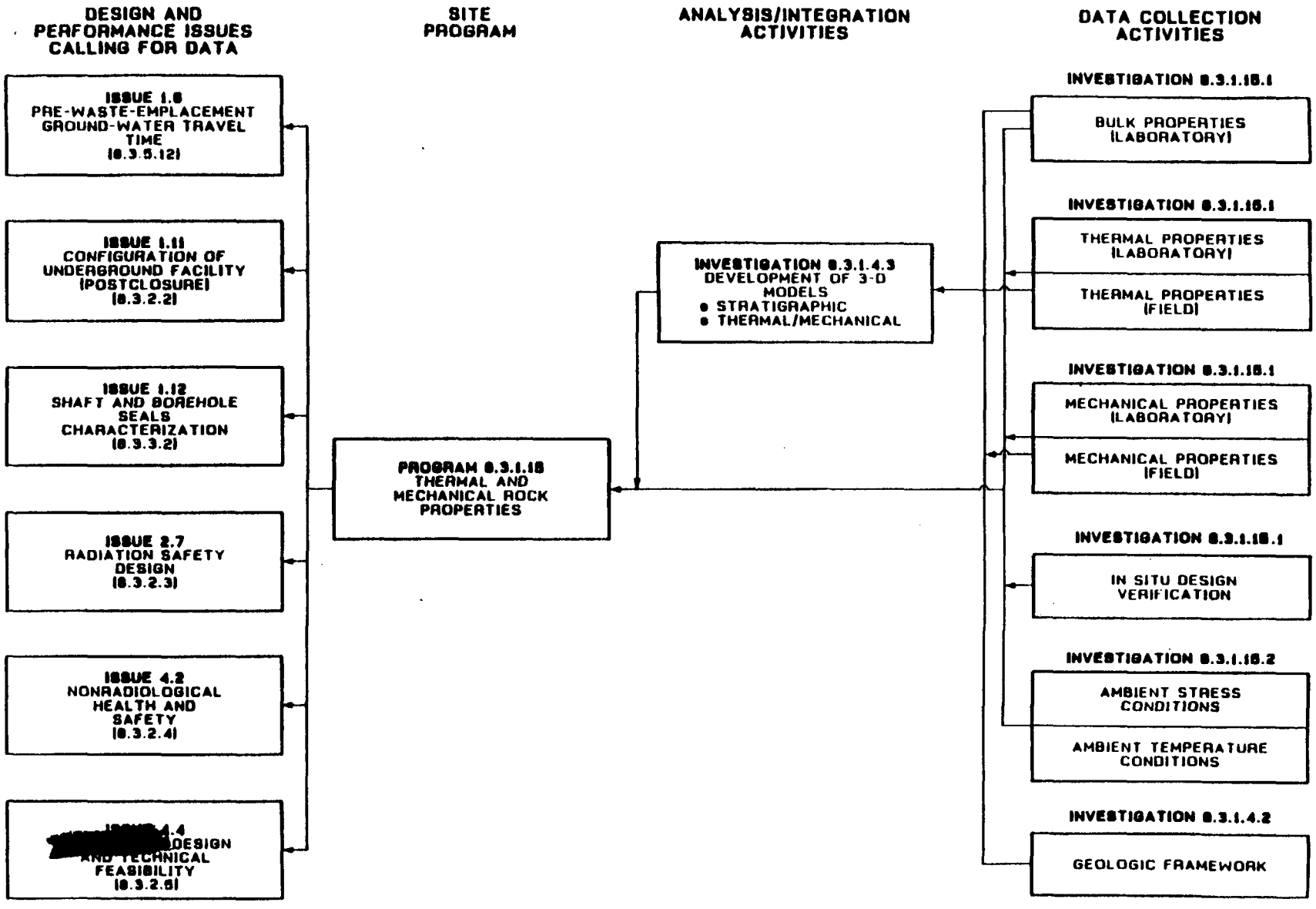

Figure 8.3.1.15-1. Relationship between data acquistion for rock properties and issues requiring the data

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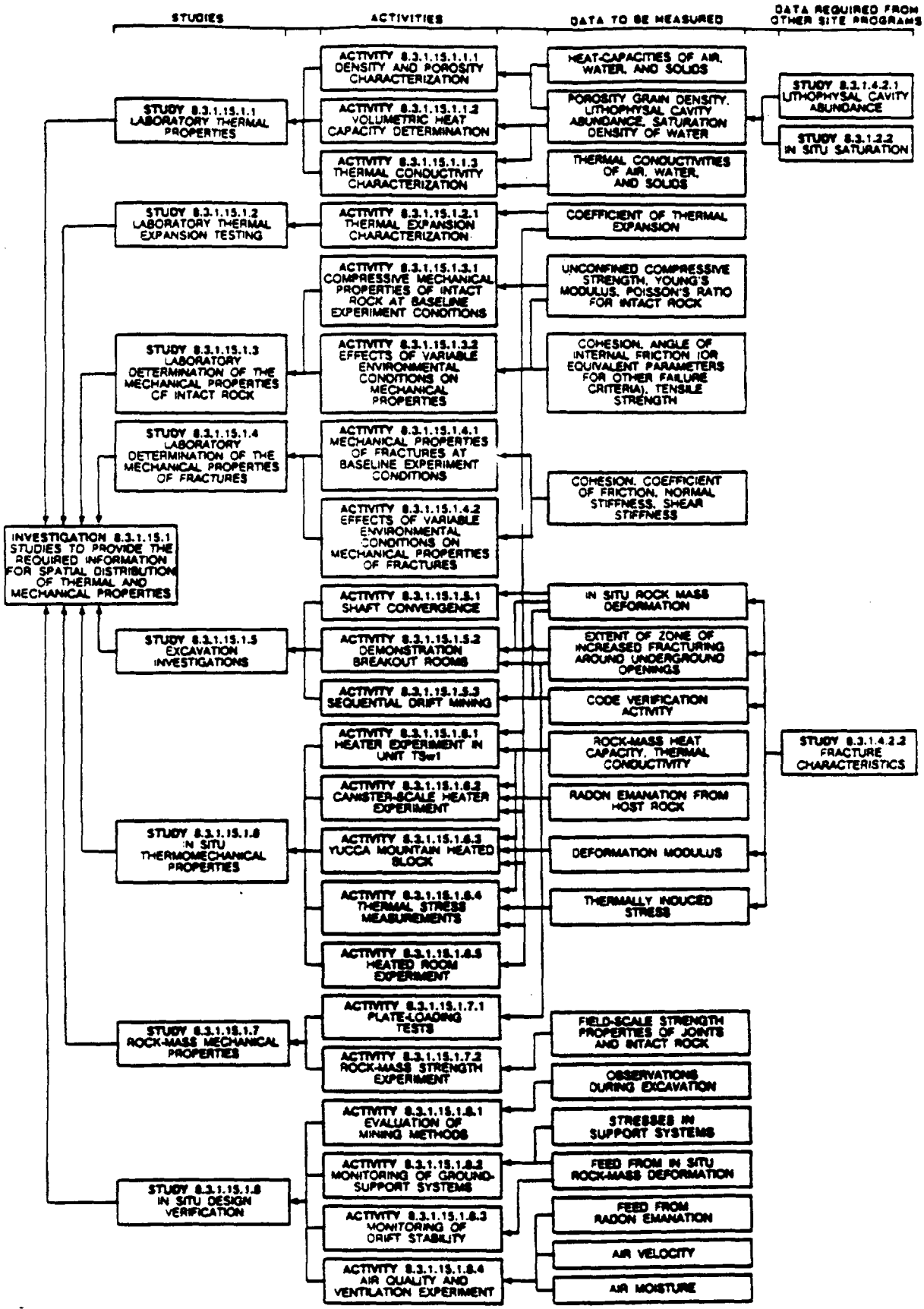

Figure 8.3.1.15-2. Logic diagram for Investigation 8.3.1.15.1, spatial distribution of thermal/mechanical rock properties

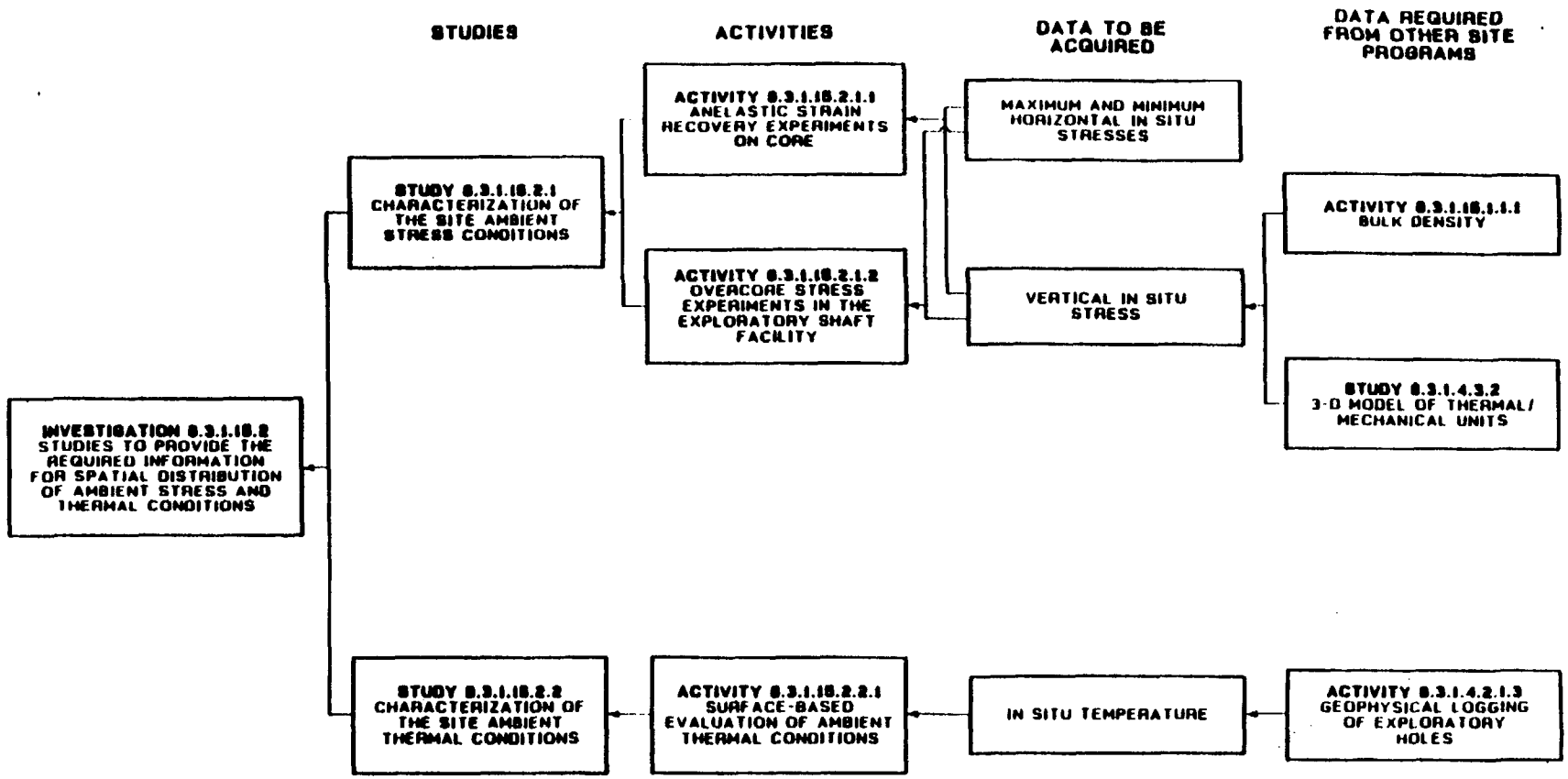

Figure 8.3.1.15-3. Logic diagram for Investigation 8.3.1.15.2, spatial distribution of ambient stress and temperature conditions

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outside the specified limits. If this occurs, the portions of the design or of the performance assessment programs affected by these data will be reevaluated to assess the impact. New limits to these data may be specified, and additional data will be collected if necessary.

In addition to the iterative process outlined in the preceding paragraph, the possibility exists that not all necessary data have been identified or that the specified limits are invalid because of the preliminary nature of the supporting sensitivity studies. In these cases, additional data may be requested or the specified limits for a parameter already requested may be changed. Either situation might lead to a modification to the investigations outlined in Sections 8.3.1.15.1 and 8.3.1.15.2.

Alternative conceptual models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses which are also consistent with available data and that may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) the activities or studies which are designed to discriminate between alternative hypotheses or to reduce uncertainty. Table 8.3.1.15-2 is the hypothesis-testing table for the site program on thermal and mechanical rock properties. Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate.

Hypotheses for modeling thermal and mechanical properties have been categorized as pertaining to the process of heat transfer or to mechanical constitutive models. These model elements are listed in column one.

The second column of the table lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Table 8.3.1.15-2 provides a judged level of uncertainty designated "high," "moderate," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Table 8.3.1.15-2. Current representation and alternative hypotheses for modeling for the thermal and mechanical rock properties program (page 1 of 3)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Process of heat transfer	Dominated by conduction	Low--existing thermal conductivity data indicate conduction is dominate heat transfer process	Convection Radiation Convection and radiation Latent heat transfer	Temperature (to limit potential for adverse geochemical, etc. effects on the host rock)	Medium to low	Medium--process of heat transfer impacts repository layout and design	Low--existing data are adequate for planning and conceptual design; additional data will increase confidence for advanced conceptual design and license application	Convection and radiation contributions will be assessed during in situ heater experiments; Study 8.3.1.15.1.6, in situ thermomechanical properties Latent-heat transfer will be assessed during laboratory thermal conductivity experiments; Study 8.3.1.15.1.1 (laboratory thermal properties)
				Temperature in retrieval area	Medium	Same as above	Same as above	
				Potential for significant displacement	Medium	Same as above	Same as above	
				Surface uplift	Low	Same as above	Same as above	
				Rock mass temperature	High	Same as above	Same as above	
				Stress, deformation, factor of safety, and potential rock fall	High	Same as above	Same as above	
				Time container is above boiling temperature of water	High	Same as above	Same as above	

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Table 8.3.1.15-2. Current representation and alternative hypotheses for modeling for the thermal and mechanical rock properties program (page 2 of 3)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Mechanical constitutive models	Time-independent deformation Elastic Elastic-plastic Elastic-plastic with compliant joint	Medium-low--existing data and excavation experience in tuffs indicate deformation is time independent	Time-dependent deformation Linear creep Nonlinear creep	Access closure Drift closure Rock movement Access sizes and grades compatible with requirements for personnel, material transport and utility routing	Medium Medium Medium High to medium	High--deformation type could affect long-term opening stability, retrievability, and nonradiological worker health and safety	Medium--existing data are adequate for planning and conceptual design; additional data are required to increase confidence for advanced conceptual design and license application	Creep experiments are planned on intact rock samples and fractured samples; Study 8.3.1.15.1.3, Laboratory determination of mechanical properties of intact rock; Study 8.3.1.15.1.4, Laboratory determination of mechanical properties of fractures
				Accesses (shafts and ramps) usable for 100 yr with reasonable maintenance	High	Same as above	Same as above	Same as above
				Rockfall quantity and retention	Medium	Same as above	Same as above	Same as above
	Material can be modeled as a continuum, with discrete slip surfaces	Medium--there is reasonable agreement between preliminary continuum model results and excavation experience in tuffs	Material is a collection of individual blocks (Cundall-type block model)	Same as above	Same as above	Low--small magnitudes of anticipated rock mass displacements are insensitive to constitutive model type	Low--existing model representation is appropriate for advanced conceptual design and licensed application design	Evaluations of the constitutive model types are planned under activities discussed in Section 8.3.2.1.4

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Table 8.3.1.15-2. Current representation and alternative hypotheses for modeling for the thermal and mechanical rock properties program (page 3 of 3)

Current representation		Uncertainty in current understanding	Alternative hypothesis and significance					Tests to distinguish hypothesis and reduce uncertainty
Model element	Current representation	Uncertainty and rationale	Alternative hypothesis	Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
Mechanical constitutive models (continued)	Matrix failure considered through post-processing of analyses	Medium--excavation experience to date indicates that matrix failure does not control rock mass failure	Matrix damage is feasible mechanism that must be modeled and and included as part of analysis	Same as above	Same as above	Low--preliminary model results indicate that post-processing of analyses is appropriate to address matrix failure because model stresses generally do not exceed matrix failure criterion	Low--existing model representation is appropriate for advanced conceptual design and license application design	Evaluations of the constitutive model types are planned under activities discussed in Section 8.3.2.1.4

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Column six gives the needed confidence in the indicated performance measure or performance parameters, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of performance parameters in column five to the selection of hypotheses in columns two and four for that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The final column identifies the characterization studies or activities that will discriminate among alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

Interrelationships of thermal and mechanical rock properties investigations

As shown on Figures 8.3.1.15-2 and 8.3.1.15-3, two investigations and ten studies are planned to collect the required rock characteristics data. The studies consist of those related to laboratory determination of thermal and mechanical properties, to in situ experiments in the exploratory shaft, and to characterization of ambient stress and thermal conditions. Studies related to laboratory testing are grouped by parameter(s). In contrast, in situ experiments are divided into four categories by type of experiment: (1) experiments related to evaluation of the effects of excavation, (2) mechanical property experiments, (3) thermomechanical property experiments, and (4) in situ design verification experiments. Characterization of ambient stress and thermal conditions will include measurements of stress and temperature in exploratory holes and in the exploratory shaft.

Data on thermal and mechanical rock properties will be needed for and/or obtained from many of the coupled-interaction tests listed in Table 8.3.2.1-1 (Studies or activities for coupled interaction tests). This includes the effects of thermal perturbations on near-field repository rocks in Study 1.10.4.2 (hydrologic properties of waste package environment).

8.3.1.15.1 Investigation: Studies to provide the required information for spatial distribution of thermal and mechanical properties

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Chapter 2 summarizes the available data relevant to thermal and mechanical properties of the tuff units at Yucca Mountain.

Parameters

Table 8.3.1.15-1 presented in the previous section summarizes the thermal/mechanical properties required for resolution of performance assessment and design issues. Table 8.3.1.15-3 summarizes the thermal and mechanical properties listed in Table 8.3.1.15-1. These properties will be used with the other data on rock characteristics to develop the three-dimensional thermal, mechanical, and thermomechanical models in Section 8.3.1.4.3. Several additional parameters also are required to enable estimates to be made for some of the parameters listed in Table 8.3.1.15-3. These additional parameters include grain density, heat capacity and thermal conductivity of zero-porosity material, lithophysal cavity abundance, and in situ saturation state. The relevance of each of these parameters is discussed later. All are to be obtained in the studies contained in Investigation 8.3.1.15.1 with the exception of lithophysal cavity abundance and saturation state. Acquisition of data on cavity abundance is discussed in Investigation 8.3.1.4.2 (geologic framework), whereas data acquisition for saturation state is discussed in Investigations 8.3.1.2.2 and 8.3.1.2.3 (site unsaturated and saturated zone hydrologic system). Information obtained from mineralogic and petrologic studies discussed in Investigation 8.3.1.3.2 (mineralogy, petrology, and rock chemistry) will be used to help determine the spatial distribution of thermal and mechanical properties.

Purpose and objectives of the investigation

The purpose of this investigation is to provide the information on spatial distribution of thermal and mechanical properties requested by performance and design issues. The performance allocation process identified performance measures and goals. To determine whether the performance goals can be met, data must be available on various site parameters, and the data must have associated levels of confidence. The parameters and associated confidence levels are identified in the performance assessment and design issues, and serve as the basis for planning of a site characterization program. The information required by performance assessment and design issues on bulk, thermal, and mechanical properties is shown in Table 8.3.1.15-1 together with the activities planned to acquire site characterization data on these properties. The general link between the site characterization program and the issues requiring data was shown in Figure 8.3.1.15-1, and Figure 8.3.1.15-2 depicts the detailed logic for completion of this investigation.

Technical rationale for the investigation

Completion of this investigation requires the acquisition of data for each parameter listed in Table 8.3.1.15-3 as well as evaluation of the spatial variation of each parameter. Preliminary data are available for most of these parameters, as summarized in Chapter 2. However, additional data are required to analyze spatial variability of properties and, for some parameters, to obtain the required number of data. In addition, existing data may be biased because of drillhole orientation or other sampling limitations; the potential bias needs to be evaluated and recognized during future work.

Table 8.3.1.15-3. Thermal and mechanical properties required by other issues

Property	Matrix	Fractures	Rock mass
Thermal			
Thermal conductivity			x
Heat capacity			x
Thermomechanical			
Coefficient of thermal expansion	x		
Mechanical			
Poisson's ratio	x		
Young's modulus	x		
Deformation modulus			x
Compressive strength	x		
Cohesion	x		
Angle of internal friction	x		
Fracture properties			
Cohesion		x	
Coefficient of friction		x	
Normal stiffness		x	
Shear stiffness		x	
Joint wall compressive strength		x	
Roughness coefficient		x	
Miscellaneous			
Bulk density			x
Radon emanation			x
Excavation observations		x	x

Of the parameters listed in Table 8.3.1.15-3, thermal expansion coefficients, Poisson's ratios, Young's moduli, and compressive strength (laboratory), will be obtained directly from laboratory measurements. Joint properties (normal and shear stiffnesses, cohesion, and friction coefficient) will also be measured in the laboratory, but with the realization that it will be necessary to scale the results to achieve relevance to in situ conditions.

Several of the parameters identified in Table 8.3.1.15-3 are intended to be representative of the rock mass; they are included in the table in recognition of the fact that the rock-mass behavior cannot be adequately characterized by laboratory-determined parameter values alone. The approach taken

in this section is to consider two categories of parameters in addressing the question of whether the laboratory and field-obtained data are representative of the rock mass.

In the first category, which includes parameters such as in situ bulk density, heat capacity, and thermal conductivity, data applicable to the rock mass will be calculated or estimated from other parameters not specifically required by performance assessment or design issues, such as grain density, mineral constituents, and porosity. Knowledge of laboratory-measured values of these non-required parameters, and their variability in the laboratory or in situ, will support the determination of rock-mass data for required parameters in the first category. Calculated data for the rock mass, together with related laboratory data, can be compared with the corresponding parameter values obtained from field experiments. Historical evidence suggests that there is likely to be good correlation between laboratory and field results for this category of in situ parameters. Any discrepancies that may arise between predicted in situ parameter values and the measured in situ values will be assessed to ascertain the adequacy of the predictive algorithm and of the measurement techniques used in field tests. If necessary, the basis of any predictive algorithm used will be reevaluated and additional laboratory or field tests may be performed. These additional tests could be required because of a need to measure different parameters, a need to repeat measurements under different test conditions, or a need to revise in situ measurement techniques.

The second category of parameters that can be obtained from in situ tests, including such parameters as rock-mass deformability and rock-mass strength, will be treated differently. The parameters in this category are not expected to be calculable using simple predictive equations and laboratory-obtained parameter values. Rather, parameters in this category are sensitive to the scale of the test (volume of rock material involved in the test). It is expected that field measurements of parameters other than the parameter of interest will be required to estimate the in situ value of the parameter. For the rock-mass deformation properties identified in this section, fracture geometry, characteristics, and properties are the most likely additional required information. Differences between laboratory and in situ measured values for parameters such as deformation modulus are expected to be caused by the presence of fractures in the rock mass on a scale that cannot be included in laboratory samples. Values for deformation properties can be calculated by combining intact-rock properties and fracture characteristics and properties in finite-element computations. Alternatively, the rock-mass properties can be estimated by applying corrections deduced from in situ fracture characteristics to intact-rock properties. Historically, such corrections in the form of reduction factors have been deduced from fracture frequency, or such indices as rock quality designation.

It would be imprudent to plan numerous large-scale tests to measure rock-mass deformation properties considering the time and expense required for such tests. Furthermore, the data from these tests is potentially

difficult to interpret. In the planned program, information about rock-mass deformation properties will be obtained through a combination of empirical approaches to rock-mass opening design, sequential instrument emplacement and excavation, and analytical modeling of excavation behavior. The analytical modeling described in Sections 6.4.8 and 8.3.2.8 of the SCP will make use of both equivalent modulus and compliant joint approaches. The equivalent modulus approach will use the reduced modulus values derived from laboratory modulus tests, observed fracture characteristics, and measured in situ deformation moduli. The compliant joint approach will use laboratory-measured moduli and joint deformation properties such as stiffness, as well as joint characteristics such as location, orientation, and spacing. The results of both modeling approaches will be used to confirm the reduction factor used to estimate in situ deformation moduli.

There are two additional considerations relevant to rock-mass deformation and strength properties. Rock-mass strength can be considered in terms of allowable movement on joints, of the strength of the intact rock, or of a combination of the two. Modeling performed to date does not provide confidence in predicting the rock-mass response because of the preliminary nature of the physical models studied and of the data used. Some of the different situations modeled should be examined further using refined codes and a more complete and representative data set. Data to be obtained from the rock-mass response experiment(s) (Section 8.3.1.15.1.7.2) will aid in this modeling effort and in the characterization of rock-mass strength.

The second additional consideration relevant to rock-mass deformability involves the estimation of in situ modulus of deformation. Estimation of in situ modulus of deformation will involve a combined examination of spatial variability in Young's modulus as determined through statistical analysis of laboratory data, of limited field measurements, demonstration excavations, modeling, and spatial variability of other in situ properties such as fracture characteristics. This approach could be sensitive to significant changes in rock-mass conditions such as fracture characteristics. The planned program should be sufficiently flexible to provide a methodology for confirming estimated values of rock-mass modulus should significant changes in fracture characteristics be encountered within the exploratory shaft facility (ESF) or within the boundaries of the repository excavation. It will not be known in advance of ESF excavation whether lateral variability in fracture characteristics would be significant to the point of requiring additional confirmatory testing of deformation modulus within the ESF beyond the testing already planned.

Parameters that vary as a function of saturation (i.e., bulk density, heat capacity, thermal conductivity, and the strength of intact rock) are difficult to characterize for all possible saturation states. Estimates of these parameters will be obtained from known parameters by following the steps described below (bulk density will be used as an example):

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1. Calculate the mean value of the parameter to be estimated using the mean values of the known parameters:

$$\rho_b = \rho_g(1 - \phi) - \rho_w \phi S \qquad (8.3.1.15\text{-}1)$$

where

ρ_b = bulk density
ρ_g = grain density
ϕ = porosity (matrix porosity and lithophysal cavities)
ρ_w = density of water
S = saturation.

2. Obtain the partial derivatives of Equation 8.3.1.15-1 (or the appropriate equation for another parameter; such equations need not be linear functions of saturation) with respect to the known parameters $\left(\text{e.g., } \frac{\partial \rho_b}{\partial \rho_g}, \frac{\partial \rho_b}{\partial \phi}, \frac{\partial \rho_b}{\partial S}, \frac{\partial \rho_b}{\partial \rho_w}\right)$

3. Calculate the standard deviation of the parameter to be estimated (e.g., ρ_{db}) using the partial derivatives from step 2 and the standard deviations of the known parameters:

$$\sigma_{\rho_b} \approx \left[\sigma^2_{\rho_g}\left(\frac{\partial \rho_b}{\partial \rho_g}\right)^2 - \sigma^2_{\phi}\left(\frac{\partial \rho_b}{\partial \phi}\right)^2 - \sigma^2_{S}\left(\frac{\partial \rho_b}{\partial S}\right)^2 - \sigma^2_{\rho_w}\left(\frac{\partial \rho_b}{\partial \rho_w}\right)^2\right]^{1/2} \qquad (8.3.1.15\text{-}2)$$

where the partial derivatives are evaluated at the mean values of the known parameters. Note that the implicit assumption is made in the use of Equation 8.3.1.15-2 that all variables on the right-hand side for which standard deviations are given are independent random variables.

The assumption is often made that rock properties are monotonic functions of saturation. This may not be true for thermal conductivity. The thermal conductivity of partially saturated materials may be higher than that of dry or fully saturated samples because of latent heat transfer (e.g., Pratt, 1969). Measurements are planned to evaluate the nature of this saturation dependence (Section 8.3.1.15.1.1.3).

Use of statistics in design of characterization program. For most of the parameters listed in Table 8.3.1.15-3, preliminary data are available that can be used to estimate future testing requirements for satisfaction of the information need. These preliminary data are the result either of measurements in the laboratory or of the estimating procedure outlined above. The parameters for which such preliminary data are not available are fracture properties (cohesion, coefficient of friction, normal stiffness, and shear stiffness). The logic for determining the fracture properties with the required confidence is presented at the end of the following discussion.

The preliminary data comprise observations from a number of sample locations (boreholes). The data were statistically analyzed to evaluate whether they represented a single unit, several units, or varied according to some

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spatial trend. For each parameter, a sample mean ($\bar{x}$) and standard deviation (s) were calculated. These quantities are estimates of the population mean (μ) and standard deviation (σ). If the samples are from the same unit, the population mean for each sample will be equal:

$$\mu_1 = \mu_2 = \mu_3 = \ldots = \mu_i$$

This hypothesis was tested by comparing the sample means statistically by an analysis-of-variance technique. On the basis of these analyses, it was concluded that the samples were from the same unit (i.e., spatial variability over large distances is not present) and the statistics for the unit ($\bar{x}$, s) were calculated from all the observations.

The parameters discussed in this section are assumed to be normally distributed. The validity of this assumption will be checked for each parameter during site characterization activities. The requirements imposed by performance and design issues are that some proportion γ of the interval $\bar{x} \pm ks$ will include $100(1 - \alpha)$ percent or more of the true distribution, where α is the level of significance (Bowker and Lieberman, 1972) and k is related to α, γ, and n, the number of samples. In this analysis, γ is a preassigned probability that the interval between $\bar{x} - ks$ and $\bar{x} + ks$ includes at least a specified proportion $(1 - \alpha)$ of the true distribution. The goals listed for the parameters in Table 8.3.1.15-1 usually take the form of $\bar{x} \pm F\bar{x}$ where F is a function of $\bar{x}$. Comparison of $F\bar{x}$ with ks, where $\bar{x}$ and s are calculated using existing data, allows estimates of a value for k.

One of three qualitative levels of confidence has been associated with each data request listed in Table 8.3.1.15-1 -- high, medium, or low. To obtain initial estimates of sampling requirements, the following numerical values of α are associated with each qualitative confidence level:

Specified confidence	α
High	0.05
Medium	0.10
Low	0.25

The qualitative levels of confidence were assigned by different individuals, all of whom have different problems to address. Thus, the values of α given above may be more restrictive than is necessary for some applications. However, the values have been selected in an attempt to satisfy even the most stringent of the qualitative requirements. For convenience, $(1 - \alpha)$ is assumed to be the same as γ. Given values of α, γ, k, and an assumed statistical distribution, statistical tables can be used to estimate n, the number of samples to be tested in order to satisfy the specified requirements. Depending on the structure of observed data, it may be appropriate to use types of distribution functions other than the normal distribution for revising the estimates of the required number of samples.

For example, to calculate the vertical in situ stress in unit TSw2 with medium confidence, the in situ bulk density of unit TSw2 must be known with

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medium confidence. Thus, from the preceding discussion, $\gamma = (1 - \alpha) = 0.90$. If the range were required to be $\bar{x} \pm 0.1\bar{x}$, then equating ks and $0.1\bar{x}$ (using existing data to estimate $\bar{x}$ and s for in situ bulk density) would give $k = 0.1\bar{x}/s = 2.13$. Entering the appropriate table in Bowker and Lieberman (1972), the number of samples is found to be 22.

Two comments on this technique are necessary. First, the values of n obtained are estimates based on the preliminary data currently available. These values of n may need to be revised as site characterization data become available because the possibility exists that statistical analysis of the site characterization data may indicate spatial trends of μ and σ within a unit.

Secondly, the values of n are for a specified set of conditions at which preliminary data were obtained. No a priori assumptions have been made about the variability in a parameter resulting from changes in the experiment environment. If a parameter should vary as a function of sample size or experiment conditions, then n measurements should be obtained at each set of relevant experiment conditions. Because of the relatively large value of n for unit TSw2 (discussed in subsequent text), fewer experiments will be performed in the initial evaluation of the effects of experiment conditions. More experiments will be performed if these initial experiments indicate the need.

For the fracture properties, values of $\bar{x}$ and s are not available, so that n cannot be estimated by the procedure discussed above. Instead, the number of samples to be tested initially will be selected arbitrarily. The data from these initial experiments then will be used to estimate n, and additional experiments will be conducted if necessary.

Some parameters have preliminary data for which the variability is quite large. Variability can result from a number of sources: natural, sampling, preparation, and analytical. Present data are insufficient to determine the magnitude of the contribution from each source. For parameters where the existing value of s is too large to allow calculation of n using the tolerance limits requested by other issues, the initial value of n is arbitrarily assumed as follows:

Specified confidence	Number of samples
High	35
Medium	10
Low	5

Data obtained from these experiments then will be used to reassess whether the requested tolerance limits can be met using the normal distribution function or other distribution functions, as applicable. If not, either new tolerance limits will be set, and the impact on repository design or performance will be evaluated, or additional experiments will be performed to determine whether an increased sample size will reduce the observed variability.

Evaluation of data sufficiency after initial sampling and testing will be used with other information to help decide if additional testing is necessary.

The preceding discussion is based in part on the assumption that the sample used to obtain $\bar{x}$ and s is a random sample of the total population. Each thermal/mechanical unit is a three-dimensional body; the five existing core holes comprise only a partially random sample of the units, as will the exploratory shaft facility (ESF) excavations. In fact, a site characterization program in which core holes and underground excavations are designed to investigate specific areas or features of interest can be considered to provide approximations rather than statistically representative sampling.

In view of the limitations on the randomness of sampling, the next best situation is one in which coverage of the repository area is maximized. The existing core holes within and close to the area are situated near the northern and southern limits. The ESF will allow expanded coverage of the northern, central, and southern portions of the repository area. Coring of several new core holes will be necessary for the determination of the spatial variability of thermal and mechanical properties.

Preliminary data suggest that spatial variability of these properties is small within TSw1 and TSw2 (Nimick and Schwartz, 1987). However, additional data are required for these and other units in the central and southern portions of the repository area. Also, data for units lying below the top of CHn1z must be obtained from at least one additional core hole in the northern part of the area. As stated earlier, the estimated values of n for individual parameters in individual thermal/mechanical units will apply for each core hole and for the ESF.

As discussed previously, acquisition of thermal and mechanical properties with the confidences requested by performance and design issues requires minimum numbers of experiments that vary with each property. The relatively large number of laboratory tests will augment the data available from a necessarily limited number of in situ tests. Values of rock-mass properties that will be obtained from in situ thermal and mechanical tests will serve as guideline properties and will be used to examine the validity of estimating rock-mass properties using laboratory data combined with information about in situ fracture characteristics.

In addition to providing estimates of rock-mass properties, in situ experiments will serve other purposes. Some tests will be used to monitor the behavior of underground excavations in units TSw1 and TSw2. Both qualitative and quantitative information will be obtained from these observations. Quantitative information for one experiment (sequential drift mining, Activity 8.3.1.15.1.5.3) will be used for code validation work on codes used to calculate mechanical response to imposed stresses. Validation work also will be performed for codes that calculate thermal, mechanical, or coupled thermal and mechanical responses to imposed temperatures and stresses using data from

the canister-scale heater and heated-block experiments. In general, the codes to be validated will be used to contribute to the resolution of Issues 1.11 and 4.4 (Sections 8.3.2.2 and 8.3.2.5). Additional discussion of code-validation work is presented in Section 8.3.2.1.4.

8.3.1.15.1.1 Study: Laboratory thermal properties

The objective of this study is to provide laboratory characterization of thermal conductivity and heat capacity and the spatial variability thereof. In order to do so, porosity, grain density, and the heat capacity and thermal conductivity of zero-porosity material also must be characterized. The discussion for Activities 8.3.1.15.1.1.1, 8.3.1.15.1.1.2, and 8.3.1.15.1.1.3 applies for each new core hole selected for characterization and for the exploratory shaft facility (ESF).

The validity of extrapolation of laboratory-determined thermal properties to in situ conditions will be examined by comparison of the properties with data obtained from in situ heater tests in the ESF. Temperature fields induced during the heater tests will be modeled using numerical techniques, with values for thermal properties being varied until an optimum match of predicted and actual temperatures is obtained. Additional discussion of the heater tests is presented for Activities 8.3.1.15.1.6.1, 8.3.1.15.1.6.2, 8.3.1.15.1.6.3, and 8.3.1.15.1.6.5 under Study 8.3.1.15.1.6.

8.3.1.15.1.1.1 Activity: Density and porosity characterization

Objectives

The objective of this activity is to obtain data on density and porosity and to evaluate the spatial variability thereof. Data will contribute to determination of in situ thermal properties (porosity and grain density), to vertical in situ stress (bulk density), and radiation-shielding properties (bulk density).

Parameters

The parameters for this activity are matrix porosity, grain density, and in situ bulk density. (Matrix porosity refers to the total void space, as distinguished from the effective porosity that is available for hydrologic flow.) Parameters required that are to be supplied by other investigations are in situ saturation and lithophysal cavity abundance.

Description

The number of experiments necessary to characterize the density and porosity of each thermal/mechanical unit in Activity 8.3.1.15.1.1.1 are given in Table 8.3.1.15-4. These numbers have been obtained using available data

Table 8.3.1.15-4. Experiments required for each location selected for characterization of spatial variability of rock properties

	Rock property and activity					
Unit[a]	Bulk density[b] (8.3.1.15.1.1.1)	Density and porosity[c] (8.3.1.15.1.1.1)	Heat capacity (8.3.1.15.1.1.2)	Thermal conductivity (8.3.1.15.1.1.3)	Thermal expansion (8.3.1.15.1.2.1)	Compressive mechanical properties (8.3.1.15.1.3)
TCw	10	10	5	5	5	10
PTn	10	10	5	5	5	10
TSw1	10	10	10	10	10	35[d]
TSw2	35	35	35	35	35	35
TSw3	10	10	4	10	10	10
CHn1v	10	10	10	10	10	10
CHn1	10	10	10	10	10	10
CHn2v	5	6	5	6	5	5
CHn2z	5	6	5	6	5	5

[a]The relationship between thermal/mechanical units and formal stratigraphic units is provided in the introduction to Chapter 2.

[b]Numbers of experiments for bulk density are calculated based on requirements for vertical in situ stress or on requirements for TSw2 related to radon emanation rate.

[c]Number of experiments for density and porosity are related to the experiments required for bulk density, characterization of heat capacity, and thermal conductivity indicated in this table.

[d]Lithophysae-poor TSw1.

as discussed under the technical rationale for this investigation. The numbers are based on the number of experiments estimated as necessary for bulk density, volumetric heat capacity, and thermal conductivity (as needed for this activity and for Activities 8.3.1.15.1.1.2 and 8.3.1.15.1.1.3). The number of experiments applies to each new core hole selected for characterization and to the exploratory shaft facility. Each experiment will require approximately 65 cm^3 of material.

In addition to the experiments listed in Table 8.3.1.15-4, grain density and porosity data will be gathered from other samples. Values will be obtained for 5 to 10 samples of material taken from instrumentation holes in the vicinity of in situ experiments in the exploratory shaft facility. These site-specific values will aid in the interpretation of in situ experiment results and will add to the data base for units TSw1 and TSw2.

Also, density and porosity data will be obtained on samples tested for thermal and mechanical properties by measurement of dry and saturated bulk densities of the samples. These data will be somewhat less accurate than those gathered by the more standardized techniques listed below but will be specific to the individual test samples. This specificity will enhance the ability to interpret mechanical and thermal test results.

Grain densities (ρ_g) and dry bulk densities (ρ_{db}) will be measured. Matrix porosities then will be calculated by

$$\phi = 1 - \frac{\rho_{db}}{\rho_g} \qquad (8.3.1.15\text{-}3)$$

Data for grain density and matrix porosity will be combined with data on lithophysal cavity abundance and in situ saturation state to calculate in situ bulk densities. These bulk densities then will be used to calculate the vertical component of in situ stress.

8.3.1.15.1.1.2 Activity: Volumetric heat capacity characterization

Objectives

The objectives of this activity are to obtain data for volumetric heat capacity and to evaluate the spatial variability thereof. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity are the estimated in situ values of volumetric heat capacity. Parameters required from other investigations include in situ saturation and lithophysal cavity abundance. Parameters required from other activities within this investigation are matrix porosity and grain density.

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Description

To estimate in situ values of volumetric heat capacity, data are required for grain density, matrix porosity, lithophysal cavity abundance, in situ saturation, and the heat capacities (C_p) of air, water, and solids. All of these, with the exception of the heat capacity of solids, will be available either in handbooks or as the result of other site characterization activities.

The number of experiments or calculations from chemistry or mineralogy to be performed in each new core hole selected for characterization to determine the heat capacity of solids for each thermal/mechanical unit in Activity 8.3.1.15.1.1.2 are given in Table 8.3.1.15-4. These numbers are the number of experiments estimated as necessary for volumetric heat capacity. Each experiment will require approximately 65 cm^3 of material. Each experiment on material from units TSw1, TSw2, TSw3, CHn1v, and CHn1z will include measurements (or calculations) over the temperature range from 25 to 275°C. For other units, the temperature range will be from 25 to 100°C. For some units that will be outside the temperature field produced by a repository, data from other units are assumed to be representative based on lithologic similarity. The impact of this assumption is expected to be negligible.

In addition to the experiments listed in Table 8.3.1.15-4, heat capacity data will be gathered from other samples. Values will be obtained for two to three samples of material taken from instrumentation holes in the vicinity of in situ experiments in the exploratory shaft facility. These site-specific values will aid in the interpretation of in situ experiment results and will add to the data base for units TSw1 and TSw2. If heat capacities of solids are calculated from chemical or mineralogic data, additional heat capacity information can be obtained using the chemical and mineralogic information to be gathered for the activities described in Section 8.3.1.3.2.1.

The data obtained from the measurements will be used to calculate volumetric heat capacity [$(\rho C_p)_{in\ situ}$] using the following equation (Nimick and Schwartz, 1987):

$$(\rho C_p)_{in\ situ} = \rho_g(1 - \phi_m - \phi_L)C_p^s + \phi_m S \rho_w C_p^{H_2O} + [\phi_m(1 - S) + \phi_L] C_p^{air} \rho_{air} \qquad (8.3.1.15\text{-}4)$$

where

ρ_g = grain density,

C_p^s = heat capacity of solid material,

S = saturation,

ϕ_m = matrix porosity,

ϕ_L = volume fraction of lithophysal cavities,

ρ_w = density of water,

ρ_{air} = density of air,

C_p^{air} = heat capacity of air,

$C_p^{H_2O}$ = heat capacity of water.

Because the density of air is so low, the last term is usually dropped from Equation 8.3.1.15-4. C_p^s and $C_p^{H_2O}$ and ρ_w are functions of temperature, so that ρC_p also is a function of temperature. The temperature ranges for which ρC_p will be obtained are the same as those specified earlier for C_p^s.

8.3.1.15.1.1.3 Activity: Thermal conductivity characterization

Objectives

The objectives of this activity are to obtain data for thermal conductivity and to evaluate the spatial variability thereof. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity are estimates of in situ thermal conductivity. Parameters required from other investigations are in situ saturation and lithophysal cavity abundance. A parameter required from another activity in this investigation is matrix porosity. These parameters will be combined in an appropriate model with the thermal conductivities of air, water, and solids to estimate in situ thermal conductivity.

Description

To estimate in situ values of thermal conductivity, data are required for the thermal conductivity of the solid material, air, and water and for matrix porosity, lithophysal cavity abundance, and in situ saturation. All of these, with the exception of the thermal conductivity of solids, will be available either in handbooks or as the result of other site characterization activities.

The number of experiments to be performed to determine the thermal conductivity of solids for each thermal/mechanical unit included in this activity are given in Table 8.3.1.15-4. These numbers are those estimated as necessary for thermal conductivity of the bulk material, using available data and the procedures outlined earlier in the technical rationale discussion for this investigation. For some units that will be outside the temperature field produced by a repository, data from other units are assumed to be

representative based on lithologic similarity. Each experiment on material from units TSw1, TSw2, TSw3, CHnlv, and CHnlz will include measurements over the temperature range from 25 to 275°C. For other units, the temperature interval will be 25 to 100°C. Each experiment will use a sample that is equal to or smaller than 13 cm of NX (approximately 50 mm diameter) core; actual size will depend on the final experimental technique.

In addition to the experiments listed in Table 8.3.1.15-4, thermal-conductivity data will be gathered from other samples. The effects of fractures, saturation state, lithophysae, and potential anisotropy on thermal conductivity will be examined using measurements on appropriate samples from units TSw1 and TSw2 taken from the ESF. Values will be obtained for two to three samples of material taken from instrumentation holes in the vicinity of in situ experiments in the exploratory shaft facility. These site-specific values will aid in the interpretation of in situ experiment results and will add to the data base for units TSw1 and TSw2.

Thermal conductivity of several samples of Yucca Mountain tuffs will be measured in support of the activity related to determination of in situ temperatures (Activity 8.3.1.15.2.2.1). Data from these measurements also will contribute to the total data base on thermal properties.

The equation that has been used to date in analysis of the Yucca Mountain Project thermal-conductivity data has been a geometric-mean equation (Nimick and Lappin, 1985):

$$K = K_s^{(1-\phi_T)} K_w^{S\phi_m} K_a^{(1-S)\phi_m - \phi_L] } \qquad (8.3.1.15\text{-}5)$$

where

K = bulk thermal conductivity
K_s = thermal conductivity of solids,
K_w = thermal conductivity of water,
K_a = thermal conductivity of air,
S = saturation,
ϕ_L = volume fraction of lithophysal cavities,
ϕ_m = matrix porosity,
ϕ_T = total porosity $(\phi_m - \phi_L)$.

This formulation will be reevaluated against other possible representations (including the possibility that the thermal conductivity is not a monotonic function of saturation); the actual equation that will be used to analyze data for site characterization has not been selected. K_s, K_w, and K_a are functions of temperature, so that K is also a function of temperature. The temperature ranges for which K will be obtained are the same as those specified earlier for K_s.

8.3.1.15.1.2 Study: Laboratory thermal expansion testing

The objective of this study is to provide laboratory characterization of thermal-expansion behavior and the spatial variability thereof. The discussion that follows applies for each new core hole and for the exploratory shaft facility (ESF). Testing frequency at the main test level in the ESF will depend on spatial variability.

8.3.1.15.1.2.1 Activity: Thermal expansion characterization

Objectives

The objective of this activity is to obtain data for thermal-expansion behavior and to evaluate the spatial variability thereof. The data will be used in calculations of thermal stress and deformation associated with the temperature field produced by the presence of heat-producing waste in unit TSw2.

Parameters

The parameter for this activity is the coefficient of thermal expansion.

Description

The number of experiments necessary to obtain the coefficient of thermal expansion for each thermal/mechanical unit in Activity 8.3.1.15.1.2.1 is given in Table 8.3.1.15-4. The numbers have been obtained using available data and the procedure outlined in the technical rationale discussion for this investigation. For some units that will be outside the temperature field produced by a repository, data from other units are assumed to be representative on the basis of lithologic similarity. The impact of this assumption is expected to be negligible. Each experiment for units TSw1, TSw2, TSw3, CHn1v, and CHn1z will include measurements over the temperature range from 25 to 275°C. For other units, the temperature range will be 25 to 100°C. Sample size will be similar to that used in previous experiments (Chapter 2), ranging from 25.4 by 25.4 by 3 mm up to cylinders 50.8 mm in diameter and 101.6 mm in length.

Thermal-expansion experiments will be performed on initially saturated samples under conditions that minimize dehydration at temperatures below 100°C. Samples will be allowed to dehydrate at approximately 100°C until a stable length is achieved, then heating will continue if the experiment includes heating to 275°C. Heating rates will be selected to minimize any kinetic effects of dehydration or mineral transformations on the rates of thermal expansion (or contraction).

For thermal/mechanical unit TSw1, data are necessary for both lithophysae-rich and lithophysae-poor portions of the unit. Both portions of unit TSw1 will be characterized by the same method used for the units discussed in the previous paragraph, although samples from the lithophysae-rich portions will be significantly larger than the sizes mentioned earlier. For unit TSw2, scoping experiments will be performed to assess the significance, if

any, of anisotropy, fracturing, or sample size on the thermal expansion behavior of unit TSw2.

In addition to the thermal-expansion experiments performed to examine spatial variability of this property, experiments will be done on samples collected from the vicinity of in situ experiments that involve elevated temperatures. These thermal-expansion data will be used in the interpretation of in situ experiment results as well as to augment the data base on the thermal expansion of units TSw1 and TSw2.

8.3.1.15.1.3 Study: Laboratory determination of mechanical properties of intact rock

The objective of this study is to provide laboratory characterization of the mechanical properties of intact rock and the spatial variability thereof. The discussion for Activity 8.3.1.15.1.3.1 applies for each new core hole and for the ESF. Testing frequency at the main test level in the ESF will depend on spatial variability.

8.3.1.15.1.3.1 Activity: Compressive mechanical properties of intact rock at baseline experiment conditions

Objectives

The objective of this activity is to obtain data for the compressive mechanical properties of intact rock, and the spatial variability thereof, for baseline experiment conditions. These data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity include uniaxial compressive strength, Young's modulus, and Poisson's ratio.

Description

As discussed in Chapter 2, the compressive strength of Yucca Mountain tuffs is a function of various conditions, including strain rate, confining pressure, temperature, sample size, and saturation state. To evaluate the effects of these parameters, a set of baseline experiment conditions must be defined for which compressive mechanical data will be obtained. These conditions will be as follows:

Sample diameter: 50.8 mm
Sample length to diameter ratio: 2.0
Saturation state: Saturated
Temperature: Room temperature (22°C)
Confining pressure: Atmospheric (0.1 MPa)
Strain rate: 10^{-5} s^{-1}

The number of experiments to be performed at these conditions for each thermal/mechanical unit in Activity 8.3.1.15.1.3.1 are summarized in Table 8.3.1.15-4. The numbers have been obtained from available data using the procedure outlined in the technical rationale discussion for this investigation. For some far-field units, data from characterized units are assumed to be representative based on lithologic similarity. Because the far-field units are outside the regions of significantly altered stress and temperature, the impact of this assumption is assumed to be negligible.

In addition to the experiments listed for this activity (8.3.1.15.1.3.1) in Table 8.3.1.15-4, compressive experiments at the baseline conditions will be performed on samples obtained in the vicinity of in situ experiments. The data from these laboratory experiments will aid in the interpretation of in situ experiment results as well as contributing to the data base for the compressive mechanical properties of units TSw1 and TSw2.

8.3.1.15.1.3.2 Activity: Effects of variable environmental conditions on mechanical properties

Objectives

The objective of this activity is to evaluate the effects of varying sample size, strain rate, temperature, confining pressure, lithophysal content, saturation state, and anisotropy on compressive mechanical properties. In addition, the tensile strength of unit TSw2 will be measured. Data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity are unconfined compressive strength, Young's modulus, Poisson's ratio, cohesion, and angle of internal friction.

Description

As discussed in Chapter 2 of the SCP, compressive mechanical properties are a function of the sample characteristics and experimental conditions at which the properties are measured. This activity will determine the effects of sample size, strain rate, temperature, confining pressure, lithophysal content, saturation state, and anisotropy on the compressive mechanical properties of unit TSw2, the proposed repository horizon. In addition, the effects of confining pressure on the mechanical properties of units TCw, PTn, and lithophysae-poor portions of unit TSw1 will be determined, as well as the tensile strength of unit TSw2. Material for testing of unit TSw2 will be ob-

tained from the walls of the excavations at the main test level in the exploratory shaft facility (ESF), whereas samples of other units will be collected from the ESF ramps and drifts.

In addition to the testing just summarized, scoping experiments are ongoing to determine whether creep deformation or deformation at very low strain rates are of concern for unit TSw2. Samples taken from outcrop at Busted Butte are being tested in compression at low strain rates (10^{-8} to 10^{-9} s^{-1}), elevated temperature (250°C), and in creep experiments. Results will be used to assess whether the experiment program mentioned in the preceding paragraph should include additional experiments at these extreme conditions.

8.3.1.15.1.4 Study: Laboratory determination of the mechanical properties of fractures

The objective of this study is to provide laboratory characterization of the mechanical properties of fractures and the spatial variability thereof. The discussion applies for each new core hole and for the exploratory shaft facility (ESF).

8.3.1.15.1.4.1 Activity: Mechanical properties of fractures at baseline experiment conditions

Objectives

The objective of this activity is to obtain data for the mechanical properties of fractures, and the spatial variability thereof, for baseline experiment conditions. The data will be used in mechanical and thermomechanical calculations of the stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity are cohesion, coefficient of friction, shear stiffness, normal stiffness.

Description

As discussed in Chapter 2 of the SCP, the mechanical behavior of fractures may be a function of various conditions, including normal stress, displacement rate, temperature, mineralogy, sample size, fracture roughness, and saturation state. To evaluate the effects of these parameters, a set of baseline experimental conditions must be defined for which the parameters listed in this section will be obtained. These conditions will be as follows:

Sample (fracture) area: 2.0×10^{-3} to 4.0×10^{-3} m^2
Saturation state: Dry
Temperature: Room temperature (22°C)
Displacement rate (shear loading): 10 µm/s
Loading rate (normal loading): 0.03 MPa/s
Fracture: Artificial (ground sawcut)

No data are presently available with which to estimate the number of fractures that must be tested. Scoping experiments are under way on samples from unit TSw2 collected from Busted Butte. These experiments will provide preliminary data that will be used to design the initial phase of fracture testing in terms of sampling frequency.

8.3.1.15.1.4.2 Activity: Effects of variable environmental conditions on mechanical properties of fractures

Objectives

The objective of this activity is to evaluate the effects of varying normal stress, displacement rate, temperature, sample size, fracture roughness, and saturation state on the mechanical properties of artificial and natural fractures. The data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters of this activity are cohesion, coefficient of friction, shear stiffness, and normal stiffness.

Description

Fracture properties are a function of the fracture surface characteristics and the experimental conditions. This activity will determine the effects of normal stress, displacement rate, temperature, sample size, fracture roughness, and saturation state on the fracture properties. Approximately 20 experiments will be performed at each set of experiment conditions for samples of unit TSw2, with fewer experiments on samples of adjacent units if such experiments appear to be necessary. Tentative ranges in experiment conditions are as follows:

Saturation state: Dry and saturated
Temperature: 22 to 200°C
Normal stress: 0.1 to 30 MPa
Displacement rate: 10^{-1} to 10^{2} µm/s
sample area: 2×10^{-3} to 100×10^{-3} m^2

In addition, several scoping experiments will be performed to examine whether creep is a realistic deformation mechanism for fractures in unit TSw2.

The range in sample size (surface area) will depend on material availability. The range probably will extend from NX-core to fracture surfaces up to 0.1 m^2 in area. Sampling plans for this activity will take into account the importance of scaling effects when extrapolating from laboratory results to in situ fractures.

The range in roughness of fracture surfaces will depend on the results of characterization of fracture sets and sensitivity calculations. All types of fractures estimated to be of potential importance to the mechanical behavior of the rock mass will be tested.

8.3.1.15.1.5 Study: Excavation investigations

The objective of this study is to obtain site-specific information concerning the behavior of underground excavations in the proposed repository horizon and overlying units. Most of the data will be used for testing of computer codes that will be used to predict mechanical behavior of the rock mass (Section 8.3.2.1.4). In addition, some of the information will serve as direct demonstration of constructability with reasonably available technology (relevant to resolution of Issue 4.4). All of the in situ experiments will be conducted in the exploratory shaft facility (ESF). Interpretation of the data to be obtained from the activities for this study (8.3.1.15.1.5) will utilize information gathered for 8.3.1.4.2.2 (characterization of structural features within the site area).

8.3.1.15.1.5.1 Activity: Shaft convergence

The shaft convergence test is to be deferred until after construction and other prioritized ESF testing activities have been completed. The status and scope of the test is currently being addressed for ESF ramp accesses to be consistent with the reference ESF design concept described in Section 8.4. The following discussion provides information on the shaft convergence test as planned for the original ESF configuration (described in the SCP) with two shafts in close proximity. The test, as described below, may be conducted to augment characterization data obtained from the ramps in the event that an optional shaft would be constructed.

Objectives

The objectives of this activity are to monitor rock-mass deformation around a vertical shaft and to measure horizontal in situ stresses. In situ stress data will contribute to definition of boundary and initial conditions for mechanical and thermomechanical analyses, whereas observations of rock-mass deformation also will contribute to empirical evaluations of nonradiological health and safety (Issue 4.2 of the SCP).

Parameters

Information will be obtained concerning rock-mass deformation and horizontal in situ stress. Both will be obtained in more than one location

(vertically), so that some information regarding spatial variability of rock-mass deformation and horizontal stresses will be obtained.

Description

The following description covers the monitoring of rock-mass deformation.

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

8.3.1.15.1.5.2 Activity: Demonstration breakout rooms

Objectives

The major objective of this activity is to demonstrate constructability and stability of underground rooms with cross-sectional dimensions equivalent to those of a repository in both lithophysae-rich and lithophysae-poor material. This demonstration will include an evaluation of the deformations that occur around the openings. A secondary objective is to provide facilities for other testing (e.g., heater tests and overcoring). Demonstration of constructability and stability will contribute to empirical evaluations of nonradiological health and safety (Issue 4.2 of the SCP).

Parameters

Data will be obtained concerning deformations caused by repository-sized excavations in welded tuff. Information also will be obtained about the extent of the zone of increased fracturing adjacent to the excavations, about rock-bolt loading, and observations about excavation efficiency.

Description

A room in lithophysae-poor material (unit TSw2) with cross-sectional dimensions equivalent to those of a repository will be excavated. The room will be stabilized using rock bolts and wire mesh. Deformations will be monitored using multiple-point borehole extensometers (MPBXs) at five stations in the room, with six MPBXs at each station. The MPBXs will be installed as soon as practicable after excavation of the relevant interval of the room. Rod extensometer measurements will be made between drift convergence anchors located in the room floor and back at eleven stations.

In addition, rock bolt load cells will be used to monitor changes in the stress-altered region.

A second room in lithophysae-rich tuff (TSw1) will be excavated. This room, however, has been deferred until after construction and other prioritized ESF testing activities have been completed.

8.3.1.15.1.5.3 Activity: Sequential drift mining

Objectives

The objectives of this activity are to obtain data on the deformation response of drifts with cross-sectional dimensions equivalent to those of a repository in welded tuff, to use the data in code evaluation activities, and to demonstrate constructability and stability of repository-sized drifts in lithophysae-poor material. Data will contribute to validation of computer codes to be used to calculate mechanical responses, as well as contributing to empirical evaluations related to nonradiological health and safety (Issue 4.2 of the SCP).

Parameters

Data will be obtained concerning deformations caused by the presence of multiple underground excavations in welded tuff (unit TSw2). Stress changes also will be monitored.

Description

Although a final design for this experiment is not available, the concept includes the following sequence:

1. Excavate observation drift with cross-sectional dimensions smaller than or equivalent to those of a repository.

2. Instrument and characterize the rock mass between the observation drifts using MPBXs, borehole stress meters, permeability and cross-hole geophysical techniques before excavating the main experiment drift.

3. Excavate the experiment drift and install MPBXs to monitor rock mass deformation as excavation proceeds.

Deformations caused by the excavation of the main experiment drift in step 3 will be measured from the observation drift using borehole deflectometers and multiple-point borehole extensometers (MPBXs), and within the experiment drifts using rod extensometers and MPBXs. Instrumentation will be installed for step 2 and also will be placed in the secondary excavation(s) in step 3 as mining progresses. Changes in near-field stresses around the drifts will be monitored with borehole stressmeters.

Quantitative information from the measurements will be used to aid in evaluation of computer codes to be used in calculation of the mechanical re-

sponse of the rock-mass. Before this site characterization experiment begins, some prototype experiments will be performed in G-tunnel. These initial experiments are designed to aid in development of appropriate instrumentation. Emphasis will be placed on the development of appropriate instruments to monitor ground motion (acceleration, velocity, and stress) associated with blasting activities in welded tuff, with application to the possible survivability of the full range of instrumentation to be used in site characterization activities in the ESF.

8.3.1.15.1.6 Study: In situ thermomechanical properties

The objective of this study is to obtain data on in situ thermal and thermomechanical properties for units TSw1 and TSw2. Properties to be obtained include heat capacity, thermal conductivity, and thermal expansion. Deformation modulus, strain ratio, and radon emanation rates also will be determined during some of the testing activities. In addition, the effects of heating on in situ water content, deformation modulus, changes in thermally induced stress, radon emanation, and the deformation response of the rock around a heated room will be observed. Some of the data will be used for testing computer codes used in heat transfer and thermomechanical calculations. Additional heater experiments will be conducted to characterize the waste container environment, as discussed in Section 8.3.4.2.4.

Interpretation of the data to be obtained from the activities for this study will utilize information gathered for Study 8.3.1.4.2.2 (characterization of the structural features within the site area).

8.3.1.15.1.6.1 Activity: Heater experiment in unit TSw1

The heater experiment in unit TSw1 has been proposed to be conducted in the primary science ramp (north ramp). The test, however, will be deferred until after construction and other prioritized ESF testing activities have been completed.

Objectives

The objectives of this activity are to estimate the in situ thermomechanical properties of lithophysae-rich tuff (unit TSw1) and to evaluate the thermal and mechanical response of this tuff unit to elevated temperatures. The data will be used to evaluate models during this and other experiments.

Parameters

The parameters obtained for this activity are thermal conductivity, heat capacity, and thermal expansion coefficient.

Description

The design of this experiment, in terms of heater dimensions and power output, has not been finalized. However, data to be measured will include temperatures, deformations, and changes in moisture content regardless of the heater used. Use of heater-induced temperature changes to estimate in situ values of thermal conductivity and heat capacity is discussed for Study 8.3.1.15.1.1 (laboratory thermal properties). A neutron probe will be used to evaluate changes in bulk moisture content near the heater; this information will be used in calculation of in situ thermal properties and in qualitative evaluation of hydrothermal mechanisms. Estimates of thermal expansion coefficients will be obtained through a combination of the measured temperatures and thermally induced deformations as measured with multiple-point borehole extensometers.

8.3.1.15.1.6.2 Activity: Canister-scale heater experiment

Objectives

The objective of this activity is to obtain thermal and thermomechanical rock-mass measurements of the effects of thermal inputs on a representative (canister-scale) waste-emplacement borehole in lithophysae-poor tuff (unit TSw2). The data will be used to evaluate the thermal and thermomechanical models. Early testing will simulate heat fluxes expected during repository operations to evaluate geomechanical models. The heat fluxes will be increased subsequently during a thermal overdrive to determine the upper heat limit for waste-emplacement borehole stability.

Parameters

The parameters to be obtained for this activity are thermal expansion coefficient, thermal conductivity, and heat capacity.

Description

A canister-scale heater will be emplaced in unit TSw2, and temperatures, deformations, and changes in moisture content and changes in stresses will be monitored. Instruments will include thermocouples, multiple-point borehole extensometers (MPBXs), borehole deformation gauges, and a neutron probe. The use of heater-induced temperature changes to estimate in situ values of thermal conductivity and heat capacity is discussed for Study 8.3.1.15.1.1 (laboratory thermal properties). Estimates of thermal expansion coefficients will be obtained through a combination of the measured temperatures and thermally induced deformations as measured with the thermocouples and MPBXs. Data will be used to test computer codes intended to estimate the thermal and thermomechanical behavior of the rock mass. Values for rock-mass thermal properties will be obtained from evaluation of the response of the rock mass and from estimates based on laboratory measurements of samples obtained from the vicinity of the canister-scale heater. Additional discussion of code evaluation activities is presented in Section 8.3.2.1.4. Qualitative information concerning stability of the heater hole under conditions of elevated

temperature will be made during a thermal overdrive and will contribute to an evaluation of retrievability.

An additional activity associated with the canister-scale experiment is the measurement of radon emissions in unit TSw2 as a function of temperature. A borehole near the heater will be monitored for radon concentrations throughout the duration of the canister-scale experiment. Results will be used to help satisfy Issue 2.7 of the SCP (Section 8.3.2.3).

8.3.1.15.1.6.3 Activity: Yucca Mountain heated block

Objectives

The objectives of this activity are to estimate in situ mechanical and thermomechanical properties of unit TSw2 and to test thermomechanical computer models. Data on the properties will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters of this activity are deformation modulus, thermal expansion coefficient, thermal conductivity, heat capacity, joint wall compressive strength, and joint roughness coefficient.

Description

Slots isolating a 2-m by 2-m block will be cut in an alcove at the main test level in the exploratory shaft facility (ESF). Flatjacks will be set in the slots adjacent to the block, enabling application of uniaxial or biaxial stresses. Two rows of heaters outside opposite sides of the block will be used to heat the block. Before and during the heated phases, stresses will be applied and deformation will be monitored to obtain values for the deformation modulus and the ratio of lateral strain to axial strain (principal strain ratio), and the variation of these two properties with temperature. Thermally induced deformation will be used to obtain estimates of the thermal expansion coefficient. Use of heater-induced temperature changes to estimate in situ values of thermal conductivity and heat capacity is discussed for Study 8.3.1.15.1.1 (laboratory thermal properties). A thermal probe also will be used as a transient-line heat source to measure in situ thermal conductivity directly. In addition to the parameters mentioned previously, changes in moisture content as a function of temperature and position will be monitored with a neutron probe. Experience gained from the G-tunnel heated block experiment (Zimmerman et al., 1986a) will guide the experiment at Yucca Mountain.

After some portion of the experiment has been completed for this activity, the feasibility of cutting slots for a second block will be assessed. If feasible, this block would be oriented in a manner allowing for measuring shear and normal mechanical properties of in situ fractures.

Instruments for measuring deformation for this activity may include set pins, strain gage rosettes, horizontal extensometers, tiltmeters, and multiple-point borehole extensometers. Stress changes during the experiment will be monitored with borehole deformation gages. As mentioned earlier, thermal and neutron probes also will be used.

To help interpret the data from this experiment, laboratory measurements will be made using core from instrumentation holes in or near the block. Thermal conductivity, heat capacity, and mechanical properties will be measured. In addition, measurements of joint wall compressive strength and joint roughness coefficient (Barton and Choubey, 1977) will be made on joints within or near the location of the block.

8.3.1.15.1.6.4 Activity: Thermal stress measurements

Objectives

The objective of this activity is to monitor changes in thermally induced stress in jointed welded tuffs in an accelerated test. The data will be used to evaluate thermally induced stresses calculated with thermo-mechanical computer codes. The focus of this experiment is directed toward evaluating drift stability as it might affect retrievability.

Parameters

Parameters for this activity are temperature, thermally induced stresses, and displacement.

Description

A slot will be cut in the roof or a rib of a drift and a flatjack will be inserted in the slot. Two rows of heaters parallel to and on either side of the slot will be energized, and a new method for stress cancellation will be used to measure the stresses induced by the temperature field. In addition, deformation in the surrounding heated volume (>36 m^3) will be monitored using MPBXs and long-gage surface extensometers. The combinations of measured deformation with measured temperatures will allow confirmation of in situ thermal expansion coefficients measured in other in situ tests (Activities 8.3.1.15.1.6.1, 8.3.1.15.1.6.2, and 8.3.1.15.1.6.3).

The specific number and location of these experiments has not yet been defined. At a minimum, experiments in the roof and rib are envisioned. Evaluation of the experiment design and prototype experiments are ongoing. The prototype experiments include development of equipment (e.g., high-pressure flatjacks) as well as the methodology.

8.3.1.15.1.6.5 Activity: Heated room experiment

Objectives

The objectives of this activity are (1) to evaluate the thermomechanical response of welded tuff around repository openings to expected repository conditions during both construction and operation, (2) to develop a data base for evaluating thermal and thermomechanical design analyses and methods applicable for repository considerations, and (3) to use actual site data in predicting drift response and support/rock interactions during construction, operation, retrievability, and postclosure.

Parameters

The following parameters and information will be obtained during this experiment: rock-mass deformation; estimate of the region in which the stress state is changed by elevation of temperature; stress changes; thermal conductivity and heat capacity; ground-support loading and deformation; and the temperature dependence of measured parameters.

Description

The design of this experiment is in the preliminary stage. The experiment will be conducted in unit TSw2. The experiment will consist of developing a representative room in a drift and heating the rock around it to expected repository operating temperatures. The length of the heated room and geometrical placement of the heat sources will be determined by evaluating the length and heat source placement with a reasonable number of heaters required to generate repository-like conditions. Preliminary plans call for the heated room to be paralleled by two drifts, which will serve as unheated access drifts where the heaters originate. The three drifts would be in the same horizontal plane. Distances between the drifts would be established to facilitate the model testing process and an accelerated testing schedule. A goal in the test planning is to develop sufficient heat for initial thermomechanical evaluations during the site characterization phase and that thermal stresses representative of repository operating conditions would be generated as early as three years after starting the heating.

The heated room experiment serves as a demonstration of the capabilities of welded tuff to sustain thermal stresses at a scale representing repository conditions. The accelerated heating is designed to reach stress conditions representative of 100 yr of emplacement. The measurements are to be used to test empirical and opening-support design models. Additional discussion of model validation activities is presented in Section 8.3.5.20.

Instrumentation will include thermocouples, multiple-point borehole extensometers, long-gage surface extensometers, borehole deformation gages, and possibly a neutron probe. If possible, flatjack-control system components of the thermal stress measurements system (Section 8.3.1.15.1.6.4) will be incorporated. Considerations will be made regarding the use of acoustic emission techniques to monitor rock-mass emissions in a spatial arrangement.

8.3.1.15.1.7 Study: In situ mechanical properties

The objectives of this study are to obtain in situ measurements of the mechanical properties of the rock mass for unit TSw2. Mechanical properties include rock-mass deformability and evaluations of responses of single and multiple joints to controlled loadings. The numbers of experiments to obtain such properties will not fulfill requirements for confidence as expressed by performance and design issues. Therefore, the data will be used as preliminary indicators of rock-mass values and as checks of the validity of extrapolation of laboratory-determined data to in situ conditions. In addition, measurements of rock-mass deformation modulus in different locations will provide an estimate of spatial variability of rock-mass mechanical properties. Necessary information about fractures that is relevant to individual test locations (as well as to Yucca Mountain as a whole) will be gathered as part of Study 8.3.1.4.2.2.

8.3.1.15.1.7.1 Activity: Plate loading tests

Objectives

The objectives of this activity are to measure the deformation modulus of the rock mass and to evaluate the zone of increased fracturing adjacent to underground openings. Modulus data are to be used in thermomechanical calculations of the stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2. Characterization of the zone of increased fracturing will contribute to the definition of initial conditions, boundary conditions, and properties to be used in the calculations.

Parameters

The parameters for this activity are rock-mass deformation modulus, joint wall compressive strength, joint roughness coefficient, and spatial variability thereof.

Description

Plate-loading experiments will be performed at numerous (10 to 20) locations in the exploratory shaft facility (ESF) and associated excavations both in unit TSw1 (upper demonstration breakout room) and in unit TSw2 at the main test level. Individual experiments will be performed with vertical and horizontal orientations at each location. Rock deformations will be measured using a multiple-point borehole extensometer (MPBX) oriented parallel to the load axis in the center of the plate area. Deformation of the loading column will be monitored using rod extensometers. Values of the rock deformation modulus will be calculated using the rock deformation and the applied stresses. Moduli from different stations will be compared to evaluate spatial variability within unit TSw2. 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 undisturbed rock mass.

Borehole dilatometer measurements performed in association with overcoring experiments (Activity 8.3.1.15.2.1.2) will be used to obtain data on the borehole deformation modulus. These data will provide another measure of the spatial variability of in situ moduli.

Acoustic emission techniques will be used to detect rock-mass responses to the loadings with the goal of detecting spatial distributions of nonuniform emissions. Emission data will be helpful in interpreting any irregular mechanical responses of the rock mass to the loadings. If possible, rock bolt load cells will be attached to bolts in the nearby rock to serve the same purpose.

To aid in the interpretation of data obtained from these experiments, mechanical properties of the intact rock will be measured in the laboratory using core from instrumentation holes at each experiment location. In addition, joint wall compressive strength and joint roughness coefficient (Barton and Choubey, 1977) and joint geometry will be measured on joints near each experiment location. Frictional and stiffness properties of the joints may be used in the analysis of the plate-loading experiments. Such properties will be measured on site-specific samples if samples can be obtained. If no site-specific samples are available, data will be taken from the results of Activities 8.3.1.15.1.4.1 and 8.3.1.15.1.4.2.

8.3.1.15.1.7.2 Activity: Rock-mass strength experiment

Objectives

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

Parameters

The following parameters will be obtained during this experiment: joint characteristics (including joint shear strength, joint wall compressive strength, and joint roughness coefficient), joint normal and joint shear deformation response, and rock mass deformation modulus.

Description

Rock-mass strength experiments will be conducted in drifts at the Topopah Spring level and in the main test level core area of the ESF. Specific areas have not yet been determined, but they will be chosen to be representative of the range of geologic conditions expected in the repository. Joint shear response will be measured on individual joints of a size of 70 by 70 cm as suggested in the International Society of Rock Mechanics

Suggested Methods (ISRM, 1981). The shear strength experiments will provide data on the in situ joint shear strength as well as the normal and shear displacement response on in situ joints. This information will be used to evaluate jointed-rock models. The rock-mass strength portion of this experiment will measure the uniaxial load-bearing capacity of large blocks (up to 1 by 1 by 2 m) of rock that include multiple joints. This will provide data on the behavior of multiple joints to compressive loads and will be used to evaluate jointed-rock models and to evaluate empirical rock-mass strength relationships such as those developed by Hoek and Brown (1980). The rock-mass strength portion of this experiment will be similar to other large-scale in situ compression tests (Jahns, 1966; Bieniawski, 1968; Pratt et al., 1972; Wagner, 1975). The block of rock will be cut using hydraulic chain saws (Zimmerman and Finley, 1987) and the compressive loads will be applied through high-pressure flatjacks being developed at Sandia National Laboratories.

8.3.1.15.1.8 Study: In situ design verification

The objectives of this study are to (1) investigate the effects of the spatial variability of the rock on drift stability, mining activities, and ground supports; (2) evaluate techniques for underground excavation and ground support, for selecting ground supports to be used in different rock types, and for monitoring drift stability; (3) quantify the emanation of radon into repository drifts and observe its dispersion with airflow, and (4) measure parameters needed to design repository ventilation systems.

8.3.1.15.1.8.1 Activity: Evaluation of mining methods

Objectives

The objective of this experiment is to develop recommendations for mining in the repository by monitoring and evaluating mining activities in the exploratory shaft facility, and by conducting mining investigations.

Parameters

This activity does not include measurement of any geomechanical parameters.

Description

Mining methods in the ramps and exploratory drifts will be monitored. Particular attention will be given to the effects of the spatial variability of the rock. Results of mining to be evaluated include characteristics of the excavated spaces (including geologic mapping), rubble size distributions, and effects of ramps and drift construction on the surrounding rock. Mining investigations will be concentrated in the repository-scale portions of the drifts and will include examination of ramp and drift construction-induced damage in boreholes.

8.3.1.15.1.8.2 Activity: Monitoring of ground-support systems

Objectives

The objective of this experiment is to develop recommendations for a ground-support methodology to be used in drifts in the repository, based on evaluations of the ground-support methodology used in the exploratory shaft facility (ESF), and on experimentation with other ground-support configurations. Recommendations will be made for support systems to be used, as well as for methods of selection of supports that are appropriate for the ground conditions encountered.

Parameters

This activity includes compiling parameters used to classify the rock mass in order to select supports. These parameters might include rock quality designation, joint orientation, spacing, and characteristics, intact rock strength, and in situ stresses.

Description

Evaluation of ground-support systems will be carried out in the long drifts to enhance the measurements made in the main test area (Activity 8.3.1.15.1.5.2 and 8.3.1.15.1.5.3). The selection, installation, and performance of the support systems used will be monitored. Monitoring of the selection of ground-support systems will involve cataloging the parameters that are evaluated to classify the rock mass in order to select supports. Monitoring of the installation process will include documenting materials and equipment used, installation procedures and schedules, and support configurations. The performance of the supports will be measured in terms of rock-mass convergence, block movement and rock falls, required maintenance (all measured as part of Activity 8.3.1.15.1.8.3), loads on rock bolts and steel sets, and observed behavior of shotcrete or concrete. Results of other tests describing the performance of ground supports in the upper breakout room and around the main test area also will be considered in these evaluations.

Further experimentation with ground-supports in the long drifts will include rock-bolt pull tests, observation of unsupported rock, strength measurements on shotcrete cores, and trial deviations from the ESF-prescribed ground-support systems.

Complete assessments of ground-support systems for use in the repository must incorporate the results of this experiment with those of other experiments and analyses (Activity 8.3.1.15.1.6.5), because the drifts to be monitored will not be heated, and behavior must be predicted through the 100-yr operational life of the underground facility.

8.3.1.15.1.8.3 Activity: Monitoring drift stability

Objectives

The objectives of this experiment are to (1) provide confidence in predictions of usability of the repository underground facilities over their 100-yr operational life, (2) contribute to evaluations of the effectiveness of mining methods and ground-supports (Activities 8.3.1.15.1.8.1 and 8.3.1.15.1.8.2), (3) calibrate and refine criteria for determining stability of the openings, and (4) develop techniques for monitoring stability of the repository drifts.

Parameters

Representative amounts and rates of closure around drifts in the repository horizon will be established.

Description

This activity involves monitoring drift convergence and drift maintenance activities at the main test level. Instrumentation will be concentrated in the long drifts, although a limited number of convergence points may be set up in the main test area, and similar measurements that will be taken in other tests will be included in final evaluations.

Convergence measurements will be taken throughout the long drifts, in a continuous manner, if practical. Rock-mass relaxation will be investigated in the repository-scale portions of the long drifts using multiple-point borehole extensometers. Rock-mass performance will be considered in light of results from geologic mapping activities (Activity 8.3.1.4.2.2.4). Rock falls and maintenance activities will be documented through observations and with photographs.

8.3.1.15.1.8.4 Activity: Air quality and ventilation experiment

Objectives

The objectives of this experiment are to (1) measure the rate of radon emanation from the repository host rock and (2) evaluate parameters and variables needed as input to or for testing of the models to be used for design of the ventilation systems in the repository underground facility.

Parameters

The rate of radon emanation from the repository host rock will be evaluated. Air flow velocity, air pressures, air temperature, humidity, air resistance factors, dust concentrations and dust characteristics will be evaluated.

Description

This activity consists of five separate items: (1) radon emanation measurements, (2) surveys of airflow velocity and pressure and of temperature and humidity, (3) determination of the heat transfer coefficient for the rock to the air, (4) determination of air resistance factors, and (5) dust characterization.

The radon emanation measurements will be made in a dead-end drift that has been sealed with a bulkhead, allowing the radon gas to come into equilibrium with its short-lived daughter products. Measurements possibly will be made in a borehole as well. The sealed drift will be repeatedly ventilated and then allowed to return to equilibrium in order to establish relationships between airflow and concentrations of radon and radon daughters.

Items 2, 4 and 5 in this activity will be performed with portable instruments over periods of a few days each. They are not expected to interfere significantly with other underground activities. Item 3 will be performed either by estimating a value for the heat transfer coefficient using information from literature sources or inferring a value based on the data gathered from item 2.

8.3.1.15.2 Investigation: Studies to provide the required information for spatial distribution of ambient stress and thermal conditions

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP provide a summary of available data relevant to ambient stress and thermal conditions and identify areas of insufficient or inconclusive information:

SCP section	Subject
1.3.2.3	Existing stress regime
1.3.2.5	Geothermal regime
1.8.1	Summary of significant results (geology)
1.8.2	Relation to design (geology)
2.4.2	Thermal and thermomechanical properties of rock at the site (intact rock)
2.5.2	Thermal and thermomechanical properties of rock at the site (large scale)
2.6.1	Stress regime in region of the site
2.6.2	Stress regime at the site

Parameters

Table 8.3.1.15-1 summarizes the information and parameters required for resolution of design and performance assessment issues.

Purpose and objectives of the investigation

The performance allocation process as implemented by performance assessment and design has identified performance measures and goals. To determine whether the performance goals can be met, data must be available on various site parameters, and the data must have associated levels of confidence. The parameters and associated confidence levels are identified in the performance assessment and design issues and serve as the basis for planning of a site characterization program.

Table 8.3.1.15-1 provides a detailed comparison of the information required by performance assessment and design issues on ambient in situ stress and temperature conditions with the activities planned to acquire site characterization data on these conditions. Figure 8.3.1.15-1 shows the general link between site characterization and the issues requiring data, and Figure 8.3.1.15-3 depicts the detailed logic for completion of Investigation 8.3.1.15.2. Completion of the activities shown in Figure 8.3.1.15-3 and discussed in the following pages will provide all required information on ambient in situ stress and temperature conditions required by performance assessment and design.

Technical rationale for the investigation

The data requirements summarized in Table 8.3.1.15-1 are straightforward. For ambient stress conditions, determination of the principal stresses and the spatial variability thereof will provide the required information. For ambient thermal conditions, measurement of the in situ temperatures and the spatial variability thereof will satisfy the requirements. In addition, heat flow data may be used as a check on the internal consistency of models of heat and water flow at Yucca Mountain.

8.3.1.15.2.1 Study: Characterization of the site ambient stress conditions

The objective of this study is to characterize the ambient (pre-repository) state of stress of the Yucca Mountain host rock and surrounding units for use as initial conditions for geomechanical models used in the design and performance assessment of the repository underground facilities.

8.3.1.15.2.1.1 Activity: Anelastic strain recovery experiments in core holes

Objectives

The objective of these experiments using samples from core holes is to determine the horizontal stresses at Yucca Mountain and especially the spa-

tial variability thereof. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

Parameters

The parameters to be determined during these experiments are the magnitude and orientation of the minimum and maximum horizontal stresses. In addition, values of Young's modulus and Poisson's ratio will be obtained on the samples to enable stresses to be calculated from measured strains.

Description

The anelastic strain recovery method of obtaining in situ stress data involves measurement of biaxial strains on core immediately after the core is removed from the core hole. Oriented core is used for the measurements. A viscoelastic model is used with the magnitude and orientation of the measured strains to calculate in situ stresses. The technique assumes that partial recoverable strain is proportional to the total recoverable strain, that the recovery behavior is linearly viscoelastic, and that the material is either isotropic or transversely isotropic. A comparison of the technique with hydraulic fracturing is presented in Teufel and Warpinski (1984).

This technique may be used in several of the new core holes at Yucca Mountain. Suitable core (i.e., unfractured and with limited lithophysae) will be measured, with the following experiment distribution in each hole:

Thermal/mechanical unit	Number of experiments
TCw	1 (if feasible)
PTn	1 (if feasible)
TSw1	2-3
TSw2	2-3
TSw3	0
CHn1v	1
CHn1z	1

The number and distribution of experiments are designed to examine both vertical and horizontal variability of in situ stress while minimizing the total number of experiments. After strains are measured on a specific interval, the core will be deformed in the laboratory to obtain Young's modulus and Poisson's ratio data with which to calculate the stresses from the measured strains.

The applicability of the technique to welded tuffs removed from relatively shallow depths (<500 m) will be evaluated by prototype testing in the Grouse Canyon Member in existing excavations in Rainier Mesa at the Nevada Test Site. The experimental program just outlined will be conducted only if

the experiment results in the Grouse Canyon Member indicate that useful data are likely to be obtainable at Yucca Mountain.

8.3.1.15.2.1.2 Activity: Overcore stress experiments in the exploratory shaft facility

Objectives

The primary objectives of these experiments are (1) to determine the in situ state of stress above, within, and below the repository host rock in that portion of the repository block penetrated by the exploratory shaft facility (ESF) and (2) to evaluate the extent to which the ambient stress conditions are redistributed adjacent to excavations. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

Parameters

The parameters of this activity are in situ stresses and spatial variability thereof.

Description

Overcoring tests to measure stresses in two dimensions will be done at both the Topopah Spring and Calico Hills levels in the ESF. For each test, a 10-m-long EX-size pilot hole will be drilled. At least three overcore stress experiments using borehole deformation gages (BDG) will be conducted in each pilot hole; overcoring will produce 14.6-cm diameter hollow core. Strain measurements will be completed on the recovered core before it is tested in a biaxial pressure chamber. This testing will be conducted to obtain a deformation modulus with which to calculate stresses from the strain data observed in situ.

A separate set of overcoring experiments, to measure stresses in three dimensions, will be performed in lateral excavations. Holes will be drilled laterally both at the upper breakout level and at the main test level and in a drilling alcove excavated laterally from the ramp in the nonwelded and zeolitized tuffaceous beds of the Calico Hills (unit CHnlz). Three types of core holes will be included in these experiments. First, 76-mm-diameter (NX-size) holes will be cored to a depth of 15 m to examine fracture characteristics in the vicinity of the overcoring experiments. Then, 38-mm-diameter (EX-size) pilot holes will be cored beginning at or near the excavation boundary, and 15.2-cm-diameter core barrels will be used to overcore the pilot holes. Actual drillhole configurations and orientations may change, depending on local geologic conditions (fracturing, lithophysal content). At each location, overcoring will extend up to 15 m radially into the rock mass from the edge of the excavation.

Each core hole involved in the overcoring work will be surveyed for fractures by a borehole video camera. The fracture surveys are intended to provide data on the location, distribution, orientation, spacing, apertures, and infilling of the fractures at each location and to assist in placement of

BDGs in the pilot holes. Borehole dilatometer experiments will be conducted in the 76-mm (NX) core holes to obtain estimates of the rock-mass deformation modulus and its variability along the length of each hole.

The number of locations at which overcoring will be performed at the main test level will depend on spatial variability of in situ stress.

8.3.1.15.2.2 Study: Characterization of the site ambient thermal conditions

The objective of this study is to characterize the ambient (pre-repository) temperature of the Yucca Mountain host rock and surrounding units for use as initial conditions for thermomechanical models used in the design and performance assessment of the repository underground facilities.

8.3.1.15.2.2.1 Activity: Surface-based evaluation of ambient thermal conditions

Objectives

The objectives of this activity are (1) to measure in existing wells the spatial variation of temperature with depth and to provide baseline temperatures within the repository host rock and surrounding units, (2) to measure thermal conductivity (near 25°C) of core samples as a check on independent thermal property determinations at various temperatures, and (3) to determine heat flow at Yucca Mountain.

Parameters

The parameters of this activity are ambient temperature and spatial variability thereof and thermal conductivity.

Description

Temperature logs will be obtained in all available wells at Yucca Mountain and in the surrounding area. Temperatures will be logged at 0.3-m depth intervals below the water table and in water-filled casing above the water table. In air-filled casing above the water table, temperatures will be measured at 30-m intervals because of long-time constants. In all instances, calibrated thermistor probes will be used. Temperature profiles and cross sections will be prepared.

Thermal conductivities will be measured on cores (in conjunction with Activity 8.3.1.15.1.1.3) or drill cuttings. In addition, least-squares analyses will be performed on nearly linear segments of temperature profiles and combined with the thermal conductivities to determine the near-surface heat flow and its variation, both vertically and laterally, within and around the proposed repository location.

8.3.1.16 Overview of preclosure hydrology program: Description of preclosure hydrologic characteristics and conditions required by the performance and design issues

Summary of performance and design requirements for hydrology information

The preclosure hydrology test program addresses the requirements of performance and design issues. The hydrologic conditions, which include the potential for flooding, the availability of water for repository construction and operation, and the subsurface hydrologic conditions both within and above the repository horizon, must be examined to determine if engineering measures that require excessive cost, or technology beyond that which is reasonably available, will be needed.

The preclosure hydrology program (this section) and the geohydrology program (Section 8.3.1.2) will obtain specific data required for the design of the systems and components that are important to safety. The descriptions and analyses will consider the margins of safety under conditions that may result from expected operational occurrences, including those of natural origin such as flooding. These analyses must also consider the adequacy of structures provided for the prevention of accidents and mitigation of their consequences, including natural phenomena. Thus, information on the flash flood potential of the site is needed to aid in the design of the flood control measures, should they be required.

Four issues (Issues 1.11, 1.12, 4.2, and 4.4) request data from the preclosure hydrology program. The requests for hydrologic data can be summarized as follows:

1. Information required for Issue 4.4 (technical feasibility, Section 8.3.2.5) and Issue 4.2 (nonradiological health and safety, Section 8.3.2.4) relates to the potential for surface flooding. Flood frequency and magnitude data are needed for analyses being performed to determine the impacts of potential flooding on the design of the surface facilities.

2. The second type of data requested by Issue 4.4 are the parameters required to locate adequate and alternative sources of water for the repository. Current plans are to develop two new wells for repository water supply. In the event of well failures, an alternative source of water also must be available. Existing wells J-12 and J-13 could be adequate for repository-related water needs and will be considered in the evaluation for suitable alternative sources. Characteristics of aquifers proximal to the site will be evaluated to identify potentially suitable sources. Modeling studies in support of Activity 8.3.1.2.3.3.3 will determine the possible changes to the flow system that might result from withdrawals made from the wells supplying water for the repository and from the proposed alternative sources.

3. Issues 4.4 (technical feasibility, Section 8.3.2.5), 1.11 (configuration of underground facilities, Section 8.3.2.2), and 1.12 (seal characteristics, Section 8.3.3.2) require a description of the hydrologic conditions within and above the repository horizon. This information is needed to estimate moisture content, flux, and potential moisture influx above and within the host horizon, as well as the potential for perched water zones, which will be used as input for the design of the repository, shaft liners, and seals.

Approach to satisfy performance and design requirements

The strategy of the preclosure hydrology program is to satisfy the requirements of design and performance issues. Three different types of preclosure hydrologic data have been identified by the design and performance issues: (1) flood frequency and magnitude, (2) water supply for repository-related water needs, and (3) subsurface hydrologic conditions at the site. These data requirements form the basis for the three investigations. Tables 8.3.1.16-1 and 8.3.1.16-2 list the parameters to be collected by this program, identify the issues that will use each parameter, and define the activities under which each parameter is to be collected. Figure 8.3.1.16-1 illustrates how the investigations of the preclosure hydrology program and the geohydrology program will obtain the data needed to satisfy the parameter requests of the design and performance issues.

The different types of data required will be obtained from three different investigations. Each investigation focuses on the specific type of data to be collected. Investigation 8.3.1.16.1 addresses the aspects of surface hydrology related to flood and debris hazards; Investigation 8.3.1.16.2 addresses the hydrologic and economic requirements of water supply; and Investigation 8.3.1.16.3 describes the subsurface conditions of the unsaturated zone that must be known to design the repository access ramps, underground facilities, shafts, shaft liners and seals. These data are required by the design issues to determine (1) the technical feasibility of constructing a repository in the unsaturated zone, (2) the compatibility of repository-related activities with the geohydrologic setting, and (3) the ability to construct the repository using available technology and at reasonable cost.

Interrelationships of preclosure hydrology investigations

Three investigations have been developed to provide the necessary information for the preclosure hydrology program. Investigation 8.3.1.16.1 (flood recurrence intervals) will obtain data that will be used to define flood recurrence intervals, flood levels, and the probable maximum flood at potential locations for the surface facilities.

Study 8.3.1.16.1.1 (flood potential of the Yucca Mountain site) will evaluate flood potential by collecting peak streamflow data, assessing the debris movement in drainages at or near the Yucca Mountain site, and investigating geologic evidence of paleofloods. The character of selected channel and floodplain deposits will be examined to determine the nature of the fluvial processes involved in deposition. Field judgments of the nature and

Table 8.3.1.16-1. Data requirements of the design and performance issues satisfied by the preclosure hydrology program for System Element 1.1.1 (surface)

SCP Issue requesting parameters	Design parameters	Goal	Confidence	Characterization parameters	Testing basis: Current estimate	Testing basis: Present confidence[a]	Testing basis: Confidence needed[b]	Studies/activities
4.4 Technical feasibility (Section 8.3.2.5)	Surface hydrology at all surface facility locations	Determine parameter values using ANSI and other standard applicable methods	High	Precipitation quantities and rates (from regional data)	Refer to Section 5.1	Low to moderate	High	8.3.1.16.1.1 (flood potential of Yucca Mountain)
4.2 Nonradiological health and safety (Section 8.3.2.4)	Magnitude of 5, 25, 50, 100, 500 yr, and probable maximum floods	Define elevation of flood levels to ±2 m		Streamflow rates, quantities, and durations (clear water	Refer to Bullard (1986)	Low	High	8.3.1.2.1.1 (regional meteorology) and 8.3.1.2.1.2 (runoff streamflow)
	Area and depth of inundation for facilities and access portals			Peak flow discharge for 5, 25, 50, 100, 500 yr, and probable maximum floods	Refer to Bullard (1986) and Squires and Young (1984)	Low to moderate	High	
				Channel morphology and surface topography	Refer to Squires and Young (1984) and Waddell et al. (1984)	Low to moderate	Moderate	
	Flow velocities	Calculate maximum tractive force of channel flow and sheet flow in area of inundation	High	Quantity and character of debris moved during flooding	Refer to Costa (1983)	Very low	High	8.3.1.16.1.1 (flood potential of Yucca Mountain)
	Debris load of flows			Define water to sediment ratio	Refer to Costa (1983)	Very low	High	8.3.1.2.1.2 (runoff and streamflow)
				Characterize sediments within watershed	Refer to Costa (1983)	Very low	High	8.3.1.2.2 (unsaturated--zone hydrologic system)

[a]Present confidence ratings of high, moderate, and low are based on the quality of data and the number of site-specific measurements currently available.
[b]Confidence needed is an indication of the level of certainty that will be necessary to demonstrate that a goal is met.

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Table 8.3.1.16-2. Data requirements of the design and performance issues satisfied by the preclosure hydrology program for System Element 1.1.2 (subsurface)

SCP Issue requesting parameters	Design parameters	Goal	Confidence	Characterization parameters	Testing basis: Current estimate	Testing basis: Present confidence[a]	Testing basis: Confidence needed[b]	Studies/activities
4.4 Technical feasibility (Section 8.3.2.5)	Sustained yield of wells	864,000 m^3/yr	Moderate	Aquifer transmissivity and storage coefficient	To be determined from well testing	Medium	Moderate	8.3.1.16.2.1 (location of adequate water supply) and 8.3.1.2.3 (regional ground-water flow system)
1.11 Configuration of underground facilities (Section 8.3.2.2) 1.12 Seal characteristics (Section 8.3.3.2)	Water inflow to underground facility (including seasonal variation)	Quantify potential inflow rate (total into mine). Expected 0-20 gpm accuracy ±10	Moderate	Fracture flow into exploratory shaft facility	≤100 gpd	Low	Moderate	8.3.1.2.2.3 (surface based exploratory shaft testing), 8.3.1.2.2.4 (unsaturated-zone percolation), and 8.3.1.16.1.1 (flood potential of Yucca Mountain)

[a]Present confidence ratings of high, moderate, and low are based on the quality of data and the number of site-specific measurements currently available.
[b]Confidence needed is an indication of the level of certainty that will be necessary to demonstrate that a goal has been met.

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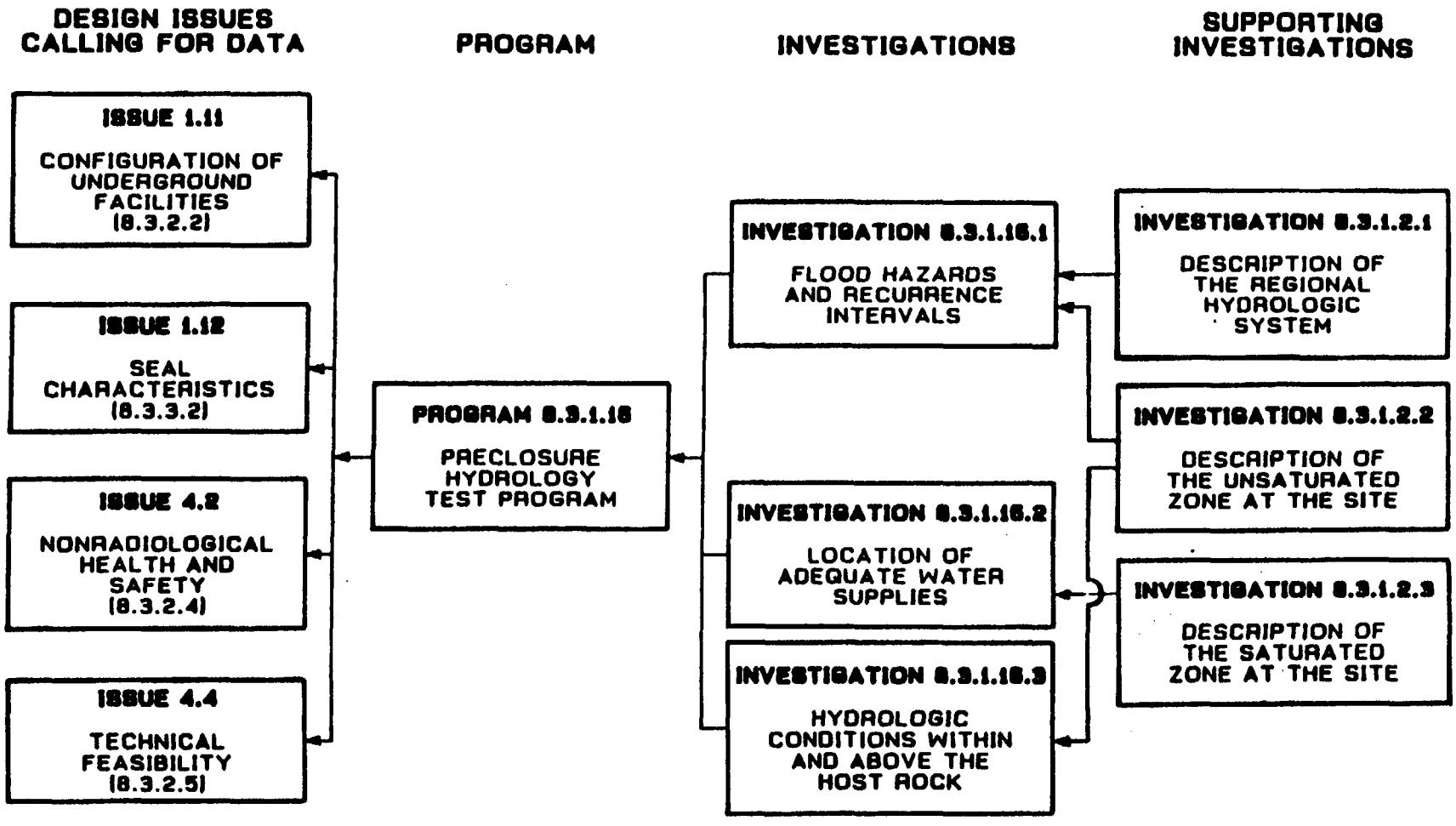

Figure 8.3.1.16-1. Relationship between the preclosure hydrology test program and its investigations.

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severity of debris transport by floods will be made to evaluate the characteristics of debris hazards posed by the floods. Pertinent engineering analytical techniques, including standard flood-frequency analysis techniques, will be applied to the data collected in the appropriate drainages. This will yield an estimate of the magnitude and frequency of future flood events. These standard flood-frequency analysis techniques will be used to determine design requirements for nonsensitive structures while more conservative flood-hazard design requirements will be used for sensitive structures such as shafts and waste-handling structures.

The specific parameters that have been defined for Study 8.3.1.16.1.1 are the maximum rates and quantities of precipitation, streamflow characteristics, flood flow and debris transport conditions, and the recurrence for runoff and flood events. By calculating flood recurrence intervals, and quantifying the probable maximum flood level, adequate design measures can be implemented to avoid and mitigate the hazards associated with flood events.

Investigation 8.3.1.16.2 (adequate water supplies) addresses the location of adequate water supply for repository construction, operation, and closure. Two subordinate concerns to this investigation are the location of an alternative water supply and the possibility of using wells J-12 and J-13 as the alternative wells.

The second study, Study 8.3.1.16.2.1 (adequate water supply for the mined geologic disposal system) consists of three activities. The parameters that will be evaluated include the hydraulic characteristics of aquifers located proximal to the site, the cost and feasibility of constructing new water wells and a distribution system, and the identification of the possible effects on the flow system that might result from water withdrawals made from the proposed primary wells or from the proposed alternative wells.

Investigation 8.3.1.16.3 (ground-water conditions) involves characterizing the unsaturated zone above and within the repository horizon to define the moisture conditions between the repository and the land surface.

Study 8.3.1.16.3.1 is primarily a synthesis activity. The characterization of the hydrologic conditions within and above the repository horizon will be accomplished by studies being performed in support of Investigation 8.3.1.2.2. Although the bases for addressing the investigations are different (repository design versus long-term performance assessment), the parameters that must be obtained to satisfy both of these investigations are the same. Information on flux, moisture content, and potential influx will be obtained from the geohydrology program (Section 8.3.1.2). The data collected under the geohydrology program will be compiled, analyzed, and evaluated under Activity 8.3.1.16.3.1.1, and will be used to define the moisture conditions at the site that are needed for design.

8.3.1.16.1 Investigation: Flood recurrence intervals and levels at potential locations of surface facilities

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Section 3.2 summarizes the current information regarding flood history, the potential for future flooding, current and future studies of flood and debris hazards, and flood protection. Local convective storms coupled with the rugged terrain at Yucca Mountain can cause intense flash flooding to occur sporadically in dry washes that drain the mountain. The meteorology and climatology of the Yucca Mountain site and the region are discussed further in Section 5.1. Further evaluation of the flood potential of these washes is necessary to ensure adequate design of the surface facilities. Flood protection design considerations are discussed in Sections 6.2.4 and 3.10.2.

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Precipitation quantities and rates.

2. Streamflow rates, quantities, and durations.

3. Peak flood discharges.

4. Quantity and character of debris moved during floods.

5. Character of fluids moved during flooding (relative proportions of water and sediment).

6. Recurrence intervals for runoff and flooding.

Most of the data for these parameters are being, or will be, collected through the following studies:

Study	Subject
8.3.1.2.1.2	Characterization of regional surface water (surface-water runoff and fluvial transport of debris by floods)
8.3.1.5.2.1	Characterization of the Quaternary regional hydrology (regional paleofloods)
8.3.1.12.2.1	Meteorological data collection at the Yucca Mountain site

Purpose and objectives of the investigation

To meet the purpose of identifying the potential hazards associated with floods and debris movement, three objectives must be met: (1) to determine the magnitudes and frequencies of major flood events that can potentially occur during the period of repository operation, (2) to identify all potential areas of inundation, and (3) to determine the quantities and size characteristics of debris transported by flooding. Figure 8.3.1.16-2 illustrates how the activities of Study 8.3.1.16.1.1, in conjunction with activities of the geohydrology program, will obtain the required parameters.

Technical rationale for the investigation

Surface facilities such as roadways, building pads, and buildings to serve as workshops, offices, laboratories, and living spaces, must be located and designed for minimum natural disturbance during their intended life (approximately 100 yr) largely for safety and economic reasons. It is also critical that all surface sites for handling the waste packages, including buildings, storage areas, and repository access facilities such as shaft collar and hoisting structures, be located in an area where flood or debris-flow events would not have serious effects on their stability during the preclosure period. To accomplish this, flood and debris-hazard studies have been designed to document flooding and severe sediment erosion, transport, and deposition to aid in predicting the maximum flood intensities and recurrence intervals, which are necessary for the design of safe facilities.

In these studies, floods will be characterized by measuring the peak streamflows and generally assessing associated debris movement in drainages that are at or near the Yucca Mountain site. The surficial character of selected channel and floodplain deposits in the numerous ephemeral drainages will also be examined in an attempt to determine the nature of the fluvial processes involved in the emplacement of the deposits. Field judgments of the nature and severity of debris transport by floods will be made to evaluate properly the characteristics of debris hazards posed by the floods. Pertinent engineering-analytical techniques, including standard-flood-frequency-analysis techniques (e.g., the log-Pearson type III distribution), will be applied to the data collected in the drainages in question to estimate the magnitude and frequency of future floods. Using this approach, non-sensitive structures can then be designed by standard engineering methods of flood analysis, while the shaft and restricted-area facilities will use more conservative flood hazard design procedures.

Peak streamflow data at and around Yucca Mountain will be collected as part of Activity 8.3.1.2.1.2.1 (surface-water runoff monitoring). The analyses of these data will also incorporate data from nearby crest-stage gages that have been operative since the 1960s as part of the U.S. Geological Survey, Nevada Department of Transportation flood-study program. The field judgments of the nature and severity of debris transport by flood flows will be made as part of Activity 8.3.1.2.1.2.2 (transport of debris by severe runoff). Pertinent information from Activity 8.3.1.5.2.1.1 (regional paleoflood evaluation) will also be transferred to this activity for use in characterizing the flood and debris hazards.

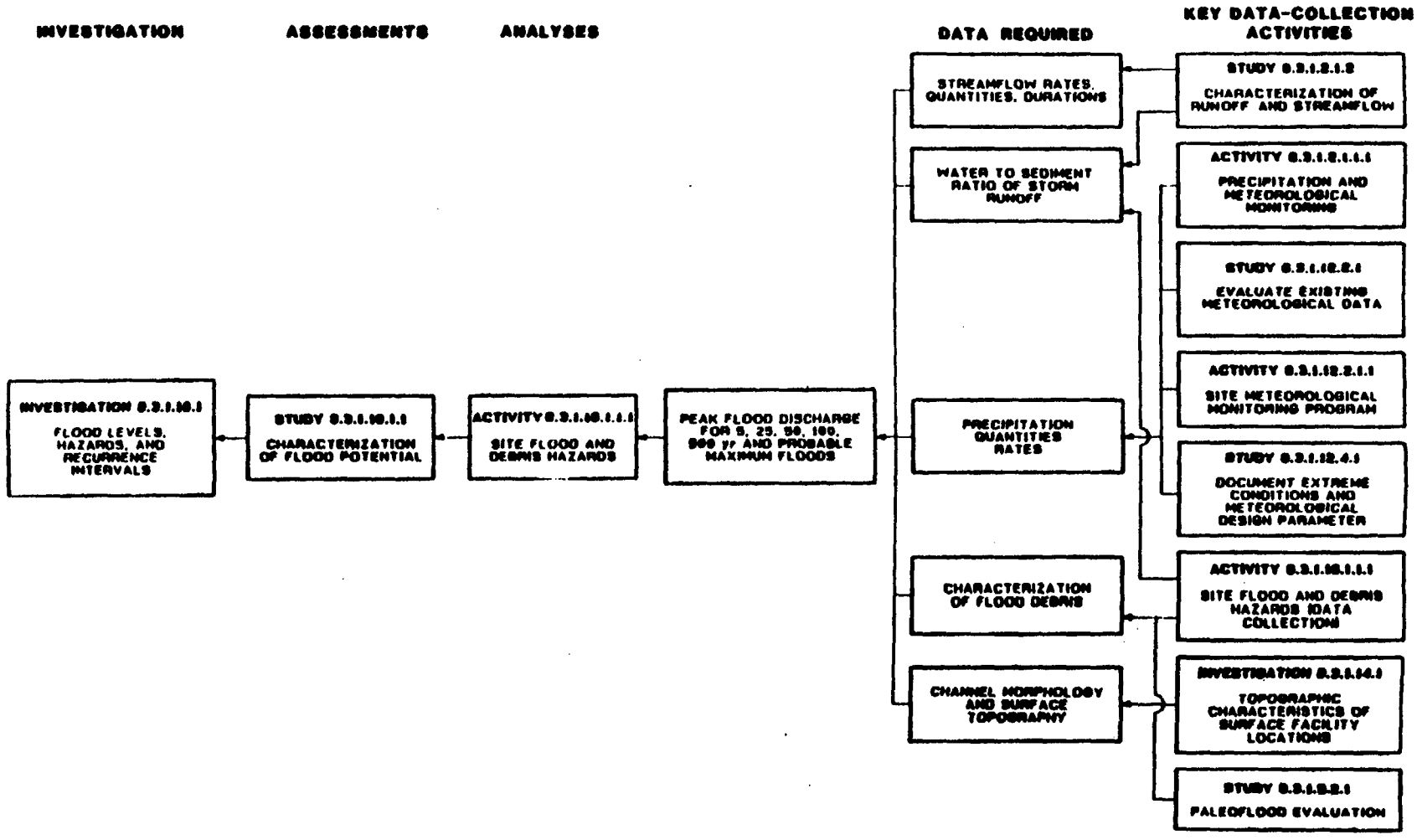

Figure 8.3.1.16-2. Logic diagram for Investigation 8.3.1.16.1 (flood recurrence intervals).

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The techniques used to obtain this information will complement each other and also will allow a comparison of data to decrease data uncertainty. It is recognized that the short period of record for direct flow measurements will be inadequate to derive confident estimates of flood recurrence intervals larger than a few years. Therefore, this study will rely upon a combination of direct and indirect techniques. In areas where the flood recurrence and intensity analyses will have to be translated to surface facility sites where actual data may not have been collected, the geologic record of paleofloods will be used to temper the probability analyses for sensitive surface facilities. Trench studies of ancient deposits and morphologic studies of the area will be used to complement the peak streamflow measurements for determining the characteristic depths of flooding, depths of scour, characteristics of sediment load, and thickness of deposits formed in the past.

Section 8.3.1.5.2 describes paleoflood studies that will be used to augment this investigation. Initial trench studies suggest that paleoflood techniques may not be adequate to fully assess flood and debris hazards because of the lack of datable materials (e.g., organics, tephra, and soil formation). Thus, a dual strategy will be maintained to determine flood and debris hazards. Crest-stage data collection will continue indefinitely, and flood events will be documented if and when they occur. Data from these modern flood studies will be supplemented by information from paleoflood reconstruction activities to be performed as part of the geohydrology program (Section 8.3.1.2).

8.3.1.16.1.1 Study: Characterization of flood potential of the Yucca Mountain site

This study contains one activity and evaluates the potential for flooding in the many small, dry, desert washes that drain Yucca Mountain. This evaluation will be used for designing the surface facilities for the proposed repository. Proper design for flood potential is necessary to ensure the safety of the workers and the surface facilities.

8.3.1.16.1.1.1 Activity: Site flood and debris hazards studies

Objectives

The objective of this activity is to assess the flood and debris hazards at and near the potential repository surface facilities locations to allow adequate design of facilities to prevent or reduce hazards to an acceptable level.

Parameters

The parameters of this activity are

1. Precipitation quantities and rates.

2. Streamflow rates, quantities, and durations.

3. Peak flood discharge.

4. Quantity and character of debris moved during severe floods.

5. Character of fluids moved during flooding (relative proportions of water and sediment).

6. Recurrence intervals for runoff and flooding.

7. Channel morphology definition.

8. Surface topography.

Description

Floods will be characterized by measuring the peak streamflows and assessing the debris movement in drainages that are at or near the Yucca Mountain site. Streamflow measurements will be made as part of Activity 8.3.1.2.1.2.1 (surface-water runoff monitoring), which includes two stream gage networks: one at the regional scale and one specific to Yucca Mountain. Surface runoff monitoring at Yucca Mountain is needed to provide detailed data for the study of natural infiltration (Activity 8.3.1.2.2.1.2 of Investigation 8.3.1.2.2, the unsaturated zone hydrologic system at the site). Many stream gages, rain gages, and some automated fluvial-sediment samplers situated at strategic locations will be used. Streamflow documented by the stream gage networks will be incorporated into the pertinent flood-prediction analyses. Twenty-five to fifty small drainages may be included in this study effort. Pertinent flood data and precipitation data from drainages throughout the southern Nevada region will be incorporated into analyses of flooding at and around Yucca Mountain.

The surface character of selected channel and floodplain deposits in the numerous ephemeral drainages in and around the proposed storage site will be examined to determine the fluvial processes involved in the emplacement of the deposits. If this reconnaissance discloses a variety of processes or significant variations within any process, an attempt will be made to differentiate the processes and degrees of differences. The results of this effort may then determine whether the variations in the characteristics of the deposits can or should be shown on surficial deposit maps of the drainages.

As part of Activity 8.3.1.2.1.2.2 (transport of debris by severe runoff), field judgments of the nature and severity of debris transport by flood flows will be evaluated to determine the characteristics of debris hazards from flood flows. No standard techniques are available to sample moving coarse-grained debris, which constitutes the major debris hazard, but flood investigators will describe both qualitatively and somewhat quantitatively (by careful field observations) the character of debris that has moved within and through the drainage during severe runoff events. Also, some debris movement characteristics will be deduced through analysis of the debris deposits. Fresh erosion that has resulted from recent flooding will be noted on maps to allow an assessment of potential slope instability. Assembling this type of semiquantitative information will, with time and experience,

form the bases for designating the degrees of debris hazards on different types of slopes. Much of the debris hazard assessment is experimental at this time, and more precise investigative plans cannot be formalized until experience with debris movement during flooding increases.

After a reasonable amount of experiences and data are gained through field investigations, laboratory experiments would seem to be the next logical step in the study process. However, laboratory efforts are not planned at this time. Scaling problems associated with laboratory models may be insurmountable, and the technology of physical modeling of debris movement is not sufficiently advanced to be a reliable alternative or supplement to the planned activities.

Pertinent engineering analytical techniques, including standard-flood-frequency-analysis techniques, will be applied to the data collected in the drainages in question to estimate future flood flows. Several computational or graphic techniques are available to estimate probable peak flood flows.

In one graphic technique, a maximum envelope curve defines the largest floods measured for variously sized drainage basins (Crippen and Bue, 1977). Thus, for a given size of drainage, the curve predicts the largest flood that would be expected on the basis of historical evidence of the largest observed floods for drainages of comparable size within the same geographic region.

Another widely used technique in the nuclear industry is the computational determination of the probable maximum flood (PMF) (ANSI/ANS 2.8-1981). This computational procedure is based on the U.S. National Weather Service estimates of probable maximum precipitation that can be expected throughout a specific geographical area. Neither of these techniques takes into account debris transport that may pose a serious hazard associated with a flood.

A computational technique based on field evidence has been proposed (Costa, 1983). In this technique, the average size of the five largest boulders deposited in the channel by fluid flows is determined. A velocity capable of moving particles of that size is computed, and physical surveys of the stream channel in the reach of the deposits are used to help assess the area of the flow section. Then the product of the velocity and the flow-sectional area determines the discharge necessary to move the largest particles. Application of the technique thus yields an estimate of the peak flood discharge that emplaced the largest debris fragments.

Flood frequencies and recurrence intervals may be evaluated with the log-Pearson type III curve. The log-Pearson type III is a theoretical, flexible frequency distribution computed by calculating the mean, standard deviation, and skewness coefficient of the logs of peak annual discharge data. A frequency factor is obtained from tables of skewness coefficients and exceedance probabilities. Regional values of the skewness coefficients are available.

Other similar techniques, if available, will also be applied to the drainages of concern. Flow predictions resulting from these applied techniques can then be compared, and a prediction of peak flood flows can result from the comparisons.

8.3.1.16.2 Investigation: Location of adequate water supplies

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Section 3.8 summarizes current information on the estimated quantity of water needed to support a mined geologic disposal system at Yucca Mountain.

Parameters

Three sets of parameters will be measured or calculated as a result of the site studies planned to obtain the information needed as follows:

1. Cost and feasibility of using wells J-12 and J-13 for repository-related water use as an alternative source.

2. Identification of a primary source of water for repository-related water needs.

3. Identification of an alternative source of water for repository-related water needs.

4. Identification and evaluation of potential effects of repository-related water withdrawals on the local flow system and water supply.

Purpose and objectives of the investigation

To meet the purpose of identifying the most suitable water supply and alternative, the following objectives must be met: (1) determine the adequacy of existing wells J-12 and J-13 in terms of available resource potential, total cost, and technologic feasibility as an alternative water supply for a repository at Yucca Mountain (water rights are discussed in Section 8.3.1.11), (2) identify and locate a primary source of water for a repository at Yucca Mountain, (3) identify and locate potential alternative sources of water, and (4) determine the potential effects of repository-related water withdrawals on the local flow system at Yucca Mountain. Figure 8.3.1.16-3 illustrates how the activities of Study 8.3.1.16.2.1 will obtain the parameters needed to satisfy the design requirements.

Technical rationale for the investigation

Current plans are to develop a primary source closer to the proposed site than wells J-12 or J-13 to supply repository-related water needs. In the event that a primary source cannot serve repository-related water needs through decommissioning, an alternative source of water must be readily available. Wells J-12 and J-13 (Figure 8.3.1.16-4) are under consideration as sources to provide water during repository site preparation and the early phases of construction if Yucca Mountain is selected. They are also being considered as possible alternative sources. The hydrostratigraphic unit source for wells J-12 and J-13, the Topopah Spring Member of the Paintbrush Tuff, is presently considered capable of yielding water at a sufficient rate to supply repository-related water needs through closure and decommissioning.

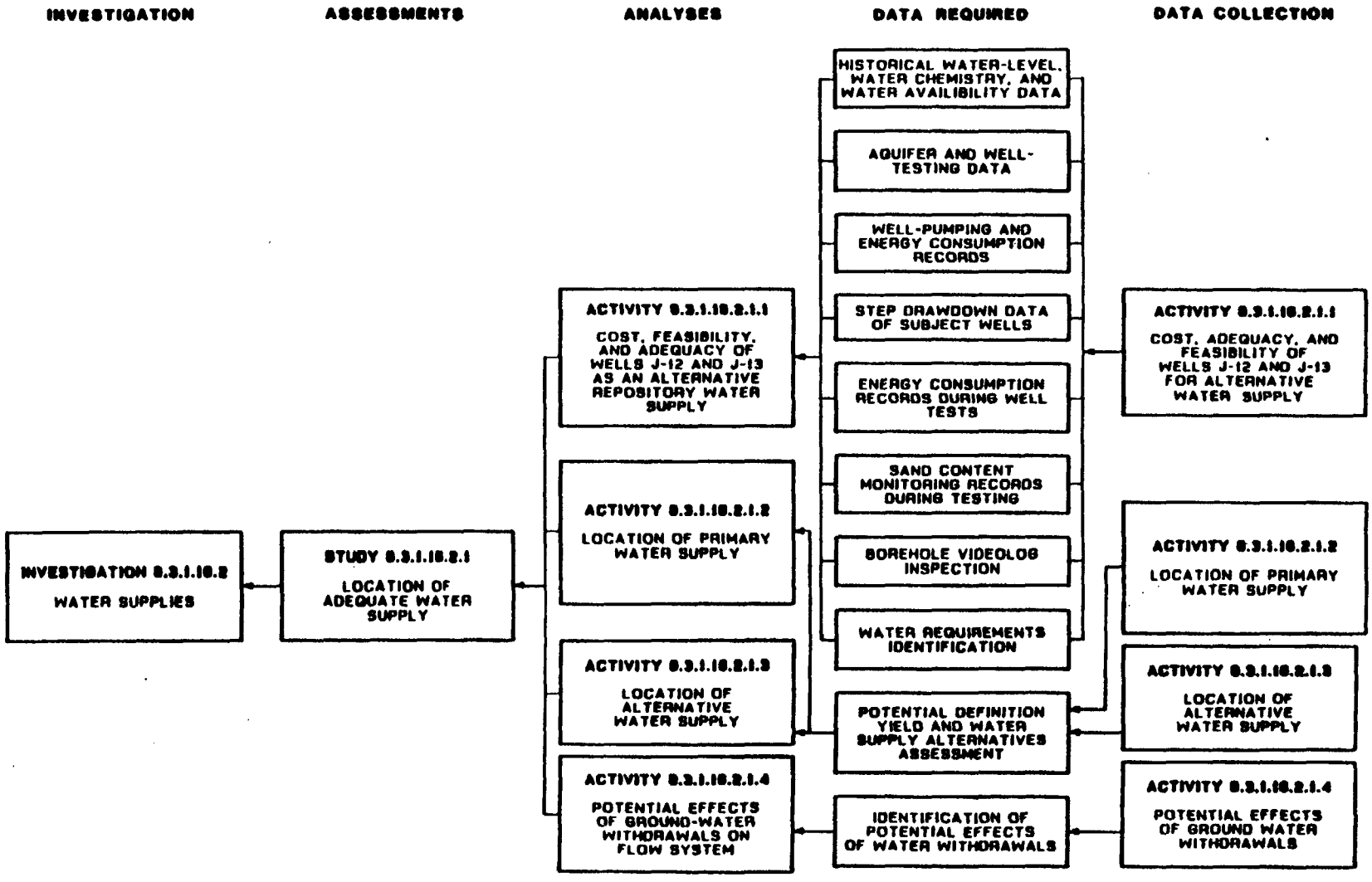

Figure 8.3.1.16-3. Logic diagram for Investigation 8.3.1.16.2 (water supplies).

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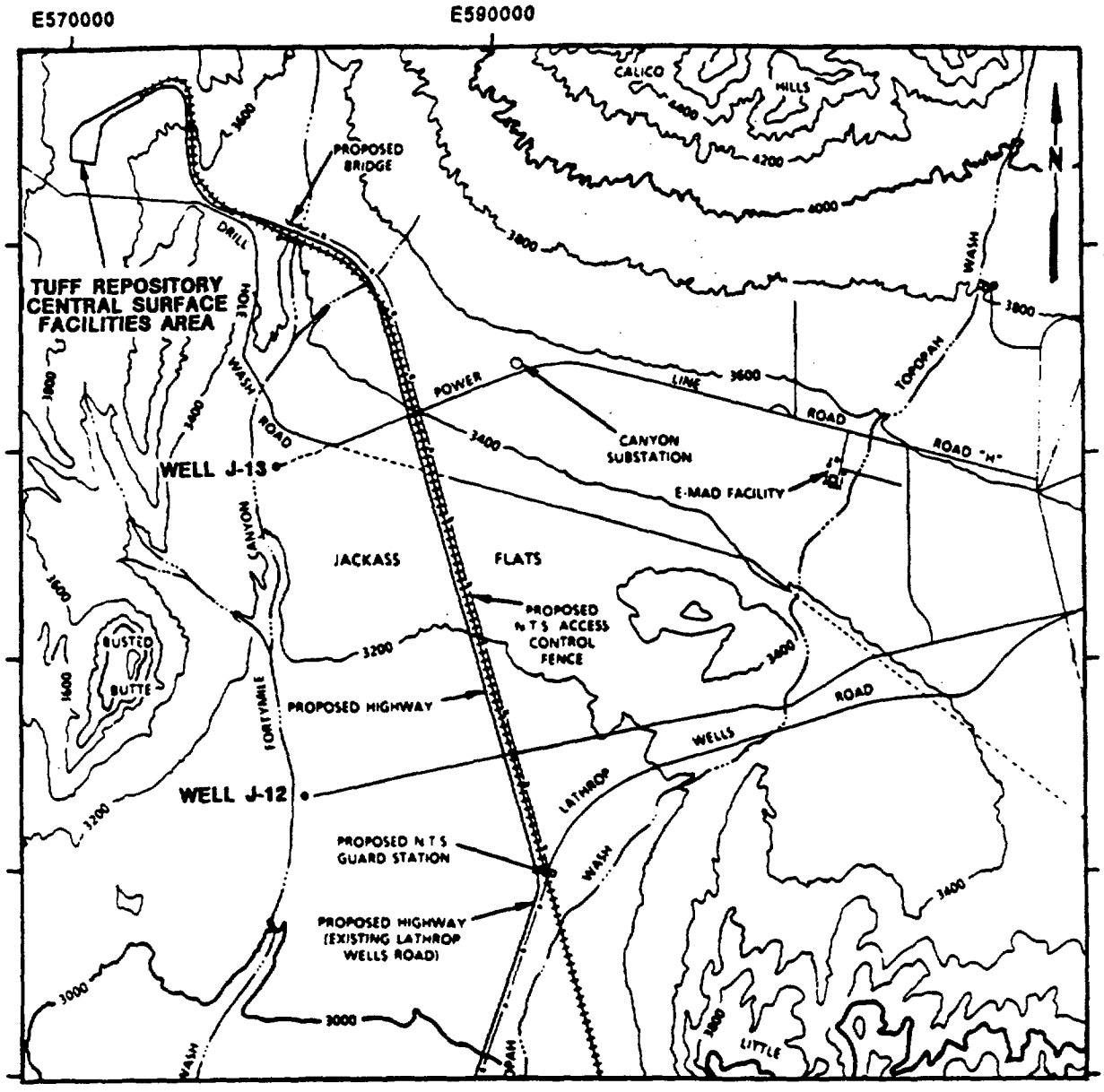

0 5000 FEET
0 1000 METERS

CONTOUR INTERVAL 200 FT

NTS - NEVADA TEST SITE

Figure 8.3.1.16-4. Locations of wells J-12 and J-13 relative to the surface facility location.

An assessment of the expected future performance, estimated total cost, and the feasibility of using these wells as alternative sources is needed to demonstrate that the wells are adequate and can be used at a reasonable cost with available technology.

The water that will be used to support repository construction, operation, and closure will cause an increase in local water use, which could affect the local flow system at Yucca Mountain. Potential effects from repository-related water withdrawals will be identified and assessed to determine if any mitigating measures might be required.

The data required to satisfy the performance and design requirements will be collected by the four activities of Investigation 8.3.1.16.2 and other studies performed in support of Investigations 8.3.1.2.1, 8.3.1.2.3, and 8.3.1.9.2.

8.3.1.16.2.1 Study: Location of adequate water supply for construction, operation, closure, and decommissioning of a mined geologic disposal system at Yucca Mountain, Nevada

This study includes four activities.

8.3.1.16.2.1.1 Activity: Assessment of the cost, feasibility, and adequacy of wells J-12 and J-13 for use as the alternative water supply for a mined geologic disposal system at Yucca Mountain, Nevada

Objectives

The objective of this activity is to determine (1) the adequacy of wells J-12 and J-13 in terms of available resource potential and (2) the total cost and technical feasibility of supplying the water needed to support a repository at Yucca Mountain. These wells will be evaluated for use as alternative sources.

Parameters

The parameters required for this activity are the total time-phased water demand through decommissioning, estimated peak annual water demand, the maximum water resources available from wells J-12 and J-13 based on historical production capabilities and existing well and pumping-test data, the estimated cost of water withdrawals (pumping, treatment, and distribution), and the quantity of water appropriated by local water users through permits and certifications.

Description

Several steps may be necessary to complete this activity. The actual field work performed will depend on the type, quality, and amount of data available. Thus, the first step will be to compile all data pertinent to the

construction, operation, and performance of wells J-12 and J-13. These data will be analyzed to determine their adequacy for predicting long-term well performance. The data to be compiled include historical water levels, water chemistries, aquifer test results, well test results, energy consumption records, and well construction records.

After all existing data have been compiled, the following methods will be applied. Hydrographs of water levels, ionic constituents, and pumping rates will be prepared to evaluate the past performance of the subject wells. Aquifer and other test results will be reanalyzed as necessary to meet the quality assurance requirements of the Yucca Mountain Project. If the existing data are found inadequate for use in assessing long-term well performance, a well test plan will be developed.

The well test plan will identify any additional tests and analyses that may be necessary to assess long-term well performance. Specific tests could include step drawdown testing of both wells, sediment-content monitoring during testing (if applicable), borehole videolog inspection of the casing and open hole, and water chemistry analyses. Step drawdown test results will be analyzed to determine well- and formation-loss coefficients, optimal and maximum well yields, and operating efficiencies. Energy consumption will be monitored during testing to aid in developing unit costs for ground-water withdrawals. Pumping of sediment will be measured and the physical condition of the wells will be described to ascertain whether the wells will require excessive maintenance during long-term operation.

The final calculated repository water requirement will be obtained from the Advanced Conceptual Design report and will be used as the baseline to assess the adequacy and viability of wells J-12 and J-13 for use as an alternative water supply. All results will be compiled and evaluated to determine the cost and technical feasibility of meeting the repository water demand.

8.3.1.16.2.1.2 Activity: Location of a primary water supply for a mined geologic disposal system at Yucca Mountain, Nevada

Objectives

The objective of this activity is to identify and locate a primary source of water for a repository at Yucca Mountain. Ideally, the primary sources would be located nearer to the surface facilities than wells J-12 and J-13, and at an elevation above the surface facilities, thereby reducing distribution costs and total pumping lifts.

Parameters

This activity will rely heavily on input from Investigations 8.3.1.2.1 and 8.3.1.2.3. Values of aquifer storativity, transmissivity, thickness, and depth to water will be provided by the hydrologic drilling and modeling activities. Remote sensing information (i.e., satellite imagery) will be used in performing lineament analyses to help identify potentially suitable well

locations. The parameters that will be measured or calculated as a result of this activity are the locations of, distances to, and relative elevations of all potentially suitable aquifers.

Other parameters that will be obtained from this activity and Study 8.3.1.9.2.2 (ground-water resource assessment) include a compilation of local water users, water uses, amounts of existing local appropriations, points of diversion, and points of use.

Description

The first part of this activity will focus on identifying the amount of unappropriated water available from sources other than wells J-12 and J-13. Other sources may include other water wells located on the NTS, or other unappropriated ground water in basins adjacent to the site. These data, in conjunction with imagery analysis techniques described by Taranik and Trautwein (1977), will be used to define the ground-water yield potential of areas located proximal to the Yucca Mountain site. Subsequent to defining the ground-water yield potential, options for a primary water source will be identified. Once the location of the potential primary source has been identified, a test well will be developed and tested. The hydraulic characteristics of the well will be determined to ensure that the source is capable of producing adequate water to meet the repository-related water demand.

8.3.1.16.2.1.3 Activity: Location of alternative water supplies for a mined geologic disposal system at Yucca Mountain, Nevada.

Objectives

The objective of this activity is to identify and locate an alternative source of water for a repository at Yucca Mountain in the event that the primary source cannot meet the water demand.

Parameters

As with Activity 8.3.1.16.2.1.2, this activity will rely heavily on input from Investigations 8.3.1.2.1, 8.3.1.2.3, and 8.3.1.9.2. Values of aquifer storativity, transmissivity, thickness, and depth to water will be provided by the hydrologic drilling and modeling activities. Remote sensing information will be used in performing lineament analyses to help identify potentially suitable well locations. The parameters that will be measured or calculated as a result of this activity are the locations of, distances to, and relative elevations of all potentially suitable aquifers.

Other parameters that will be obtained from this activity and Study 8.3.1.9.2.2 (water resource assessment) include a compilation of local water users, water uses, amounts of existing local appropriations, points of diversion, and points of use.

Description

The first part of this activity will focus on identifying the amount of unappropriated water available from potential alternative sources. These sources may include other water wells located on the Nevada Test Site or other unappropriated ground water in basins adjacent to the site. These data, in conjunction with imagery analysis techniques described by Taranik and Trautwein (1977) will be used to define the ground-water yield potential of areas located proximal to the Yucca Mountain site. Subsequent to defining the ground-water yield potential, options for alternative water sources will be identified. A potential well location will be identified, and a test well will be drilled and tested.

8.3.1.16.2.1.4 Activity: Identification and evaluation of potential effects of repository related withdrawals on the local flow system at Yucca Mountain, Nevada

Objectives

The objective of this activity is to determine the potential effects of repository-related water withdrawals on the local flow system at Yucca Mountain. The potential effects from water withdrawal include modifications to the preclosure ground-water travel path and the lowering of the potentiometric surface. Such effects will be identified and quantified to establish any mitigating measures that might be required.

Parameters

The parameters that will be collected from this activity are the effects of the time-phased water withdrawals from the primary and alternative water supply wells on the local flow system.

Description

Using the parameters and computer codes from Investigations 8.3.1.2.1 and 8.3.1.2.3, the effects of the time-phased water withdrawals on the local flow system will be modeled. The results of these computer simulations will be evaluated, and any effects on the flow system will be identified. If any adverse effects on the flow path or potentiometric surface are identified, plans to mitigate the effects will be developed. It is quite likely that any effect on the potentiometric surface may be beneficial to waste isolation, as the thickness of the unsaturated zone will increase in areas where drawdown is induced due to pumping. This will be assessed and documented for further evaluation of repository performance.

8.3.1.16.3 Investigation: Ground-water conditions within and above the potential host rock

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of Chapter 3 provide a technical summary of existing data relevant to this investigation:

Section	Title
3.9.1.3	Hydrochemistry
3.9.2.1	Hydraulic characteristics of the unsaturated zone
3.9.3.2	Potentiometric levels and head relationships in the unsaturated zone

Parameters

The following parameters will be measured or calculated as a result of the planned site studies:

1. Subsurface moisture content above the repository horizon.
2. Flux above and within the repository horizon.
3. Moisture content of the repository horizon.
4. Locations and descriptions of perched water zones.
5. Potential influx to the repository and access shafts.

Purpose and objectives of the investigation

To meet the purpose of describing the baseline characteristics of the unsaturated zone within and above the repository horizon, the following objectives must be met: (1) determine the amount of water inflow to the repository horizon including seasonal variations in inflow rate, (2) determine the existence of perched water, and (3) define the locations, depths, thickness, lateral extent, seasonal variation, and degree of saturation of perched water zones if any are identified. These data will be obtained from the geohydrology program (8.3.1.2); the preclosure hydrology program will synthesize the data to help resolve the design issues. Figure 8.3.1.16-5 illustrates the strategy that will be used to obtain and compile the required parameters for the design issues.

Technical rationale for the investigation

Measurements of the subsurface hydrologic conditions both above and within the repository horizon are required for design of the repository shafts, and seals. Preliminary data presented in Chapter 3 indicate that no special technology will be needed to construct and operate a repository at

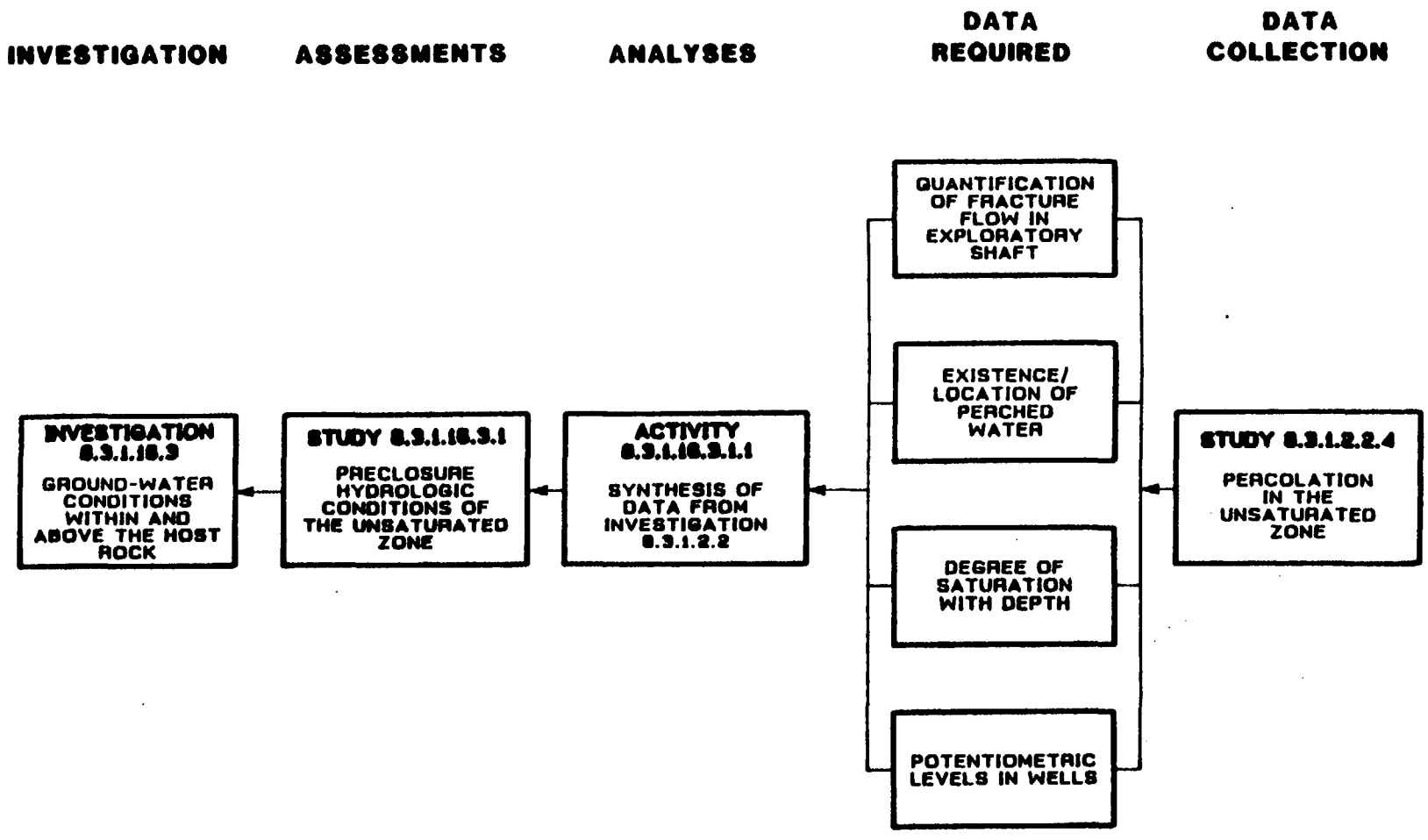

Figure 8.3.1.16-5. Logic diagram for Investigation 8.3.1.16.3 (ground water conditions).

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Yucca Mountain as a result of existing hydrologic conditions. Data obtained from this investigation will provide the design bases required to construct and operate a repository.

8.3.1.16.3.1 Study: Determination of the preclosure hydrologic conditions of the unsaturated zone at Yucca Mountain, Nevada

This study includes one activity.

8.3.1.16.3.1.1 Activity: Synthesis of data from site program 8.3.1.2 to determine the preclosure hydrologic characteristics of the unsaturated zone at Yucca Mountain, Nevada

Objectives

The objectives of this activity are to compile the data collected under geohydrology Investigation 8.3.1.2.2, in Study 8.3.1.2.2.4 (exploratory shaft facilities investigations) for input to design Issue 4.4 (Section 8.3.2.5).

Parameters

Among the parameters that will be collected from Investigation 8.3.1.2.2 are flux, moisture content above and within the repository horizon, and locations and descriptions of perched water zones.

Description

The parameters obtained from Study 8.3.1.2.2.4 will be compiled and evaluated to ensure that data collected from the exploratory shaft is sufficient to satisfy the objectives set by the design issues. The information will then be passed to the design issues to be used as input.

8.3.1.17 Overview of preclosure tectonics: Description of tectonic and igneous events required by performance and design requirements

Summary of performance and design requirements for preclosure tectonics information

The preclosure tectonics program (Program 8.3.1.17) is designed to develop an understanding of and to characterize the tectonic events and processes that could impact proposed repository structures, systems, or components considered to be important to safety through the operational phase; i.e., until permanent closure is achieved. In addition, characterizations of tectonic processes and events will be developed for consideration in the design and operation of certain structures, systems, and components required for exercising the retrieval option. Tectonic processes and events that are relevant to waste isolation following permanent closure will be investigated within the postclosure tectonics program (Program 8.3.1.8).

Performance and design issues that require data from the preclosure tectonics program are indicated in the left half of Figure 8.3.1.17-1; the right half of the figure indicates investigations that provide the requested data. Data requirements come from Issue 4.4 (Section 8.3.2.5), which evaluates the technical feasibility of repository construction, operation, closure, and decommissioning, and from postclosure Issue 1.12 (Section 8.3.3.2), which considers the design of seals for shafts, drifts, and boreholes. Investigations of technical feasibility include data requirements from three additional performance and design issues, also noted in Figure 8.3.1.17-1. These three issues are preclosure radiological safety (Issue 2.7, Section 8.3.2.3), potential radiologic exposure to the public due to credible accidents (Issue 2.3, Section 8.3.5.5), and preservation of the waste retrieval option (Issue 2.4, Section 8.3.5.2). In addition, data developed by the preclosure tectonics program will be used by the postclosure tectonics program (Program 8.3.1.8) and the preclosure and postclosure rock characteristics programs (Programs 8.3.1.15 and 8.3.1.4).

The evaluation of technical feasibility (Issue 4.4, Section 8.3.2.5) establishes the major requirement for characterizing potentially disruptive tectonic events.

The required characterization data are summarized in part a of Tables 8.3.1.17-1 through 8.3.1.17-6; part b of these tables provides summary information on the characterization program designed to provide the required data. The technical content of these tables is discussed in detail below. The data requirements are organized by the type of potential tectonic event: volcanic, including eruption and ashfall; faulting; and vibratory ground motion from natural earthquakes and underground nuclear explosions. Two tables are presented for each type of event, one for considerations of surface facilities and one for underground facilities.

The following information is used to specify each data requirement: design and performance parameters, to specify the type of data that is required; goal, to establish the precision or level of conservatism that is required; and needed confidence, to indicate the degree of certainty that the goal will be met. The needed confidences are specified using the terms high, medium, and low to denote the relative importance of each parameter-goal pair

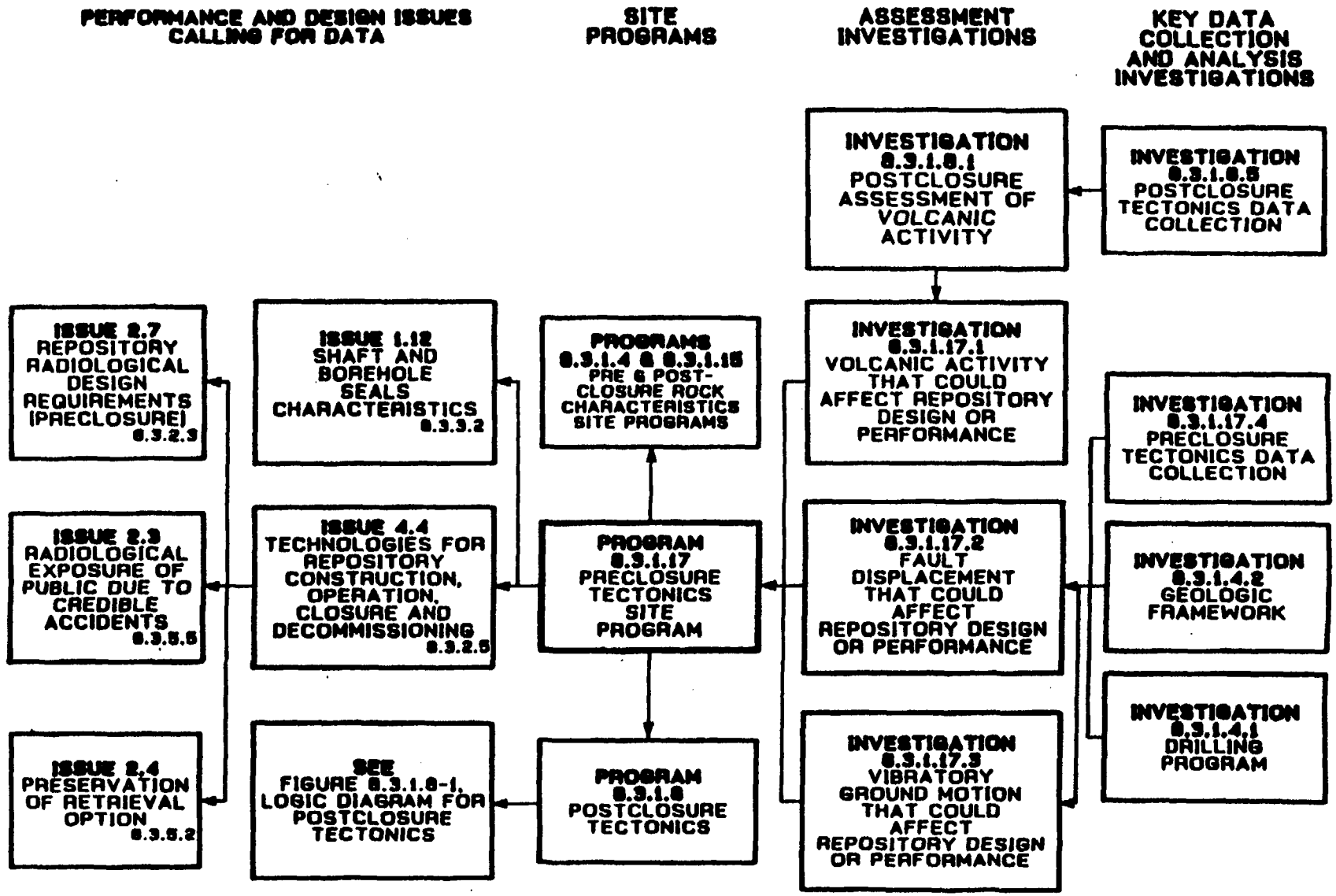

Figure 8.3.1.17-1. Logic diagram for the preclosure tectonics site program.

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8.3.1.17-1a. Design and performance parameters related to surface facilities and preclosure volcanic activity

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Probability of volcanic eruption that would disrupt surface facilities	Less than 1 chance in 10,000 in 100 yr	High	Annual probability of volcanic disruption at the site
Design-basis ash-fall thickness for facilities important to safety (FITS) ventilation systems	Less than 1 chance in 10 of exceeding design-basis ash-fall thickness in 100 yr	Low to medium	Probability of ash fall at the site as a function of ash-fall thickness 1,000-yr(+) ash-fall thickness at the site
Ash-fall particle density and size distribution	TBD[b]	Low to medium	Potential density and distribution of ash-fall particles

[a]These parameters are from Issue 4.4 (technical feasibility, Section 8.3.2.5), and corresponding performance measures are given in that issue.
[b]TBD = to be determined.

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Table 8.3.1.17-1b. Characterization parameters related to surface facilities and preclosure volcanic activity

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Annual probability of volcanic disruption at the site	10^{-7} to 10^{-9} per yr	Moderate	Medium to high	8.3.1.8.1.1.4--Probability calculations (of volcanic disruption) and assessment
Probability of ash fall at the site as a function of ash-fall thickness	TBD[a]	TBD	Low to medium	8.3.1.17.1.1.2--Assess potential ash-fall thickness at the site
1,000-yr(+) ash-fall thickness at the site	0.1-2.0 cm	Low	Low to medium	8.3.1.17.1.1.2--Assess potential ash-fall thickness at the site
Potential density and distribution of ash-fall particles	TBD	TBD	Low to medium	8.3.1.17.1.1.3--Assess potential density and size distribution of ash fall at the site

[a]TBD = to be determined.

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Table 8.3.1.17-2a. Design and performance parameters related to underground facilities and preclosure volcanic activity

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Probability of volcanic eruption through the underground facilities	Less than 1 chance in 10,000 in 100 yr	High	Annual probability of volcanic disruption of the underground facilities
Design-basis ash-fall thickness (at ventilation shaft locations)	Less than 1 chance in 10 of exceeding design-basis ash-fall thickness in 100 yr	Low to medium	Probability of ash fall at the site as a function of ash-fall thickness 1,000-yr(+) ash-fall thickness at the site
Ash-fall particle density and size distribution	TBD[b]	Low to medium	Potential density and size distribution of ash-fall particles

[a]These parameters are from Issue 4.4 (technical feasibility, Section 8.3.2.5), and corresponding performance measures are given in that issue.
[b]TBD = to be determined.

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Table 8.3.1.17-2b. Characterization parameters related to underground facilities and preclosure volcanic activity

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Annual probability of volcanic disruption of the underground facilities	4.7×10^{-8} to 3.3×10^{-10} per yr	Medium	Medium to high	8.3.1.8.1.1.4--Probability calculations (of volcanic disruption) and assessment
Probability of ash fall at the site as a function of ash-fall thickness	TBD[a]	TBD	Low to medium	8.3.1.17.1.1.2--Assess potential ash-fall thickness at the site
1,000-yr(+) ash-fall thickness	0.1-2.0 cm	Low	Low to medium	8.3.1.17.1.1.2--Assess potential ash-fall thickness at the site
Potential density and size distribution of ash-fall particles	TBD	TBD	Low to medium	8.3.1.8.1.1.3--Assess potential particulate size distribution of ash fall at the site

[a]TBD = to be determined.

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Table 8.3.1.17-3a. Design and performance parameters related to surface facilities and preclosure fault displacement (page 1 of 2)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Identification of any fault within 100 m of facilities important to safety (FITS) with greater than 1 chance in 100 of producing more than 5 cm of surface offset during the preclosure period (approximately 100 yr)	Determine existence	High	Identification and characterization of potentially significant Quaternary faults within 5 km of FITS
If existence is determined, establish			
Classification	Standard practice	High	Identification and characterization of faults within 100 m of FITS that have apparent Quaternary slip rates >0.001 mm/yr or that measurably offset materials less than 100,000 yr old
Location at surface	±5 m	High	
Orientation at surface	±10°	High	

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Table 8.3.1.17-3a. Design and performance parameters related to surface facilities and preclosure fault displacement (page 2 of 2)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Total probability of exceeding 5 cm fault displacement at locations proposed for FITS	Less than 1 chance in 100 of exceeding 5 cm displacement beneath surface FITS in 100 yr	High	Estimate of total probability for >5 cm displacement beneath FITS, considering known and possibly concealed faults and tectonic interrelationships among local faults

[a]These parameters are from Issue 4.4 (technical feasibility, Section 8.3.2.5), and corresponding performance measures are given in that issue.

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Table 8.3.1.17-3b. Characterization parameters related to surface facilities and preclosure fault displacement

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Identification and characterization of potentially significant Quaternary faults within 5 km of facilities important to safety (FITS)	4 such faults	Low	Medium to high	8.3.1.17.4.6.1--Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
Identification and characterization of faults within 100 m of FITS that have apparent Quaternary slip rates > 0.001 mm/yr or that measurably offset materials less than 100,000 yr old	No such faults	Low	High	8.3.1.17.4.2.2--Conduct exploratory trenching in in Midway Valley
Estimate of total probability for >5 cm displacement beneath FITS, considering known and possibly concealed faults and tectonic interrelationships among local faults	Less than 1 chance in 100 of exceeding 5 cm displacement beneath FITS in 100 yr	Low	High	8.3.1.17.2.1.1--Assess the potential for surface faulting at prospective sites of surface FITS

Table 8.3.1.17-4a. Design and performance parameters related to underground facilities and preclosure fault displacement (page 1 of 2)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Identification and characterization of significant Quaternary faults in the repository block:			Surface locations of faults in the repository with > 1 m offset of Quaternary materials or with > 100 m offset of Tertiary rocks
Classification	Standard practice	High	
Location at surface	±5 m	High	
Orientation at surface	±10°	High	
Identification and characterization of any fault within the waste emplacement area with greater than 1 chance in 100 of producing more than 7 cm (waste-package air-gap distance) of subsurface offset during the preclosure period (approximately 100 yr)	Determine existence; for any such faults (none are now known to exist), determine location within the waste emplacement area	High	Surface and subsurface locations of faults with Quaternary slip rates > 0.005 mm/yr that intersect underground facilities

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Table 8.3.1.17-4a. Design and performance parameters related to underground facilities and preclosure fault displacement (page 2 of 2)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Total probability of exceeding 7 cm fault displacement on any fault that intersects areas of waste emplacement	Less than 1 chance in 10 in 100 yr of exceeding 7 cm displacement on any fault that intersects areas of waste emplacement	Medium	Estimated total probability of fault displacement exceeding 7 cm in areas of emplaced waste, considering known and possibly concealed faults and tectonic interrelationships among local faults

[a]These parameters are from Issue 4.4 (technical feasibility, Section 8.3.2.5), and corresponding performance measures are given in that issue.

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Table 8.3.1.17-4b. Characterization parameters related to the underground facilities and preclosure fault displacement

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Surface locations of faults in the repository block with >1 m offset of Quaternary materials or with >100 m offset of Tertiary rocks	2 such faults exist	Low to medium	Medium	8.3.1.17.4.6.1--Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
Surface and subsurface locations of faults with Quaternary slip rates >0.005 mm/yr that intersect underground facilities	No such faults exist	Medium	Medium to high	8.3.1.17.4.6.1--Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2--Evaluate age and recurrence of movement on suspected and known Quaternary faults within the site area 8.3.1.17.4.7--Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain
Estimated total probability of fault displacement exceeding 7 cm in areas of emplaced waste, considering known and possibly concealed faults and tectonic interrelationships among local faults	Less than 1 chance in 100 in 100 yr of exceeding 7 cm displacement in areas of emplaced waste	Medium	Medium	8.3.1.17.2.1.2--Assess the potential for rupture on faults that intersect underground facilities

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Table 8.3.1.17-5a. Design and performance parameters related to surface facilities and preclosure vibratory ground motion (page 1 of 3)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Design-basis ground motion time histories (minimum band width = 0.5 to 33 Hz) and corresponding response spectra (at 1 Hz intervals) for surface facilities important to safety (FITS)	Representative of 10,000-yr cumulative slip earthquakes on nearby faults, or maximum potential underground nuclear explosions (UNEs) that would control site ground motion at any frequency between 0.5 and 33 Hz (including any effect of local geology or building embedment)	Medium to high	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Magnitude of 10,000-yr cumulative slip earthquakes on local sources Magnitude of 10,000-yr cumulative slip earthquakes on regional sources Maximum future underground nuclear explosion Closest distance of future UNEs Ground motion attenuation with distance Spectral modification due to local geology Controlling ground motion event(s) Time histories and reponse spectra representative of controlling event(s)

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Table 8.3.1.17-5a. Design and performance parameters related to surface facilities and preclosure vibratory ground motion (page 2 of 3)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Combined potential for vibratory ground motion at FITS, considering all faults	Less than 1 chance in 10 of exceeding design-basis ground motion in 100 yr	Medium to high	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Earthquake recurrence relationships for local and regional sources Ground motion attenuation with distance Spectral modification due to local geology Ground motion exceedance probabilities
Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies, at surface locations of FITS	Values estimated for annual probabilities ranging from 10^{-2} to 10^{-6} per yr	Medium	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Earthquake recurrence relationships for local and regional sources

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Table 8.3.1.17-5a. Design and performance parameters related to surface facilities and preclosure vibratory ground motion (page 3 of 3)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies, at surface locations of FITS (continued)			Ground motion attenuation with distance Spectral modification due to local geology Ground motion exceedance probabilities

[a]These parameters come from Issues 4.4 (technical feasibility, Section 8.3.2.5) and 1.12 (seal characteristics, Section 8.3.3.2), and corresponding performance measures are given in those issues.

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Table 8.3.1.17-5b. Characterization parameters related to surface facilities and preclosure vibratory ground motion (page 1 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Identification of potential earthquake sources in the controlled area	See Chapter 1	Medium	Medium to high	8.3.1.17.3.1.1--Identify relevant earthquake sources
Potentially relevant earthquake sources in the region (≤100 km)	See Chapter 1	Low to medium	Medium	8.3.1.17.3.1.1--Identify relevant earthquake sources
Magnitude of 10,000-year cumulative slip earthquakes on local sources	≈6 1/2	Low to medium	Medium to high	8.3.1.17.3.1.2--Characterize 10,000-year cumulative slip earthquakes for relevant seismogenic sources
Magnitude of 10,000-year cumulative slip earthquakes on regional sources	6 1/2 to 8 1/2	Low	Medium	8.3.1.17.3.1.2--Characterize 10,000-year cumulative slip earthquakes for relevant seismogenic sources
Maximum future underground nuclear explosion (UNE)	150-750 kt	Medium	Medium	8.3.1.17.3.2.2--Determine maximum UNE source(s)
Closest distance of future future UNEs	23 km (Buckboard Mesa area)	Medium	Medium	8.3.1.17.3.2.2--Determine maximum UNE source(s)

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Table 8.3.1.17-5b. Characterization parameters related to surface facilities and preclosure vibratory ground motion (page 2 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Ground motion attenuation with distance	Published models for California and western U.S.	Low to medium	Medium	8.3.1.17.3.3--Ground motion from earthquakes and UNEs
Spectral modification at facilities important to safety due to local geology	1/2 to 4	Low	Medium	8.3.1.17.3.4--Effects of local site geology on surface and subsurface motions
Controlling ground motion event(s)	≈6 1/2 M earthquake on Paintbrush Canyon	Low to medium	Medium to high	8.3.1.17.3.5.1--Identify controlling seismic events
Time histories and response spectra representative of controlling event(s)	TBD[a] (0.4-0.6g peak acceleration)	Low to medium	Medium to high	8.3.1.17.3.5.2--Characterize ground motion from controlling seismic events
Earthquake recurrence relationships for local and regional sources	See section 1.4.2	Low to medium	Medium	8.3.1.17.3.6.1--Evaluate earthquake sources

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Table 8.3.1.17-5b. Characterization parameters related to surface facilities and preclosure vibratory ground motion (page 3 of 3)

Characterization parameters	Testing basis			Key studies/activities supplying parameters
	Current estimate (range)	Confidence in current estimate	Needed confidence in final values	
Ground motion exceedance probabilities	1-5 x 10^{-4}/yr for 0.5g	Low to medium	Medium	8.3.1.17.3.6.2--Evaluate ground motion probabilities

[a]TBD = to be determined.

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Table 8.3.1.17-6a. Design and performance parameters related to underground facilities and preclosure vibratory ground motion (page 1 of 4)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Design-basis ground motion time histories and corresponding response spectra for underground facilities (at various depths) (minimum band width = 0.5 to 33 Hz; 1 Hz interval for response spectra)	Representative of 10,000-year cumulative slip earthquakes or nearby faults, or maximum potential underground nuclear explosions (UNEs) that would control site ground motion at any frequency between 0.5 and 33 Hz (including any effects of local geology or depth of burial)	Medium	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Magnitude of 10,000-year cumulative slip earthquakes on local sources Magnitude of 10,000-year cumulative slip earthquakes on regional sources Future maximum UNE Closest distance of future UNEs Ground motion attenuation with distance

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Table 8.3.1.17-6a. Design and performance parameters related to underground facilities and preclosure vibratory ground motion (page 2 of 4)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Design-basis ground motion time histories and corresponding response spectra for underground facilities (at various depths) (minimum band width = 0.5 to 33 Hz; 1 Hz interval for response spectra) (continued)			Spectral modification due to local geology and depth of burial Controlling ground motion event(s) Time histories and response spectra representative of of controlling event(s)
Combined potential for vibratory ground motion at underground facility locations, considering all faults	Less than 1 chance in 10 of exceeding design-basis ground motion in 100 yr	Medium	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Earthquake recurrence relationships for local and regional sources

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Table 8.3.1.17-6a. Design and performance parameters related to underground facilities and preclosure vibratory ground motion (page 3 of 4)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Combined potential for vibratory ground motion at underground facility locations, considering all faults (continued)			Ground motion attenuation with distance Spectral modification due to local geology and depth of burial Ground motion exceedance probabilities
Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies at underground facility locations	Values estimated for annual probabilities ranging from 10^{-2} to 10^{-6} per yr	Low to medium	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Earthquake recurrence relationships for local and regional sources

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Table 8.3.1.17-6a. Design and performance parameters related to underground facilities and preclosure vibratory ground motion (page 4 of 4)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies at underground facility locations (continued)			Ground motion attenuation with distance Spectral modification due to local geology and depth of burial Ground motion exceedance probabilities

[a]These parameters are from Issues 4.4 (technical feasibility, Section 8.3.2.5) and 1.12 (seal characteristics, Section 8.3.3.2), and corresponding performance measures are given in those issues.

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Table 8.3.1.17-6b. Characterization parameters related to underground facilities and preclosure vibratory ground motion (page 1 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Identification of potential earthquake sources in the controlled area	See Chapter 1	Medium	Medium	8.3.1.17.3.1.1--Identify relevant earthquake sources
Potentially relevant earthquake sources in the region (≤100 km)	See Chapter 1	Low to medium	Medium	8.3.1.17.3.1.1--Identify relevant earthquake sources
Magnitude of 10,000-yr cumulative slip earthquakes on local sources	≈6.5	Low to medium	Medium to high	8.3.1.17.3.1.2--Characterize 10,000-yr cumulative slip earthquakes for relevant seismogenic sources
Magnitude of 10,000-yr cumulative slip earthquakes on regional sources	6.5-8.5	Low	Medium	8.3.1.17.3.1.2--Characterize 10,000-yr cumulative slip earthquakes for relevant seismogenic sources
Maximum future underground nuclear explosion (UNE)	150-750 kt	Medium	Medium	8.3.1.17.3.2.2--Determine maximum UNE source(s)
Closest distance of future future UNEs	23 km (Buckboard Mesa area)	Medium	Medium	8.3.1.17.3.2.2--Determine maximum UNE source(s)

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Table 8.3.1.17-6b. Characterization parameters related to underground facilities and preclosure vibratory ground motion (page 2 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Ground motion attenuation with distance	Published models for California and western U.S.	Low to medium	Medium	8.3.1.17.3.3--Ground motion from regional earthquakes and UNEs
Spectral modification due to local geology and depth of burial	.25-1	Low	Medium	8.3.1.17.3.4--Effects of local site geology on surface and subsurface motions
Controlling ground motion event(s)	≈6.5 M earthquake on Paintbrush Canyon fault	Low to medium	Medium	8.3.1.17.3.5.1--Identify controlling seismic events
Time-histories and response spectra representative of controlling event(s)	TBD[a]	Low to medium	Medium	8.3.1.17.3.5.2--Characterize ground motion from controlling seismic events
Earthquake recurrence relationships for local and regional sources	See Section 1.4.2	Low to medium	Medium	8.3.1.17.3.6.1--Evaluate earthquake sources

Table 8.3.1.17-6b. Characterization parameters related to underground facilities and preclosure vibratory ground motion (page 3 of 3)

Characterization parameters	Testing basis			Key studies/activities supplying parameters
	Current estimate (range)	Confidence in current estimate	Needed confidence in final values	
Ground motion exceedance probabilities	10^{-4}/yr for 0.5g	Low	Low to medium	8.3.1.17.3.6.2--Evaluate ground motion probabilities

[a]TBD = to be determined.

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for contributing to the resolution of design and performance issues. High confidence indicates that the parameter is of primary importance, and, consequently, that the goal should be met by a characterization of the parameter that conservatively accounts for residual uncertainties. Low confidence indicates that resolution of design and performance issues is not strongly influenced by the parameter and that the goal should be met by a best estimate of the parameter, based on limited data. Medium confidence is used for parameters of intermediate importance.

Investigations performed to satisfy the data requirements will produce information that will also be used by the postclosure tectonics program (Section 8.3.1.8), and conversely, investigations performed by that program will provide information that will be used in the preclosure tectonics program. The postclosure tectonics program requires information on (1) current seismicity, to help evaluate tectonic processes, including the presence of magma bodies; (2) the potential for earthquake ground motions, to support evaluations of the stability of underground facilities; (3) the potential for fault displacement, to support evaluations of possible disruption of waste packages and to support evaluations of possible changes in the hydrologic environment; and (4) tectonic stress and rate of tectonic deformations, to support evaluations of possible changes in the hydrologic environment. The postclosure tectonics program will supply information on the potential for local volcanic eruptions to support the preclosure tectonics program in the characterization of such events. Technical considerations of the information contained in Tables 8.3.1.17-1 through 8.3.1.17-6 are discussed in the next section, on the approach to satisfying the performance and design requirements.

Approach to satisfying performance and design requirements

General methodology

The approach that has been developed to satisfy performance and design requirements is based on current knowledge and uncertainties about the local tectonic environment, and consideration has been given to state-of-the-art capabilities for resolving or bounding the effects of these uncertainties. The design and characterization parameters that will be used to satisfy performance and design requirements are listed in Tables 8.3.1.17-1b through 8.3.1.17-6b.

For each data requirement presented in the tables, one or more characterization parameters have been identified to serve as the technical basis for satisfying the requirement. The tables also present current estimates for the characterization parameters (where available and quantifiable) along with assessments of the current confidence in these estimates and the confidences needed to satisfy the data requirement. Differences between the current and needed confidence for each characterization parameter provide a measure of the remaining amount of work that is required to finalize the result. The last column of Tables 8.3.1.17-1b through 8.3.1.17-6b lists the key studies or activities that will be providing results for each characterization parameter, and the corresponding section numbers where descriptions of these studies and activities are provided. The technical considerations summarized in these tables are discussed below.

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The tectonic characteristics of the site will be investigated in sufficient scope and detail to provide reasonable assurance that the processes are understood and that the characterization parameters are determined with the confidences specified in Tables 8.3.1.17-1 through 8.3.1.17-6. The investigations will use data from a variety of sources, including scientific literature, current and historical seismicity, geologic maps, logs from boreholes and surface trenches, gravity surveys, aeromagnetic and paleomagnetic observations, seismic reflection and refraction profiles, and magnetotelluric soundings.

The planned approach is to use both deterministic and probabilistic methods for analyzing the effects of tectonic events during the preclosure period. The deterministic approach will be used to model cause-and-effect mechanisms and to develop particular tectonic event scenarios in greater detail than is typically provided by probabilistic methods. In addition, all final results for volcanic, faulting, and ground-motion events will be evaluated using probabilistic methods (1) to ensure that adequate consideration is given to the full range of potential tectonic processes and to their associated uncertainties, and (2) to help identify those processes that are key to characterizing the geologic hazards at the site.

Using the deterministic approach, results (e.g., ground motions) will be determined for specific events that are postulated to occur (e.g., an earthquake or an underground nuclear explosion). Judgment is required for postulating the specific source events to ensure adequate conservatism. The deterministic approach will be used to establish ground-motion conditions to be considered in the next phase of design (advanced conceptual design) and, if appropriate, in the final design. This approach is suited to the determination of detailed ground-motion conditions that would likely be produced by postulated earthquakes and underground nuclear explosions (UNEs) including the amplitude and duration of shaking over the frequency band relevant to design. Because source events that will be postulated are not likely to change as more refined fault data become available, the resulting motions are expected to provide a stable basis for use in design.

The probabilistic approach will be used to characterize the range of possible seismic-source interpretations as constrained by contemporary knowledge about the local tectonic framework, including uncertainties. In addition to the cause-and-effect relationships basic to the deterministic approach, the probabilistic approach facilitates consideration of the full range of potential source events (e.g., earthquakes of varying magnitude and distance) in conjunction with probability estimates that the various source events will occur (e.g., spatially varying recurrence relationships for earthquakes of varying magnitude) and probability estimates that a particular outcome will result from the various source events, assuming they do occur. The probabilistic approach will explicitly quantify the effect of including uncertainty in interpretations on the estimated seismic hazard.

The current plan is to apply probabilistic methods for evaluating adequacy of deterministic final results. These methods will also be useful for constraining the technical judgments required for postulating deterministic source events and to help focus field investigations on the resolution

of those conditions most relevant to satisfying the performance and design requirements. Probabilistic methods will also be used to provide input for the assessment of risk of accidental release of radionuclides.

Review of the local tectonic environment

Consideration of local faults with evidence of movement during the Quaternary period (about the last 2 million years) is essential to the characterization of the potential for fault displacement and vibratory ground motions at the site of repository facilities. Fault data that are particularly relevant to the characterization approach are reviewed here; more detailed information is presented in Section 1.3.2.2.2.

Figure 8.3.1.17-2 shows north-trending faults with evidence of Quaternary movement on both the east and west side of Yucca Mountain. Midway Valley, the proposed location of the waste handling facilities on the east side of Yucca Mountain, is bounded to the east and west, respectively, by the Paintbrush Canyon and Bow Ridge faults. The Solitario Canyon fault passes just west of the proposed underground facilities, and the Windy Wash fault lies a few kilometers farther to the west. The Ghost Dance fault, on the east side of the repository block, may not have moved in the Quaternary, but evidence confirming this has not yet been obtained.

It is possible that other faults in the site area have experienced movement during the Quaternary period. (The site area is defined for this section as the rectangular area 237 km^2 (91 mi^2) encompassing the central Yucca Mountain block and its structural and physiographic boundaries (Fortymile Wash, Yucca Wash, Solitario Canyon, and the Stagecoach Road fault.) These faults include the northeast-trending Stagecoach Road and Rock Valley faults and postulated detachment faults (the Rock Valley fault, outside the area shown in Figure 8.3.1.17-2, is discussed in Section 8.3.1.17.4.4). The approach discussed here for evaluating faulting and ground motion potential is intended to include conservative characterizations of such faults. As yet unidentified Quaternary faulting is particularly likely at the southern extent of the site area, as discussed subsequently.

The Paintbrush Canyon, Bow Ridge, Solitario, and Windy Wash faults show evidence of normal dip-slip movement along surfaces that dip steeply to the west (see Figure 1-32 of Section 1.3.2.2.2). The lengths of these faults have not been precisely determined, either because their projected trace is obscured by late Quaternary deposits without recognized geomorphic expression of the faults, or because potential linkages between discrete faults segments have not been unambiguously established. However, on the basis of published mapping, the length of the Paintbrush Canyon fault is inferred to be 17 to 31 km, the Bow Ridge fault 10 to 19 km, the Solitario Canyon fault 15 to 17 km, and the Windy Wash fault 6 to 19 km (Table 1-8, Section 1.3.2.2.2). The Paintbrush Canyon fault could be longer than the estimate given above if it links at its southern end to the Stagecoach Road fault (Figure 8.3.1.17-2).

Quaternary deposits are demonstrably offset by the faults at scattered localities along their trace. Preliminary study of the faults at a few of these localities, using trenching and dating of offset Quaternary deposits, indicates that reliably dated middle-to-late Quaternary soils have been

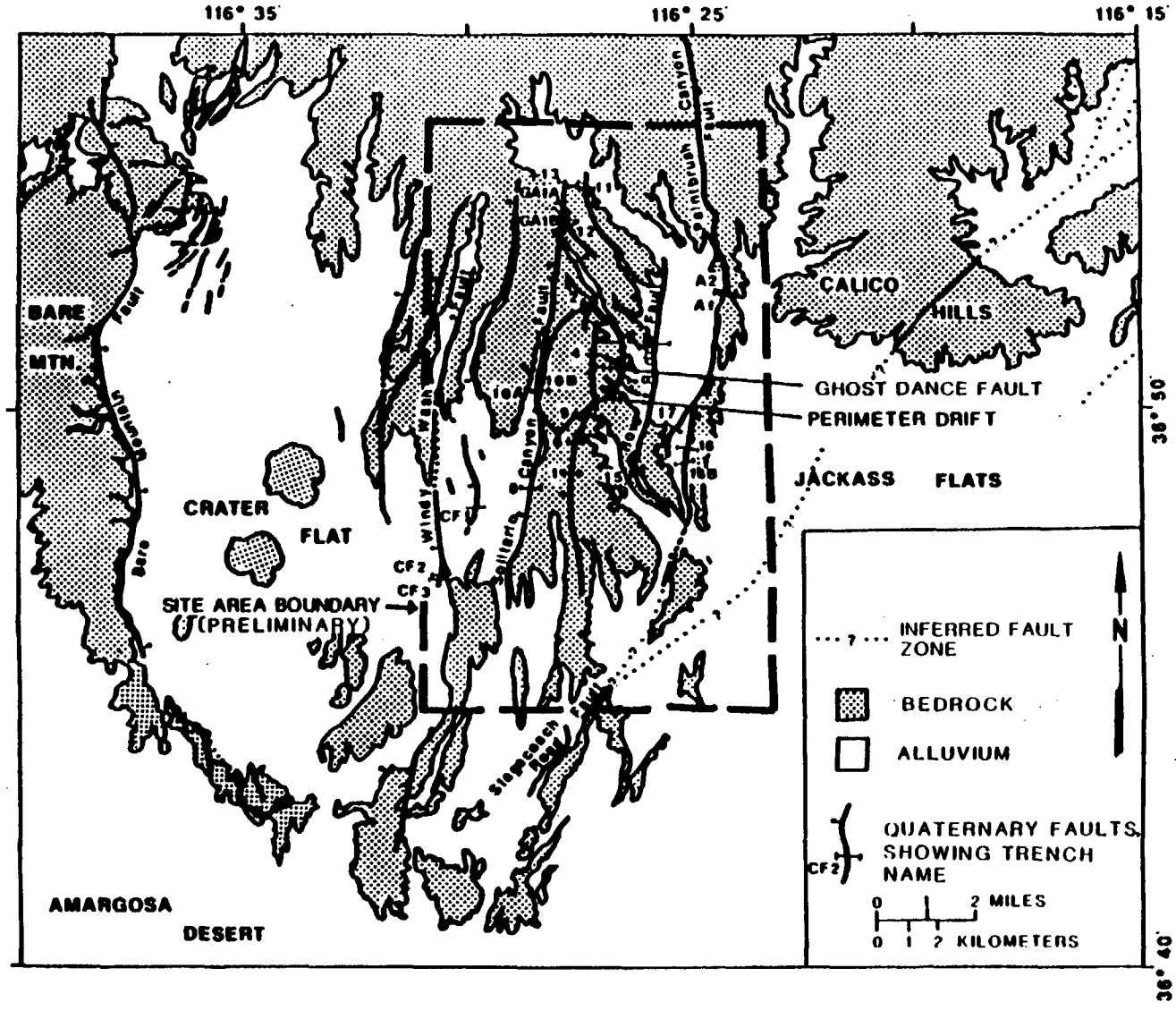

Figure 8.3.1.17-2. Quaternary normal faults and postulated detachment faults on or near Yucca Mountain Modified from Swadley et al (1984), USGS (1984), and Reheis (1986)

offset by dip-slip movement on the faults at rates up to approximately 0.01 mm/yr. Uncertainty in slip-rate values exists due to uncertainty in the age of soil layers, particularly ash layers. Slip-rate values will have to be revised if new age dates become available. Lateral offset of Quaternary deposits that indicate a strike-slip component of fault movement have not been recognized but cannot be ruled out on the basis of available data.

The Paintbrush Canyon fault, which dips under Midway Valley, is particularly important for evaluating the potential for future vibratory ground motion at the proposed site of the waste-handling facilities. Considering the length and nature of this fault, it could have been the source of moderate earthquakes (M 6.5) in the past, although such events would appear to be rare based on the low rate of movement. Assuming the Quaternary rate of displacement for the Paintbrush Canyon fault is about 0.01 mm/yr, the recurrence time between magnitude 6.5 earthquakes on this fault should be about 50,000 yr (Slemmons and Depolo, 1986). If larger-magnitude earthquakes were postulated for this feature, their recurrence times would be longer. Long recurrence intervals appear to be typical of the local faults (Sections 1.3 and 1.5). Whitney et al. (1986) have estimated the recurrence interval between faulting events on the Windy Wash fault to be about 70,000 yr. Further investigations will be performed to test this conclusion.

The Bare Mountain fault, about 18 km west of Midway Valley, appears to be a more likely source of a moderate earthquake than the local faults (Section 1.4.2). Dated displacements presented in Table 1-8 indicate that this fault appears to be over ten times as active as the local faults. Thus, the Bare Mountain fault may be a significant contributor to probabilistic assessments of future ground motions at the site. Also, this fault, which dips eastward and southeastward (along its northern extent), may be tectonically linked at depth to the local faults (which dip to the west) via a detachment fault or graben structure.

The east-west spacing between adjacent local faults, illustrated in Figure 8.3.1.17-2, is less than their mapped lengths, and less than the 10 to 15 km thickness of the seismogenic zone found in this area (Section 1.4). The close proximity of the local faults suggests the possibility of interconnections at depth, most notably between the Paintbrush Canyon and the Bow Ridge faults, which appear to converge near their southern extent. One important hypothesis is that the local north-trending faults flatten with depth and merge into a detachment fault that dips gently to the west (Section 1.3.2). Another possibility that must also be considered is that the local faults continue downward at a steep dip through the seismogenic zone with possible interconnections at intermediate depths. Until such uncertainties are resolved, the evaluation and characterization of potential ground motion and faulting at the site must allow for alternate interpretations of the local tectonics.

Considerations of volcanic activity

A volcanic eruption within close proximity to the repository facilities could be highly disruptive. Current estimates described in Section 1.5.1.2.3 indicate that the probability of such an event is well below that considered to be significant for the preclosure time period. Additional work will be

conducted under the postclosure tectonics program (Investigation 8.3.1.8.1) to develop increased confidence in the probability estimates for a local eruption.

Significant deposition of volcanic ash on the surface of the repository could temporarily disrupt operations. However, the nearest silicic volcanism during the Quaternary is at the margins of the Great Basin (Crowe et al., 1983b). A thousand-year ash-fall event will be characterized, but because of the considerable distances and infrequent occurrences, the event is not expected to be a significant design factor.

Tables 8.3.1.17-1a and 8.3.1.17-2a show information on ash fall thickness and particle size distribution for the design of ventilation systems for the surface and underground facilities, respectively. Analyses will be conducted using data already available in the literature (Investigation 8.3.1.17.1). Probabilistic methods will be used to characterize the results.

Consideration of fault displacement

As noted previously, faults with evidence of Quaternary displacement are present in the site area, and the possibility exists that additional, undetected faults may also be present. Significant displacement on a fault or along a distributed zone of faulting immediately adjacent to repository facilities could disrupt operations and damage facilities. Performance and design issues require characterization of the potential for fault displacement at the proposed site for surface facilities that are considered important to safety (Table 8.3.1.17-3a) and at the location of the underground facilities (Table 8.3.1.17-4a). Currently, the waste handling facilities are the only surface facilities considered to be important to safety (Section 6.2).

Faulting considerations are particularly important for establishing a suitably stable site for the waste handling facilities, currently planned for Midway Valley. The concern is for avoiding relative displacement at the base of the structural foundation in excess of a few inches; smaller displacement is not expected to cause serious damage. The primary goal expressed in Table 8.3.1.17-3a is to demonstrate, with a high degree of confidence, that there is less than a one-percent chance of exceeding 5 cm of net (combined dip-slip and strike-slip) fault displacement at the site of the waste handling facility in 100 yr. Displacements less than 5 cm are not expected to cause serious damage to waste-handling facilities, based on preliminary, conservative engineering judgment.

This goal, which establishes the maximum allowable annual probability for exceeding 5 cm of fault displacement at 10^{-4}/yr, appears to be consistent with safety considerations for this and other types of facilities. For example, comparable and higher annual probabilities have been found to be acceptably conservative for the seismic designs of nuclear power plants to withstand vibratory motions (Reiter and Jackson, 1983). While this comparison is not analogous in several respects, the risk resulting from fault displacements in excess of 5 cm at the site of the waste handling facilities is probably less than the risk resulting from vibratory ground motions that exceed the design basis for a nuclear power plant, and, therefore, the comparison does provide a useful check on the acceptance goal for faulting.

Another useful comparison can be made with criteria used to identify repository structures, systems, and components considered important to safety. Importance to safety is established if the probability of failure is greater than 10^{-5}/yr and if the failure would lead to radiation exposures of 0.5 rem or greater at or beyond the restricted area (Laub and Jardine, 1987). The annual probability that failure of this magnitude would result from faulting is expected to be less than 10^{-5}/yr for a site in which the annual probability for 5 cm of displacement is less than 10^{-4}/yr. This line of reasoning indicates that the goal for siting the waste handling facilities provides adequate safeguards to avoid areas of potentially significant faulting.

Additional field data are needed to achieve the required high degree of confidence in the determination of faulting probabilities. This need is indicated in Table 8.3.1.17-3b in which the current confidence in the values of the characterization parameters is considered to be low and the needed confidence is generally high.

Significant faulting is sometimes accompanied by sympathetic displacement at other locations. The first consideration then is to identify and characterize those faults within 5 km that could have significant impact on faulting at the proposed site. Geomorphic and other evidence that a Quaternary fault might trend toward Midway Valley in the vicinity of the site will be evaluated and characterized. Additional information will be obtained on the properties of the Paintbrush Canyon fault, which dips under the east side of Midway Valley, to evaluate the possibility of it becoming listric at shallow depth. Midway Valley will be carefully examined for geomorphic evidence of faulting, and trenching may be required to confirm the existence of suspected faults at distances up to one kilometer or more from the proposed site.

The most important data for constraining the possibilities for faulting at facilities important to safety are expected to come from extensive field investigations in the immediate site vicinity. Geologists will work with engineers in siting the waste-handling facilities to ensure that adequate stability is provided with respect to the possibility of faulting. The design parameter gives preliminary guidance on the distance (100 m) detailed studies (continuous trenching) should extend from the location of facilities important to safety and the accuracy that these studies should have in recognizing faulting. The parameters were selected so that any significant displacement resulting from faulting or deformation associated with main, branch, or secondary faulting in the vicinity of the surface facilities important to safety would be recognized and evaluated. Preliminary surveys may include small test pits or trenches to evaluate the stratigraphy and the possibility of previous local faulting. One or more trenches will be excavated across the site (or adjacent to the site) and extended to the east and the west beyond the proposed boundaries of the waste handling building. While the exact length of these trenches is yet to be determined, it is anticipated that at least one trench will be hundreds of meters long. It is anticipated that these exploratory trenches will intersect surficial units that were deposited at least 100,000 yr ago (based on the results of mapping by Swadley et al., 1984). Cross section B-B′ in Scott and Bonk (1984)

indicates that the alluvium of Midway Valley varies in thickness from zero meters at Exile Hill on the west side of the valley, to an undetermined amount in the valley center, to about 50 m in borehole UE-25 WT#5 near the Paintbrush Canyon fault on the east side of the valley.

The assessment of the total probability of faulting beneath facilities important to safety will consider the preliminary probability of significant faulting, before the results of the detailed site (trenching) studies are available, the probability that a normal or strike-slip fault capable of producing significant offset could go undetected by the trenching program, and the probability of new faulting. The preliminary probability of faulting will be assessed considering such factors as the regional density and nature of Quaternary faulting, concealed extensions of nearby Quaternary faults, secondary faulting associated with rupture on nearby faults, tectonic interrelationships between local faults, and rates of regional seismic moment release and regional crustal deformation. The exact methodology for integrating the information discussed above and estimating the total probability of faulting beneath facilities important to safety will be developed as part of site characterization. Very likely a number of different approaches using different types of information will be used and the results compared.

A final assessment of surface faulting probabilities at locations of facilities important to safety (FITS) will be prepared when detailed site studies are completed. Displacement amplitudes will be estimated for annual probabilities ranging from 10^{-2} to 10^{-6} or less per year for use in risk assessments.

Faulting conditions for underground facilities will also be evaluated. The primary issue here is that significant fault displacement could disrupt normal operations or impede execution of the option for waste retrieval.

The first requirement presented in Table 8.3.1.17-4a is to identify and characterize late Quaternary faults within close proximity of the proposed underground facilities. This requirement is to aid in developing the layout and design of underground facilities. The second part of the table notes that current data provide low to moderate confidence that two such faults exist; namely, the Bow Ridge fault and the Solitario Canyon fault. Further work is required to provide added confidence that there are no additional late Quaternary faults in this area.

A further requirement is presented in Table 8.3.1.17-4a to identify, characterize, and locate at the repository horizon any fault with greater than a one-percent chance of displacing more than 7 cm in the area of waste emplacement during the preclosure period. This requirement is to ensure viability of the waste-retrieval option. Less than 7 cm of fault displacement is not expected to significantly impact normal retrieval operations because the diameter of the waste package will be about 7.6 cm smaller than the diameter of the emplacement hole (See Section 8.3.2.5). Larger displacements might bind or shear the waste packages thereby creating off-normal conditions for waste retrieval.

Assuming a preclosure period of 100 yr, the requirement just discussed is to identify, characterize, and locate at depth any fault passing through the area of waste emplacement that has an annual probability greater than

10^{-4}/yr for displacing more than 7 cm. Assuming event recurrences are random in time, the average rate of slip for such a fault would need to be considerably larger than 7 cm per 10^4 yr (i.e., 0.007 mm/yr) to account for excess displacement from events that produce less than and more than 7 cm. Accordingly, the screening criterion presented in Table 8.3.1.17-4b for locating faults in the underground, an average Quaternary slip rate greater than 0.005 mm/yr, provides considerable margin with respect to requirements presented in part a of this table.

As noted above, the Bow Ridge fault and the Solitario Canyon fault are late Quaternary faults within close proximity to the proposed underground facilities. The Bow Ridge fault crosses the planned access ramp that enters the repository block from the east. The rate of Quaternary displacement for the Bow Ridge fault is not well constrained. However, assuming the rate of activity is similar to other faults in the area, long recurrence intervals between faulting events would be expected. For example, Whitney et al. (1986) have identified four faulting sequences within about 270,000 yr on the Windy Wash fault, giving an average recurrence interval of about 70,000 yr between faulting events (Section 1.3.3.3.3). Preliminary estimates, assuming the local Quaternary faults have a similar rate of activity, indicate that the annual probability for exceeding 10 cm of displacement on faults such as the Bow Ridge fault is about 1×10^{-5}/yr (URS/Blume, 1987). Additional field investigations will be conducted to develop more information about the characteristics of this fault, particularly with respect to its Quaternary rate of activity. Design measures are being implemented to minimize possible fault-induced damage and to facilitate rapid repair in the unlikely event that movement should occur on this fault during the preclosure period.

The western boundary of the underground facilities will extend to the proximity of the Solitario Canyon fault, which is known to have Quaternary displacement. As with other local faults, the probability for experiencing significant displacement during the preclosure period appears to be well below that required by considerations for waste retrieval. Additional investigations will be conducted to further constrain fault characteristics, particularly the possibility of extension of the Solitario Canyon fault into the repository block.

Analyses will be performed to estimate the total probability for experiencing significant fault movement anywhere in the underground facilities during the preclosure period. These estimates will consider possible effects from known and unknown faults in the area.

Consideration of vibratory ground motion

Repository facilities will be designed and constructed to withstand the effects of vibratory ground motions. Conventional standards will be used for most facilities; however, more conservative design measures will be used for those facilities considered important to safety, specifically the waste handling facilities. Thus, the requirement is to determine ground-motion characteristics for consideration in the design of facilities important to safety.

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Performance and design requirements for characterizing the potential for vibratory ground motion are presented in Table 8.3.1.17-5a. The design-basis ground motions are to be characterized for frequencies significant to facilities important to safety such that there is less than a 10-percent chance for being exceeded during 100 yr. Accordingly, the design-basis motions are to have an annual exceedance probability less than 10^{-3}/yr, which translates to an average recurrence period greater than 1,000 yr. This goal appears to be consistent with the level of conservatism used for other facilities with important considerations for safety.

An important precedent is provided by nuclear power plants where annual probabilities for exceeding the design-basis motions have been found to be on the order of 10^{-3}/yr to 10^{-4}/yr for several operating plants (Reiter and Jackson, 1983).

Based on current understanding of design needs, the approach that has been developed here uses both deterministic and probabilistic methods to their best advantage. The role of the deterministic approach is primary. It provides the level of detail needed by design engineers in the characterization of ground motions. The probabilistic approach provides a logical, structured procedure for integrating the range of possible earthquakes that contribute to the ground-motion hazard at the site. This capability will be used to guide, test, and substantiate the deterministic analyses. Sensitivity analyses will be performed using probabilistic methods to evaluate the effect of uncertainties on the ground motion potential. Results from these analyses will be used to help focus field investigations toward refinement of those seismic parameters that most strongly influence ground-motion potential at the site. In addition, probabilistic methods will be used as needed to provide input for the assessment of risk of accidental release of radionuclides.

Vibratory ground motions at the site can result from natural earthquakes on local and regional faults, and from underground nuclear explosions (UNEs) detonated at the Nevada Test Site. Much of the discussion to follow on the current approach for developing design-basis ground motions focuses on issues of natural earthquakes. The deterministic methods that will be applied for analyzing ground motions from UNEs parallel, in most respects, those described for dealing with natural earthquakes.

The ground-motion potential near Yucca Mountain differs considerably from that in much of California where a major portion of the relative plate motions are being accommodated, and also from that in the true plate interior regions of the midwestern and eastern U.S. There is an abundance of faults local to the site, but their rate of movement appears to be low. On the basis of fault data and historical seismicity, severe earthquakes are probably not as common in the vicinity of Yucca Mountain as in the more active regions surrounding much of the Great Basin.

To adequately characterize the local earthquake hazards, some of the terminology and procedures used in characterizing potential ground motions elsewhere are being refined to meet the needs of a waste repository. For example, in the determination of design ground motions for some types of critical facilities, professional practice has been to define maximum earthquake magnitudes with the understanding that a larger earthquake magnitude

may be possible, although very unlikely. This practice is being made more explicit for characterizing this site. In particular, 10,000-yr cumulative slip earthquakes will be identified for consideration in repository design. A 10,000-yr cumulative slip earthquake is defined here to be an earthquake that, occurring every 10,000 yr, would produce the observed or estimated average Quaternary slip rate on a fault. A detailed discussion of the concept is provided in the description of Activity 8.3.1.17.3.1.2.

An important advantage of this refinement is that a 10,000-yr cumulative slip earthquake magnitude, being associated with a particular recurrence interval, can be determined with greater confidence than a true maximum magnitude. Because large earthquakes occur infrequently, few observational data are available for calibrating the maximum seismogenic potential of individual faults. This is particularly true for faults of the type found in the southern Great Basin, where recurrence intervals for large earthquakes appear to range from about 10,000 to 100,000 yr (Section 1.4.2). Therefore, conventional methods for determining maximum earthquake magnitudes from the physical characteristics of local faults appear to be subject to larger uncertainties than for the more active faults associated with plate motions. Use of slip-rate data (to constrain recurrence times) in conjunction with more conventional fault data provides added assurance that adequately conservative assessments of the local seismogenic potential will be accomplished.

The planned procedure for characterizing potential ground motions at the site is as follows: First, the active surface faults and potentially active fracture zones at depth that could produce locally severe ground motions will be identified. Second, 10,000-yr cumulative slip earthquakes, as defined previously, will be determined. Third, controlling earthquakes will be identified as those 10,000-yr cumulative slip earthquakes that produce the most severe motions at the site. The resulting vibratory ground motions will then be characterized by a suite of representative time histories and response spectra that have been scaled to the magnitudes and distances of the controlling earthquakes and modified, as needed, to account for the effects of local site geology. A suite of representative strong-motion records may be needed for more than one controlling earthquake, to cover the possibility that different source regions could control ground motions at the site in different frequency bands.

To characterize potential ground motions from UNEs, a similar procedure will be followed. First, the possible locations and upper limits on the yields of future UNEs at the Nevada Test Site will be identified. With this information, the maximum UNEs with respect to generating ground motions at the site will be determined. If the resulting site ground-motion estimates are comparable to those for the controlling earthquake sources, the UNE ground motions will be further characterized by a suite of representative time histories and spectra.

Preliminary evaluations of potential earthquake sources in the vicinity of Yucca Mountain have identified several local faults as long as 20 km or more. If, as is currently planned, the waste handling facilities were located on Midway Valley, the controlling source would appear to be the north-south trending Paintbrush Canyon fault, which bounds Midway Valley on the east. The closest approach of the Paintbrush Canyon fault to the proposed site of the waste handling facilities is about one kilometer. This

fault may be capable of producing a moderate earthquake (M about 6.5) with a recurrence interval greater than ten thousand years. Site characterization will determine which fault or faults control the ground motion at frequencies within the range of engineering interest.

Because the annual probability for the controlling earthquake is expected to be low (less than about 10^{-4}, assuming the Paintbrush Canyon fault is controlling), and because the components required to contain radioactive materials within the waste-handling building can be expected to survive ground motions more severe than those used for design, ample conservatism can be achieved by using the most probable motions from the 10,000-yr cumulative slip earthquake(s) on the controlling earthquake source(s) as the basis for seismic design. Probabilistic calculations will be performed to test and verify that the resulting ground motions exceed the thousand-year estimate from the combined hazard from natural earthquakes and underground nuclear explosions.

Alternative conceptual models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses which are also consistent with available data and that may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) activities or studies which are designed to discriminate between alternative hypotheses or to reduce uncertainty. Tables 8.3.1.17-7 and 8.3.1.17-8 summarize current understanding in the modeling of local and regional tectonics, respectively, that is being performed as part of the preclosure tectonics site program. Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate.

To help ensure comprehensiveness of the hypotheses considered in Tables 8.3.1.17-7 and 8.3.1.17-8, hypotheses for preclosure tectonics modeling have been divided into elements or components that describe the physical domain defined by the model, the driving forces/processes that influence the behavior of the model, the boundary conditions that affect the model, the system geometry of the physical components of the model, and a series of elements that describe the system response/dynamics of the model in response to its driving forces, boundary conditions, and system geometry. These elements are listed in column one.

The second column of the tables lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Tables 8.3.1.17-7 and 8.3.1.17-8 provides a judged level of uncertainty designated "high," "moderate," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Column six gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of the performance parameters in column five to the selection of hypotheses in columns two and four of that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The final column identifies the characterization studies or activities that will discriminate between alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

Interrelationships of preclosure tectonics investigations

The interrelationships of the investigations in the preclosure tectonics site characterization program are shown in Figure 8.3.1.17-1. There are three analysis and assessment investigations that correspond to potentially disruptive volcanic activity, fault displacements, and vibratory ground motion, respectively. These three investigations are designed to provide the required characterization parameters. A fourth investigation comprises a number of data collection and synthesis activities that support one or more of the three analysis and assessment investigations.

Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 1 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Physical domain	Area extending 25 km from boundary of controlled area	Low-medium--events or processes outside preferred domain unlikely to affect facility design or waste isolation in the controlled area[a]	Area extending >25 km from boundary of controlled area	Design-basis ground motion time histories and corresponding response spectra for facilities important to safety (FITS)	Medium to high	Medium--potential events that control ground-motion design are probably in or near the controlled area	Medium--need to determine distance that tectonic events could influence performance in controlled area	8.3.1.17.4.12.2, 8.3.1.8.1.1.4, 8.3.1.17.3.5.1
				Probability of faulting with displacements over 5 cm in repository and at location of faciltities important to safety	Medium to high	Low--only faulting or deformation at repository and facilities impor- to safety significant	Low--size of domain does not significantly affect	8.3.1.17.2.1.1, 8.3.1.17.2.1.2
Driving forces/ processes	Mechanically driven through plate interaction of local and regional structures	Low--geophysical, geochemical, and heat flow data support preferred hypothesis	Thermally driven through mantle convection cell Combination of thermal and mechanical driving forces	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--mantle convection (incipient rift) hypothesis could affect faulting rate	Low--existing data generally sufficient to differentiate	8.3.1.17.4.12.2

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Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 2 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Boundary conditions	Horizontal strains must be consistent with Quaternary Pacific-North American plate movement history and regional controls that affect the distribution of strain in the region surrounding the domain Vertical strains--no boundary condition specified	Low--no alternatives available	(No alternative, but need to reduce uncertainty)	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	High--local strain rates will affect faulting probabilities, size of events	Medium--strain rates in the local domain will affect faulting rates and probabilities	8.3.1.17.4.12.2
				Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	Same as above	8.3.1.17.4.12.2
System geometry	Brittle crust--15 km thick, underlain by ductile lithosphere Brittle crust is cut by inactive and active faults of various orientations Ductile crust and underlying mantle are relatively passive elements	Low--geophysical and heat flow data provide some support for preferred hypotheses	Convection cell in mantle introduces heat and strain into brittle crust and results in crustal thinning (Death Valley-Pancake Range zone is incipient rift)	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--mantle convection hypotheses could affect faulting rate	Medium--existing data nearly sufficient to differentiate	8.3.1.17.4.12.2, 8.3.1.17.4.3.1

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Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 3 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			SYSTEM RESPONSE/DYNAMICS					
Faulting geometry and mechanisms	No hypothesis selected (one or more alternative hypotheses may apply to domain)	High--no data on on subsurface geometry of local faults, no measurements of strike-slip component of movement	Faults in the domain are Planar-rotational faults (north-trending faults in domain are planar normal and extend to base of brittle crust)	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--local fault geometries could significantly affect ground-motion and fault slip estimates	High	8.3.1.17.4.7.1, 8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, 8.3.1.17.4.2.2, 8.3.1.17.4.1.2, 8.3.1.4.2.3.1
				Combined potential for vibratory ground motion at facilities important to safety	Medium to high	Same as above	High	Same as above
			Detachment faults (north-trending faults in domain are listric, merging with west-dipping low-angle extensional fault at or below base of Tertiary), NE trending strike-slip are shallow features that mark the boundaries of detached faults	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	High	Same as above

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Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 4 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
SYSTEM RESPONSE DYNAMICS (continued)								
Faulting geometry and mechanisms (continued)			Part of Walker Lane system (faults in domain are part of or related to an en echelon system of NW and NE-trending right- and left-lateral fault strands that have a significant strike-slip component of movement; faults are high angle and extend to base of brittle crust) Related to a strike-slip fault concealed beneath a detached upper fault plate Normal faults resulting from incipient rifting along the Death Valley-Pancake Range zone due to thermally driven processes					

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Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 5 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE DYNAMICS (continued)				
Fault activity	Some faults in and near the controlled area have been active in Quaternary time	Low--trenching data show Quaternary activity	None identified	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--presence of Quaternary faulting increases design and performance assessment concerns related to faulting	None	None
				Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	None	None
Faulting rates	Slip rates on faults near the controlled area are low (<0.01 mm/yr) with long recurrence intervals (>10,000 yr	Medium--no direct measurements of strike-slip component	Slip rates are higher because of an unrecognized component of strike-slip faulting	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--slip rates important in estimating probability of various sized faulting	High	8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, and 8.3.1.17.4.3.2
				Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	High	Same as above

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Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 6 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE/DYNAMICS (continued)				
Fault rupture pattern	No hypothesis selected	High--current data insufficient to choose among possible alternatives	Individual faulting events are confined to single fault strands on the north-trending faults around the site	Design-basis ground motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--nature of single event displacements significant in estimating earthquake magnitude and probability of faulting	High	8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, 8.3.1.17.4.3.2
			Movement occurs on several parallel north-trending faults during a single faulting event	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	High	Same as above
			The north-trending faults are secondary faults or splays off a larger fault (major strike-slip or detachment feature) and move at the same time movement occurs on the larger fault	Same as above	Medium to high	Same as above	High	Same as above

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Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 7 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
SYSTEM RESPONSE/DYNAMICS (continued)								
Distribution of seismic potential	Ground-motion hazard is controlled by moderate earthquakes on faults in and near the the controlled area	Low—presence of surface fault rupture on local faults shows events are large enough to overshadow underground nuclear explosions and large distant sources	Underground nuclear explosions and large distant earthquakes are significant factors that also control facility ground-motion design	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	Medium--alternatives to preferred hypothesis would probably produce lower ground motion design values	Low	8.3.1.17.3.3, 8.3.1.17.3.5.1, 8.3.1.17.3.2, 8.3.1.17.3.1.1, 8.3.1.17.4.5
			Local faults are detachments on which movement is aseismic resulting in a different basis for assessing ground-motion hazard	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Same as above	Low	Same as above
Adequate seismic design basis	A deterministic model based on a 10,000-yr cumulative-slip earthquake provides an adequate basis for design of surfacilities important to safety	Low--10,000-yr design events adequately conservative for facilities important to safety with a <100-yr design life; recurrence of safe shutdown earthquake for reactor design generally about 1,000 to 5,000 yr; facilities important to safety pose lower hazard than reactor	A probabilistic 1,000 a probabilistic model provides a reasonable basis for design A deterministic model based on a "maximum" credible earthquake provides a reasonable basis for design	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--would change basis for estimating ground-motion hazard for facility design	High--requires consensus on relative hazard posed by facility and acceptable design approach	8.3.1.17.3.6, 8.3.1.17.3.5.2

[a]Controlled area is the actual area chosen according to the 10 CFR 60.2 definition.

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Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 1 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Physical domain	Brittle crust, southern Great Basin	Low--regional processes outside model domain unlikely to affect site design or performance	NA[a]	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low--events outside of model domain unlikely to affect potential ground motion	Low--processes outside domain unlikely to affect design or performance	8.3.1.17.4.12.2
				Design basis ash-fall thickness for facilties important to safety ventilation systems	Low to medium	Medium--volcanic events outside model domain may affect ash-fall probability	Same as above	8.3.1.17.4.12.2
Driving forces/ processes	Mechanical plate interaction	Low--geophysical, geochemical, and heat flow data support current representation	Mantle convection cell	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--mantle convection hypothesis could affect faulting rate	Low--existing data generally sufficient to differentiate	8.3.1.17.4.12.2

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Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 2 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Boundary conditions	Horizontal strains must be consistent with Quaternary Pacific-North American plate movement history Vertical strains-no boundary condition specified	Low--no alternatives available	None identified	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--regional strain rates influence faulting probabilities but local variations more significant	Low-existing data sufficient and increased accuracy probably not reasonably achievable	8.3.1.17.4.12.2
				Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	Same as above	8.3.1.17.4.12.2
System geometry	Brittle crust--15 km thick, underlain by ductile lithosphere Brittle crust is cut by inactive and active faults of various orientations Ductile crust and underlying mantle are relatively passive elements	Low--geophysical and heat flow data provide support for current representation	Convection cell in mantle introduces heat and strain into brittle crust and results in crustal thinning (Death Valley-Pancake Range zone is incipient rift)	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--mantle convection hypotheses could affect faulting rate	Medium--existing data nearly sufficient to differentiate	8.3.1.17.4.12.2 and 8.3.1.17.4.3.1

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Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 3 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE/DYNAMICS				
Regional faulting mechanisms	None selected	High--data do not support a single hypothesis; geologic and seismic reflection data indicate extensional model with detachments; data from historical earthquakes indicate planar normal faults with a strike-slip component and high-angle, deep-focus strike-slip faults	Regional extension dominates; any strike-slip motion is the result of extensional processes (e.g., detachment faulting with bounding shallow strike-slip faults) Strike-slip faulting is a primary feature that controls the Quaternary tectonics of at least part of the domain; a part of Pacific-North American right-lateral transform movement is communicated inland to Death Valley-Furnace Creek faults and Walker Lane; faulting results from right-lateral movement on en echelon strands of the Walker Lane, and dip-slip movement on N-to-NE trending normal faults connecting these strands	Design-basis ground motion time histories and corresponding response spectra for facilities important to safety	Medium to high	Medium--regional dynamics affect ground-motion estimates, but local faulting relationships more significant; regional models may allow a variety of local fault geometries	Medium--more important to reduce uncertainties about nature of local faulting for design and performance than to resolve faulting mechanisms throughout the domain	8.3.1.17.4.12.2, 8.3.1.17.4.3.1, and 8.3.1.17.4.3.2
				Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Same as above	Same as above	Same as above
				Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	Same as above	Same as above

Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 4 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
SYSTEM RESPONSE/DYNAMICS (continued)								
Frequency and distribution of events	None selected	High--frequency and distribution of significant events across domain not well known	Volcanism and faulting in the domain are episodic; probability of events may be modeled as Poissonian Volcanism and faulting in the domain are cyclic; zones in the domain may be active for a period and then quiescent as activity migrates to another zone	Design-basis ground time histories and corresponding response spectra for facilities important to safety	Medium to high	Low-medium--variability of event occurrence probably great enough that Poissonian assumptions are sufficient even if processes are cyclic; cyclic hypotheses most significant if assumed site is in quiescent zone	Low-medium--hazard analyses will generally assume site is in active part of a cycle, and use the highest measured rate for a definable part of the Quaternary	8.3.1.17.4.12.2, 8.3.1.17.4.3.2, 8.3.1.8.5.1.5, 8.3.1.8.5.1.2
				Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Same as above	Same as above	Same as above
				Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safey	Medium to high	Same as above	Same as above	Same as above

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Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 5 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
SYSTEM RESPONSE/DYNAMICS (continued)								
Extension rate and distribution	Average east-west extension rate across domain is about 1 cm per year in the Quaternary, but extension is concentrated in local zone	Medium--degree of localization of extension not well known	Average east-west extension rate across domain is about 1 cm per year in the Quaternary, and extension is evenly distributed across Great Basin	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--regional strain rates influence faulting probabilities but local variations more significant	Low--existing data on regional rates sufficient and increased accuracy probably not reasonably achievable; local model will assess local rates	8.3.1.17.4.12.2
				Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	Same as above	8.3.1.17.4.12.2

[a]NA = not applicable.

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8.3.1.17.1 Investigation: Studies to provide required information on volcanic activity that could affect repository design or performance

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.5.1	Volcanism
1.8.1.3.1	Significant results
1.8.1.3.2	Discussion of significant results
1.8.1.5.1	Significant results

Parameters

This investigation will provide the following characterization parameters related to potential ash fall at the site from distal silicic volcanic centers (Tables 8.3.1.17-1a, -1b, -2a, and -2b):

1. Probability of ash fall at the site as a function of ash-fall thickness.

2. Expected ash-fall thickness at the site in a 1,000-yr period.

3. Potential ash-fall particle densities and size distributions.

Investigation 8.3.1.8.1 (direct releases resulting from volcanic activity--postclosure) will provide the following characterization parameters related to the potential for a basaltic volcanic eruption at the site (Table 8.3.1.8-1):

1. Location and timing of volcanic events near the site.

2. Evaluation of structural controls on the occurrence of basaltic eruptions.

3. Presence of magma bodies in the vicinity of the site.

4. Effects of Strombolian eruptions.

5. Effects of hydrovolcanic eruptions.

Purpose and objectives of the investigation

Two types of volcanic hazards that could credibly affect preclosure repository performance will be characterized: (1) ash fall from distal silicic volcanic centers in the western Great Basin and (2) a basaltic volcanic eruption at the site. Ash fall is being addressed under preclosure tectonics because of its potential impact on surface and subsurface ventilation systems (dust filters). However, the study of basaltic volcanism in the site region will be conducted under the postclosure tectonics program (Section 8.3.1.8), because the probability of basaltic volcanism at the site is greater over the longer postclosure time frame. The probability of a basaltic volcanic eruption at the site during the preclosure period will be estimated there. No studies are planned of potential silicic volcanism in the site region because a silicic volcanic eruption at the site is not considered a credible event (Section 1.5.1).

The characterization parameters related to ash fall are being provided so that the filtration systems of the surface-facility and mining ventilation systems can be designed to accommodate potential ash falls at the site. The characterization parameters related to basaltic volcanism are intended to provide assurance that the probability of a volcanic eruption at the site is acceptably low (i.e., as interpreted here, less than one chance in 10,000 in 100 yr).

Technical rationale for the investigation

A logic diagram for the investigation of preclosure volcanic activity is presented in Figure 8.3.1.17-3. The potential for ash falls at the site from distal silicic volcanic centers will be addressed in Study 8.3.1.17.1.1. Since much work has already been published on silicic volcanism in the region, data will be compiled primarily through a literature survey in Activity 8.3.1.17.1.1.1. For the western Great Basin, locations of silicic volcanic center, rates and volumes of past eruptions, tephra dispersal patterns for past eruptions, and tephra particle-size, distributions in past eruptions will be compiled. The ash-fall potential at the site will be assessed by assuming that silicic volcanic eruptions are a stationary random process and, hence, that observed Quaternary rates and distributions can be projected into the future.

The potential ash-fall thickness at the site will be assessed in Activity 8.3.1.17.1.1.2 and expressed in terms of the characterization parameters listed in Tables 8.3.1.17-1a, -1b, -2a, and -2b. A probability-versus-thickness function will be estimated, and a particular ash-fall thickness that has less than one chance in 10 of occurring in 100 yr (i.e., a greater-than-1,000-yr ash fall) will be estimated for consideration in the design of mining and surface ventilation systems. The potential particle density and particle-size distribution of an ash fall at the site will be assessed in Activity 8.3.1.17.1.1.3.

The potential for a basaltic volcanic eruption to directly disrupt the repository is being addressed in Investigation 8.3.1.8.1, under postclosure tectonics. The probability of a basaltic eruption penetrating the repository will be estimated in Study 8.3.1.8.1.1, and the potential geologic effects of

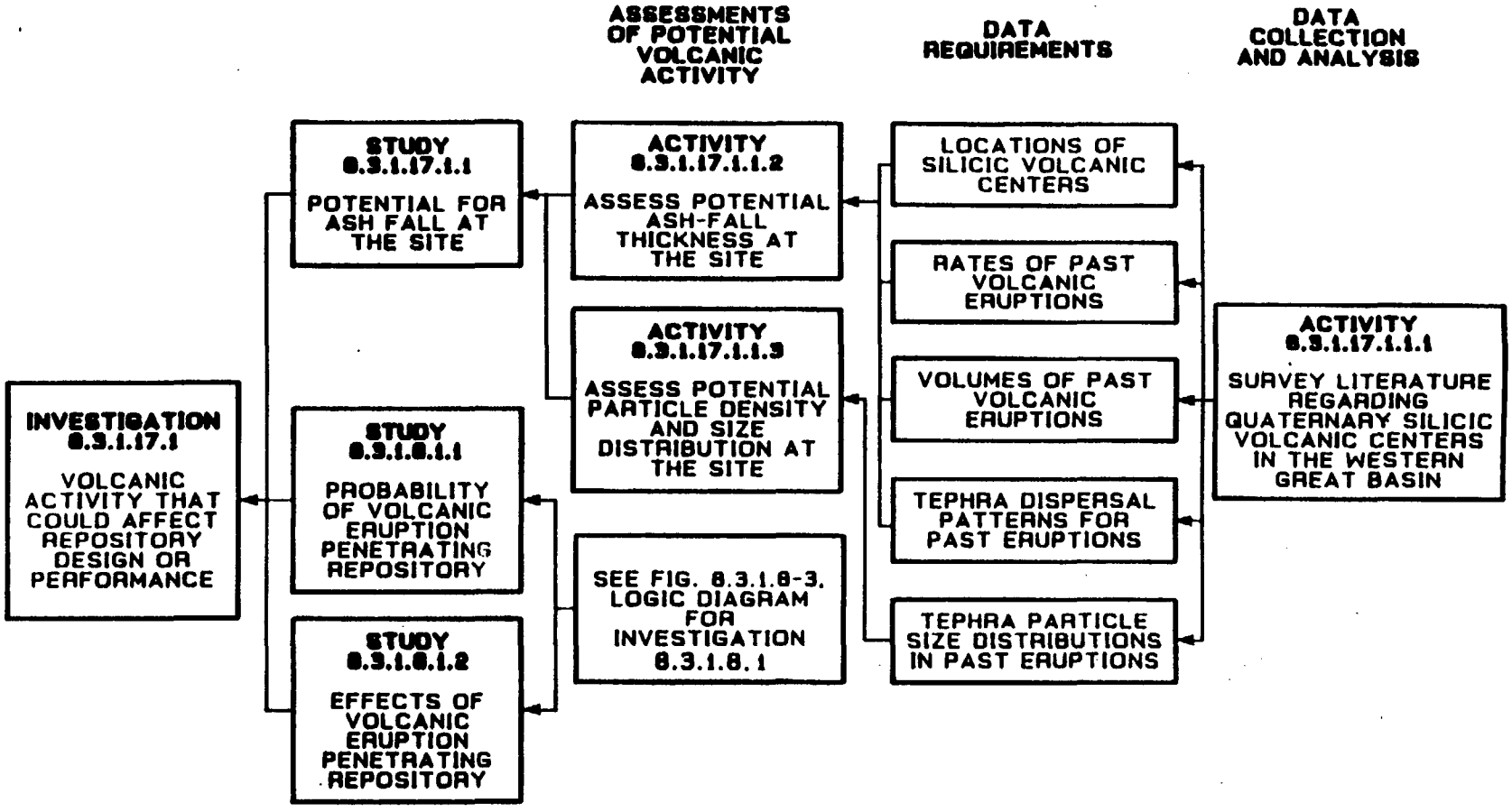

Figure 8.3.1.17-3. Logic diagram for Investigation 8.3.1.17.1 (preclosure volcanic activity)

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such an eruption on the site will be assessed in Study 8.3.1.8.1.2. The supporting activities and data requirements for these two studies are indicated in the logic diagram for Investigation 8.3.1.8.1 (Figure 8.3.1.8-3).

8.3.1.17.1.1 Study: Potential for ash fall at the site

Three activities are included in this study.

8.3.1.17.1.1.1 Activity: Survey literature regarding Quaternary silicic volcanic centers in the western Great Basin

Objectives

The objective of this activity is to compile information on Quaternary silicic volcanism in the western Great Basin, the reoccurrence of which might produce an ash fall at the site.

Parameters

Information to be compiled includes locations of silicic volcanic centers, rates of past eruptions, volumes of past eruptions, tephra dispersal patterns in past eruptions, and tephra particle size distributions in past eruptions.

Description

Required data will be gathered from the geological literature. Volcanic fields of interest include the Coso field, the Big Pine field, Long Valley caldera, and the Mono-Inyo Dome chain.

8.3.1.17.1.1.2 Activity: Assess potential ash-fall thickness at the site

Objectives

The objective of this activity is to produce an approximate probability-versus-thickness function for potential ash falls at the site and to estimate a particular ash-fall thickness that has less than one chance in ten of occurring in 100 yr. These hazard estimates will be considered in the design of filters in the mining and surface-facility ventilation systems.

Parameters

The parameters required for this assessment activity include the following:

1. Locations of Quaternary silicic volcanic centers in the western Great Basin.

2. Rates, volumes, and tephra dispersal patterns of Quaternary silicic volcanic eruptions in the western Great Basin.

Description

The ash-fall hazard estimates will be produced by extrapolating the observed Quaternary rates, volumes, and tephra dispersal patterns of silicic volcanic eruptions in the western Great Basin into the future and by calculating the probabilities of experiencing different ash-fall thicknesses at the site, considering the site location relative to the silicic volcanic centers. These estimates will be based on the information compiled in Activity 8.3.1.17.1.1.1.

8.3.1.17.1.1.3 Activity: Assess potential particle density and size distribution of ash fall at the site

Objectives

The objective of this activity is to estimate the potential particle densities and particle-size distributions of ash falls at the site for consideration in the design of filters in the mining- and surface-facility ventilation systems.

Parameters

The parameters required for this assessment activity are historical ash-fall particle densities from silicic volcanic eruptions and particle-size distributions in ash beds corresponding to Quaternary silicic volcanic eruptions in the western Great Basin.

Description

Potential ash-fall particle densities at the site will be assumed to be comparable to particle densities that have been observed historically in ash falls from silicic volcanic eruptions, at distances similar to those between the site and the silicic volcanic centers in the western Great Basin. Potential particle size distributions at the site will be estimated on the basis of observed size distributions in ash beds that correspond to Quaternary silicic volcanic eruptions in the western Great Basin and that are at distances comparable to that of the site from the volcanic centers. The analyses will be based on information compiled in Activity 8.3.1.17.1.1.1.

8.3.1.17.2 Investigation: Studies to provide required information on fault displacement that could affect repository design or performance

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The sections of the SCP data chapters that summarize existing data relevant to this investigation are as follows:

SCP section	Subject
6.1.4	Surface structures, systems, and components considered important to safety
1.3	Structural geology and tectonics
1.5	Long-term stability with respect to tectonics and geologic processes

Parameters

This investigation will compile or develop the following characterization parameters related to the potential for fault displacement beneath surface facilities considered important to safety (Tables 8.3.1.17-3a and -3b):

1. Identification and characterization of potentially significant Quaternary faults within 5 km of facilities important to safety (FITS).

2. Identification and characterization of faults within 100 m of FITS that have apparent Quaternary slip rates greater than 0.001 mm/yr or that measurably offset materials that are less than 100,000 yr old.

3. Estimated total probability of exceeding 5 cm displacement beneath FITS, considering known faults, possibly concealed faults, and tectonic interrelationships among local faults.

The following characterization parameters related to the potential for underground fault displacement in areas of emplaced waste will also be compiled or developed in this investigation (Tables 8.3.1.17-4a and -4b):

1. Surface locations of faults in the repository block that offset Quaternary materials by more than 1 m or Tertiary rocks by more than 100 m.

2. Surface and subsurface locations of any faults that intersect prospective underground facilities and that have average Quaternary slip rates greater than 0.005 mm/yr.

3. Estimated total probability of exceeding 7 cm displacement on any fault in the the area of emplaced waste, considering known and possibly concealed faults and the tectonic interrelationships among local faults.

Purpose and objectives of investigation

The siting objective vis-a-vis potential surface faulting is to avoid fault displacement in excess of a few inches beneath the structural foundations of surface facilities considered important to safety. The corresponding goal of this investigation, expressed in Table 8.3.1.17-3a, is to demonstrate, with a high degree of confidence, that there is less than a one percent chance of exceeding 5 cm of fault displacement beneath surface facilities important to safety during the preclosure period (approximately 100 yr). (A discussion of the reasonableness of this goal is provided in the overview of this section.)

The primary concern regarding faulting in the underground facilities during preclosure is that waste packages might be sheared or become jammed in their waste-emplacement boreholes, making retrieval more difficult and time consuming than it otherwise would be. The corresponding goal (Tables 8.3.1.17-4a and -4b) is to demonstrate with a moderate degree of confidence that there is less than a ten percent chance of exceeding 7 cm of fault displacement in areas of emplaced waste in 100 yr, considering all faults that may intersect these areas. (A displacement of 7 cm is the minimum value at which the sides of a faulted waste-emplacement borehole would be expected to contact a waste package.) No single fault with the potential to exceed this goal is currently thought to exist, but if such a fault is identified, an attempt will be made to determine its location underground for consideration in the positioning of waste-emplacement boreholes.

Technical rationale for investigation

A logic diagram for the investigation of preclosure fault displacement is presented in Figure 8.3.1.17-4.

The potential for surface faulting at locations of surface facilities important to safety (FITS) will be assessed in Activity 8.3.1.17.2.1.1 and expressed in terms of the characterization parameters listed in Table 8.3.1.17-3b. The most important information pertaining to potential fault displacement beneath FITS is expected to come from detailed geologic mapping of alluvial deposits in Midway Valley and from exploratory trenching in the immediate vicinity of prospective surface FITS. Exploratory trenches are expected to intersect surficial units that are at least 100,000 yr old. Any faults that measurably displace units less than 100,000 yr old and any faults found to have Quaternary slip rates exceeding 0.001 mm/yr (10 cm/100,000 yr) will be identified.

Because significant faulting is sometimes accompanied by sympathetic displacements in adjacent areas, information on fault-zone widths and recurrence of movement on Quaternary faults within 5 km of surface FITS will also be analyzed. Of particular interest for any such fault will be any evidence of concealed extensions that may trend toward Midway Valley and the sites of prospective FITS.

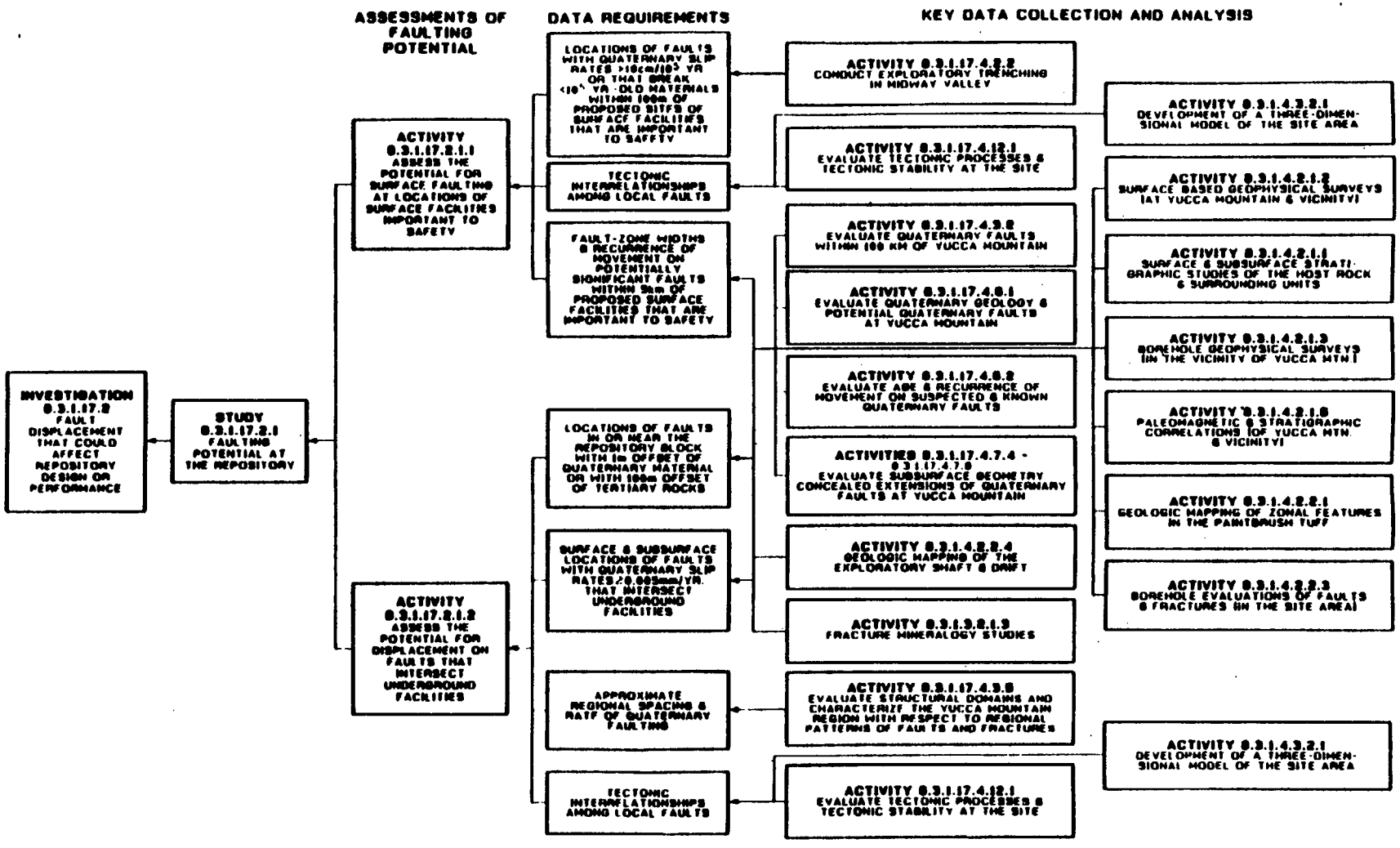

Figure 8.3.1.17-4. Logic diagram for the Investigation 8.3.1.17.2 (preclosure fault displacement)

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The probability of exceeding 5 cm displacement on any fault beneath prospective surface FITS will be estimated in Activity 8.3.1.17.2.1.2, considering, in addition to the information cited previously, the tectonic interrelationships between local faults, the possible existence of concealed faults, and the potential for the surface trace of a fault to change locations from event to event. The goal is to locate the surface FITS in an area where there is less than a one percent chance of exceeding 5 cm of net (combined dip-slip and strike-slip) displacement in 100 yr, with high confidence.

Any site without faults having apparent Quaternary slip rates greater than 0.001 mm/yr and faults that measurably offset materials less than 100,000 yr old is expected to meet the above goal conservatively, even if an undetected component of strike-slip motion exists that is as large as the measured dip-slip components. This expectation is based in part on the observation that main, branch, and secondary faulting generally recurs at the same location. An example is the 1983 Borah Peak earthquake, where new ruptures were found to coincide with older scarps that defined both the main trace and graben-bounding antithetic faults (Crone et al., 1985; Schwartz and Crone, 1985). The 1932 Cedar Mountain earthquake is another example where trenches across the 1932 ruptures revealed many previous events (Bell, 1988). The prior Cedar Mountain events coincide with the 1932 breaks even though the general pattern of faulting was distributed. Data from these earthquakes and others indicate that a trenching program of the type proposed here, if conducted before the recent faulting, would have detected these faults and accurately identified the locations of future ruptures.

The potential for displacement on faults that intersect underground facilities will be assessed in Activity 8.3.1.17.2.1.2; the corresponding design parameters and characterization parameters are listed in Tables 8.3.1.17-4a and -4b.

To meet the design-parameter goal of identifying and characterizing significant late Quaternary faults in the repository block, the locations of faults with more than 1-m offset of Quaternary materials, or with more than 100-m offset of Tertiary rocks, will be determined. Current data provide low-to-moderate confidence that only two such faults exist, namely the Bow Ridge and Solitario Canyon faults. Further work will be performed in Study 8.3.1.17.4.6 (Quaternary faulting within the site area) to provide added confidence that there are no additional significant late-Quaternary faults in the repository block.

A second design-parameter goal is to identify, characterize, and locate within the waste-emplacement area any fault with more than a one percent chance of producing displacement greater than 7 cm during the preclosure period. Faults with slip rates less than 0.005 mm/yr would be very unlikely to exceed this threshold (see overview discussion of the preclosure tectonics site program in this section), and current data indicate that, with moderate confidence, no faults with Quaternary slip rates greater than 0.005 mm/yr exist in the repository block. Further work will be performed in Study 8.3.1.17.4.7 to achieve a moderate-to-high level of confidence in this finding.

Information on particular Quaternary faults in the repository block, data on the regional spacing and rate of movement of Quaternary faults, and interpretations of tectonic interrelationships among local faults will be synthesized in Activity 8.3.1.17.2.1.2 to estimate a total probability of exceeding 7 cm displacement on faults that intersect areas of emplaced waste. This work is expected to corroborate the current assessment that, with moderate confidence, the total probability of exceeding 7 cm displacement in 100 yr on any fault in the area proposed for waste emplacement is less than one percent.

8.3.1.17.2.1 Study: Faulting potential at the repository

This study includes two activities.

8.3.1.17.2.1.1 Activity: Assess the potential for surface faulting at prospective sites of surface facilities important to safety

Objectives

The objective of this activity is to assess the stability of the site surface with respect to fault displacement, at locations proposed for facilities important to safety (FITS). Particular objectives are to develop the characterization parameters listed in Table 8.3.1.17-3b and discussed previously with the indicated levels of confidence.

Parameters

The data required for this synthesis activity include the following:

1. Locations of faults within 100 m of locations proposed for FITS that have apparent Quaternary slip rates greater than 0.001 mm/yr or that measurably offset materials less than 100,000 yr old.

2. Fault-zone widths and recurrence of movement on potentially significant faults within 5 km of locations proposed for FITS.

3. Tectonic interrelationships among local faults.

The key parameter to be produced by this activity is an estimate of the total probability of exceeding 5 cm fault displacement at locations proposed for FITS.

Description

This is a synthesis and assessment activity that draws on data collected elsewhere, mostly from the Quaternary faulting studies in Investigation 8.3.1.17.4 and the studies of stratigraphy and structure in Investigation 8.3.1.4.2. The data sets that will be synthesized, the general approach to the synthesis, and the required assessments are described previously in

the discussion of the technical rationale for this investigation and in the overview of the preclosure tectonics site program. A few more details on the synthesis of the faulting potential are provided here.

The assessment of the probability of fault displacement beneath FITS may benefit from a consideration of the fractal characteristics of local fault systems and of the mechanical interactions between local faults.

Surface FITS will be sited where there is no evidence of substantial Quaternary faulting, but concealed faults and the possibility of the surface trace of a fault appearing at a new location cannot be ruled out and will be evaluated. Since fault systems tend to have self-similar geometries (i.e., to have similar degrees of branching and complexity over a wide range of map scales) an analysis of the fractal characteristics of local fault systems may be useful for estimating the spatial density and lengths of subsidiary faults that may lie concealed in the vicinity of FITS.

The reasonableness of postulated tectonic interrelationships among local faults can be checked to some extent by analyzing the stresses generated by the displacements that are assumed to be occurring; the local stress field generated by assumed slip on one fault should not act to oppose the slip that is assumed for other faults. If slip directions and magnitudes are constrained by geologic data, stress analyses may indicate areas of stress concentration that may be accommodated by concealed faults.

8.3.1.17.2.1.2 Activity: Assess the potential for displacement on faults that intersect underground facilities

Objectives

The objective of this activity is to assess the potential for displacement on faults that intersect underground facilities. Particular objectives are to develop the characterization parameters listed in Table 8.3.1.17-4b with the indicated levels of confidence.

Parameters

Data required for this synthesis activity include the following:

1. Locations of faults in the repository block that offset Quaternary materials by more than 1 m or Tertiary rocks by more than 100 m.

2. Surface and subsurface locations of faults with Quaternary slip rates greater than 0.005 mm/yr that intersect areas proposed for waste emplacement.

3. Approximate regional spacing and rate of Quaternary faults.

4. Tectonic interrelationships among local faults.

The key parameter to be provided by this activity is an estimate of the total probability of exceeding 7 cm displacement in 100 yr on any fault that intersects areas proposed for waste emplacement.

Description

This is a synthesis and assessment activity that draws on data collected by other activities, as indicated in Figure 8.3.1.17-4. The data sets that will be synthesized, the general approach to the synthesis, and the required assessments are described previously in the discussion of the technical rationale for this investigation and in the overview of the preclosure tectonics site program. A few observations on the general approach are presented here.

The assessment of faulting potential at depth will be predominantly inferential, because the recency and amount of movement on a fault encountered at depth while mining is nearly impossible to determine from the limited exposure in the mine. Also, the subsurface projections of faults that are expressed at the surface are often poorly constrained by surface geophysical evidence. In the unexpected instance that a fault is found that may project through proposed areas of emplaced waste and that has surface evidence of a slip rate exceeding 0.005 mm/yr, the fault will be located (perhaps by drilling and coring) in the underground.

The inference of faulting potential will be based in part on the average spacing of Quaternary faults that is estimated for the structural domain that encompasses the site. (A structural domain is a crustal block within which faulting of a given genetic type generally occurs with uniform characteristics.) Key information for defining the structural domain of the site will come from Activity 8.3.1.17.4.3.5. The assessment of faulting potential will also consider estimates of slip rates on Quaternary faults in the site area (from Activity 8.3.1.17.4.6.2), the fractal geometry of local fault systems (see description of Activity 8.3.1.17.2.1.1), interpreted tectonic (mechanistic) interrelationships among local faults, and models for the accommodation of regional strain by local faults.

8.3.1.17.3 Investigation: Studies to provide required information on vibratory ground motion that could affect repository design or performance

Technical basis for obtaining the information need

Link to the technical data chapters and applicable support documents

Sections 1.3, 1.4, and 1.5 of the SCP data chapters provide a technical summary of existing data relevant to this investigation.

Parameters

This investigation will provide the following characterization parameters related to potential vibratory ground motion at the site from natural and man-made seismic sources (Tables 8.3.1.17-5a -5b, -6a, and -6b):

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1. Identification of potential earthquake sources in the controlled area.

2. Identification of earthquake sources within 100 km of the site that could be relevant to the site (i.e., that could conceivably control the design-basis ground motions at the site in any frequency band of engineering significance).

3. Magnitudes of 10,000-yr cumulative slip* earthquakes on local earthquake sources.

4. Magnitudes of 10,000-yr cumulative slip* earthquakes on regional earthquake sources.

5. Maximum potential yields of future underground nuclear explosions (UNEs) at the Nevada Test Site (NTS).

6. Closest distance between the site and potential future UNEs at NTS.

7. Ground-motion models/attenuation relationships for the site region (i.e., mathematical models for predicting the values of ground-motion parameters as a function of the distance from and the strength of the earthquake or UNE source).

8. Spectral amplification functions that represent the effects of local site geology on surface seismic motions and the effects of depth on underground seismic motions.

9. Identification of controlling seismic events--those 10,000-yr cumulative slip earthquakes and/or potential largest and closest UNEs that would generate the most severe ground motions at the site in any frequency band of engineering significance, taking into account an local-geologic or depth effects on the ground motion.

10. Time histories and response spectra that are representative of potential ground motion at the site from the controlling seismic event(s).

11. Magnitude-recurrence relationships for all regional earthquake sources that could contribute to the earthquake hazard at the site.

12. Probabilities of exceeding selected ground-motion parameters at the site, developed through probabilistic seismic hazard analysis.

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*10,000-yr cumulative earthquakes are defined here to be earthquakes that, occurring every 10,000 yr, would produce the observed or estimated average Quaternary slip rate on a fault; see discussion in description of Activity 8.3.1.17.3.1.2.

Purpose and objectives of the investigation

The purposes of this investigation are to (1) develop a seismic-design basis for repository facilities that are important to safety and (2) provide other information that will facilitate the assessment of the adequacy of the seismic-design basis and the identification of credible accidents that might be initiated by seismic events and lead to release of radioactive materials. The seismic-design basis will account for both the potential occurrence of earthquakes on nearby faults and potential future underground nuclear explosions at the Nevada Test Site.

The planned methodology for developing the seismic-design basis is, as is discussed in detail below, intended to result in design levels such that the probability of the design level being exceeded is comparable to typical exceedance probabilities for the seismic-design bases of operating nuclear power plants in the United States (i.e., annual probabilities of exceedance on the order of 1×10^{-3} to 1×10^{-4}).

Although this investigation is motivated by the need to develop a seismic-design basis and other information related to the design of facilities important to safety (FITS), the resulting design-basis ground-motion descriptions also may be considered in the design of other repository facilities. (Presently, only the shipping cask and certain components of the waste-handling facilities are considered potentially important to safety (Laub and Jardine, 1987). Current plans call for the FITS seismic-design basis to be considered also in the design of underground facilities (Information Need 4.4.1, site and performance assessment information needed for design, Section 8.3.2.5.1).

The approach that is currently considered appropriate for developing a seismic design basis is deterministic, meaning that the design-basis ground-motion description will correspond to the postulated occurrence of a discrete seismic event or events (e.g., the occurrence of an earthquake of specified magnitude on a particular fault). This type of approach parallels that used to develop the seismic design bases of all nuclear power plants in the United States. In addition, probabilistic estimates of the seismic hazard at the site will be developed that integrate individual contributions to the site's ground-motion potential from earthquake sources at different distances and with different earthquake recurrence characteristics. The probabilistic seismic hazard estimates will be used to evaluate and constrain required technical judgments in the deterministic approach, evaluate the adequacy of the deterministic results, and help identify and focus efforts to refine those parameters that are most important for the deterministic calculations. The probabilistic hazard estimates will also provide input needed to determine credible accidents that are applicable to the repository (Information Need 2.3.1, Section 8.3.5.5.1).

In summary, probabilistic seismic hazard estimates will be an important adjunct to the deterministic estimates that will be developed for consideration in the seismic design of FITS. A discussion of the reasons for using deterministic and probabilistic methodologies in this fashion is given in the Overview section for this investigation.

Technical rationale for investigation

Ten-thousand year cumulative slip earthquakes are defined here to be earthquakes that, occurring every ten-thousand years, would produce the observed or estimated average Quaternary slip rate on a fault (see detailed discussion in description of Activity 8.3.1.17.3.1.2). Controlling seismic events are those exceptional earthquakes and/or potential largest and closest UNEs that would generate the most severe ground motions at the site in any frequency band of engineering significance. The seismic design basis for FITS will be suites of ground-motion time histories and corresponding response spectra that are representative of the controlling seismic events.

A logic diagram for this investigation is presented in Figure 8.3.1.17-5.

Study 8.3.1.17.3.1 will identify and characterize earthquake sources that could potentially be relevant to a deterministic seismic hazard analysis of the site, i.e., sources that could conceivably produce exceptional earthquakes that would control the seismic-design basis in any frequency band of engineering significance. Characterization of earthquake sources for the deterministic hazard assessment will include a determination of each source's location, orientation, depth, likely style of faulting, and an evaluation of the 10,000-yr cumulative slip earthquake magnitude. Here, and elsewhere, uncertainty in the determination of input parameters will be estimated so that the sensitivity of the final results to key assumptions can be estimated.

The identification and characterization of relevant earthquake sources will consider the historical record of regional seismicity; the potential for seismicity to be induced at the site by human activities; the location, nature, and rate of Quaternary faulting in the site area; crustal stresses at seismogenic depths; evidence of neotectonic deformation in the Yucca Mountain area; and the overall tectonic framework of the region.

Study 8.3.1.17.3.2 will determine the potential locations and maximum yields of future UNEs at the NTS, considering constraints such as damage thresholds in Las Vegas. The UNE(s) that would cause the most severe ground motions at the site will then be identified using a predictive model for UNE ground motions.

Models for predicting UNE ground motions and models for predicting earthquake ground motions will be selected or developed in Study 8.3.1.17.3.3. Published ground-motion models for UNEs at NTS will be used where appropriate. If published models are not available for all ground-motion parameters needed, available data will be compiled and the needed models will be developed through regression analyses. Earthquake ground-motion data from the Great Basin and tectonically analogous areas will be tested for statistically significant deviations from published earthquake ground-motion models that have been developed for California and western North America. If the deviations are not statistically significant, a published model will be selected. If needed, new models will be developed through regression analyses.

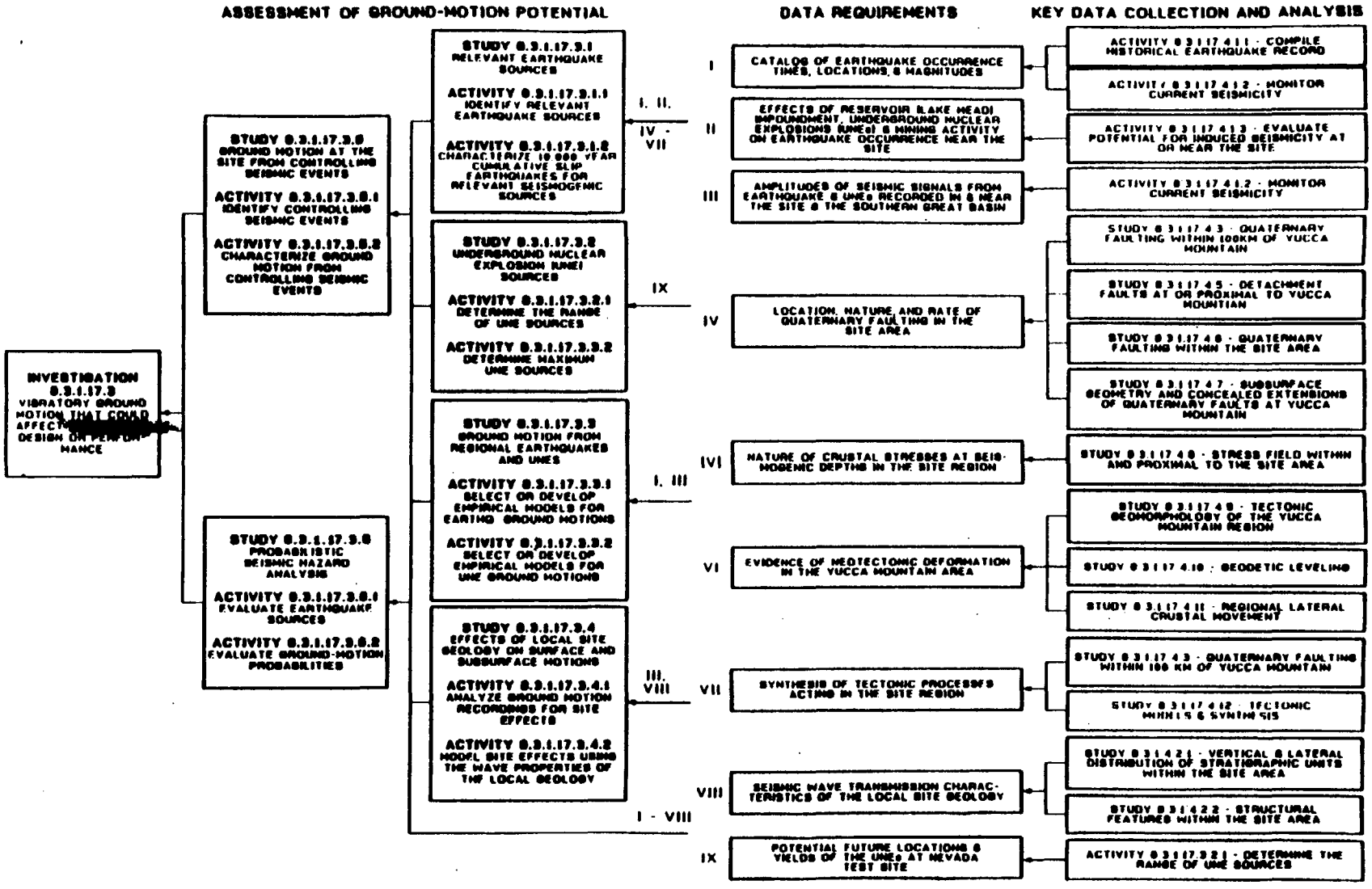

Figure 8.3.1.17-5. Logic diagram for the Investigation 8 3 1 17 3 (preclosure vibratory ground motion) (Roman numerals indicate data flow)

Systematic effects on surface and subsurface ground motions resulting from the local site geology will be identified and used to correct predictions of the regional ground-motion models developed in Study 8.3.1.17.3.3. These correction factors will be based, to the extent possible, on actual ground-motion recordings obtained in Study 8.3.1.17.4.1. Theoretical models based on the wave properties of the local geology will be developed to the degree necessary to explain the observations to first order and then used to extrapolate the observations to locations and depths where ground motions must be predicted but where recordings are not available.

Identification of controlling seismic events and characterization of the resulting ground motion at the site will be accomplished in Study 8.3.1.17.3.5. Identification of the controlling seismic events will follow directly from the identification of 10,000-year cumulative slip earthquakes on relevant sources in Study 8.3.1.17.3.1, the determination of potential maximum future UNEs in Study 8.3.1.17.3.2, the earthquake and UNE ground-motion models developed in Study 8.3.1.17.3.3, and the local site correction factors developed in Study 8.3.1.17.3.4.

Controlling-event ground motions will be characterized by suites of strong-motion time histories that are representative in terms of expected amplitudes, frequency content, and duration. Methodologies for constructing these time histories will be evaluated. Two different methodologies may be implemented and the results compared to help assess the uncertainty in the final results.

The probabilistic seismic hazard analysis of the site constitutes Study 8.3.1.17.3.6. The first step in the analysis is to identify and characterize earthquake sources that contribute to the hazard (the probability of exceeding different ground-motion levels) at the site. Sources that are more distant and sources with smaller earthquake potential than the "relevant" sources addressed in Study 8.3.1.17.3.1 will be characterized so that exceedance probabilities for ground-motion levels below the design-basis levels can be estimated. (Exceedance probabilities for motions beyond the design-basis will also be estimated.) Each seismic source will be characterized as to location, depth, shape, and magnitude-recurrence characteristics, including maximum-magnitude potential. The considerations in characterizing the contributing earthquake sources in the probabilistic analysis are essentially the same as those in characterizing relevant sources in the deterministic analysis, and so the same types of data are required.

There are different methodologies available for encoding uncertainty in seismic-source-zone interpretations and for aggregating the results of multiple interpretations in a probabilistic seismic hazard analysis. The advantages and disadvantages of available methodologies will be assessed before an approach is chosen.

A probabilistic seismic hazard analysis of the site is expected to be performed concurrently with the deterministic analysis and repeated one or more times, with detail increasing as more data become available. The sensitivity of estimated hazard to various input parameters is easy to assess within the probabilistic framework, and the preliminary analyses will help to identify the parameters of greatest importance to both the probabilistic and deterministic analyses; this information will be used to redirect and focus

the characterization activities. The calculated probabilistic hazard levels will also be used to help assess the adequacy of the deterministically derived design-basis ground motions. As was stated earlier, a measure of adequacy that is adopted here is that the annual probability of the design-basis ground motions being exceeded is between 10^{-3} and 10^{-4} per yr, which is the range of probabilities that appears to correspond to seismic-design bases that have been accepted for nuclear power plants in the United States.

8.3.1.17.3.1 Study: Relevant earthquake sources

The objectives of this study are to identify and characterize those earthquake sources that are relevant to a deterministic seismic hazard analysis of the site (i.e., those sources that could be active) and, if active, could cause severe ground shaking at the site. Potential earthquake sources include faults with surface geologic expression as well as concealed faults. Each seismic source will be characterized by its location, depth, orientation, likely style of faulting, and 10,000-yr cumulative slip earthquake magnitude.

8.3.1.17.3.1.1 Activity: Identify relevant earthquake sources

Objectives

The objective of this activity is to identify earthquake sources that could generate severe ground motions at the site.

Parameters

The following types of information will be synthesized in this activity:

1. Maps and cross sections of historical earthquake locations.
2. Maps showing Quaternary faults with lengths greater than about 20 km within 100 km of the site and Quaternary faults with lengths greater than about 1 km within 10 km of the site.
3. Data on the style and rate of Quaternary faulting in the site region.
4. Evidence of neotectonic deformation or stability in the site region.
5. Regional heat-flow anomaly maps and regional and local magnetic-anomaly and gravity-anomaly maps.
6. Regional and local crustal seismic data.
7. Information on local and regional crustal stresses.
8. Local and regional tectonic models.

These information items will be supplied mostly by the data-collection-and-analysis activities in Investigation 8.3.1.17.4 (Figure 8.3.1.17-5).

Description

Relevant earthquake sources will be identified through a synthesis of information of the types listed in the parameter section. Surface evidence of Quaternary faulting and patterns of historical seismicity will be paramount considerations. Magnetic and gravity anomalies, crustal seismic data, and heat-flow will be analyzed for indications of faulting at depth. The assessment of whether a geophysical anomaly corresponds to a fault will consider information on the local structural geology and surface geomorphology. The likelihood of a buried fault being active will be evaluated considering the spatial correlation of the fault with historical seismicity, the orientation of the feature with respect to measured or inferred crustal stress orientations, potential tectonic interrelationships with other local faults, and conceptual models of the regional tectonics.

The assessment of relevance of an identified seismic source requires an assessment of the magnitude capability of the source. Hence, this activity will be performed concurrently and iteratively with the effort to define 10,000-yr cumulative slip earthquakes for relevant earthquake sources in Activity 8.3.1.17.3.1.2.

Relevance to a deterministic seismic hazard analysis of the site of identified earthquake sources will be judged according to a preliminary estimation of the 10,000-yr cumulative slip earthquake magnitude of the source and the distance of the source from the site, using criteria similar to the following:

Source distance (R)	10,000-year cumulative slip earthquake magnitude (M)
$0 \leq R < 3$ km	$M > 5$
$3 \leq R < 100$ km	$M > 4 + 2 \log_{10} R$

Relevance to a deterministic seismic hazard analysis of identified earthquake sources is determined by the potential for such sources to possibly control the severity of ground shaking at any frequency of engineering significance. The determination of relevance involves the determination of the 10,000-yr cumulative slip earthquake for each source and the prediction of potential ground motion in different frequency bands. Attenuation relationships for frequency-specific measures of ground-motion severity (e.g., spectral ordinates of pseudo-relative velocity response) are thus required for the relevancy determination.

The conceptual approach for identifying potentially relevant earthquake sources is illustrated graphically in Figure 8.3.1.17-6. The curve in this figure is based on preliminary professional judgment. No numerical calculations were performed to construct the curve; it is intended to be illustrative only.

The curve drawn in Figure 8.3.1.17-6 reflects the expectation that local faults will control potential high-frequency ground motion and that larger, more distant faults could control lower frequency ground motions. The curve

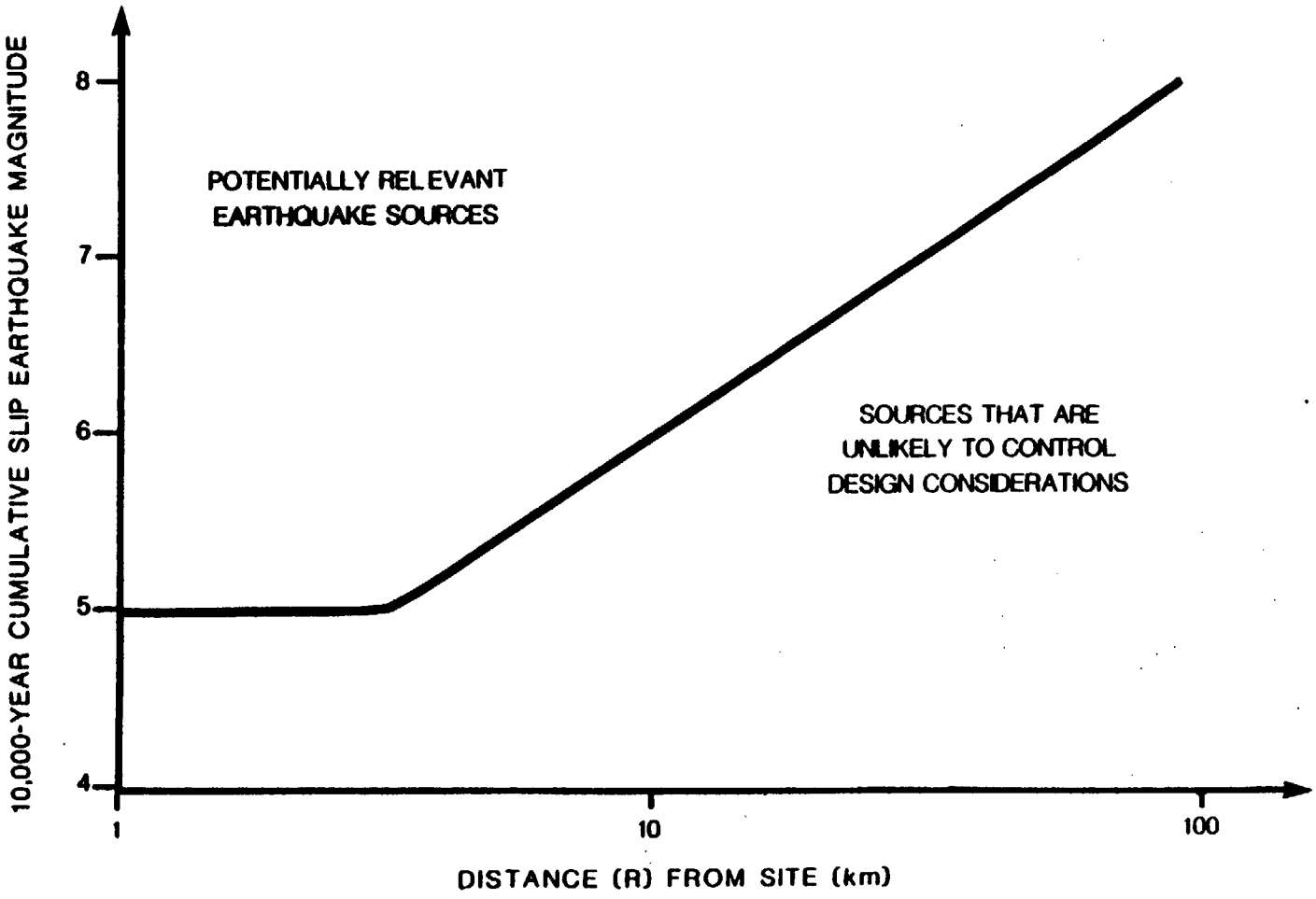

Figure 8.3.1.17-6. Conceptual approach for identifying potentially relevant earthquake sources

is not permitted to go below magnitude 5 because faults with cumulative-slip earthquake magnitudes less than this value are probably too small to detect with any confidence. (If it is determined that earthquakes smaller than magnitude 5 could impact repository design or performance, their occurrence will be considered to be spatially and temporally random and the associated hazard will be modeled probablistically as part of Study 8.3.1.17.3.6.)

The relevancy criteria will be refined through analysis of the earthquake ground-motion (attenuation) relationships that will be selected or developed in Study 8.3.1.17.3.3 and considering any revisions to the parameters needed for seismic design (Section 8.3.2.5.1) and design analysis (Section 8.3.2.5.7). Given the uncertainty in estimating magnitudes and ground motions, any criteria developed will be applied conservatively to avoid the premature screening of potentially relevant sources.

8.3.1.17.3.1.2 Activity: Characterize 10,000-yr cumulative slip earthquakes for relevant seismogenic sources

Objectives

The objective of this activity is to characterize 10,000-yr cumulative slip earthquakes for each of the relevant seismogenic sources identified in the previous activity. The nature, size, and location of 10,000-yr cumulative slip earthquakes are to be established based on the seismogenic properties of the potential sources.

Description

The concept of 10,000-yr cumulative slip earthquakes is being established to develop deterministic characterizations of potential severe vibratory ground motion for consideration in the design of repository facilities important to safety. Available data (Section 1.3) for faults in the site region that have moved during the Quaternary suggest that recurrences intervals may be on the order of 1×10^4 to 1×10^5 yr. Such low rates suggest that the use of fault length or displacement to develop deterministic estimates of magnitude for a given fault may be misleading in terms of the hazard posed by the fault. The concept of the 10,000-yr cumulative slip earthquake takes recurrence rates into account, in addition to the fault characteristics, for determining a maximum magnitude for the purpose of estimating potential severe vibratory ground motion at the site. 10,000-yr cumulative slip earthquakes for Quaternary faults are defined as those earthquakes that, occurring every 10,000 yr, would produce the observed or estimated average Quaternary slip rate on a fault. The magnitude of a 10,000-yr cumulative slip earthquake is a best estimate based on the equivalent 10,000-yr displacement and available information on fault dimensions and geometry and possible interactions with other faults. To ensure applicability of the concept in cases where slip rates are such that major strain-releasing earthquakes are expected more often than every 10,000 yr (e.g., the San Andreas fault), the 10,000-yr cumulative slip earthquake magnitude is constrained to not exceed the best-estimate maximum magnitude. Finally, to ensure adequate conservatism of the design vibratory ground motion, an additional constraint

on the magnitude is that the resulting design-basis ground motion for facilities important to safety have an annual probability of exceedance between 10^{-3} and 10^{-4} per yr.

Various types of data will be used to evaluate 10,000-yr cumulative slip earthquakes, including estimated slip rates, mapped fault lengths, fault displacement (per event if available), fault type, and other pertinent geologic data. The following hypothetical calculation is presented to illustrate how data collected during site characterization studies will be used to estimate the 10,000-yr cumulative slip earthquake for the ground motion design of surface facilities.

Sample Calculation: A fault in the vicinity of the site is identified by the procedures in Activity 8.3.1.17.3.1.1 as a potentially relevant earthquake source. Mapping and trenching studies find that the fault is 30 km long and that it displaces a 740,000-yr-old layer 7.5 m vertically and 1.5 m horizontally. Trenching at other localities along the fault indicate that the above values are representative of the behavior of the fault through the Quaternary. The above data are used to calculate a net slip of 7.65 m over 740,000 yr and a Quaternary slip rate of 0.01 mm/yr. The average cumulative slip over 10,000 yr can then be calculated as 0.1 m. The 10,000-yr cumulative slip earthquake assumption is that all this displacement is released as a single event. The magnitude of this event can be estimated using empirical regression curves such as Bonilla et al. (1984) and Slemmons (1982). The published regression curves use maximum displacement rather than average displacement to estimate magnitude, so a maximum displacement must be estimated for the 10,000-yr event. Bonilla (1982) found that the maximum displacement is about 3 times the average displacement for most events. Using this value, the maximum displacement for the 10,000-yr event is about 0.3 m. When these calculations are conducted for the final evaluations, all published methods will be evaluated and compared. New regression analyses may also be prepared for the Basin and Range province comparing displacement with magnitude or moment. For the purposes of this example, the results of Bonilla et al. (1984) will be used. Using the wna.dm (western North American; displacement-magnitude) relation of Bonilla et al. (1984), a 0.3 m displacement would indicate an earthquake of M_s 6.6. The rupture length of this event can be estimated using the wna.dl (western North American; displacement-length) relation of Bonilla et al. (1984) as 18.8 km. The reasonableness of these estimates can be checked by calculating the percentage of the total fault length hypothesized to rupture (63 percent) and comparing the results with historical events in the province or with data on measured scarp lengths along the subject fault. Any data on single event displacements and recurrence intervals can also be compared with the design event to evaluate the results.

Uncertainty in the estimation of the magnitude of the 10,000-yr event can come from the statistical uncertainty associated with the use of regression curves and the uncertainty in the estimate of average displacement rates. The statistical uncertainty in the magnitude estimates can be quantified using the techniques discussed in Bonilla et al. (1984). The uncertainty in the slip rate estimates will be

evaluated by reviewing the results from multiple locations along the subject fault and the data on the accuracy of displacement and age-dating measurements.

Earthquake magnitude-frequency relationships will be estimated (using available data) considering characteristic-earthquake models or other relationships such as exponentially decaying models or maximum likelihood models. A probability distribution for true maximum magnitude, M_{max}, will be estimated for the probabilistic seismic hazard analysis of the site--Activity 8.3.1.17.3.6.1. The magnitude-frequency relationship will be used to evaluate the recurrence interval associated with M_{max} and will assist in determining whether the 10,000-yr cumulative slip earthquake magnitude should differ from M_{max}.

The 10,000-yr cumulative slip earthquakes for each relevant earthquake source will be characterized by an expected depth or depth-range and earthquake magnitude.

The 10,000-yr cumulative slip earthquake methodology and the planned adjunct probabilistic seismic hazard analysis provide a useful and sufficient framework for scoping, organizing, and prioritizing seismic-hazard-related site-characterization activities. Together the cumulative slip earthquake methodology and the probabilistic analysis require, and the planned site-characterization activities are designed to provide, all types of information that are material to the characterization of seismic hazard, including data on fault lengths and displacements, slip rates, faulting styles, maximum-magnitude estimates, recurrence-rate estimates, attenuation relationships, local and regional tectonic models, historical seismicity, and the uncertainties associated with all these items. The cumulative slip earthquake methodology may be revised or a different methodology may be used to actually develop a design basis for the advanced conceptual design and the license application design. In any instance, the data gathered will be comprehensive and sufficient for application to any methodology.

8.3.1.17.3.2 Study: Underground nuclear explosion sources

The objective of this study is to characterize the potential future underground nuclear explosions (UNEs) at the Nevada Test Site (NTS) that region would result in the most severe motions at the repository site.

8.3.1.17.3.2.1 Activity: Determine the range of UNE sources

Objectives

The objective of this activity is to determine potential locations and upper limits on the yield of future UNE tests within the NTS.

Description

Previous work on potential UNE ground motions at the site has assumed that a 700-kiloton explosion is detonated in the Buckboard Mesa area of the NTS, at a distance of 23 km from the repository shaft (Vortman, 1986). This activity will review the basis for these assumptions, in particular, the constraints on maximum UNE yields, such as damage thresholds in Las Vegas. (The current test-ban treaty threshold is 150 kiloton.) Factors that could influence the locations of future UNEs, such as terrain and rock types at the NTS, will be reviewed. Information on depth of burial as a function of yield will be compiled. Information available in the open literature is expected to adequately constrain the potential locations, depths, and maximum yields of future UNEs at the NTS.

8.3.1.17.3.2.2 Activity: Determine maximum underground nuclear explosion source(s)

Objectives

The objective of this activity is to identify the potential future UNE(s) that would generate the most severe ground motions at the site.

Description

UNE ground-motion (attenuation) models (which will be developed or selected in Activity 8.3.1.17.3.3.2) will be used to estimate site ground motions that would result from the largest and/or closest potential future UNEs, as identified in Activity 8.3.1.17.3.2.1. The UNE or UNEs that would generate the most severe ground motions at the site, in any frequency band of engineering significance, will be identified.

8.3.1.17.3.3 Study: Ground motion from regional earthquakes and underground nuclear explosions

Objectives

The objective of this study is to select or develop ground-motion models that are appropriate for estimating ground motion at the site from earthquakes and UNEs. These models will be used to determine the relevancy of seismic sources to a deterministic seismic hazard analysis (Activity 8.3.1.17.3.1.1), identify controlling seismic events (Activity 8.3.1.17.3.5.1), constrain simulated ground motions from controlling seismic events (Activity 8.3.1.17.3.5.2) and estimate the probabilities of exceeding given ground-motion levels at the site (Activity 8.3.1.17.3.6.2).

8.3.1.17.3.3.1 Activity: Select or develop empirical models for earthquake ground motions

Objectives

The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating earthquake ground motion at the site. The models will predict ground motion as a function of earthquake magnitude and distance between the earthquake source and the site.

Parameters

Models will be determined for a number of ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral amplitudes at frequencies sampled over the range of engineering significance.

Description

The approach here will be to test available ground-motion data from the Great Basin and areas elsewhere that are tectonically analogous for statistically significant deviations from published models that have been developed for California and western North America. If the deviations are not statistically significant, a published model will be selected. If the deviations are statistically significant or if published models are not available for any of the ground-motion parameters to be modeled, then new models will be developed through regression analyses. Each model selected or developed will include an explicit description of the uncertainty in the model predictions.

8.3.1.17.3.3.2 Activity: Select or develop empirical models for ground motion from underground nuclear explosions

Objectives

The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating ground motion at the site from UNEs at the NTS. The models will predict ground motion as a function of the yield and distance of the UNE.

Parameters

As for earthquakes, models will be determined for a number of ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral amplitudes sampled over the range of engineering significance.

Description

If possible, published ground-motion models for NTS explosions (Vortman, 1986) will be used. If appropriate published models are not available for all ground-motion parameters needed, available data will be compiled and the needed models will be developed through regression analyses.

8.3.1.17.3.4 Study: Effects of local site geology on surface and subsurface motions

Objectives

The objective of this study is to document systematic effects on surface and subsurface ground motions resulting from the local site geology. Local correction factors will be developed for application to predictions of the regional ground-motion models developed in Study 8.3.1.17.3.3. These correction factors will be based, to the extent possible, on instrumental recordings of ground motion obtained in Study 8.3.1.17.4.1. Theoretical models for the observed site effects will be developed to the extent necessary to explain the observations to first order and then used to extrapolate the observations to locations and depths where ground motions must be predicted but where recordings are not available.

8.3.1.17.3.4.1 Activity: Determine site effects from ground-motion recordings

Objectives

The objectives of this study are to determine, from ground-motion recordings, systematic effects of the local site geology on surface and subsurface motions, and to identify any significant site-wide bias in ground-motion levels, as compared with average levels for the southern Great Basin. These empirical determinations will be used to calibrate theoretical site-effects models in Activity 8.3.1.17.3.4.2.

Parameters

Ground-motion biases in the proximity of proposed locations of surface facilities important to safety, as compared with area averages obtained on rock sites, will be characterized using ratios of Fourier spectra and ratios of peak ground-motion parameters (peak accelerations and peak velocities). Corresponding ratios will be used to characterize reductions in ground motions recorded at the approximate depth of underground facilities as compared to area averages of surface recordings on rock sites.

Description

Recordings of teleseisms, regional earthquakes, local microearthquakes (if any), and UNEs will be obtained at several (3 to 6) surface and two or more borehole sites in Midway Valley, and at the proposed location of surface facilities, as described in Activity 8.3.1.17.4.1.2. The recorded motions will be examined for variation with position to identify any systematic biases, particularly with respect to the depth of the valley sediments. These recorded motions and the spatial variability will be used to help calibrate theoretical models developed in Activity 8.3.1.17.3.4.2 and to determine motion averages representative of proposed locations of surface facilities important to safety.

Spectral amplification functions will be estimated by forming ratios of recorded earthquake spectra at individual locations on Midway Valley to local-array-averaged spectra obtained on nearby rock stations. Amplification factors for peak ground-motion parameters will be similarly determined. The possibility of a site-wide bias in ground-motion levels will be checked by comparing amplitudes recorded at site locations to amplitudes recorded at sites elsewhere in the southern Great Basin, for earthquakes of similar size and at comparable distances.

The spectral amplitudes of subsurface motions will be compared with the spectral amplitudes for the corresponding surface motions and with the area averages for surface motions at rock stations. Previously recorded relevant NTS data will also be considered. These data will be used to quantify spectral reductions in motion with depth as a function of frequency. Instruments will be installed at two or more surface sites on Yucca Mountain, above proposed underground facilities, and at several sites within the exploratory shafts and drifts. The local array stations will be installed during the first phase of a planned upgrade of the current regional seismic network. These stations will digitally record and buffer incoming signals and then telemeter them via a satellite link to Golden, Colorado. In addition, a dense array of portable seismic event recorders will be temporarily deployed at some point for the study of local site effects. This temporary array will likely be deployed to take advantage of announced nuclear tests at the NTS.

8.3.1.17.3.4.2 Activity: Model site effects using the wave properties of the local geology

Objectives

The objective of this activity is to develop a calibrated theoretical site-effects model for use in extrapolating the observations documented in Activity 8.3.1.17.3.4.1 to locations and depths where ground-motion predictions are needed, but where instrumental recordings are not available.

Parameters

The product of this activity will be theoretical spectral amplification functions. Corresponding amplification factors for peak-ground-motion parameters will be estimated from the spectral amplification functions, if needed.

Description

Theoretical site-effects models will be developed, based on measurements of the wave properties (shear- and compressional-wave velocities, material damping, and densities) as determined in the investigation of soil and bedrock properties (Section 8.3.1.14.2). As part of that investigation, the seismic velocity structure of the site will be determined to a depth of at least 1 km, particularly under Midway Valley.

The approach to modeling will be to construct the simplest model that predicts the first-order features of the observed site-response functions. The initial model will assume a one-dimensional velocity structure, linear

soil response, and vertically incident body waves. More complexity (e.g., nonvertically incident body waves, surface waves, equivalent-linear soil response, or two-dimensional velocity structure) will be introduced as necessary.

8.3.1.17.3.5 Study: Ground motion at the site from controlling seismic events

The objectives of this study are to identify the controlling seismic events and to characterize the resulting controlling ground motions. Controlling seismic events are those UNEs or 10,000-yr cumulative slip earthquakes that would generate the most severe ground motions at the site, at frequencies of engineering significance.

Two activities are included in this study.

8.3.1.17.3.5.1 Activity: Identify controlling seismic events

Objectives

The objective of this activity is to identify those UNEs or 10,000-yr cumulative slip earthquakes that would produce the most severe ground motions at the site at frequencies of engineering significance. There may be more than one controlling seismic event because different events may generate the most severe ground motions in different frequency bands.

Parameters

The controlling earthquake(s) will be characterized by earthquake magnitude and hypocentral location. Controlling earthquakes will be additionally characterized by the fault strike and dip and expected slip direction. The controlling UNE(s), if any, will be characterized by distance, azimuth, depth, and yield.

Description

Identification of the controlling seismic events will follow directly from the identification of 10,000-yr cumulative slip earthquakes on relevant sources in Study 8.3.1.17.3.1, the identification of potential future UNEs in Study 8.3.1.17.3.2, the earthquake and UNE ground-motion models developed in Study 8.3.1.17.3.3, and the local site correction factors developed in Study 8.3.1.17.3.4. Site ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral ordinates at several frequencies, will be calculated for the 10,000-yr cumulative slip earthquakes and for the closest, largest potential UNEs. The seismic sources that produce the most severe ground motions as indicated by the calculated ground-motion parameters will be designated as controlling.

8.3.1.17.3.5.2 Activity: Characterize ground motion from the controlling seismic events

Objectives

The objective of this activity is to generate suites of strong-motion time histories and corresponding response spectra that are representative in amplitude, frequency content, and duration of site ground motions that could be generated by the controlling seismic events.

Parameters

The parameters for this activity are identified in the previous section on objectives.

Description

A number of methodologies are available for simulating strong ground motions, and the first task in this activity will be to determine which method or methods will be used. At present, two general approaches appear promising.

The first approach is to scale selected instrumental strong-motion records to the sizes (earthquake magnitudes or UNE yields) and distances of the controlling seismic events. The advantage of this approach is that the instrumental records can be chosen to minimize the necessary size and distance scaling. The disadvantage of this approach is that the available strong-motion records come from locations other than Yucca Mountain and therefore reflect different site conditions and, for earthquakes, perhaps different source characteristics.

The second approach is to model motion from a controlling seismic event by a summation of motions recorded at the site for smaller events (i.e., to use the small-event records as Green's functions in the simulation of the larger, controlling event (Hartzell, 1985; Spudich, 1985)). The advantage of the Green's function summation method is that propagation-path and local-geologic effects on site ground motions are inherently accounted for. The disadvantage (for earthquakes) is the uncertainty associated with scaling source characteristics of small events to those of large events.

The feasibility of both approaches described above, and possibly others, will be evaluated for application to Yucca Mountain. It may be appropriate to implement more than one approach and compare the results to help assess the uncertainty in the final results.

The peak ground-motion parameters, durations, and spectral ordinates of the resulting time histories will be checked for consistency with the regional ground-motion models developed in Study 8.3.1.17.3.3 and any necessary corrections will be made. The spectral content of the time histories will be corrected for local site effects, as necessary, using the spectral amplification functions developed in Study 8.3.1.17.3.4.

8.3.1.17.3.6 Study: Probabilistic seismic hazards analyses

The primary objective of this study is to quantify the probability for experiencing ground motions of varying degrees of severity that might result from earthquakes of varying magnitude and distance from the site. Results from this study will be used to evaluate and constrain required technical judgments in the deterministic evaluation of design-basis ground motions (such as the determination of exceptional earthquake magnitudes), evaluate the adequacy of the deterministic results, and help identify and focus efforts to refine those parameters that are most important for the deterministic calculations. The probabilistic hazard estimates will also provide information needed to assess the credibility of postulated accidents at the repository that might lead to releases of radioactive materials (Information Need 2.3.1, Section 8.3.5.5.1).

8.3.1.17.3.6.1 Activity: Evaluate earthquake sources

Objectives

The objective of this activity is to determine average rates for earthquake recurrence as a function of magnitude for the southern Great Basin to a distance of about 100 km from the site, and then to apportion these rates onto active faults and subregional seismic source zones.

Parameters

Earthquake sources will be characterized by location, shape, depth, and earthquake-recurrence rates as a function of magnitude, including the specification of a maximum magnitude or probability distribution for maximum magnitude.

The following types of information will be synthesized in this activity:

1. Maps and cross sections of historical earthquake locations.
2. Maps showing Quaternary faults with lengths greater than about 20 km within 100 km of the site and Quaternary faults with lengths greater than about 1 km within 10 km of the site.
3. Data on the style and rate of Quaternary faulting in the site region.
4. Evidence of neotectonic deformation or stability in the site region.
5. Regional and local magnetic-anomaly and gravity-anomaly maps.
6. Regional and local crustal seismic data.
7. Information on local and regional crustal stresses.
8. Local and regional tectonic models.

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Description

The earthquake catalog developed in Study 8.3.1.17.4.1 will be used to determine the rate that earthquakes have occurred in the region surrounding the site during historical time as a function of magnitude. The completeness of the historical earthquake record in different areas and time intervals will be evaluated considering the number of events reported in the catalog as a function of magnitude and time, past human population distributions, and past distributions of recording instruments. Different types of magnitudes reported in the catalog will be converted to a uniform magnitude measure, possibly M_L, moment-magnitude, or both. (Statistical uncertainty in the conversions will be carried through the hazard analysis.) Additional checks will be made to reconcile the gross rates of crustal deformation for the southern Great Basin with deformation rates implied from observations of seismic-moment release rates. Estimates of the upper-magnitude limits for earthquakes in this area will be required to translate rates of earthquake occurrences to rates of crustal deformations. From these investigations, best estimates, accompanied by estimates of uncertainty, will be developed for characterizing the regional rate of earthquake occurrences.

This regional rate of earthquake occurrences will then be apportioned onto active faults and subregional source zones according to models of the local and regional tectonics. More than one model will likely be required for apportioning the earthquake activity in order to express the uncertainty in current scientific interpretations and to focus efforts to refine those source representations that have the greatest impact on the site.

In this activity, seismologic and geologic data will be used to interpret earthquake sources that contribute to the probability of exceeding given ground-motion levels at the site in essentially the same manner as they will be used in Study 8.3.1.17.3.1 to interpret earthquake sources that might control site ground motions in a deterministic hazard analysis. See the description sections of Activities 8.3.1.17.3.1.1 and 8.3.1.17.3.1.2. The scope of this activity is more comprehensive in that more seismic sources will be characterized, multiple interpretations of seismic sources will most likely be retained and their relative likelihoods judged, any dependencies in the interpreted existence of source zones (e.g., perfect dependence or mutual exclusiveness of some sources) must be specified, and maximum magnitudes must be estimated explicitly.

Source-zone maps will be produced by this activity to indicate the earthquake probability as a function of magnitude and location within the southern Great Basin.

8.3.1.17.3.6.2 Activity: Evaluate ground motion probabilities

Objectives

The objectives of this activity are (1) to estimate the probability of exceeding given ground-motion levels at the site and (2) to integrate the contributions to that probability from all identified earthquake sources that could generate potentially damaging ground motion at the site.

Parameters

The basic information items needed for a probabilistic seismic hazard analysis are as follows:

1. Boundaries of seismic source zones, including, if warranted, alternative interpretations and corresponding judgments of the relative likelihood that each interpretation is correct.

2. Earthquake-magnitude recurrence rates for each source zone, including estimates of maximum magnitudes and assessments of uncertainty.

3. Specification of any dependencies in the interpreted existence or activity of source zones (e.g., perfect dependence or mutual exclusiveness of some sources).

4. Ground-motion (attenuation) models for predicting expected values and variances of required ground-motion parameters (e.g., peak velocity) as a function of distance and source size.

Description

There are a number of software packages available for computing probabilistic seismic hazard estimates given the information listed in the parameters section (e.g., codes developed by the Electric Power Research Institute (EPRI, 1986) and Lawrence Livermore National Laboratory (Bernreuter et al., 1986)). Some codes embody different means of propagating uncertainties through the analysis to the final results, and the alternative approaches will be evaluated. It may be appropriate to calculate hazard levels using different codes for comparison.

As stated previously, the probabilistic seismic hazard analysis will be performed iteratively, in parallel with the deterministic hazard analysis. The sensitivity of calculated hazard to different input parameters will be tested to identify what interpretations impact the site the most and may, therefore, warrant refinement. The final hazard estimates will be compared with the deterministically derived design-basis ground motions to verify that they correspond to annual exceedance probabilities of 10^{-3} to 10^{-4} per year.

8.3.1.17.4 Investigation: Preclosure tectonics data collection and analysis

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections provide a summary of existing data relevant to this investigation:

SCP section	Subject
1.3.1	Tectonic framework
1.3.2	Tectonic history
1.4.1	Seismology of the southern Great Basin
1.4.2	Seismology of Yucca Mountain
1.5.1	Volcanism
1.5.2	Faulting
1.5.3	Vertical and lateral crustal movement
1.8.1	Summary of significant results

Parameters

Information to be provided by the studies under this investigation include the following:

1. Catalog of historical earthquake occurrence times, locations, and magnitudes.

2. Analysis of potential for UNEs, mining activity, or reservoir (Lake Mead) impoundment to induce seismicity near the site.

3. Recordings obtained at the site and at other locations in the southern Great Basin of ground motions from earthquakes and UNEs.

4. Geological and geophysical evidence of large-scale Quaternary faulting within 100 km of the site and of smaller-scale Quaternary faulting in the site area.

5. Analysis of the seismogenic potential of detachment faults in the site area.

6. Evaluation of crustal stresses at seismogenic depths in the site region.

7. Morphologic and morphometric analysis of neotectonic deformation in the site region.

8. Geodetic and survey evidence of recent crustal movements in the site region.

9. Synthesis of tectonic processes acting in the site region (development of tectonic models).

Purpose and objectives of the investigation

The primary purpose of this investigation is to provide data and analyses that are required by Investigation 8.3.1.17.2, assessment of fault displacement that could affect repository design or performance, and

Investigation 8.3.1.17.3, assessment of vibratory ground motion that could affect repository design or performance (refer to logic diagrams for these two investigations, Figures 8.3.1.17-4 and 8.3.1.17-5). The limited data collection and analysis that is required by Investigation 8.3.1.17.1, volcanic activity that could impact the repository, will be performed within that investigation (Figure 8.3.1.17-3).

Technical rationale for the investigation

The data-collection-and-analysis studies have been aggregated under this fourth investigation for two reasons. Much of the information that will be provided by the data-collection-and-analysis studies is needed for more than one assessment. For example, information on Quaternary faulting near the site is germane to both the faulting and the ground-motion potential at the site. Also, most of the studies are most naturally organized around a geological problem, the solution of which may require a broader focus than the repository site itself. All studies are intended to contribute to the resolution of design or performance issues, even though the linkage may sometimes be indirect for studies that have a broad focus, such as the evaluation of tectonic models (Study 8.3.1.17.4.12).

8.3.1.17.4.1 Study: Historical and current seismicity

The objective of this study is to compile information on reported and instrumentally recorded earthquakes that characterize the earthquake potential near Yucca Mountain. This information will be used (1) to help identify and characterize potentially relevant earthquake sources for the deterministic hazard analysis (Study 8.3.1.17.3.1) and potentially contributing earthquake sources for the probabilistic hazard analysis (Study 8.3.1.17.3.6), (2) to develop regional earthquake ground-motion models (Activity 8.3.1.17.3.3.1), and (3) to determine local-geologic and depth-of-burial effects on ground motion at the site (Activity 8.3.1.17.3.4.1).

8.3.1.17.4.1.1 Activity: Compile historical earthquake record

Objectives

The objective of this activity is to compile a record of historical seismic events in the southern Great Basin or within 100 km of Yucca Mountain. The record will be as complete and accurate as is reasonably achievable, and will indicate whether each cataloged seismic event is thought to be a natural earthquake, induced earthquake, underground nuclear explosion (UNE), cavity collapse, or blast. For potentially damaging earthquakes ($M \geq 5.5$) in the study region, available information will be compiled on ground-motion intensity, availability of strong-motion records, and extent and style of faulting.

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Parameters

Parameters to be compiled for recorded seismic events include the following:

1. Date.
2. Origin time.
3. Hypocentral location.
4. Hypocenter uncertainty estimate.
5. Magnitude (and magnitude type).
6. Magnitude uncertainty estimate.
7. Annotation of whether the event is an earthquake, UNE, cavity collapse, etc.

Additional parameters to be compiled as available for the larger ($M \geq 5.5$) earthquakes include the following:

1. Focal mechanism (dip, strike, and rake).
2. Seismic moment.
3. Stress drop.
4. Extent of surface rupture.
5. Epicentral intensity.
6. Epicentral intensity uncertainty estimate.
7. Total felt area.
8. Falloff of intensity with distance.
9. Peak ground accelerations.
10. Peak ground velocities.
11. Durations.
12. Selected spectral amplitudes.

Description

The required parameters will be obtained primarily through a literature survey. Meremonte and Rogers (1987) have compiled a catalog of historical earthquakes in the southern Great Basin that provides most of the needed information. The catalog will be updated periodically to add new information, and the geographic coverage of the catalog may need to be extended somewhat to cover all areas of interest. Also, uncertainty estimates for magnitudes and epicentral intensities need to be added to the catalog. Most of the additional parameters for the larger earthquakes will also be obtained from the literature. If source parameters (focal mechanism, seismic moment, and stress drop) have not been published for any of the larger earthquakes in the record and sufficient data are available to determine them, these data will be obtained and the source parameters will be determined.

8.3.1.17.4.1.2 Activity: Monitor current seismicity

Objectives

The objective of this activity is to provide empirical information on how often earthquakes are currently occurring in the southern Great Basin; what the orientation, depth, and style of faulting are; how seismic wave amplitudes scale with magnitude and attenuate with distance in the region; and how ground motions vary with depth and with surface geology in the site area. The information on faulting and earthquake location and recurrence will be used to identify potentially relevant earthquake sources for the deterministic hazard analysis (Study 8.3.1.17.3.1) and potentially contributing earthquake sources for the probabilistic hazard analysis (Study 8.3.1.17.3.6). The information on magnitude and distance scaling will be used to develop regional ground-motion models (Study 8.3.1.17.3.3). The data on ground-motion variations at the site will be used to develop site correction factors and response functions (Study 8.3.1.17.3.4). Recordings obtained at Yucca Mountain of small earthquakes may be used as Green's functions in the simulation of controlling earthquake motions (Activity 8.3.1.17.3.5.2).

Parameters

Parameters to be compiled for recorded seismic events include the following:

1. Date.
2. Origin time.
3. Hypocentral location.
4. Hypocenter uncertainty estimate.
5. Magnitude (and magnitude type).
6. Magnitude uncertainty estimate.
7. Annotation of whether the event is a earthquake, UNE, cavity collapse, etc.

For the larger ($M \geq 5.5$) earthquakes, available information will be compiled as follows:

1. Focal mechanism (strike, dip, and rake).
2. Seismic moment.
3. Stress drop.
4. Extent of surface rupture.
5. Epicentral intensity.
6. Epicentral intensity uncertainty estimate.
7. Total felt area.
8. Falloff of intensity with distance.
9. Peak ground accelerations.

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10. Peak ground velocities.
11. Durations.
12. Spectral amplitudes.

Description

Current seismicity will be monitored by a regional seismograph network, a local accelerograph array, and a portable array of digital seismic event recorders that can be deployed with seismometers, accelerometers, or both. The southern Great Basin (SGB) regional seismograph network has been in operation since 1978 (Rogers et al., 1981; 1983) and will continue to be operated and maintained. The SGB network consists of 49 high-gain seismograph stations within a 150-km radius of Yucca Mountain and an additional subnet of six seismometers on Yucca Mountain, providing a local detection threshold of about local magnitude (M_L) 0.0, and a regional detection threshold of about M_L 1.0.

The output of each seismometer in the SGB network is converted to an FM radio signal and telemetered via microwave links and telephone lines to Golden, Colorado. The bandwidth and dynamic range of the current seismometer-telemetry system is somewhat limited. For example, the usable dynamic range (of about 40 dB) is such that a local earthquake that is recorded with good fidelity in one area of the network will likely be in the noise or off-scale in another area of the network because of the attenuation of earthquake ground motion with distance. It may, therefore, be appropriate to upgrade the network recording capability. A subtask of this activity is to assess what enhancements of recording capability are needed, if any, to provide the required data parameters. If warranted, available options for enhancing network performance will be evaluated and an appropriate option will be implemented.

A local accelerograph array will be installed at the site as described in Activity 8.3.1.17.4.1.2, with about a half-dozen three-component transducers located on Yucca Mountain and in Midway Valley. The primary purpose of this array will be to record, on scale, strong ground motions from a nearby moderate-to-large earthquake should one occur.

A portable array of digital seismic event recorders with about a 30-channel capacity will be used for special studies, such as obtaining high-dynamic-range data that are suitable for calculating earthquake source parameters (e.g., stress drop and moment), obtaining accurate aftershock locations, monitoring microseismicity in the vicinity of suspect tectonic features, or measuring local site effects on ground motion.

It will be useful to record with good fidelity a number of UNEs from the Nevada Test Site at surface and subsurface locations on Yucca Mountain and near the sites of prospective surface facilities in Midway Valley. Such records will enable regression relations for UNE ground motions to be calibrated against actual observations at the site and will provide important information on the local variability of surface ground motion and on the variation of ground motion with depth. These data could be obtained by adding seismometers and higher- gain channels to the local accelerograph array (in which case digital recording for the array would be indicated) or by a

several-year deployment of portable digital event recorders. The costs and benefits of each approach will be evaluated and the most cost-effective approach will be implemented.

8.3.1.17.4.1.3 Activity: Evaluate potential for induced seismicity at the site

Objectives

The objective of this activity is to evaluate the potential for human activities to significantly perturb the natural seismic hazard at the site by inducing seismicity at or near the site. To date, the human activities that have been identified as having a potential to induce seismicity in the site region are the impoundment of Lake Mead, the testing of nuclear devices at Nevada Test Site (NTS), and the mining of the repository itself. The information developed in this activity will be used in estimating of magnitude-recurrence relationships for earthquake sources that are relevant to the deterministic hazard analysis (Activity 8.3.1.17.3.1.1) and for earthquake sources that contribute to the probabilistic seismic hazard at the site (Activity 8.3.1.17.3.6.1).

Parameters

Data needed for this activity include

1. Historical catalog of southern Great Basin earthquakes.

2. Locations, times, and yields of UNEs at the NTS.

3. Survey of literature on seismicity induced by the impoundment of Lake Mead.

4. Survey of literature on mining-induced seismicity (rock bursts).

Information to be provided by this activity includes

1. Correlation between earthquake occurrences and UNE occurrences.

2. Correlation between earthquake occurrences and the impoundment of Lake Mead.

3. Identification of induced earthquakes in the historical catalog.

4. Assessment of likelihood of mining induced seismicity.

Description

The catalog of southern Great Basin earthquakes will be examined to determine if significant changes in rates of occurrence of earthquakes are detectable following nuclear tests at the NTS. An estimate of background levels of seismicity in various annuli surrounding Pahute Mesa and Yucca Flats will be compared with seismicity levels in those annuli for short time

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spans (on the order of several hours to several weeks) following nuclear tests. A search for significant differences in rates will be conducted. If a statistically significant increase in earthquake activity (after-shocks) following nuclear tests is found, the correlation between earthquake rates and UNEs will be evaluated as a function of distance form the test, time after the test, and yield of the test. The feasibility of correcting historical earthquake-recurrence rates for bias from nuclear-event after shocks will be explored, as will the means of identifying individual induced events in the historical catalog.

Because Lake Mead is about 120 mi from the site, it is not expected that reservoir-induced seismicity will impact the site. A survey of the literature on Lake Mead-induced earthquakes will be performed to confirm this expectation. Should the literature survey prove inconclusive, a statistical analysis will be performed of the correlation between earthquake occurrences, distance from the lake, time since impoundment, and fluctuations in water level.

Mining-induced earthquakes (rock bursts) are believed to occur when relatively small local cavity stresses trigger failure in a much larger volume of highly prestressed rock. This type of failure has occurred mostly in deep mines (McGarr, 1984) under conditions where rock sample testing shows the rock to be both very strong and very brittle (McGarr et al., 1975). Sudden exfoliation has accompanied excavation at shallow depths in granite quarries (Suppe, 1985). The failure is apparently associated with a "buckling beam" instability as slabs of rock flex upward as the load is removed. This is associated with large horizontal compressive stresses.

Of particular relevance to the planned excavations in Yucca Mountain is experience from coal mines in the eastern Wasatch Plateau. Earthquake-like activity, clearly related to mining, extends from near the base of the mine to some depth (Williams, 1987). However, the activity is associated with the removal of massive amounts of material (several million tons per year) that is then transported far from the site.

Considerable mining experience exists at the NTS (e.g., Zimmerman and Finley, 1987), and no reports of mine-induced catastrophic failure are known. The prospective Yucca Mountain mine excavation will not be much greater in size and no deeper than other cavities on the test site and will be tiny when compared with the Utah coal workings. Also, the material mined will be left on the surface to minimize the change of loading.

No examples of explosive catastrophe associated with conditions of extensional tectonics similar to those found in Yucca Mountain have been found in a limited survey of the literature. A more comprehensive review of the literature will be performed to increase the confidence in this finding. In the improbable event that seismic activity does appear when excavation starts, its study will, at least in the first instance, be covered by the standard needs of the seismology program.

Procedures to invert for earthquake parameters, such as origin time and hypocentral location, will take into account, when appropriate, the structural velocity models developed in Activity 8.3.1.17.4.1.2. In addition, a variety of algorithms will be used to model P- and S-wave propagation through homogenous plane layers, and layers with velocity gradients.

8.3.1.17.4.2 Study: Location and recency of faulting near prospective surface facilities

Two activities are included in this study.

8.3.1.17.4.2.1 Activity: Identify appropriate trench locations in Midway Valley

Objectives

The objective of this activity is to identify appropriate trench locations at proposed locations for repository surface facilities that are important to safety through detailed geologic mapping and remote sensing studies. The recommended locations will be used in trenching investigations in Activity 8.3.1.17.4.2.2.

Parameters

The parameters for this activity include

1. Displacement history on mappable faults in bedrock and alluvium.

2. Distribution of mappable surficial deposits (1:5000 scale) based on regional geomorphic categorization.

3. Ages of units in item 2; absolute where possible and relative otherwise.

4. Topographic features or lineaments that may be expressions of previous fault rupture.

5. Potential for surface rupture from underlying structural features.

Description

The alluvial area in Midway Valley and adjacent bedrock on Exile Hill will be mapped geologically at a scale of 1:5000. The bedrock units are to be identified according to attitude, distribution, age, and salient features, e.g., weathering, fracturing, composition, and texture (size of particles and mineral components). The surficial deposits will be mapped using geomorphic expression, degree of carbonate cementation, and lithology. The mapping will be supplemented by small test pits, coupled with subsurface data obtained

from existing boreholes and geophysical profiles. The mapping will be carried out using existing color aerial photography and observations from field traversing.

Tiva Canyon units of the Paintbrush Tuff are the only bedrock expected; preliminary mapping has identified caprock, upper cliff, and upper lithophysal units. Only minor faults have been observed on the east side of Exile Hill, and a geologic map and accompanying geologic cross sections (Scott and Bonk, 1984) are inconclusive regarding extent of faulting. Neal (1986) indicates that closely spaced faults (<50 m) occur beneath the surficial deposits, but not necessarily on the exposed part of the east flank of Exile Hill. Q1, Q2, and QTa deposits are known to occur, based on preliminary mapping by Swadley et al. (1984). Faults are not believed to penetrate alluvial units; surface expression is not evident.

The mapping will use commonly recognized chronology for Quaternary units, i.e., Holocene (Q1), intermediate (Q2), and older (QTa). Age assignments will be based on chronostratigraphic correlation (e.g., relative to known, dated units such as the Bishop ash (738,000 yr)), on dating of deposits using applicable soil techniques where possible, and on correlations based on geomorphic expression and lithology.

The dating of stratigraphic or soil horizons frequently depends on extrapolation of mapped units and generally must be grouped within broad age categories. Dating by almost any method is subject to limitations inherent in the methods (Szabo et al., 1981; Rosholt, 1985). Several appropriate dating methods are possible for use at Yucca Mountain and more than one method of dating may be required to establish confidence at a given location.

The siting approach for the waste handling building is to position it where there is no evidence of faults with Quaternary slip rates exceeding 0.001 mm/yr or faults that measurably offset materials less than 100,000 yr old (refer to discussion of purpose and objectives of Investigation 8.3.1.17.2, studies to provide information on fault displacement that could affect repository design or performance). Possible areas of Quaternary faulting will be identified by interpreting aerial photography of various scales and sun-angles in addition to the geologic mapping. Remote sensing studies will identify linear topographic breaks, alignment of drainages, or vegetation changes that could be related to Quaternary faulting. Any lineaments that are found will be investigated on the ground during the geologic mapping. Areas of suspected Quaternary faulting may also be investigated using topographic profiling or shallow geophysical techniques (e.g., seismic refraction and reflection).

8.3.1.17.4.2.2 Activity: Conduct exploratory trenching in Midway Valley

Objectives

The objective of this activity is to investigate the possible occurrence of late Quaternary surface fault rupture in the vicinity of planned surface facility locations important to safety and to identify sites without evidence of significant late Quaternary faulting. This activity will provide input

into the location and design of surface facilities important to safety, particularly those associated with waste handling.

Parameters

The characterization parameters for this activity are the identification and characterization of faults that have apparent Quaternary slip rates greater than 0.001 mm/yr or that measurably offset materials less than 100,000 yr old, within 100 m of proposed locations of facilities important to safety (FITS).

Note that the 100 m distance is not intended to represent an appropriate standoff distance for FITS from faults that have a potential for displacement. Should the faulting investigations identify a fault within 100 m of proposed FITS locations, the appropriate standoff distance and/or mitigative engineering measures will be assessed.

Description

The potential for Quaternary faulting in the immediate vicinity of proposed sites for waste-handling facilities will be evaluated by excavating a trench across the site, in the surficial deposits of Midway Valley. The proposed sites of any other surface facilities identified as being important to safety will be explored by excavating similar trenches.

The trenching pattern to be used will either be a cross centered on the proposed site with arms extending in a north-south and east-west direction or a perimeter trench around the waste-handling facility. The trenches will extend at least 100 m from the proposed facility site and will be excavated to a depth that exposes material at least 100,000 yr old and preferably substantially older (including QTa deposits). Older deposits are preferred because of the added potential for detecting cumulative displacements on minor faults. The trenches will also be excavated deep enough to expose bedded material that can be reliably used to detect displacements.

One wall of the trenches will be logged in sufficient detail to demonstrate the continuity of bedding and the absence of displacement. More detailed investigations will be conducted in areas where faulting is suspected or cannot be disproved. The deposits exposed by the trenches will be dated using applicable techniques or by correlation with nearby dated deposits. Credible demonstration of the absence of faulting during the late Quaternary and the estimation of slip rates on observed faults will rely on the accuracy of measured or extrapolated ages of deposits.

Additional trenching across Midway Valley will be considered, pending the results of the above trenching.

8.3.1.17.4.3 Study: Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane

The objectives of this study are (1) to identify Quaternary faults within 100 km of Yucca Mountain and (2) to characterize those faults capable

of future earthquakes with magnitude such that associated ground shaking could impact design or affect performance of the waste facility. This study is complemented by more specialized studies of faults at and proximal to the site. These studies are 8.3.1.17.4.2 (faulting potential near prospective surface facilities); 8.3.1.17.4.6 (Quaternary faulting within the site area); 8.3.1.17.4.4 (Quaternary faulting proximal to the site within northeast-trending fault zones); 8.3.1.17.4.5 (detachment faults at or proximal to Yucca Mountain).

The existing geologic and geophysical data base for Yucca Mountain and areas to the north and east is substantial. That area (Figure 8.3.1.17-7) is covered in its entirety by modern geologic maps of bedrock at a scale of 1:24,000 or larger, and the information contained therein is supplemented by numerous specialized geologic and geophysical studies. Figure 8.3.1.17-8 shows areas to the south (Amargosa Desert) and west (Crater Flat, Bare Mountain, Beatty area) that are less well known. Mapping of Quaternary geology, including distribution of Quaternary geologic materials, and analysis of Quaternary geomorphic evolution is not yet complete.

Yucca Mountain lies within a northwest-trending zone of structural transition between parts of south-central Nevada characterized by north-trending basins and ranges, and the Inyo-Mono area of eastern California, characterized by northwest-trending basins and ranges. This zone of transition was referred to as the Walker Belt by Stewart (1980). The northeastern boundary of the zone is diffuse; the southwestern boundary is formed by the Death Valley-Furnace Creek fault zone (Carr, 1984), a right-lateral wrench fault that cuts Holocene deposits over much of its extent. The Walker Belt contains within it zones of wrench faulting, including the Las Vegas Valley shear zone on the southeast and the shear zone near Cedar Mountain on the northwest (Gianella and Callaghan, 1934b). These shear zones were thought to be elements of a continuous zone of right-lateral shearing that was named the Walker Lane by Locke et al. (1940) (Figure 8.3.1.17-9).

The Walker Belt, then, is the zone of structural transition between adjacent structural provinces, and the Walker Lane is the postulated through-going zone of right-lateral faulting located within the Walker Belt. The Walker Lane is not a continuous linear fault, at least at the surface. Near Cedar Mountain, site of the M = 7.2 to 7.3 earthquake of 1932, the shear zone is interpreted to be structurally overlain by a detached upper plate of Tertiary volcanic and sedimentary rocks (Molinari, 1984). According to Molinari (1984), right-lateral movement on the subsurface shear zone during the 1932 earthquake was expressed by movement of small, en echelon faults in the overlying upper plate.

At the Nevada Test Site, the Las Vegas Valley shear zone, which forms the southeastern element of the Walker Lane, as defined by Gianella and Callaghan (1934b) and Locke et al. (1940), cuts Paleozoic rocks and is overlain by Oligocene-Miocene sedimentary deposits and Miocene ash flows (Ekren, 1968).

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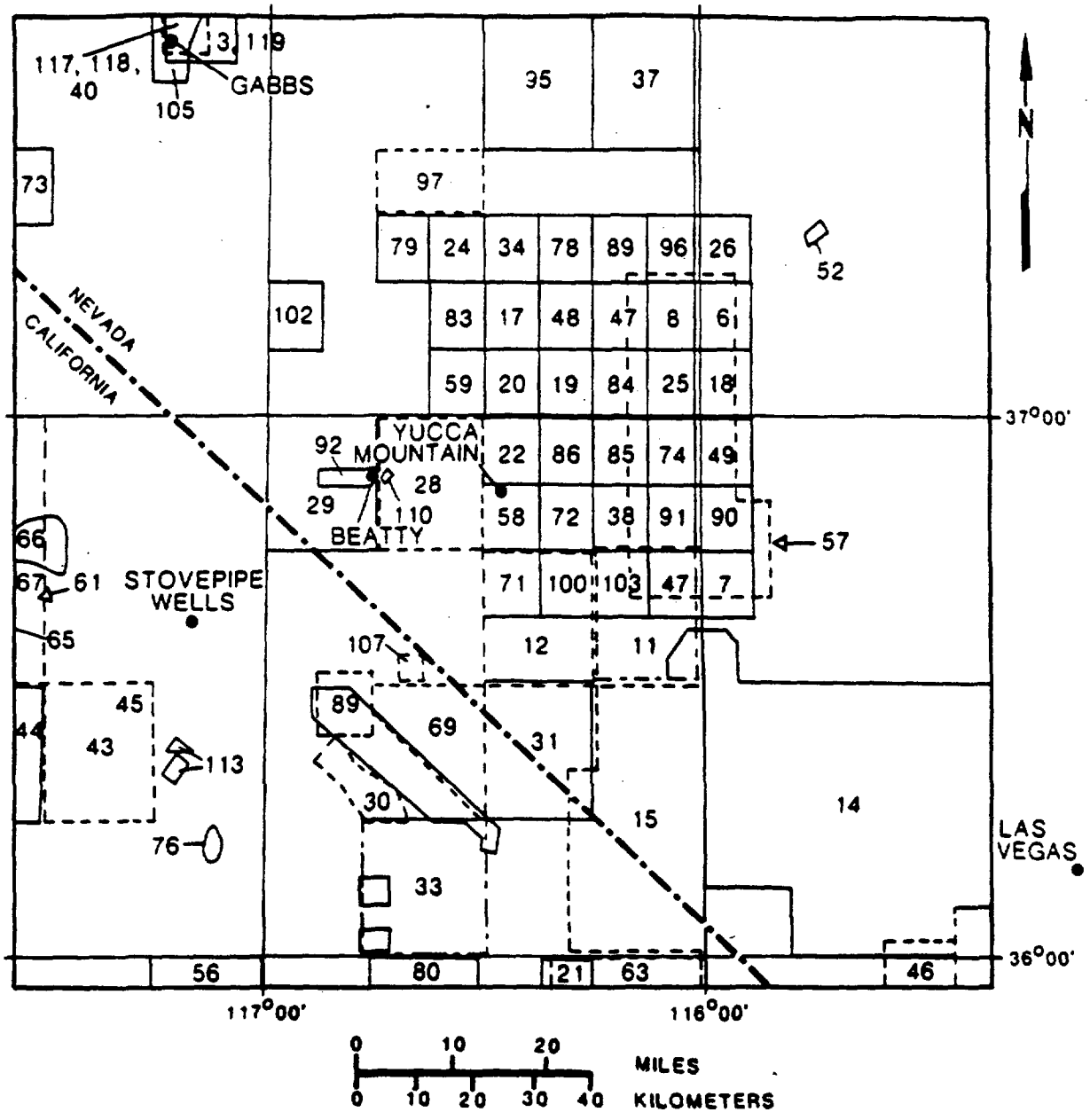

Figure 8.3.1.17-7. Index map showing published geologic map coverage at scales of 1:63,630 and larger. Map areas (numbered) referenced in Fouty (1984).

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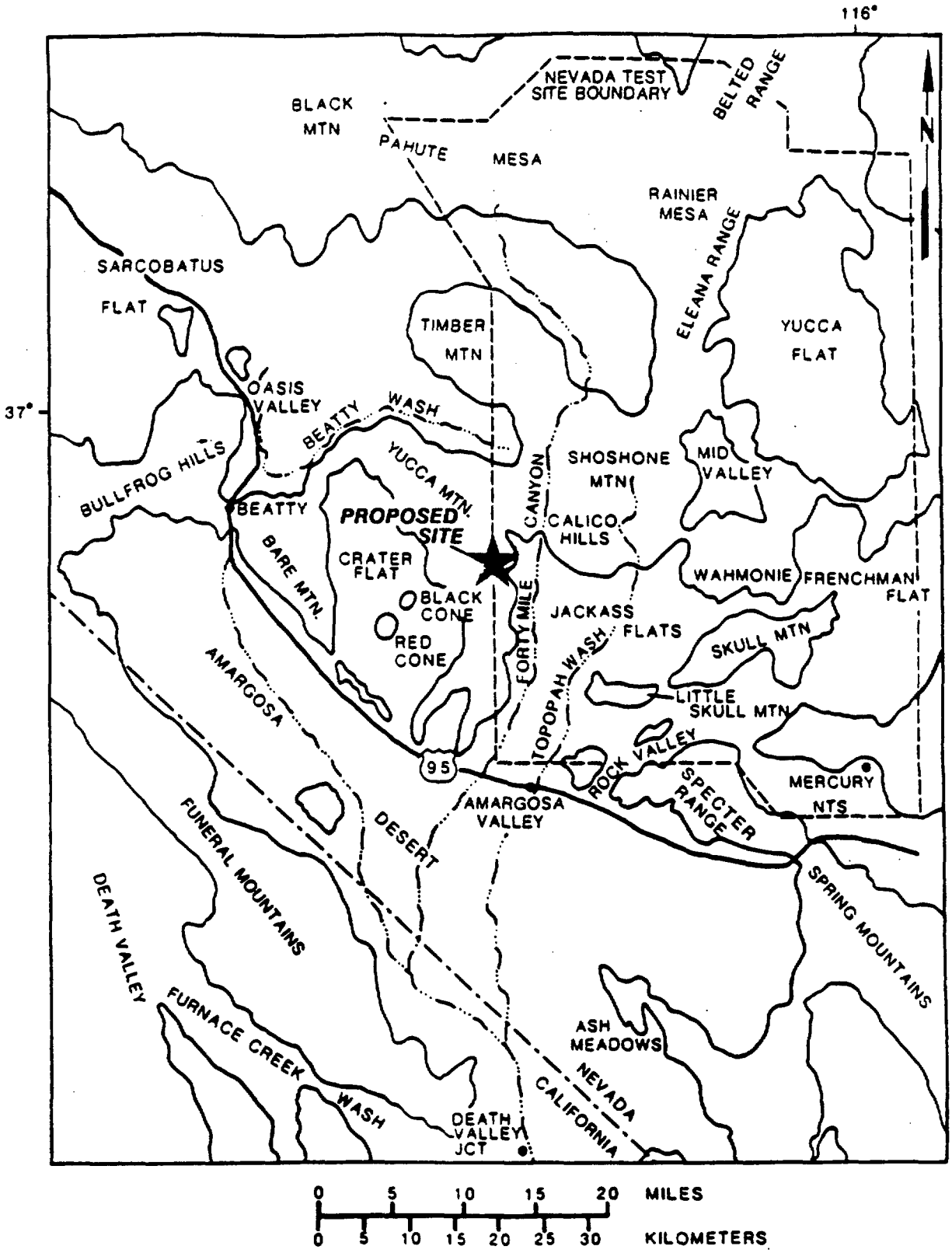

Figure 8.3.1.17-8. General localities map showing areas of exposed bedrock.

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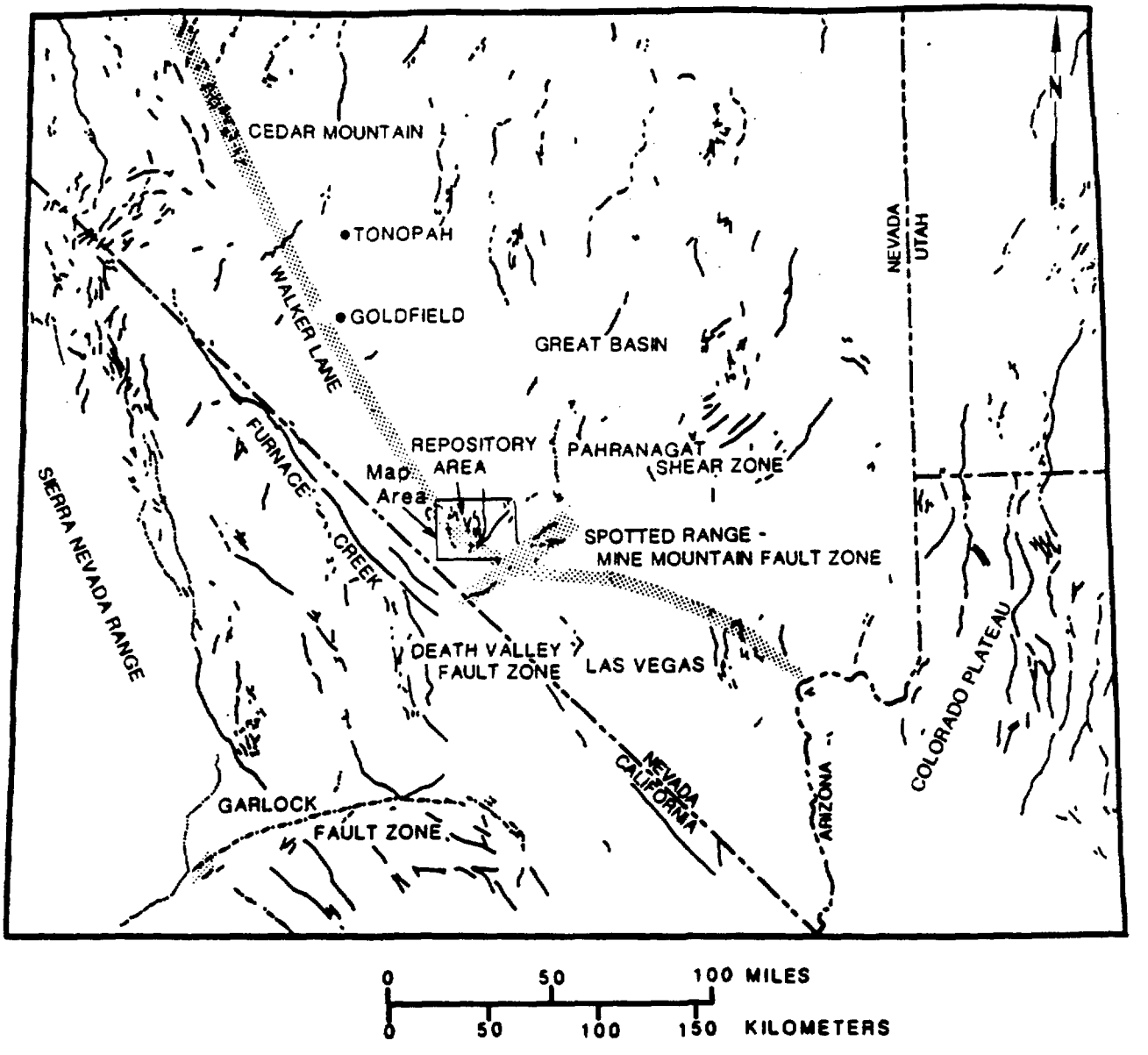

Figure 8.3.1.17-9. Regional structure map showing location of the repository area, map areas of Figure 8.3.1.17-2 and 8.3.1.17-11, and major Quaternary structural features

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The Oligocene-Miocene rocks are thought to be part of an upper plate (Figure 8.3.1.17-10) that is structurally detached from subjacent basement blocks bounding either side of the subsurface extension of the Las Vegas Valley shear zone (Burchfiel, 1965). An alternative interpretation is that the Las Vegas Valley shear zone curves westward and, concealed below the upper plate, connects with the Furnace Creek fault, rather than with other elements of the Walker Lane to the northwest (Burchfiel, 1965).

Northwest-trending lineaments and right-lateral strike-slip faults exposed at Yucca Mountain and vicinity could be surface expressions of the Walker Lane. These include faults at Yucca Wash (Carr, 1984), Drill Hole Wash (Spengler and Rosenbaum, 1980), and the Yucca-Frenchman shear zone (Carr, 1974). Quaternary movement on these faults has not been recognized. As shown in Section 1.4, current seismicity is not identified with these faults, and focal mechanisms of earthquakes within and proximal to the site do not show northwest-trending fault planes. This may suggest that this part of the Walker Lane has not been seismically active since records have been kept.

In addition to the change in orientation of basins and ranges that occurs within the Walker Belt, the structural grain of certain structural blocks within the belt is sharply deflected from the regional trend. These blocks appear to have been rotated about a vertical axis forming an oroflex (Albers, 1967). Recent paleomagnetic and structural studies of Miocene ash flows suggest that Yucca Mountain has been bent into an oroflex since middle Miocene time, with the southern part of the mountain apparently rotated clockwise up to 30 degrees relative to the northern part (Scott and Rosenbaum, 1986); thus, it appears to have been deformed within a right-lateral couple, as have other parts of the Walker Belt.

In summary, two potential seismic source zones within a 100-km radius of the site are the Walker Lane, whose postulated subsurface continuation passes below the Miocene volcanic and volcaniclastic rocks of the NTS (Ekren, 1968; Burchfiel, 1965), and the Death Valley-Furnace Creek fault zone, which at its closest approach lies 52 km southwest of the site. Both of these structures are right-lateral wrench zones. The Death Valley-Furnace Creek fault zone offsets Holocene deposits in its central and southern segments and is long enough to generate a great earthquake; hence the zone is thought to be the most significant potential source of ground shaking outside a 50-km radius of the site.

The Walker Lane is approximately 600 km long, shows substantial (25 to 30 km) post-Miocene right-lateral displacement, and is seismically active in its northern and central parts. The Cedar Mountain earthquake of 1932 (M = 7.2 to 7.3) was located on the central part of the Walker Lane, approximately 175 km northwest of the site. Post-Miocene right-lateral displacement is not obvious on the part of the Walker Lane within 100 km of the site. Thus, either the southern part of the Walker Lane is pre-Quaternary in age, Quaternary movement has not been translated through the overlying Miocene volcanic rocks of Yucca Mountain and the Nevada Test Site, or Quaternary movement has occurred but has not yet been recognized.

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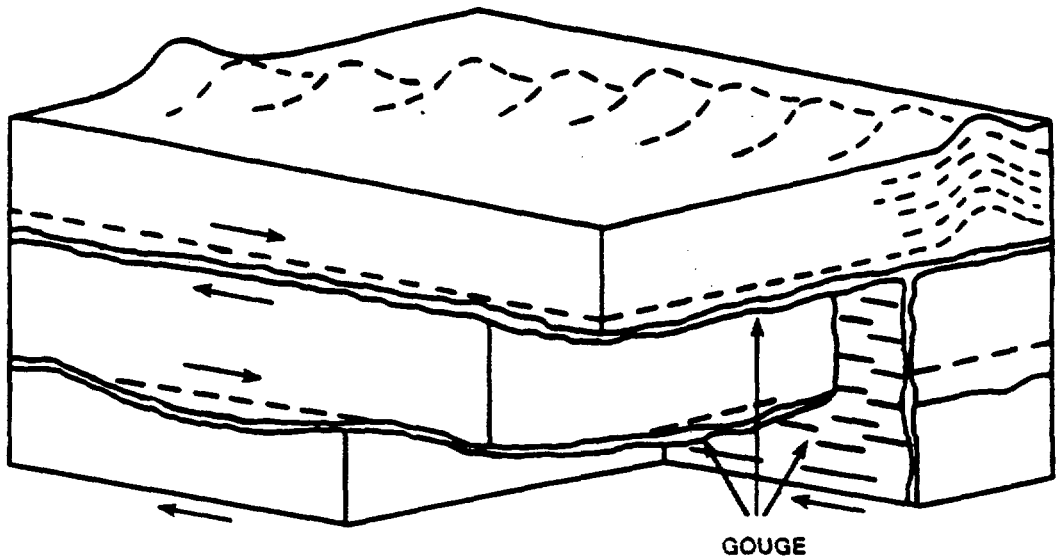

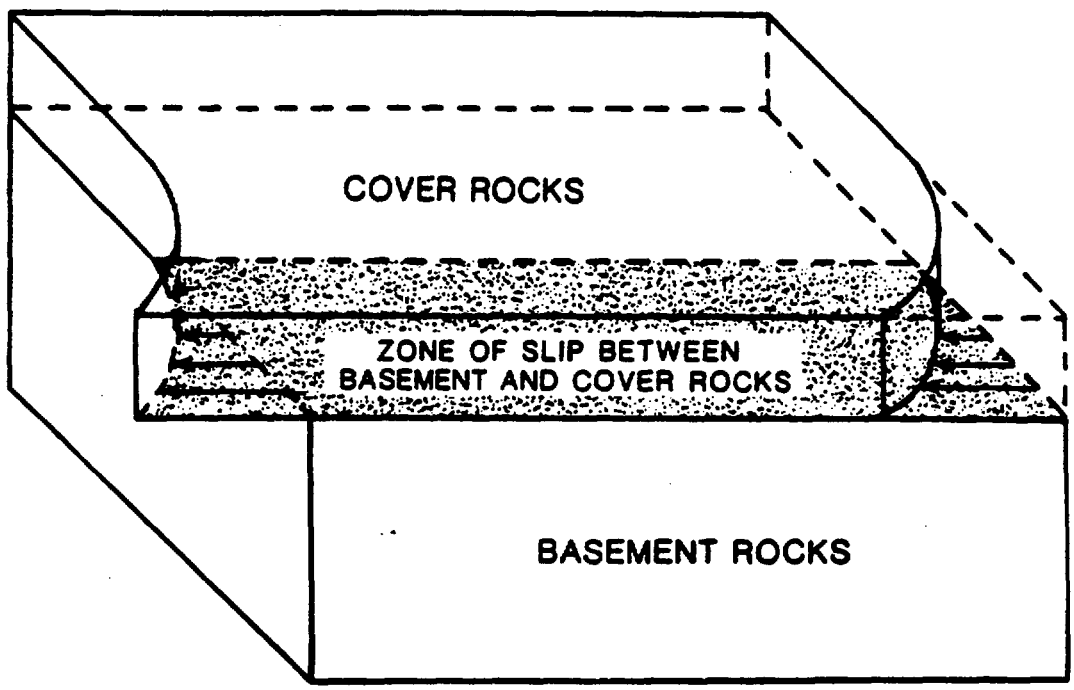

Figure 8.3.1.17-10. Idealized models of upper crustal deformation involving right-lateral shear on through-going wrench fault and displacement on overlying detachment fault, as postulated for Cedar Mountain area by Molinari (1984) and southern Nevada Test Site by Burchfiel (1965).

Although the principal focus of this study is on the Walker Lane and the Death Valley-Furnace Creek fault zone, other potentially significant Quaternary faults within a 100-km radius of the site will be identified through a search of the existing data, supplemented by examination of air photos and ground reconnaissance. Features that could be significant sources of ground motion include the Beatty scarp (if it is a fault) and the Bare Mountain fault zone.

Because of the geologic investigations at and near the site area, the density of known Quaternary faults in that area (Figure 8.3.1.17-11) now substantially exceeds that of much of the surrounding region. (The site area is defined here as the rectangular 237 km^2 (91 mi^2) area encompassing the central Yucca Mountain block and its structural and physiographic boundaries (Fortymile Wash, Yucca Wash, Solitario Canyon, and the Stagecoach Road fault.) Mapping of Quaternary faults and surficial deposits within the Beatty 1:100,000 quadrangle should clarify whether this concentration is real or is simply an artifact of the focusing of effort on the Yucca Mountain area. In any instance, to evaluate the likelihood of future faulting within the site area (an objective of Study 8.3.1.17.4.6--Quaternary faulting within the site area) the boundaries of the structural domain, including Yucca Mountain, within which Quaternary faults have a uniform density and common genesis will be defined. Structural domains within 100 km of Yucca Mountain will be delineated on the basis of regional variation in fracture density and fracture pattern as observed on Landsat V Thematic Mapper imagery. The Landsat V imagery will also provide information on distribution of desert varnish, which is related to the presence of stable geomorphic surfaces (whose definition is an objective of Study 8.3.1.17.4.9--tectonic geomorphology of the Yucca Mountain region).

Activities planned for this study are (1) an evaluation of crustal structure and subsurface expression of Quaternary faults in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane; (2) an evaluation of surface expression of Quaternary faults within a 100-km radius of the site (Yucca Mountain); (3) an evaluation of the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane; (4) an evaluation of the Bare Mountain fault; and (5) an evaluation of structural domains and characterization of the Yucca Mountain region with respect to regional patterns of faults and fractures.

8.3.1.17.4.3.1 Activity: Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane

Objectives

The objectives of this activity are

1. To help identify and locate potentially significant seismic source zones, including possible through-going extensions of the Walker Lane, beneath the Oligocene-Miocene cover of the Yucca Mountain area; to determine the width and subsurface geometry of such extensions and of the Furnace Creek fault zone and the relation of

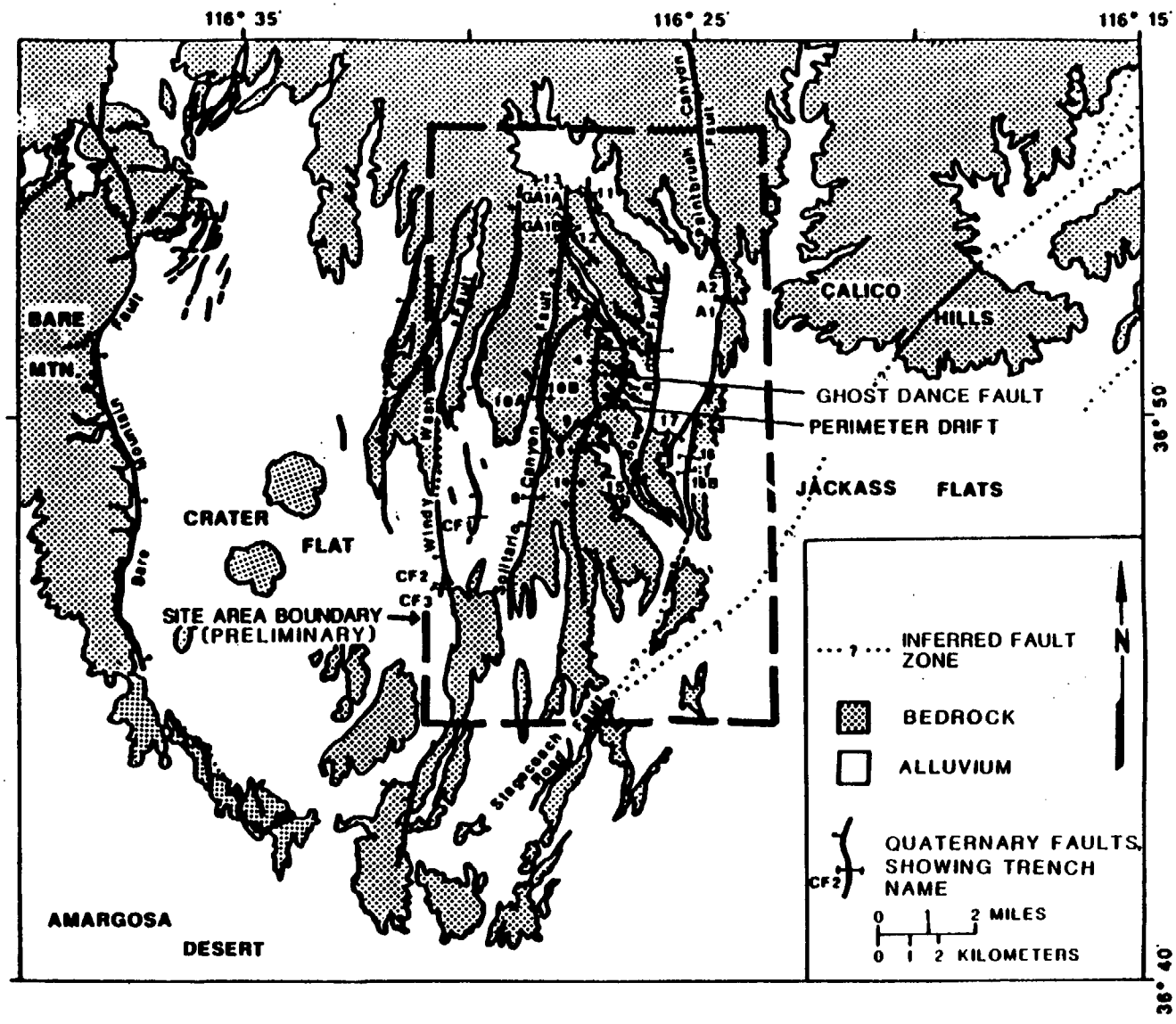

Figure 8.3.1.17-11. Generalized Quaternary fault map of Yucca Mountain and vicinity, showing trench locations (CF1, 1, GA1A, etc) and site area

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these features to detachment faults and to Quaternary faults; and to evaluate the postulated incipient rift zone at Crater Flat.

2. To characterize the crustal velocity structure and define lateral inhomogeneities in that structure in the Yucca Mountain area.

3. To trace the 5- and 10-s events found on Death Valley Consortium for Continental Reflection Profiling (COCORP) profiles through the Yucca Mountain region and, if possible, to trace reflections from the upper and lower carbonate aquifers, the Precambrian-Cambrian Pahrump Group and Noonday Dolomite, and the Proterozoic basement across the Furnace Creek fault and through the area of the projected northwest continuation in the subsurface of the Las Vegas Valley shear zone.

4. To identify differences in mass caused by variation in source lithology in the upper few kilometers of the crust, and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magneto-telluric survey.

5. To identify differences in magnetic field caused by sources in the upper few kilometers of the crust and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magnetotelluric survey.

6. To characterize the conductivity structure of the crust in the Yucca Mountain region, focusing in particular on the conductivity signature of the Walker Lane and Walker Belt, and if possible, tracing the signature into the subsurface of conductive units such as the Eleana Formation or nonconductive units such as the lineated and mylonitized gneisses (lower plate?) of the northern Amargosa Desert, and to correlate these features or their offsets with Quaternary faults.

7. To provide data for analysis to determine if buried magma bodies are present in the vicinity of Yucca Mountain. These data and analyses will be used to address the objective of Activity 8.3.1.8.1.1.3, (presence of magma bodies in the vicinity of the site).

Parameters

The parameters for this activity are

1. Lateral discontinuities in seismic refraction profiles.

2. Lateral discontinuities in seismic reflection profiles.

3. Gravity anomalies.

4. Magnetic anomalies.

5. Lateral and vertical discontinuities in crustal conductivity structure.

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Description

Geophysical methods may be useful for locating possible subsurface extensions of surface or near-surface geologic structures of interest. At Yucca Mountain, this includes the subsurface geometry of postulated detachment faults, interconnections between northeast-trending and north-trending faults, and possible through going extensions of the Walker Lane beneath the Oligocene-Miocene cover.

Proposed geophysical studies are summarized in Tables 8.3.1.17-9 and -10. As indicated in the tables, a variety of geophysical studies are planned at different locations and scales, to address a number of questions. Planned studies include deep and shallow seismic refraction; deep, intermediate, and shallow seismic reflection; gravity and magnetic surveys of the region and the site; gravity surveys coincident with the deep-seismic reflection surveys; magnetic surveys coincident with the deep and shallow reflection surveys; electrical conductivity surveys; radiometric and remote-sensing investigations; and paleomagnetic investigations.

In general, the shallow studies will focus on individual geologic structures, such as a specific Quaternary fault, and the deep studies will examine regional structures that may play a part in Quaternary tectonic processes in the southern Great Basin.

The geophysical studies will be conducted under Activity 8.3.1.17.4.3.1, described in this section, and in Study 8.3.1.17.4.7. The studies in Activity 8.3.1.17.4.3.1 are directed at deep, regional geologic features, whereas Study 8.3.1.17.4.7 addresses the subsurface geometry and possible concealed extensions of specific Quaternary faults at and near Yucca Mountain through intermediate- and shallow-depth geophysical surveys.

The geophysics program is designed to obtain different types of data that, when analyzed as a whole, will aid in the interpretation of recorded seismicity and surface geologic data. The simultaneous interpretation of geophysical, seismological and geologic data may help resolve such issues as the width, dip, and geometry of north-trending Quaternary normal faults at and near the site and whether there are subsurface structures that are related to known Quaternary structures.

Planned locations of geophysical surveys, as described below, may change. Activity 8.3.1.4.2.1.6 will be responsible for reviewing and integrating the planned geophysical data-gathering activities for all studies and programs. Several surveys involve feasibility tests and decision points before implementation. Before any planned geophysical surveys are conducted, Activity 8.3.1.4.2.1.6 will review the results of any feasibility tests or past surveys to estimate the likelihood that useful data will be generated by the planned effort. Activity 8.3.1.4.2.1.6 will also review the location, scheduling, techniques, and objectives of the planned survey to determine if the objectives of this activity and activities in other programs (such as 8.3.1.8.1.1.3) that also require this data are being met. Locations of surveys and data collection techniques will not be finalized until the review by Activity 8.3.1.4.2.1.6 is complete. Final plans and changes will be reported in SCP progress reports and study plans.

Table 8.3.1.17-9. Summary of geophysical studies in preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 1 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			SEISMOLOGY		
Deep refraction	8.3.1.17.4.3.1	E-W Transect Indian Springs-Stovepipe Wells (Figure 8.3.1.17-12)	Reversed profiles and cross-profiles, shot-points 8 to 20 km spacing	None	Existing surveys shown in Figure 8.3.1.17-12. See Pankratz (1982), Mooney et al., (1982), Hoffman and Mooney (1983), Hoover et al. (1982), Monfort and Evans (1982), and Sutton (1984).
Shallow (bison) refraction and shear wave refraction and reflection	8.3.1.17.4.4.1 and others	Quaternary faults, Yucca Mountain and vicinity	250 to 500 m traverses, portable instruments sledgehammer energy source. Shear wave method uses 12 (or more) geophones, 3 m spacing	Number and location to be decided on the basis of geological and geophysical mapping	Maximum depth of penetration 100 m. Used to detect offset in surficial deposits. Shear wave method capable of detecting 30 cm offset.
Evaluation of proposed deep reflection survey	8.3.1.17.4.3.1	Proposed survey crosses Yucca Mountain and Crater Flat; 15 km test line to be located south of Amargosa Valley or southwest of Beatty	To be determined	Decision to proceed (DTP) after evaluation of preliminary tests (15 km reconnaissance line) and peer review	COCORP[a] survey extending northward into southern Death Valley produced marginal quality data, although data in the upper one second are locally good. Six second reflections were imaged with local continuity. See de Voogd et al. (1986).
Intermediate reflection and intermediate refraction	8.3.1.17.4.7.1	Site-controlled area, Yucca Mountain (Figure 8.3.1.17-11)	Evaluate previous results, assess potential for application of this method to Yucca Mountain, plan new application if appropriate	None	This is a planning activity only. Previous reflection survey using Vibroseis at Yucca Mountain failed (McGovern, 1983). More recent surveys using air gun at Mid Valley produced useful results (McArthur and Burkhard, 1986). See also Hoover et al. (1982).
Shallow (mini-sosie) reflection	8.3.1.17.4.7.8 and others	Yucca Mountain, Crater Flat, Jackass Flats (Figure 8.3.1.4-8)	7 to 15 profiles, 1 to 5 km in long, hand carried instruments. Energy from battery of hand-operated tampers	DTP after evaluation of two preliminary profiles	Maximum depth of penetration 1 km. Used to map shallow structural and stratigraphic features.
			GRAVITY INVESTIGATIONS		
Regional maps	8.3.1.17.4.12.1	Yucca Mountain and vicinity	Beatty 1:100,000 quadrangle, Pahute Mesa 1:100,000 quadrangle, Nevada Test Site 1:100,000 map area, Yucca Mountain 1:48,000 map area	None	Field work complete, compilation complete, preliminary drafts available. See Snyder and Oliver (1981), Kane et al. (1981), Ponce (1981), Ponce and Oliver (1981), Hoover et al. (1982), Ponce and Hanna (1982), Jansma et al. (1982), Ponce (1984), and Snyder and Carr (1984).

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Table 8.3.1.17-9. Summary of geophysical studies in preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 2 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			GRAVITY INVESTIGATIONS (continued)		
Site area map	8.3.1.17.4.7.2	Yucca Mountain (Figure 8.3.1.17-11)	1:24,000 map of site and vicinity, 200 ft spacing of stations along E-W lines spaced 500 ft apart (where topography permits)	None	Will require additional 7,500 stations. Useful for establishing stratigraphic variability of repository host rock and fault location and offset. See Snyder (1981), Snyder and Carr (1982), Jansma et al. (1982), Kane et al. (1982), Ponce et al. (1985)
Detailed surveys, deep reflection profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Mountain, Indian Springs. Precise location to be determined.	Gravity determinations along profiles at 500 ft spacing	DTP only if seismic surveys run	Assists interpretation of seismic results.
			MAGNETIC METHODS		
Regional aeromagnetic maps	8.3.1.17.4.12.1	Yucca Mountain and vicinity	Beatty-, Pahute Mesa-, Indian Springs-, and Pahrangat 1:100,000 quadrangles to be compiled from existing surveys	None	Field investigations complete, compilation 80% (?) complete. See Kane et al. (1981), Hoover et al (1982), Ponce and Hanna (1982), Kane and Bracken (1983), U.S. Geological Survey (1984), Ponce (1984).
Site area aeromagnetic map	8.3.1.17.4.7.3	Yucca Mountain (Figure 8.3.1.17-11)	1:12,000 scale map of site and vicinity, continuous aeromagnetic survey along E-W flight lines spaced 1/16 mile apart.	None	1:62,500 scale map complete (U.S. Geological Survey, 1984), See also Jansma et al. (1982), Bath et al. (1982), Kane et al. (1982), Kane and Bracken (1983), and Bath and Jahren (1984).
Ground magnetic survey, deep reflection profiles and shallow reflection profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Mountain, Indian Springs. Precise location to be determined	Magnetic determinations along profiles at 10- to 20-ft spacing where accessible by truck, 50 to 100 ft spacing elsewhere	DTP only if seismic surveys run	Assists interpretation of seismic results.

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Table 8.3.1.17-9. Summary of geophysical studies in preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 3 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			MAGNETIC METHODS (continued)		
Site ground magnetic surveys	8.3.1.17.4.7.4	Yucca Mountain (Figure 8.3.1.4-11)	Ground magnetic surveys at (1) known and inferred structures, (2) vicinity of drill-holes (3) vicinity of shaft and surface facilities, (4) anomalies detected in site aeromagnetic map (described previously). Surveys to be semicontinuous (10 to 20 ft spacing)	Number and location to be determined through evaluation of geologic and geophysical mapping	Primary purpose is to locate concealed extensions of faults. See Bath and Jahren (1984; 1985), Scott et al. (1984).
Curie isotherm	8.3.1.8.5.2.1	Yucca Mountain Region	Analysis of existing regional aeromagnetic data	None	Purpose is to map configuration of Curie isothermal surface, and to compare areas of shallow isotherms with areas of high heat flow and recent volcanism. See Connard et al. (1983).
			ELECTRICAL METHODS		
Regional magnetotelluric (MT)	8.3.1.17.4.3.1	Yucca Mountain, Crater Flat, Jackass Flats, Amargosa Desert, Death Valley (Figure 8.3.1.17-8)	Detailed survey with stations at 3 to 5 km spacing of Yucca Mountain, Crater Flat, and northern Amargosa Desert, reconnaissance survey with stations at 10-km spacing in remainder of area	None	Previous survey by Furgerson (1982) shows mappable conductivity contrasts in 1-15 km depth range. See also Kauahikaua (1981), Hoover et al. (1982).
Surface geoelectric investigations (airbourne electromagnetic slinggram, very low frequency, dc resistivity, electromagnetic soundings, tensor audio magnetotellurics, and telluric profiling)	8.3.1.17.4.7.5	Yucca Mountain	Assess potential for application of these methods, evaluate previous results, plan new applications if appropriate, conduct prototype tests	DTP with full scale application of selected methods only if warranted by results of prototype testing	Applied to structural and stratigraphic problems at the site by Flanigan (1981), Smith and Ross (1982), Fitterman (1982), Hoover et al. (1982), Senterfit et al. (1982), Scott et al. (1984), Frischknecht and Raab (1984). Other studies in region include Zablocki (1979), Anderson (1982), Smith et al. (1981), Greenhaus and Zablocki (1982).

Table 8.3.1.17-9. Summary of geophysical studies in preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 4 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			RADIOMETRIC AND REMOTE SENSING METHODS		
Surface and airbourne gamma ray investigations	8.3.1.17.4.7.6	Yucca Mountain	Assess potential for application of these methods with preliminary survey over known faults using static ground measurements	DTP with full-scale application of airbourne methods only if warranted by results of preliminary survey	Could detect percolation of radon through fault zones.
Thermal infrared investigations	8.3.1.17.4.7.7	Yucca Mountain	Assess potential for application of aircraft and satellite thermal infrared imagery in mapping of fracture network	DTP based on evaluation of cost and expected results	Method depends on detection of surface temperature variation, which is largely dependent on soil moisture content, which in turn is in part related to infiltration along fractures.
Thematic Mapper Satellite Imagery	8.3.1.17.4.3.5	Yucca Mountain and vicinity	Tapes of the four Thematic Mapper V scenes encompassing the Yucca Mountain Region (Beatty, Indian Springs, Pahute Mesa, and Pahrangat Range 1:100,000 quadrangles) to be used to produce spectral and spectral ratio maps, from which areas containing distinctive patterns of lineations will be delineated	None	Used to define structural domains, areas of well-developed desert varnish, and areas of hydrothermal alteration.
			PALEOMAGNETISM		
Region	8.3.1.17.4.3.2	Yucca Mountain, Little Skull Mountain, Crater Flat, Skull Mountain, southern Yucca Mountain, eastern Yucca Flat	5 to 6 sites at Yucca Mountain will be sampled. If useful results are obtained, other sites as listed may be sampled	DTP only if useful results obtained at Yucca Mountain, and if suitable strata are present	Preliminary results at Yucca Mountain suggest 30° rotation (Scott and Rosenbaum, 1986).

[a]COCORP = Consortium for Continental Reflection Profiling.

Table 8.3.1.17-10. Summary of other geophysical studies contributing to preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 1 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			SEISMOLOGY		
Vertical seismic profiling/ tomography	8.3.1.4.2.2.5	Repository block and vicinity	15-25 geotomographic profiles, 0.2 to 2 km in length, cross-hole and surface down-hole surveys. Directional shear- and compression-energy sources	Decision to proceed (DTP) after prototype of feasibility DTP after calibration in shaft and drifts	Used to map 3-dimensional network of rock mass fractures. 20 m pixel geometry.
Shallow seismic refraction	8.3.1.14.2.3.3	Vicinity of surface facilities	TBD[a]	None	Will provide data for modeling soil-structure interaction and local site effects on vibratory ground motion.
Intermediate depth seismic refraction	8.3.1.4.2.1.2	E-W line across Yucca Mountain, N of block	Explosive sources; shotholes	None	See Sutton (1985).
			PALEOMAGNETISM		
Site	8.3.1.4.2.1.5	Yucca Mountain	Orient drill core as it becomes available. Establish reference orientation through study of outcrop samples. Determine magnetic character of outcrop samples to aid in interpretation of aeromagnetic data.	None	See Rosenbaum (1983), Rosenbaum and Rivers (1984), Rosenbaum and Snyder (1985), Rosenbaum (1985)
			BOREHOLE GEOPHYSICAL METHODS		
Geophysical logging					
Borehole gravimetry	8.3.1.4.2.1.3	Yucca Mountain	15 water-table drillholes, existing deep holes that can be made available, and all new holes that reach the base of the Topopah Spring Member	None	Already have data in drillholes H-1, P-1, G-1, G-3, and G-4. Data will be used to model structure in the immediate vicinity of each borehole, to study lithophysal zones, and to model the Paleozoic surface beneath Yucca Mountain. See Robbins et al. (1982), Healey et al. (1984), and Healey et al. (1986).

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Table 8.3.1.17-10. Summary of other geophysical studies contributing to preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 2 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			BOREHOLE GEOPHYSICAL METHODS (continued)		
Borehole magnetic logs	8.3.1.4.2.1.3	Yucca Mountain	15 water-table drillholes, and new drillholes prior to casing operations	None	Used to determine mappable magnetic events for studying structural integrity of Yucca Mountain, and to supplement paleomagnetic and lithophysal studies. See Hagstrum et al. (1980).
Induced potential logs	8.3.1.4.2.1.3	Yucca Mountain	Test in one or two drillholes	Evaluate for effectiveness after 1 or 2 drillholes	Feasibility study to determine if the method can be used to map zeolitized rock.
Commercially available logs	8.3.1.4.2.1.1	Yucca Mountain	All existing unlogged drillholes, all new holes, and relog selected holes	None	To obtain parameters for hydrologic, geologic, and geophysical models, and to determine uniformity and lateral distribution of rock properties within the stratigraphic units. Refer to Spengler et al. (1979), Maldanado et al. (1979), Daniels and Scott (1981), Hagstrum et al. (1980), Daniels et al. (1981), Muller (1982), Muller and Kibler (1984), Spengler and Chornack (1984), Muller (1985), and Muller and Kibler (1985).
Borehole radar logs	8.3.1.4.2.1.3	Yucca Mountain	Drillholes that penetrate the base of the Topopah Spring Member	Evaluate for effectiveness after 1 or 2 drillholes	Primarily used for fracture detection or to demonstrate the absence of fractures in the unsaturated zone.
Acoustic televiewer logs and TV camera logs	8.3.1.4.2.2.3	Yucca Mountain	All Yucca Mountain drillholes	None	For fracture and fault zone detection, and stratigraphic and lithologic correlation. See Healy et al. (1984), Stock et al. (1984), Stock and Healy (1984), Stock et al. (1985).
Large spacing electromagnetic and resistivity logs	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	To determine accurate large volume in situ values for studying fracture and lithophysal zones, and for interpretating anomalies detected with surface and borehole data.

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Table 8.3.1.17-10. Summary of other geophysical studies contributing to preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 3 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			BOREHOLE TO SURFACE METHODS		
Resistivity and electromagnetic methods	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	For fracture studies in the unsaturated zone, to obtain detailed structure in areas of anomalous surface geophysical data and in critical locations such as the shaft site and surface facilities locations, and to verify projected faults at critical locations. See Daniels and Scott (1981).
High resolution P and S wave seismic	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as previously, and to obtain parameters for designing effective deeper-penetrating seismic surveys.
Surface-to-hole seismic refraction	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as two previous, and for critical fault location and bed tracing.
Up-hole and down-hole seismic	8.3.1.14.2.3.3	Vicinity of surface facilities	TBD	After evaluation of shallow seismic refraction survey	Will provide data for modeling soil-structure interaction and local site effects on vibratory ground motion
			BOREHOLE TO BOREHOLE METHODS		
Borehole to borehole methods	8.3.1.4.2.2.5	Yucca Mountain close-spaced holes for hydrologic testing and for surface facilities studies	Selected drillholes	None	Geotomography to map fractures and demonstrate mappability of features that intersect the drillholes using resistivity, electromagnetic radar, and high resolution P and S seismic (Yo Yo) methods.
Cross-hole seismic	8.3.1.14.2.3.3	Vicinity of surface facilities	TBD	After evaluation of shallow seismic refraction survey	Will provide data for modeling soil-structure interaction and local site effects on vibratory ground motion

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Table 8.3.1.17-10. Summary of other geophysical studies contributing to preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 4 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			PETROPHYSICS		
Petrophysics	8.3.1.4.2.1.4	Yucca Mountain	Selected core from cored drillholes	None	To verify geophysical log accuracy, calibrate computed logs, determine properties that are not or cannot be measured in situ, and to model and interpret surface geophysical studies.

*TBD = to be determined.

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The seismic reflection studies will be preceded by a preliminary test to determine if the results of the technique will be useful for evaluating subsurface structure in the Yucca Mountain region. A peer-review panel conducted as part of Activity 8.3.1.4.2.1.6 will review the initial results and will determine if further work is warranted.

A detailed description of the planned geophysical studies follows.

Seismic refraction methods have been used to characterize the general velocity structure of the upper crust in the Yucca Mountain area (Figure 8.3.1.17-12), and to establish the location and nature of major discontinuities in that velocity structure (Hoffman and Mooney, 1983). When used in conjunction with gravity and magnetic surveys, the method is useful in limiting applicable structural models (Snyder and Carr, 1984), although resolving power is low. The refraction survey will include an east-west profile spanning the transect, and three shorter cross-profiles (Figure 8.3.1.17-12).

Seismic reflection methods are used where clear resolution of upper crustal stratigraphy and structure is required. A seismic reflection survey across the northern Walker Lane successfully imaged strands of northwest-trending faults within the zone (Knuepfer et al., 1987). The Walker Lane in that area appears to be the surface expression of a southwest dipping (45°) fault that soles into a midcrustal detachment (Knuepfer al., 1987). Analogous features in the Yucca Mountain region include major structures such as a 6-s (two-way sonic travel time) reflection in Death Valley that may be interpreted as a mid-crustal brittle-ductile transition zone (de Voogd et al., 1986), the Furnace Creek fault zone and the Walker Lane, and the mylonitic detachment-bounded upper surface of the Precambrian, exposed in the northern Amargosa Desert. Other potential reflectors in the Yucca Mountain region include the upper and lower carbonate aquifers within the Paleozoic sequence (Winograd and Thordarson, 1975), and the Miocene-Paleozoic contact.

If good quality reflections can be obtained in this area, then high-resolution reflection seismology, supplemented by gravity and magnetic surveys, could define the width, continuity, and depth of these features, thus constraining the location and character of potential sources of ground motion and rupture within 100 km of the site. This possibility will be evaluated through testing of a preliminary seismic reflection survey.

Magnetotelluric (MT) soundings (Furguson, 1982) in the Yucca Mountain region indicate the presence of substantial conductivity contrast between Precambrian crystalline rocks, Paleozoic aquifers and aquitards, argillaceous units of the Paleozoic such as the Eleana Formation, Miocene volcanic rocks, and Quaternary basin fill deposits. Furguson's (1982) soundings are too widely spaced to permit reliable interpretation of structure. Additional soundings, planned as part of this study, should help constrain the location of fault zones, the identity of deep reflectors observed on the high-precision seismic reflection profiles, and in addition will help distinguish deep-seated bodies of molten rock.

The MT survey will include a detailed net with stations spaced at 3 to 5 km, and a reconnaissance net with stations spaced at 8 to 10 km. The detailed net will extend from Stovepipe Wells eastward to Mercury, Nevada,

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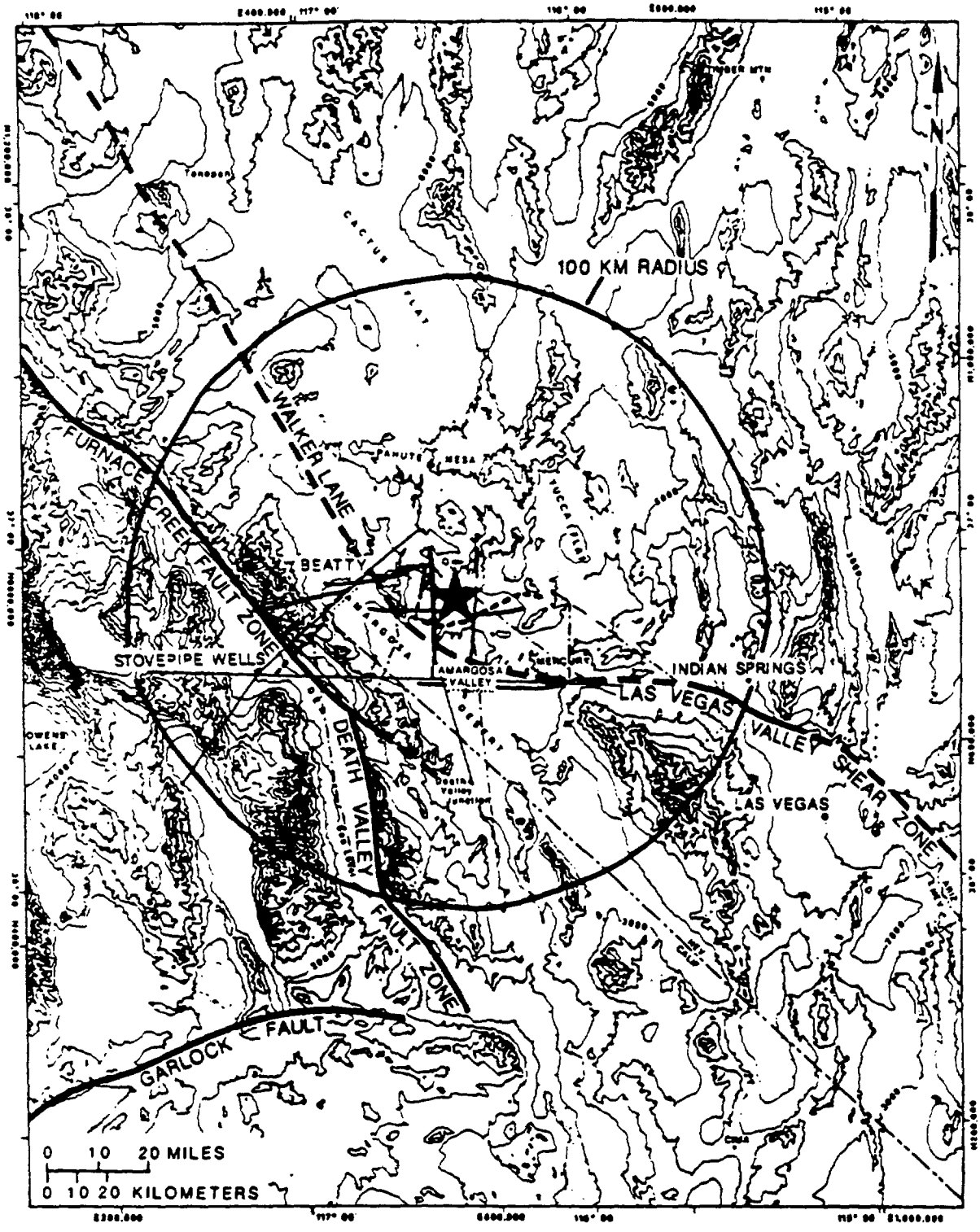

Figure 8.3.1.17-12. Location of seismic refraction and magnetotelluric sounding traverses.

with additional offline stations in the northern Amargosa Desert and in Crater Flat. The reconnaissance net will include north-south lines designed to tie the Yucca Mountain area to the Consortium for Continental Reflection Profiling (COCORP) reflection surveys to the south. The MT survey and refraction survey will provide a gross characterization of crustal structure at low cost.

Seismic refraction survey (Death Valley-Beatty Junction-Sheep Range). Four seismic refraction profiles are tentatively planned. As presently conceived, a 160-km long east-west profile centered on Yucca Mountain will consist of two 80-km deployments, each using 120 instruments spaced at 0.7 to 1.0 km and recording seven 900- to 1,800-kg shots spaced at 8 to 20 km. Three cross-profiles, potentially including an 80-km profile extending southward from the northern end of Crater Flat, a 110-km profile extending southwestward from the northern end of Crater Flat, and a 70-km northwest-southeast profile centered on Stovepipe Wells, will consist of one to two deployments of 120 instruments recording two to three 900- to 1800-kg shots per deployment. Field work for the central and eastern part of the survey is currently under way, and completion is planned in 1987 or early 1988. The full extent of the survey will be determined after further consideration of the applicability of the expected results to Project needs.

Evaluation of proposed deep seismic reflection survey. A proposal to conduct a seismic reflection survey crossing Yucca Mountain and possibly extending across the Furnace Creek fault and the Walker Lane will be evaluated through preliminary testing and peer review.

The preliminary test will consist of a field survey of one line at a location to be determined, 15 km long, plus noise tests. The preliminary survey will use 10-km spreads, 24 geophones per group, 50-m group interval, 240 groups per spread, Vibroseis energy source, 100-m vibrator interval, 54,000-kg minimum peak vibrator force, and 240 channel floating-point digital recording. This configuration will be varied to optimize shallow and midcrustal reflections. Results of the preliminary tests and the design, scope, and potential application of the proposed survey to Yucca Mountain Project needs will be evaluated by a panel convened for that purpose. Two alternative locations for the test line have been proposed, including (1) an east-west line located in the Amargosa Valley, approximately 5 km south of the town of Amargosa Valley and (2) a northeast-trending line located about 10 km southwest of Beatty (Figure 8.3.1.17-12). Desired features of the proposed location include good access, low noise levels, and presence of alluvial cover.

Gravity survey (Stovepipe Wells-Death Valley-Beatty-Mercury-Indian Springs). If the proposed deep seismic reflection survey is implemented, a detailed gravity survey (using the La Costa Romberg gravimeter) will be conducted along a traverse coincident with the seismic reflection survey, possibly from Stovepipe Wells northeastward to Beatty, thence eastward to the northern Specter Range, thence northward to the northeast corner of the Nevada Test Site (NTS) through Yucca Flat. Gravity measurements will be made using portable devices, and surveying will use standard field methods.

Low-level magnetic survey (Stovepipe Wells-Death Valley-Beatty-Amargosa Valley-Indian Springs). If the proposed deep seismic reflection survey is implemented, a detailed low-level magnetic survey will be conducted along a traverse coincident with the seismic reflection survey, possibly from Stovepipe Wells northeastward to Beatty, thence eastward to the northern Specter Range, thence northward to the northeast corner of the NTS through Yucca Flat. Magnetometer measurements will be made using portable devices and surveying will use standard field methods.

Magnetotelluric survey (Stovepipe Wells-Death Valley-Beatty-Crater Flat-Mercury). Natural ambient magnetic fields and their induced electric fields at oscillations between 0.003 and 10 Hz will be measured using: high-precision voltage measurements across 150-m long electrode spreads; high-sensitivity induction coils; four-matched-channel, band-passed filtering with amplification; and real-time, floating-point, digital processing, and recording.

A 100-km long east-west line crossing the southern part of the NTS and the suspected subsurface extension of the Walker Lane (Las Vegas Valley shear zone) was surveyed in 1986 using close-spaced (3 to 6 km) field stations. The line included a 25-km traverse from Beatty, northeastward to northern Crater Flat, thence southwestward between Big Cone and Red Cone and across Bare Mountain to Highway 95, and thence eastward through the southern part of Yucca Mountain. The location and scope of additional traverse lines to be surveyed in 1988 and beyond will be based on application of expected results to Project needs.

8.3.1.17.4.3.2 Activity: Evaluate Quaternary faults within 100 km of Yucca Mountain

Objectives

The objectives of this activity are

1. To establish the abundance, distribution, and geographic orientation of known and suspected Quaternary faults within 100 km of the site.

2. To characterize the Quaternary and Holocene fault and fracture pattern within 100 km of the site and, if feasible, to relate that pattern to regionally important wrench fault systems, including the Walker Lane, the Death Valley-Furnace Creek fault zone, and the Mine Mountain-Pahranagat shear zone.

3. To characterize those Quaternary faults within 100 km of the site whose apparent length or recurrence rate indicate potential for future earthquakes of magnitude sufficient to affect design or performance of the waste facility.

4. To evaluate the recurrence history of that part of the Death Valley-Furnace Creek fault zone within 100 km of the site.

5. To identify fault scarps within 100 km of the site that may have been overlooked during conventional geologic field surveys and that may not have been apparent on conventional vertical aerial photography.

6. To verify the existence and age of scarps in the NTS area that were detected by low-sun-angle photogeologic interpretation.

7. To determine whether the Beatty scarp originated through tectonic or fluvial processes, or both; the nature of movement along the scarp, if tectonic; and the age of the scarp.

8. To ascertain the amount of post-middle Miocene horizontal rotation of bedrock alongside wrench faults and of bedrock suspected to be part of upper plate above subsurface wrench faults.

Parameters

The parameters of this activity are

1. Location, orientation, patterns, displacement, age and nature of Quaternary faults.

2. Fault scarp morphology and offset of Quaternary deposits.

3. Relative and absolute ages of Quaternary faults.

4. Abundance, dimensions, and orientations of Quaternary ruptures in the path of suspected subsurface wrench fault.

5. Rotation of upper-plate rock in Yucca Mountain region as defined by deflections of paleomagnetic pole declinations.

6. Quaternary rate of fault movement.

Description

This activity will supply information on the nature and rate of faulting during the Quaternary within 100 km of the site, and identify and characterize any faults whose length or recurrence rate indicate potential for earthquakes of magnitude sufficient to affect design or performances of the waste facility. The abundance of mapped Quaternary faults within the NTS and vicinity is substantially greater than that elsewhere within any part of the Walker Lane southeast of Monte Cristo Valley. This contrast is at least in part an artifact of the lack of detailed mapping outside of the Nevada Test Site (NTS) (Figure 8.3.1.17-7).

As an initial step, a map of Quaternary faults within 100 km of the site will be compiled from published and unpublished sources. Vertical aerial photographs of the same area will then be examined and a photogeologic map prepared to illustrate suspected Quaternary scarps and faults. A selected proportion of the suspected faults will be verified and examined in the

field, and the age and amount of movement estimated. The relation of the fault pattern to major regional structures, including the Walker Lane, will also be evaluated.

This map will define the source regions of major earthquakes that have produced surface faulting during late Quaternary time and, thus, provide an estimate of regional variations in the long-term rates of occurrence of large magnitude earthquakes.

Conventional vertical photography has been carried out for the Yucca Mountain area. To minimize the number of scarps that have been overlooked, low-sun-angle vertical photographs covering selected areas will be procured and photogeologic maps of suspected Quaternary scarps will be prepared and verified in the field.

As originally conceived by Gianella and Callaghan (1934b), the Walker Lane includes a curvilinear fault near Beatty, Nevada, defined by a prominent Quaternary scarp. If real, the fault could be a potential source of future ground motion at the site. However, the origin of the scarp is somewhat uncertain. It could have originated through fluvial processes (as postulated by Swadley et al., 1988), tectonic processes, or some combination of the two. To address this problem and the potential significance to design or performance issues, the scarp will be dated by a variety of methods, mapped, and its relation to faults at depth investigated.

The Walker Lane is commonly believed to be a zone of oroclinal or oroflexural bending because the structural grain of bedrock terranes curve abruptly as it intersects the zone forming a reverse S-shaped pattern indicating right-lateral wrenching. The structural grain in the vicinity of Yucca Mountain is obscured by the intersection of the Walker Lane with the left-lateral faults of the Mine Mountain-Spotted Range belt. To ascertain the degree to which oroflexural bending affects the Miocene volcanic cover at Yucca Mountain, paleomagnetic poles of selected ash flows will be measured at various locations from one side of the zone to the other. Comparison of the declination of these poles should provide a measure of the oroflexural bending since middle Miocene time.

Development of map of Quaternary faults within 100 km of the site (Las Vegas to Cedar Mountain). Known and suspected Quaternary faults within 100 km of the site will be identified from published and unpublished literature. A map showing the distribution of these faults will be compiled at a scale of 1:500,000. This subactivity is 50 percent complete. The duration of future work is three months.

Development of photogeologic map of Quaternary scarps within 100 km of the site. Quaternary scarps will be identified within 100 km of the site through photogeologic interpretation of existing 1:20,000- to 1:80,000-scale black-and-white, vertical aerial photographs. Photographs have been or will be obtained from Federal, State, and County archives. Study of potentially significant Quaternary faults will be augmented through analysis of low-sun-angle photographs. Scarps are to be compiled on 1:100,000- to 1:200,000-scale base maps. This effort is estimated to be 25 percent complete. The duration of future work is eighteen months.

Field verification of Quaternary scarps within 100 km of the site. Scarps identified through photogeologic interpretation will be selectively examined in the field. The age of these scarps will be estimated from scarp morphology and bracketed by ages of units judged to be offset by or overlapping the scarps. Trenching will be done at scarps whose age would significantly constrain age of the Walker Lane or other large faults with potential for significant future ground motion. As yet, no scarps of this character have been identified.

Development of low-sun-angle photogeologic Quaternary scarp map (Yucca Mountain area). Medium-scale vertical aerial photographs taken during periods of low-sun-angle will be procured for that part of the Walker Lane, proximal to Yucca Mountain, focusing on Jackass Flats, Crater Flat, and northern Amargosa Desert. Photographs will be interpreted using conventional procedures and scarps compiled on 1:100,000 scale base maps of the Yucca Mountain area. Estimated duration of this subactivity is one year.

Field verification of low-sun-angle photogeologic Quaternary scarps (Yucca Mountain area). Scarps that are identified through low-sun-angle photogeology will be examined in the field, their age estimated from scarp morphology and bracketed by ages of units judged to be offset by or overlapping the scarp. Trenching will be done at scarps whose age would significantly constrain age of faults with potential for significant future ground motion. The estimated duration of this subactivity is six months.

Mapping of Quaternary faults and deposits of the Beatty 1:100,000 quadrangle. Quaternary deposits and faults displacing those deposits will be mapped, using standard field methods, including annotating contacts on 1:20,000-scale aerial photographs, and compiling at 1:24,000 and 1:100,000 scales. Local stratigraphic type localities and sections will be established. Deposits will be dated using soil development, cation ratio (desert varnish), uranium-trend, and uranium-series, ash fingerprinting, as appropriate. Approximately 50 percent of the quadrangle has been completed. The estimated duration of future work is three years.

Evaluation of nature of Beatty scarp and relation to geologic boundary. The Beatty scarp and its southeastern extension was considered a segment of the Walker Lane by Gianella and Callahan (1934b). The apparent length of the scarp, including its poorly defined southeastern extension, is 15 to 25 km. Detailed mapping of Quaternary deposits of the Beatty scarp will be supplemented by mapping of Quaternary datums in trenches crossing the scarp. Ages of the datums will be determined by analysis of soil development, uranium-series and uranium-trend analyses, radiocarbon dating, and cation-ratio (desert varnish) dating. Shallow seismic reflection (mini-sosie) and seismic refraction (Bison-type) surveys along traverses crossing the scarp and extending for 1 to 2 km (0.6 to 1.2 mi) to either side of the scarp will be performed to investigate the relation of the scarp to faults at depth. The duration of future work is three to six months.

Quaternary recurrence rate of the Death Valley-Furnace Creek fault zone. The Quaternary recurrence rate of this fault zone will be evaluated, using published and unpublished data, supplemented by limited field reconnaissance. The field investigation will focus on scarp morphology and age of surficial

deposits intersected by or overlapping the fault. No excavations are planned. The estimated duration of this subactivity is 6 to 12 months.

Analysis of rotation (drag) of bedrock alongside or over suspected wrench faults based on rotation of paleomagnetic poles. Paleomagnetic orientations of samples collected from localities within the Tiva Canyon Member of the Paintbrush Tuff suggest that the Yucca Mountain area has been oroflexurally bent. Bending is clockwise and preliminary data suggest that the amount of bending relative to the north end of the mountain progressively increases through the central part and then increases sharply across the Stagecoach Road fault, reaching approximately 30 degrees at the south end (Scott and Rosenbaum, 1986). Bending could be related to right-lateral wrench faulting along the Walker Lane or, more speculatively, to detachment faulting in which a horizontal rotation of the detached plate is combined with dip-slip motion. The rotation occurred after 12.5 million years ago, the age of the Tiva Canyon Member.

This subactivity is designed to evaluate the preliminary results of paleomagnetic sampling at Yucca Mountain cited above through sampling of five to six additional localities to be selected from within the Tiva Canyon Member. If the rotation at Yucca Mountain is confirmed, then (1) the eastward extent of rotation and the possible influence of left-lateral faulting within the Mine Mountain-Spotted Range belt will be evaluated through sampling of two to five sites to be selected from within the Tiva Canyon Member at Little Skull Mountain or Skull Mountain, provided suitable localities are present, and (2) the age of rotation will be evaluated through sampling of late Miocene and Pliocene basalt flows in Jackass Flats and southeastern Crater Flat, provided suitable volcanic units are present.

Individual Miocene ash flows will be cored using hand-held drills at localities to be selected. Eight to ten oriented specimens will be obtained per site. After thermal demagnetization (Activity 8.3.1.4.2.1.5) the orientation of the magnetic pole for each specimen will be measured and corrected for inclination of the strata at the sample site. Comparison of declination from site-to-site will provide a measure of relative horizontal tectonic rotation. The estimated duration of future work is one to two years.

8.3.1.17.4.3.3 Activity: Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site

Objectives

The objective of this activity is to evaluate the relevance of the Cedar Mountain earthquake of 1932 to potential sources of ground shaking and rupture in that part of the Walker Lane within 100 km of Yucca Mountain.

Parameters

The parameters for this activity are

1. Geologic structure and stratigraphy of Stewart and Monte Cristo valleys.

2. Stewart and Monte Cristo Valley faults and their relation to the Walker Lane.

3. Surface ruptures formed during 1932 Cedar Mountain earthquake.

4. Focal mechanism of the 1932 Cedar Mountain earthquake.

Description

This activity will entail a review of the published geologic literature concerning the Cedar Mountain earthquake, photogeologic interpretation, limited fieldwork, and evaluation of concurrent research by investigators not affiliated with the Project. Emphasis will be on the tectonic setting (is it part of Walker Lane, Churchill Arc, or both?), continuity with Quaternary faults of Stewart Valley and with through-going shears mapped by Ekren and Byers (1985), distribution and character of surface breaks, and recurrence history.

Ruptures will be classified according to style and length measured by scaling from maps by Molinari (1984), and Gianella and Callaghan (1934a,b). Selected ruptures will be examined in the field. The width of the rupture zone, the width of individual ruptures, and other attributes (length, offset, aperture, fissure-fillings, brecciation) will be noted. The rupture zone has been trenched by investigators not affiliated with the Yucca Mountain Project. Additional trenching is not anticipated. This activity is estimated to be 50 percent complete. The estimated duration of future work is 6 to 12 months.

8.3.1.17.4.3.4 Activity: Evaluate the Bare Mountain fault zone

Objectives

The objectives of this activity are to

1. Evaluate the potential for ground shaking associated with future movement along the Bare Mountain fault zone.

2. Estimate the age of the most recent faulting on the Bare Mountain frontal fault.

3. Estimate the recurrence intervals of faulting.

4. Determine the nature and age of faulting within the fault complex east of the frontal zone, and to determine nature of tectonic

control of the location and orientation of the main wash in Crater Flat.

5. Determine the subsurface configuration of fault zones.

Parameters

The parameters for this activity are

1. Age of datums.
2. Amount and direction of offset of datums.
3. Geologic structure and stratigraphy, seismic reflections.

Description

Bare Mountain has a steep, curvilinear eastern range front, the configuration of which is controlled by a complex of steeply eastward and moderately southeastward-dipping faults having Quaternary displacement. This complex is referred to as the Bare Mountain fault zone.

This activity consists of (1) geologic mapping of the fault zone and (2) trenching and dating of deposits cut by the fault zone.

Alluvial fans and stream deposits within Crater Flat along the eastern flank of Bare Mountain (Bare Mountain 15-min quadrangle (USGS, 1954)) will be mapped and deposits dated through soil development, uranium-series, and uranium-trend analysis, thermoluminescence, and cation ratios (desert varnish). Trenches intersecting the trace of the frontal fault will be excavated and mapped. Deposits offset by and overlapping the rupture zones exposed in the trenches will be dated.

Two new trenches are planned, and two existing prospect pits are to be enlarged, as follows:

1. Bulldozer trench, south side Tarantula Canyon, existing road. SW/4, NE/4, sec. 29, T.12S., R.48E. Estimated depth 3 to 4 m, width 5 m, length 15 to 20 m.

2. Backhoe trench, no existing road. SE/4, NW/4, sec. 24, T.13S., R47-1/2E. Estimated depth 2 to 3 m, width 2 to 3 m, length 5 m.

3. Enlargement of two existing adjacent prospect pits using backhoe, existing road. SW/4, SW/4, sec. 25, T.13S., R.47-1/2E. Estimate increase depth from 3 to 5 m, enlarge slightly.

This activity is 75 percent complete, and one report has been published (Reheis, 1986). Information derived from this activity will be integrated with information on bedrock geology (Activity 8.3.1.17.4.5.2), geomorphology (Activity 8.3.1.17.4.9.3), and geophysics in an integrating and synthesis activity (Activity 8.3.1.17.4.12.1, evaluate tectonic processes and tectonic stability at the site). The duration of the future work is 6 to 12 months.

8.3.1.17.4.3.5 Activity: Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures

Objectives

The objectives of this activity are to

1. Map faults and lineaments within a 100 km radius of the site and to identify those with geomorphic expression indicative of Quaternary faulting.

2. Classify the area into subareas (domains) containing relatively homogeneous fault and lineament populations (prominent geomorphic expression, density, and orientation) suggestive of Quaternary faulting. This information will be used in Activity 8.3.1.17.2.1.2 to help assess the faulting potential in areas of emplaced waste.

3. Map the areal extent of desert varnish coatings. This information will be used in Activity 8.3.1.17.4.9.1 to help establish the areal extent of tectonically stable areas near Yucca Mountain.

4. Identify areas of suspected hydrothermal alteration. This information will be used in Study 8.3.1.9.2.1 (natural resource assessment) to evaluate the relationship of the suspected hydrothermal alteration to potential mineralization in Activity 8.3.1.5.2.1.5 (calcite- and opaline-vein deposits) to aid in evaluating the possible origin of calcite-silica deposits and in Study 8.3.1.8.5.2 to aid in evaluating local heat flow anomalies.

Parameters

The parameters for this activity are

1. Fracture orientation, length, distribution.
2. Optical reflectance and absorption for selected wavelengths.
3. Age and distribution of desert varnish.
4. Distribution of hydrothermal alteration.

Description

High-quality Landsat V Thematic Mapper (TM) data provide a uniform set of data for the region and can be applied to numerous geologic problems. In this activity, a variety of remote sensing techniques will be applied to geologic problems being investigated in the region, including (1) analysis of linear features detectable with the high-resolution TM data, and characterization of regional fracture patterns, (2) mapping of the distribution of hydrothermal alteration related to near-surface igneous processes based on the spectral reflectance characteristics of alteration-associated minerals by using computer-enhanced TM data supplemented by field evaluations, and (3) mapping of surfaces with a substantial coating of desert varnish to aid in defining areas of tectonic stability.

The area under study comprises most of four 1:100,000-scale quadrangles --Beatty, Indian Springs, Pahute Mesa, and Pahranagat Range. Tapes of the four Thematic Mapper V scenes encompassing this area will be purchased, and spectral and spectral ratio maps will be prepared including bands sensitive to hydroxyl-containing minerals in the ultraviolet part of the spectrum. Computer-enhanced images will be interpreted, linear features identified, and their length and orientation measured. Domains containing distinctive patterns of fractures and lineaments will be delineated.

Color-ratio composite TM images will be used to identify areas of alteration. These areas will be reconnoitered in the field to determine the type of alteration and the nature of the causal volcanic or igneous processes. The estimated duration of the future work is two years.

8.3.1.17.4.4 Study: Quaternary faulting proximal to the site within northeast-trending fault zones

Objectives

The primary objective of this study is to evaluate the potential for ground motion resulting from future movement on Quaternary left-lateral(?) strike-slip faults east and south of the site-area.

The left-lateral(?) strike-slip faults in that area strike to the northeast or east-northeast, and form an en echelon pattern within the Mine Mountain-Spotted Range structural zone (Carr, 1974), cutting across the northwestern extension of the Las Vegas Valley shear zone. The belt is aligned with the Pahranagat shear zone to the east-northeast, and the Garlock fault to the west-southwest (Figure 8.3.1.17-9). Four of the left-lateral(?) faults show evidence of significant Quaternary displacement. From northwest to southeast, they are the Stagecoach Road fault, the Mine Mountain fault, the Cane Spring fault zone, and the Rock Valley fault zone (Figure 8.3.1.17-13).

The Stagecoach Road fault cuts across the southern end of Yucca Mountain. It could connect to the northeast with the Paintbrush Canyon fault (to be studied as part of Activity 8.3.1.17.4.6.2 (evaluate age and recurrence of movement on suspected and known Quaternary faults) or alternatively, continue northeastward across western Jackass Flats into the Calico Hills, as shown by Maldanado (1985a). The Mine Mountain fault zone (not to be confused with the Mine Mountain thrust fault) trends northeast, with mapped extent of approximately 27 km (scaled from Figure 7 of Carr, 1984), and extends from Jackass Flat through Mid Valley to Yucca Flat. The Rock Valley fault zone trends east-northeast, with mapped extent of approximately 68 km (scaled from Figure 7 of Carr, 1984), if discontinuous segments are included, and extends from Amargosa Desert through Rock Valley to Frenchman Flat. The Cane Spring fault zone trends northeast, with mapped extent of 23 km (scaled from Figure 7 of Carr, 1984).

The part of the Mine Mountain-Spotted Range structural zone in the area between and adjacent to the Mine Mountain and Rock Valley fault zones is marked by above average seismic activity. However, focal mechanism solutions

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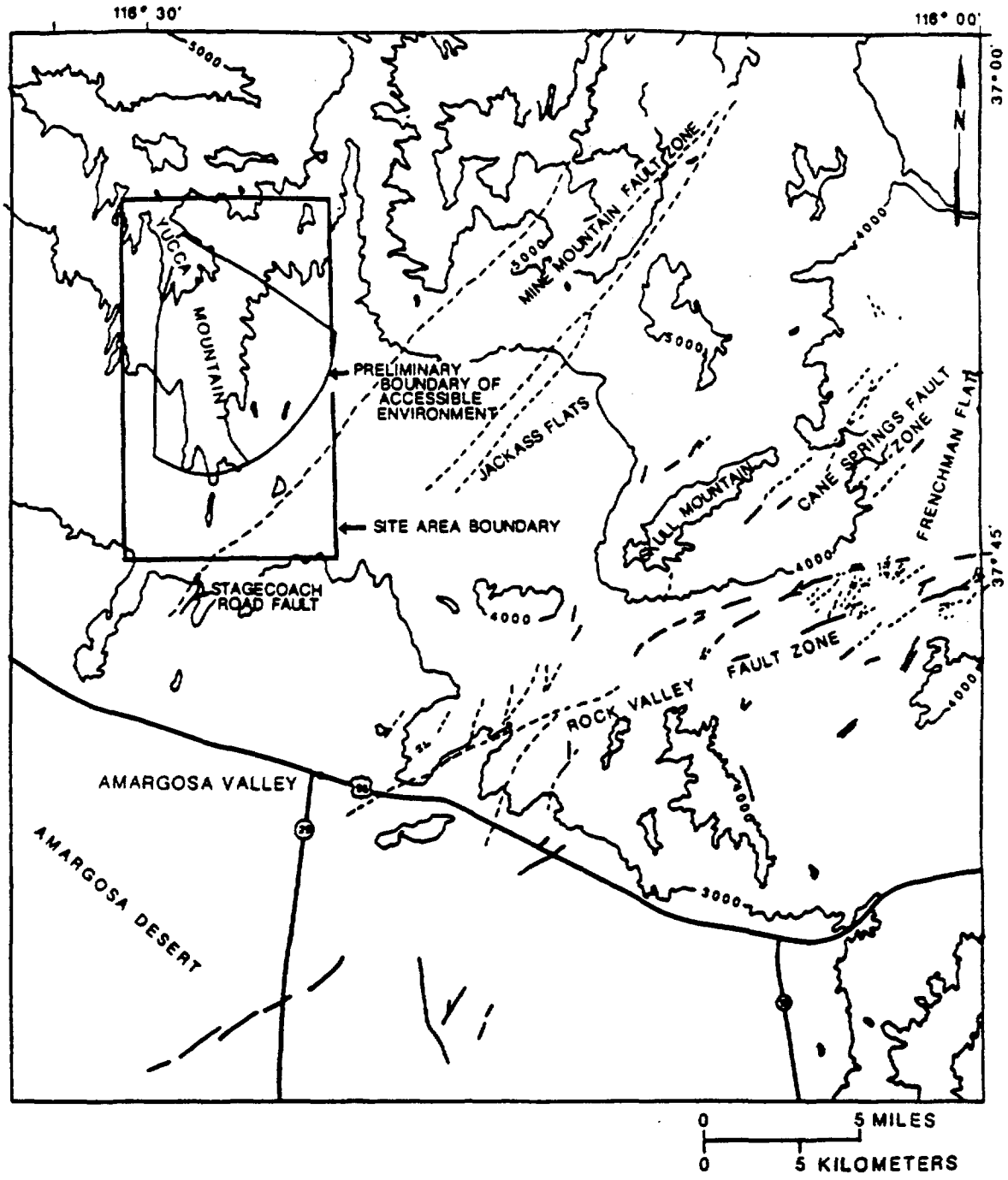

Figure 8.3.1.17-13. Map showing relation of proposed repository area to Mine Mountain, Cane Spring, Rock Valley, and Stagecoach Road fault zones.

generally indicate right-lateral movement on north-trending faults, rather than left-lateral movement parallel to the northeast to east-northeast-trending faults.

Activities planned for this study are (1) an evaluation of the Rock Valley fault system, (2) an evaluation of the Mine Mountain fault system, (3) an evaluation of the Stagecoach Road fault zone, and (4) an evaluation of the Cane Spring fault zone.

8.3.1.17.4.4.1 Activity: Evaluate the Rock Valley fault system

Objectives

The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Rock Valley fault system. An objective of the trenching is to estimate the total displacement, including strike-slip and dip-slip components, of Quaternary datums. Accordingly, trenching will use methods designed to facilitate measurement of these components, as described in Section 8.3.1.17.4.6.2.

Parameters

The parameters for the activity are

1. Length, location, and spatial orientation of the fault system.
2. Segmentation within the fault system.
3. Width of the fault system.
4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary strands within the fault system.
5. Location, amount, and direction of displacement of Quaternary deposits and Quaternary surfaces.
6. Age, lateral extent, and height of fault scarps.

Description

This activity focuses on estimating the Quaternary rate of activity on the Rock Valley fault through trenching and mapping and dating of strata cut by the fault. Traces of the main strands of the fault will be examined and mapped, and the subsurface expression of the fault zone will be investigated through shallow seismic refraction and reflection surveys.

Evaluation of Quaternary displacement along main trace of the Rock Valley fault system as established by trenching and very shallow seismic refraction (Bison-type) and seismic reflection (mini-sosie). Two to four trenches will be excavated across fault scarps and fault lines, and the Quaternary stratigraphy exposed in trench walls and floor mapped. Areas of

lateral disruption and discontinuity of Quaternary datums will be identified, and the age of disrupted Quaternary datums and overlying undisrupted Quaternary datums established, if present. The age of datums will be established through stratigraphic correlation, chemical fingerprinting, soil development analysis, radiocarbon dating, uranium-trend and uranium-series analysis, cation ratio dating, and other methods, as appropriate. The orientation of clast fabric in zones of rupture will be measured. Fracture-filling minerals will be identified and dated. The orientation of all fractures cutting the Quaternary deposits will be measured. By using portable seismic refraction apparatus (Bison-type), velocity profiles within very shallow (to depth of 100 m) deposits along selected traverses crossing known and suspected fault traces will be established. The subsurface configuration of the fault zone will be examined using shallow seismic reflection (mini-sosie) along a 1.5-km (0.9 mi) long traverse orthogonal to the fault. This subactivity is 95 percent complete.

Evaluation of Quaternary displacement along the southern extension of the Rock Valley fault system, south of Amargosa Valley. Faults cutting fine-grained sands and muds approximately 12 km (7 mi) south of Amargosa Valley appear to represent an extension of the Rock Valley fault system. Mapping, trenching, and shallow (Bison) seismic refraction will be undertaken to determine fault width, the horizontal and vertical components of slip along these faults, and the age of the deposits cut by the faults. Where applicable, all techniques described in the evaluation of the main trace of the Rock Valley fault will be used. One or two trenches at locations to be determined are planned. The estimated duration of this work is one year.

8.3.1.17.4.4.2 Activity: Evaluate the Mine Mountain fault system

Objectives

The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Mine Mountain fault system.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of the fault system.
2. Segmentation within the fault system.
3. Width of the fault system.
4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary strands within the fault system.
5. Location, amount and direction of displacement of Quaternary deposits and Quaternary surfaces.
6. Age, lateral extent, and height of fault scarps.

Description

A substantial body of data on the Mine Mountain fault system at Mid Valley, 25 to 30 km east-northeast of Yucca Mountain, has been collected, indicating that the fault is a wide zone with substantial dip-slip displacement, possibly merging with or terminating at a low-angle extensional fault at depth (McArthur and Birkhard, 1986). McArthur and Birkhard (1986) citing Orkild (personal communication), state that older alluvium is disturbed along the trace of the fault and conclude on this basis that some movement occurred within the last one million years.

The fault zone projects below alluvial cover southwestward from Mid Valley into jackass Flats (Maldonado, 1985b), thus possibly approaching to within 15 km of Yucca Mountain (Figure 8.3.1.17-13). However, no displacement of Quaternary deposits along the trace of the fault within Jackass Flats has been recognized.

In this activity, published data (cited above) will be reviewed and interpreted. The reported disturbance of older alluvium in Mid Valley will be verified and evaluated. In addition, Quaternary deposits in Jackass Flats along the projected trace of the fault will be examined for evidence of faulting. Any scarps and lineaments indicative of Quaternary faulting will be evaluated and, if necessary, trenched to determine slip rate and style of faulting. Supporting data on subsurface geometry of the possible projection of the fault into Jackass Flats will be provided by Activity 8.3.1.17.4.7.8 (evaluate shallow seismic reflection (mini-sosie) methods and, if appropriate, conduct surveys of selected structures at and proximal to the site area). Additional data on Quaternary expression of faults in Jackass Flats will be gathered by Activity 8.3.1.17.4.3.2 (evaluate Quaternary faults within 100 km of Yucca Mountain).

8.3.1.17.4.4.3 Activity: Evaluate the Stagecoach Road fault zone

Objectives

The objectives of this activity are to

1. Determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Stagecoach Road fault system.

2. Evaluate the possibility that the Stagecoach Road fault zone is a continuation of the Paintbrush Canyon fault.

3. Evaluate the geometry of the intersection in the subsurface of the Paintbrush Canyon fault and hypothesized shallow detachment faults.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of the fault system.

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2. Segmentation within the fault system.

3. Width of the fault system.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or younger than Quaternary strands within the fault system.

5. Location, amount and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

7. Subsurface geometry of the fault zone.

8. Geometry of intersection with Paintbrush Canyon fault.

9. Continuity in subsurface between southern Yucca Mountain and Calico Hills.

Description

This activity focuses on (1) estimating the Quaternary rate of activity on the Stagecoach fault through trenching, mapping, and dating of strata and geomorphic features cut by the fault and (2) determining the chronologic and tectonic relationship between the Stagecoach fault and the Paintbrush Canyon-Busted Butte fault system. In addition, the subsurface expression of the fault zone will be investigated through shallow seismic refraction surveys and possibly reflection surveys. An objective of the trenching is to estimate the total displacement, including strike-slip and dip-slip components, of Quaternary datums. Accordingly, trenching will use methods designed to facilitate measurement of these components, as described in Section 8.3.1.17.4.6.2.

Surficial deposits and geomorphic features will be mapped in detail to determine the apparent strike-slip component of fault movement. Two to four trenches will be excavated across fault scarps and fault lines at locations to be determined, and the Quaternary stratigraphy exposed in trench walls and floor mapped. Areas of lateral disruption and discontinuity of Quaternary datums will be identified, and the age of disrupted datums and overlying undisrupted Quaternary datums established, if present. The age of the datums will be established through stratigraphic correlation, chemical fingerprinting, soil development analysis, radiocarbon dating, uranium-trend and uranium-series analysis, cation-ratio dating, and other methods, as appropriate. The orientation of clast fabric in zones of rupture will be measured. Fracture-filling minerals will be identified and dated. The orientation of all fractures cutting the Quaternary deposits will be measured. Scarps and lineaments will be mapped, and the subsurface geometry investigated using shallow seismic refraction methods. A shallow seismic reflection profile (mini-sosie) will be surveyed as part of Activity 8.3.1.17.4.7.8 (evaluate shallow seismic reflection (mini-sosie) methods) provided that method proves to be effective. Information on the subsurface geometry will also be provided through application of other geophysical methods, as described in Activity 8.3.1.17.4.3.1 (evaluate crustal structure

and subsurface expression of Quaternary faults in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane). Expected duration of this activity is two years.

8.3.1.17.4.4.4 Activity: Evaluate the Cane Spring fault system

Objectives

The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Cane Spring fault system.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of the fault system.
2. Segmentation within the fault system.
3. Width of the fault system.
4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary strands within the fault system.
5. Location, amount, and direction of displacement of Quaternary deposits and Quaternary surfaces.
6. Age, lateral extent, and height of fault scarps.

Description

This activity focuses on evaluation of the potential of the Cane Springs fault system to produce moderate to large earthquakes. The Cane Spring fault system trends northeast between Skull Mountain and Frenchman Flat, bisecting the region lying between the Rock Valley fault zone and the Mine Mountain fault zone. Offset of bedrock by the fault indicates significant left-lateral movement in later Tertiary. Distinct alinements of brush and physiographic features in Quaternary material along the fault trace suggests that movement has continued into the Quaternary, particularly at the northeast end of the fault system. Detailed mapping of surficial deposits along the fault trace, including soil description and shallow seismic (Bison) refraction is planned to evaluate the possibility that the lineaments are caused by faulting of Quaternary deposits. If strong indications of faulting are found, then selected fault traces will be trenched, and the age of faulted and unfaulted units intersected by the fault will be determined. The expected duration of this activity is six months.

8.3.1.17.4.5 Study: Detachment faults at or proximal to Yucca Mountain

Objectives

The objective of this study is to supply information pertaining to the distribution, displacement rate, and age of detachment faults proximal to Yucca Mountain. The key questions regarding detachment faults are (1) whether they represent a significant earthquake source and (2) whether they conceal a significant earthquake source at depth. To resolve both questions, activities are focused on resolving the Quaternary behavior of postulated detachment faults.

Review of detailed (1:24,000 to 1:62,500 scale) maps of the Nevada Test Site and adjacent areas to the west (Bare Mountain and Beatty areas), using current concepts of structural geology, suggests that some features mapped as depositional contacts or thrust faults are in fact detachment faults. In particular, the basal contact of Oligocene-Miocene sedimentary rocks or Miocene volcanic rocks on Paleozoic rocks in the Mercury, Calico Hills, and Bare Mountain areas appears at several localities to be a detachment fault of moderate (perhaps one to several kilometers) displacement. Recent mapping south and west of Beatty shows that the basal contact of the Miocene volcanic rocks is a detachment fault with substantial displacement (Maldanado, 1985b).

Structural analysis of deformed and faulted Miocene ash-flows suggests that the entire area of Yucca Mountain, including the area of the proposed repository, is underlain at unknown depth by one or more detachment faults (Scott, 1986; Scott and Whitney, 1987). This possibility has not been confirmed, nor has the depth, attitude, and total extent of the postulated detachment(s) been determined. Conjecturing that the uppermost detachment fault corresponds to the contact between Miocene volcanic rocks and subjacent Paleozoic rocks, preliminary reinterpretation of published gravity data (Synder and Carr, 1984), suggests that this detachment(?) surface slopes moderately in a N.60°W. direction, which is the direction of least horizontal stress (Stock et al., 1985). That surface, or a high-angle fault offsetting it (M. D. Carr et al., 1986) was intersected in drillhole UE-25p#1 at a depth of about 1,200 m.

If detachment faults exist at depth below the site, their relevance to repository design and performance as potential sources of ground motion, rupture, or hydrologic conduits or barriers hinges on their age, depth, and nature of the intersection of the detachment faults with the steeply dipping Quaternary normal faults within the site area. This study focuses on examination of suspected detachment faults where they are exposed in areas adjacent to Yucca Mountain. Information on the potential subsurface extent and geometry of detachment faults and their possible connection to listric Quaternary faults at Yucca Mountain is derived through geophysical studies described in Activity 8.3.1.17.4.3.1 (evaluate crustal structure and subsurface expression of Quaternary faults in an East-West transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane) and Study 8.3.1.17.4.7 (subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain).

Yucca Mountain Project strategy for investigating the age and displacement rate of detachment faults includes five elements:

1. Observation of contact relations of detachment faults and Quaternary deposits at the outcrop and measurements of the radiometric age of detachment surfaces, to be undertaken as part of this study.

2. Evaluation of the subsurface geometric relationship of detachment faults (as deduced from geophysical studies described above and hydrologic and site-geology drillhole data) to Quaternary high-angle faults, such as the Bare Mountain fault, the Windy Wash fault, and the Paintbrush Canyon fault.

3. Evaluation of the recurrence rate and displacement history of Quaternary high-angle faults that could merge with detachment faults in the subsurface, to be undertaken as part of Study 8.3.1.17.4.6 (Quaternary faulting within the site area) and other studies of faulting.

4. Evaluation of in situ stress data developed within Study 8.3.1.17.4.8 (stress field within and proximal to the site area).

5. Evaluation of focal mechanism solutions developed in Study 8.3.1.17.4.1 (historical and current seismicity).

This information is to be synthesized in Study 8.3.1.17.4.12 (tectonic models and synthesis), which will (1) evaluate the possibility that one or more detachment faults are present in the subsurface below or in the vicinity of the proposed repository site, and (2) if considered to be present, evaluate the direction and rate of movement of the upper plate, the depth and configuration of the fault surfaces, and the nature of the association, if any, between the detachment fault(s) and the normal faults in the upper plate.

Activities planned for this study are to evaluate (1) the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area, (2) postulated detachment faults in the Beatty-Bare Mountain area, (3) the potential relationship of megabreccia within and south of Crater Flat to detachment faulting, (4) postulated detachment faults in the Specter Range and Camp Desert Rock areas, and (5) the age of detachment faults by using radiometric ages.

8.3.1.17.4.5.1 Activity: Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area

Objectives

The objectives of this activity are (1) to determine whether the contact of Miocene volcanic rocks on Paleozoic strata is tectonic or depositional, (2) if tectonic, to determine the Quaternary activity, if any, of the possible detachment fault, and (3) if Quaternary, the direction and age of move-

ment, attitude of fault plane, and nature of deformation of the Miocene (upper plate?) sequence.

Parameters

The parameters for this activity are geologic structure and stratigraphy.

Description

The contact between Miocene volcanic (and volcaniclastic) rocks and subjacent Paleozoic strata, which lies a kilometer or more below the surface at the site of the proposed repository at Yucca Mountain, surfaces a few kilometers to the northeast in the Calico Hills. The volcanic rocks are broken by faults, some with displacement in excess of 200 m, and locally are moderately to steeply tilted. This activity is designed to establish whether the contact with Paleozoic strata is tectonic or depositional, and if tectonic, whether the Miocene volcanic rocks are part of a detachment-bounded upper plate or not. The activity calls for conventional geologic mapping.

The suspected tectonic contact between Miocene rocks and Paleozoic rocks in the Calico Hills area will be mapped in detail with particular attention to evidence bearing on age of movement and displacement rate, including apparent offset of the Miocene-Paleozoic contact by pre-Quaternary faults. The Calico Hills area and vicinity will be mapped using conventional field methods, including annotation of field observations on large-scale (1:12,000) aerial photographs (color or false color, where available), and compiled at 1:24,000 scale. This activity is estimated to be 75 percent complete. The expected duration of the future work is six months.

8.3.1.17.4.5.2 Activity: Evaluate postulated detachment faults in the Beatty-Bare Mountain area

Objectives

The objectives of this activity are

1. To determine if postulated detachment faults in the Beatty-Bare Mountain have been active in the Quaternary.

2. If Quaternary, to

   a. Establish the displacement rate, location, and nature of the low-angle imbricate fault zones between lineated and mylonitized and variably recrystallized gneiss of the northern Amargosa Desert and the Paleozoic and Miocene rocks of the Beatty area, and to ascertain the nature of deformation of the Miocene (upper plate?) rocks.

   b. Establish the displacement rate, location, and nature of the low-angle fault zone between Paleozoic rocks of Bare Mountain and the Miocene volcanic rocks north of Bare Mountain, and to

ascertain the nature of deformation of the Miocene (upper plate?) rocks.

c. Ascertain the nature of internal deformation of Paleozoic rocks, their degree of metamorphism, the nature of suspected low-angle tectonic contact with the lineated and mylonitized gneiss of the northern Amargosa Desert, and the nature of the suspected low-angle tectonic contact with Miocene rocks at the northern end of Bare Mountain.

Parameters

The parameters for this activity are geologic structure and stratigraphy, age of datums, and amount and direction of offset of datums.

Description

The Beatty-Bare Mountain area, centered about 27 km west of the proposed repository at Yucca Mountain, is interpreted as an eroded and beveled stack of imbricated detachment-fault-bounded plates. The lowest exposed plate, cropping out in the northern Amargosa Desert southwest of Beatty, consists of lineated and mylonitized crystalline rocks, schist, and semischist. It is structurally overlain by one or more intermediate plates, consisting of moderately to weakly metamorphosed Precambrian and Paleozoic strata that form the Bare Mountain massif. The Bare Mountain massif is in turn structurally overlain by an upper plate, which west of Beatty, consists of Miocene volcanic and volcaniclastic strata. Older geologic maps have been reinterpreted and this reinterpretation suggests that the detachment between the intermediate (Bare Mountain) plates and the upper plate extends east of Beatty, curving around the north side of Bare Mountain, and is cut off by the Bare Mountain frontal fault.

This activity is designed to work out the structural geology of this detachment complex through conventional geologic mapping.

Detailed mapping and analysis of Beatty-Bare Mountain area--Bullfrog N.E. 7.5-min quadrangle. The Miocene rocks and their contact with subjacent units will be mapped using conventional field methods, including annotation of field observations on medium-scale (1:20,000) black-and-white and color-aerial photographs, and compilation at 1:24,000 scale. This subactivity is 95 percent complete. A map-report describing results of this mapping is in review.

Detailed mapping and analysis of Beatty-Bare Mountain area--Bare Mountain N.W. 7.5-min quadrangle. The Miocene rocks and their contact with subjacent units will be mapped using conventional field methods, including annotating field observations on medium-scale (1:20,000) black-and-white and color aerial photographs, and compiling at 1:24,000 scale. Estimated duration of work is one year.

Detailed mapping and analysis of Bare Mountain area--Bare Mountain S.W. 7.5-min quadrangle, plus parts of adjoining quadrangles. The Paleozoic rocks and their contact with overlying Miocene units and with subjacent units will be mapped using conventional field methods, including annotating field

observations on medium-scale (1:20,000) black-and-white and color aerial photographs, and compiling at 1:24,000 scale. This subactivity is estimated to be 75 percent complete. The duration of the future work is six months.

8.3.1.17.4.5.3 Activity: Evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting

Objectives

The objective of this activity is to determine whether breccias tectonically emplaced on low-angle surfaces beveled across Paleozoic and younger strata are slide masses or near-surface parts of a detached upper plate; and if either, how they relate to postulated Quaternary detachment faulting.

Parameters

The parameters for this activity are

1. Distribution of breccia in the subsurface below Crater Flat.

2. Nature of fragmentation of the breccia.

3. Nature of basal contact of the breccia, including indicators of direction of relative movement.

Description

Breccias intersected in VH-2 (Carr and Parrish, 1985), located in the central part of Crater Flat between Red Cone and Black Cone, could be the lateral extension of similar material cropping out above Miocene volcanic rocks along the southern rim of Crater Flat. The breccias appear to be monolithologic, composed chiefly of Paleozoic carbonate rock, possibly derived from Bare Mountain, or from now-concealed outcrops of correlative strata east or south of Crater Flat. In this activity, recently completed detailed maps of the area within which the breccia crops out will be reviewed, as will cores from USW VH-1 and USW VH-2. Field work, limited to examination of outcrops along the southern rim of Crater Flat, will focus on evaluation of the internal character and nature of the basal contact of the breccia, and evaluation of potential sources of the breccia. The expected duration of this work is six months.

8.3.1.17.4.5.4 Activity: Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas

Objectives

The objective of this activity is to determine whether the basal contact of the Horse Spring Formation is depositional or tectonic; and if tectonic, to determine whether movement was Quaternary or older and, if Quaternary, to

determine the direction and amount of offset, the amount of extension, and the style of internal deformation of the upper plate.

Parameters

The parameters of this activity are geologic structure and stratigraphy.

Description

The contact between Miocene strata and Paleozoic strata crops out in the Specter Range and Camp Desert Rock areas. Preliminary reconnaissance indicates that in places the contact is tectonic and that the Miocene rocks locally form a detachment-fault-bounded upper plate. In this area, the basal Miocene (possible partly Oligocene) strata are dominantly lacustrine and fluvial deposits that become progressively more volcanogenic up-section. This activity includes conventional geologic mapping, with emphasis on structure of the Paleozoic-Miocene contact and on stratigraphy and basin analysis of the Miocene sedimentary deposits. Ashes intercalated in the section will be dated using potassium-argon dating methods. Although the primary area of interest is the Specter Range and Camp Desert Rock area, Miocene (Oligocene?) stratigraphy in other areas, including the Funeral Mountains and the Sheep Mountains, will be studied for purposes of comparison.

The stratigraphy and structure of the Horse Springs-Pavits Spring sequence in the Specter Range and Camp Desert Rock areas will be evaluated. The basal contact of the Horse Springs will be mapped in detail using conventional field methods, with field mapping annotated on 1:20,000 scale vertical black-and-white or color aerial photographs, and then compiled at 1:24,000 scale. Internal structure, stratigraphy, provenance, and age of the Horse Springs-Pavits Spring sequence will be investigated using conventional procedures. This activity is approximately 50 percent complete. The estimated duration of the remaining work is two years.

8.3.1.17.4.5.5 Activity: Evaluate the age of detachment faults using radiometric ages

Objectives

The objectives of this activity are to

1. Determine if the subdetachment basement and the Bare Mountain massif cooled through the blocking temperatures of zircon and appetite during the Quaternary period.

2. Determine if the Northern Amargosa core complex cooled through the blocking temperatures of muscovite and biotite during the Quaternary period.

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Parameters

The parameters of this activity are

1. Fission-track ages of zircon and apatite.
2. Location of dated samples with respect to detachment surfaces.
3. Potassium-argon dating method ages of muscovite and biotite.

Description

Rocks forming the Northern Amargosa core complex include lineated and mylonitized crystalline rocks, schist, and semi-schist. These rocks were probably deformed at or below the ductile-brittle transition zone (i.e., at crustal depths in excess of 5 km). Exposure of these rocks requires substantial tectonic denudation. The rate and timing of this denudation is not known. Structurally higher detachment faults cut volcanic rocks as young as 7.5 million years; possibly all the denudation took place since that time. The detachment faults are also possibly in part rejuvenated Mesozoic features; if so, much of the denudation is pre-Neogene. This activity is designed to determine if the mid-crustal rocks of the core complex cooled through the blocking temperatures of zircon or apatite during the Quaternary. The Precambrian and Paleozoic rocks of the Bare Mountain massif may form a detached plate structurally overlying the Northern Amargosa rocks. Fission-track dating of zircon and apatite from these rocks should constrain the age of denudation and cooling.

Fission-track dating of the northern Amargosa Desert core complex (area of high-grade lineated and mylonitized gneiss, schist, and semi-schist constituting the subdetachment basement) and the Bare Mountain massif (deformed Precambrian and Paleozoic strata). Samples will be collected from the central part of the northern Amargosa Desert core complex, from the shear zones marking the detachment surfaces between the core complex and the overlying plate of Paleozoic rocks, and from between that plate and the uppermost plate of Miocene volcanic rocks. At Bare Mountain, samples will be collected at low elevation from the deeply disected central part of the massif, from the shear zone marking the detachment at the northern end of the massif, and from the shear zone exposed at low elevation along the eastern front of the range. Zircon and apatite separated from these samples will be dated using standard fission-track dating procedures. This subactivity is approximately 25 percent complete. The estimated duration of this work is two years.

Potassium-argon dating of the northern Amargosa core complex (area of high-grade lineated and mylonitized gneiss, schist, and semi-schist constituting the subdetachment basement). Samples will be collected from the central part of the core complex, from suitable targets nearest the shear zone marking the detachment surface separating the core complex from structurally overlying plate of Paleozoic rocks, and from dike rocks within the uppermost plate that are truncated by the basal detachment of that plate. Suitable minerals (muscovite and biotite) will be separated from these samples and their age determined using standard potassium-argon dating techniques. This subactivity is currently under way and approximately 25 percent complete. The estimated duration of this work is two years.

8.3.1.17.4.6 Study: Quaternary faulting within the site area

Objectives

The objectives of this study are (1) to identify and characterize Quaternary faults that intersect or project toward the surface facility, the repository, or the controlled area and (2) to identify and characterize Quaternary faults at the site whose length or recurrence rate suggest a potential for future earthquakes with magnitude such that associated ground shaking could impact design or affect performance of the waste facility.

The site area is defined here as the rectangular 237 km^2 (91 mi^2) area encompassing the central Yucca Mountain block and its structural and physiographic boundaries (Fortymile Wash, Yucca Wash, Solitario Canyon, and the Stagecoach Road fault) (Figure 8.3.1.17-11). Except for the southwest-striking, possibly left-lateral Stagecoach Road fault at the south boundary of the site, Quaternary faults within the site are predominantly north-trending, west-dipping normal- or oblique-slip faults. Potentially significant representatives of this group include the Paintbrush Canyon, the Bow Ridge, the Windy Wash, and the Solitario Canyon faults. Northwest-trending lineaments and faults are also present, but no Quaternary movement on them has been recognized.

Activities planned for this study are to (1) evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain and (2) evaluate age and recurrence of movement on suspected and known Quaternary faults.

Knowledge of the age, length, width, displacement rate, and recurrence interval of the Quaternary faults is required to establish the rate of faulting within the site area during the Quaternary, and the potential for ground shaking and rupture. Included in this study are investigations of known faults, relying primarily on mapping and trenching of Quaternary materials intersected by the faults to establish which datums are cut, and the direction and amount of offset. Also included are investigations of the precise age of Quaternary datums using direct dating methods and mapping to establish relative ages.

Information from this study will be useful in estimating the probability of future rupture or ground shaking. Knowledge of the age, recurrence interval, and length of faults are required for this estimate; this information will be provided through parallel investigations described previously, and other studies of faulting.

Faulting at the surface facility is the subject of a separate study (Study 8.3.1.17.4.2, location and recency of faulting near prospective surface facilities). The Stagecoach Road fault, which intersects the southeastern boundary of the site area, is to be evaluated as part of Study 8.3.1.17.4.4 (Quaternary faulting proximal to the site within northeast-trending fault zones). Other geologic studies contributing to the evaluation of faults at the site include Study 8.3.1.17.4.3 (Quaternary faulting within 100 km of Yucca Mountain) and Study 8.3.1.17.4.5 (detachment faults at or proximal to Yucca Mountain).

Geophysical methods, including gravity surveys, magnetic surveys, and shallow reflection seismic surveys, will be used to establish continuity in the subsurface of fault segments observed at the surface at Yucca Mountain and vicinity and to evaluate the geometric relation of high-angle faults exposed at the surface to postulated detachment faults at depth. The geophysical work will be done as part of Study 8.3.1.17.4.7 (subsurface geometry and concealed extension of Quaternary faults at Yucca Mountain) and Activity 8.3.1.17.4.3.1 (evaluate crustal structure and subsurface expression of Quaternary faults in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane).

The characteristics to be evaluated include (1) fault length, (2) scarp height, (3) scarp morphology, (4) datums cut by fault and datums overlapping fault, (5) age of datums, (6) width of fault zone (including subsidiary fractures), (7) width and character of rupture zones, (8) fabric of sheared material within rupture zones, (9) age and character of mineral coatings and fracture fillings, (10) character of fracture surfaces, (11) gravity and magnetic expression of fault zones, (12) fault orientation at surface and at depth, (13) areal fault pattern, and (14) seismic expression of faults.

8.3.1.17.4.6.1 Activity: Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain

Objectives

The objectives of this activity are to

1. Synthesize and evaluate data pertaining to the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of faults within the site area.

2. Identify hitherto unrecognized Quaternary faults within the site area.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of faults.

2. Segmentation within individual faults.

3. Width of faults.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary faults within the site area.

5. Location, amount, and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

7. Lineaments with expression in surficial deposits.

Description

This activity focuses on the (1) synthesis and evaluation of data pertaining to the length, age, recurrence rate, and displacement rate of faults within the site area; (2) search of the site area for hitherto unrecognized Quaternary faults; and (3) determination of the distribution of surficial deposits within the site area. The principal vehicle for accomplishing these objectives is through the preparation of 1:24,000-scale maps of the site area, one with emphasis on Quaternary faults (to be compiled in this activity), and the other with emphasis on surficial deposits (to be compiled in Activity 8.3.1.5.1.4.2). The fault map will depict the location and extent of faults, as well as the amount and timing of displacement of Quaternary datums.

Calculation of rates of faulting requires delineation of areas within which recognition of pre-Holocene faulting would not be possible because of cover by Holocene deposits. To satisfy this requirement, Holocene deposits of Yucca Mountain will be mapped in detail at 1:24,000 scale.

Surficial deposits mapping of Yucca Mountain. In Activity 8.3.1.5.1.4.2, existing unpublished maps of surficial deposits at Yucca Mountain will be reviewed and upgraded, then compiled at a scale of 1:24,000. Surficial deposits along known Quaternary faults extending outside the site area will be mapped in conjunction with investigations of those specific faults. This subactivity is 25 percent complete. Duration of future work is estimated to be two years.

Quaternary fault map of Yucca Mountain. In this activity, Quaternary faults will be mapped at a scale of 1:24,000. Information will be compiled from existing geologic mapping (Scott and Bonk, 1984) and all Quaternary faults will be examined in the field to determine the age of youngest offset Quaternary deposits. Information on the age and recurrence intervals of individual faults will be added to the map from detailed trench studies described in Activity 8.3.1.17.4.6.2 (evaluate age and recurrence of movement on suspected and known Quaternary faults). The map will be periodically updated as other studies of faults are completed and released in final form when site characterization is completed.

8.3.1.17.4.6.2 Activity: Evaluate age and recurrence of movement on suspected and known Quaternary faults

Objectives

The objectives of this activity are to

1. Determine, through trenching and mapping, the location, spatial orientation, length, width, Quaternary recurrence rate, interconnections at the surface, and the location, amount, and nature of Qua-

ternary movement of the Paintbrush Canyon, Solitario Canyon, Windy Wash, and Ghost Dance faults, and other suspected or possible Quaternary faults within the site area.

2. Determine through trenching and dating, the age, amount and nature of offset, and the recurrence history of the Bow Ridge fault system and to evaluate that information in context with data contributed by other studies on the age, nature, and origin of fracture coatings and fissure fillings deposited within that zone.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of faults.

2. Segmentation within individual faults.

3. Width of faults.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary faults within the site area.

5. Location, amount, and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

7. Age of soils overlapping or displaced by faults.

8. Age of volcanic ashes intercalated in surficial deposits that overlap or are displaced by faults, or that have filled fissures within the fault zones.

Description

This activity is designed (1) to characterize, through geologic mapping and trenching, potentially significant Quaternary faults in the Yucca Mountain area and (2) to define interconnections between these faults at the surface. The Paintbrush Canyon, Bow Ridge, Windy Wash, and Solitario Canyon fault zones are zones where multiple episodes of Quaternary movement are suspected, hence have been singled out for special attention. Other suspected or possible Quaternary faults will be examined and their potential significance to design or performance issues will be evaluated. Trenching at locations to be determined may be required to assess the significance of these faults.

Large-scale (approximately 1:6000 scale), low-sun aerial photographs of suspected or known fault traces will be examined for evidence of ponded alluvium, shutterridges, brushlines, scarps, lineaments, and offset drainages. Recognition of these and other geomorphic features commonly associated with Quaternary faults will assist in focusing field studies on likely locations of faults and in locating trenches intended to intersect faults.

Determination of direction and amount of fault slip depends on identification of Quaternary datums and measurement of the displacement or offset of those datums by faults. Suitable datums include depositional contacts between distinctive soils, paleosols, debris flows, and alluvial deposits. These units are typically thin (0.1 to 2 m thick), subplanar and subhorizontal, thus the vertical component of displacement is in general easily recognized and measured in trenches excavated through these deposits where they are intersected by faults. Because the lateral extent of these deposits is commonly large, direct measurement of the strike-slip component of displacement is more difficult. Direct measurement is feasible, however, if intersections of faults with lateral boundaries or with clearly identifiable linear features (i.e., channels) within the surficial deposits can be found.

An objective of trench mapping planned as part of this and other studies of Quaternary faults is to determine the direction, amount, and age of slip on faults. Accordingly, at each trench locality, one or more trenches 20 to 50 m in length and 2 to 5 m in depth will be excavated across the fault zone. The location of fault(s) will be pinpointed, and the age and amount of the dip-slip component of displacement determined.

Where feasible, the direction and amount of the strike-slip component of slip will be established through mapping of Quaternary datums exposed in walls and floors of smaller subsidiary trenches excavated along the fault trace. These trenches will be progressively deepened and mapped, thus enabling development of a detailed three-dimensional representation of Quaternary structure and stratigraphy within the dimensions of each trench. If suitable markers are found, the direction and amount of fault slip can then be calculated.

Alternative procedures will also be used where circumstances dictate. These procedures allow calculation of total displacement, including the strike-slip component, provided that both the dip-slip component and the direction of fault slip are known. The direction can in rare cases be inferred from orientation of slickensides or, less precisely, from orientation of elongate pebbles and cobbles that have been rotated by shear within the fault zone. Slickensides are commonly present on bedrock fault surfaces, but their age can seldom be determined. Slickensides are rarely present on fault surfaces within the surficial deposits. These approaches to determination of total displacement are thus of limited utility. Offset of small stream channels and other geomorphic features intersected by Quaternary faults may also provide a measure of strike-slip displacement.

Determination of total fault displacement depends on exposing concealed intersections of faults with Quaternary datums. Because these features are irregularly distributed, their discovery is to a degree fortuitous. Thus, it is not expected that all trenches will reveal Quaternary datums or stratigraphic features that would permit calculation or measurement of total fault displacement. It thus may be necessary to excavate additional trenches at certain localities.

Dating of fault movement depends on accurate determination of the age of soils and other deposits cut by the fault and the age of vein materials deposited in fissures along the fault surface. These materials are to be

dated by uranium-trend, uranium-series, and varnish cation ratio methods, and the methods themselves will be calibrated by dating deposits of known age elsewhere within the immediate region. The ages of soils are to be established through quantitative chemical and physical comparison with soil development indexes established within Activity 8.3.1.5.1.4.1 (modeling of soil properties in the Yucca Mountain region).

Where exact ages are difficult to measure, relative ages can commonly be determined through stratigraphic correlation of deposits involved in the faulting. Stratigraphic correlation is planned at two scales; large-scale, detailed stratigraphic mapping of surficial deposits of Yucca Mountain (to be contributed by Activity 8.3.1.17.4.6.1--evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain), and medium-scale regional stratigraphic mapping of surficial deposits of the Beatty 1:100,000 quadrangle (to be contributed by Activity 8.3.1.17.4.3.2--evaluate Quaternary faults within 100 km of Yucca Mountain).

Volcanic ashes are commonly intercalated within the Quaternary deposits, as at Busted Butte. Their identification, correlation, and dating depends on chemical fingerprinting and recognition of the source eruptions of the ash, which typically are volcanic centers in the eastern Sierra Nevada, Yellowstone, or Cascades. Volcanic ashes from the Yucca Mountain area will be collected and chemically analyzed, and the analyses compared with analyses of reference samples from the western United States.

Mapping and analysis of offset of Quaternary datums in trenches and outcrop (Paintbrush Canyon fault zone). Quaternary deposits and faults within and proximal to the Paintbrush Canyon fault zone, including the Busted Butte area will be mapped using conventional field methods. Existing trenches (see Figure 8.3.1.17-11 for location) across fault traces and scarps will be supplemented with two to four additional trenches in the Busted Butte area. The distribution of Quaternary datums, rupture zones, fracture zones, and fracture fillings in trenches will be mapped. Datums will be sampled and their age determined through appropriate procedures, including uranium-trend, uranium-series, soil development, and ash correlation. The work is 25 percent completed, and the duration of the future work is estimated to be two years.

Analysis of offset of Quaternary datums in trenches (Bow Ridge fault system, Yucca Mountain area). The distribution of Quaternary datums, rupture zones, fracture zones, and fracture and fissure fillings will be mapped at large scale in trenches excavated across the fault zone. The orientation of fractures and slickensides for paleostress determination will be recorded. Age of datums, fracture coatings and fissure fillings will be determined through appropriate procedures, including uranium-trend, uranium-series, and soil development. Vein material and fracture coatings will be identified using standard petrographic techniques, x-ray diffraction, x-ray fluorescence, and wet-chemical analyses. Information on the carbon and oxygen isotopes in the carbonate in these materials will be provided by Activity 8.3.1.5.2.1.5 (studies of calcite and opaline-silica vein deposits). The fault has been trenched at two locations (Figure 8.3.1.17-11), and logging of these trenches is 50 percent completed. Provided suitable locations can be found, one or two additional trenches may be excavated. The duration of the future work is estimated to be one year.

Mapping and analysis of offset of Quaternary datums in trenches and outcrop (Windy Wash fault zone). Quaternary deposits and faults within and proximal to the Windy Wash fault zone will be mapped using conventional field methods. Fault traces and scarps will be trenched. The distribution of Quaternary datums, rupture zones, fracture zones, and fracture fillings in trenches will be mapped. Datums will be sampled and their age determined through appropriate procedures, including uranium-trend, uranium-series, thermoluminescence, soil development, and ash correlation. Two trenches have been excavated and logged (Figure 8.3.1.17-11). Additional trenching at these same locations is planned to define the strike-slip component of offset. The duration of the future work is estimated to be one year.

Mapping and analysis of offset of Quaternary datums in trenches and outcrop (Ghost Dance fault zone). Quaternary deposits and faults within and proximal to the Ghost Dance fault zone will be mapped using conventional field methods.

The distribution of Quaternary datums, rupture zones, fracture zones, and fracture and fissure fillings will be mapped at large scale in trenches excavated across the fault zone. The orientation of fractures and slickensides for paleostress determination will be recorded. Age of datums, fracture coatings, and fissure fillings will be determined through appropriate procedures, including uranium-trend, uranium-series, soil development, and thermoluminescence. Five trenches have been excavated along or near the fault zone without revealing definitive data on Quaternary movement. Provided suitable locations can be found, two additional trenches are planned. The duration of the future work is estimated to be one year.

Mapping and analysis of offset of Quaternary datums in trenches and outcrop (Solitario Canyon fault zone). Quaternary deposits and faults within and proximal to the Solitario Canyon fault zone will be mapped using conventional field methods.

The distribution of Quaternary datums, rupture zones, fracture zones, and fracture and fissure fillings will be mapped at large scale in trenches excavated across the fault zone. The orientation of fractures and slickensides for paleostress determination will be recorded. Age of datums, fracture coatings, and fissure fillings will be determined through appropriate procedures, including uranium-trend, uranium-series, soil development, and thermoluminescence. Six trenches have been excavated across the trace of the fault (Figure 8.3.1.17-11). Provided suitable locations can be found, one to two additional trenches will be excavated. The duration of the future work is estimated to be six months.

Uranium-trend, uranium-series, and varnish cation ratio dating of Quaternary datums and fracture fillings. Samples of alluvium, colluvium, eolian deposits, and fracture fillings will be collected. Uranium-trend (open-system) methods will be used to date sediments. Carbonate-rich fracture fillings will be dated by uranium-series (closed-system) methods. Rock varnish will be dated by the cation-ratio method.

The dating effort will be focused on (1) collecting and analyzing samples of units of unknown age at Yucca Mountain and vicinity that are cut by or overlap faults and also are key marker beds within the Beatty 1:100,000

quadrangle and (2) collecting and analyzing samples of units of known age within the region to calibrate the method. This subactivity will be conducted on an as-needed basis to support the analyses in this activity.

Quaternary volcanic ash correlation and dating. Glass shards from bulk samples of ash intercalated in Quaternary deposits cut by or overlapping Quaternary faults will be separated. The glass will be chemically analyzed using microprobe neutron activation and x-ray fluorescence procedures. Analytical data will be compared with that of known and well-dated ashes within the region. Biotite, muscovite, and zircon from bulk samples of ashes intercalated in Quaternary and older deposits will be dated with potassium-argon dating method or fission-track techniques, as appropriate, where these minerals are present in the sample. This subactivity will be conducted on an as-needed basis to support the analyses in this activity.

8.3.1.17.4.7 Study: Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain

The objectives of this study are to (1) provide data on distribution of mass, magnetic gradients, geoelectric features, and seismic velocities and reflections that will aid in evaluating the continuity of Quaternary faults where concealed by Holocene and late Pleistocene surficial deposits; (2) evaluate that data and its limitations; and (3) evaluate the possibility that Quaternary faults exposed as high-angle faults at the site continue to depth as planar, high-angle faults, or alternatively, flatten at depth and merge with one or more low-angle faults. The geophysical methods used in this study measure rock properties (mass, magnetism, electrical resistivity, gamma radiation), sensing faults as discontinuities in those properties. The same methods are therefore useful in solving the converse problem, determination of continuity of rock units at the site. A third objective, then, is to provide information on continuity of rock units within the repository and controlled area to assist the investigation of site geology (Section 8.3.1.4).

Activities planned for this study include (1) evaluation of intermediate depth (2 to 3 km) reflection and refraction methods and planning of potential application of these methods at the site; (2) detailed gravity survey of the site; (3) detailed aeromagnetic survey of the site; (4) detailed ground magnetic surveys of specific features at the site; (5) evaluation of surface geoelectric methods and planning of potential applications of these methods at the site; (6) evaluation of methods to detect buried faults using gamma ray measurements, and conduct an airborne gamma-ray survey of the site; (7) evaluation of thermal infrared methods and planning for potential applications of these methods at the site; and (8) shallow seismic reflection (mini-sosie) survey of selected structures at and proximal to the site. These and other geophysical methods being applied in other studies that contribute to site and regional tectonic and geologic problems are listed in Tables 8.3.1.17-7 and -8. Synthesis of the geophysical data is to be done in Study 8.3.1.17.4.12 (tectonic models and synthesis).

The activities planned as part of this study will be reviewed by Activity 8.3.1.4.2.1.6 before any surveys are started. Activity 8.3.1.4.2.1.6 will be responsible for reviewing and integrating the planned geophysical data gathering activities for all studies and programs. Some surveys involve feasibility tests and decision points before implementation. Before planned geophysical surveys are conducted, Activity 8.3.1.4.2.1.6 will review the results of any feasibility tests or past surveys to estimate the likelihood that useful data will be generated by the planned effort. Activity 8.3.1.4.2.1.6 will also review the location, scheduling, techniques, and objectives of the planned survey to determine if the objectives of this activity and activities in other programs that also require this data are being met. Locations of surveys and data collection techniques will not be finalized until the review by Activity 8.3.1.4.2.1.6 is complete. Final plans and changes will be reported in SCP progress reports and study plans.

8.3.1.17.4.7.1 Activity: Evaluate intermediate depth (2 to 3 km) reflection and refraction methods and plan potential application of these methods within the site area

Objectives

The objectives of this activity are to (1) evaluate previous attempts to use seismic refraction and reflection methods at the site, (2) evaluate technology currently available, (3) evaluate potential contribution to information on velocity structure and on subsurface geometry of faults, (4) review potential applications of these methods to Yucca Mountain Project needs, and (5) if appropriate, plan applications of these methods at the site.

Parameters

Parameters for this activity are

1. Seismologic reflections and discontinuities.
2. Seismic velocity structure.

Description

A previous attempt to apply reflection seismology using Vibroseis energy source at Yucca Mountain failed to produce useful results (McGovern, 1983). More recent surveys at Mid Valley using an air gun energy source produced excellent reflections to 1.5 s (two-way travel time), resulting in satisfactory resolution of faults and thickness and inclination of subsurface units. These results will be reviewed and their potential application to the site evaluated. If appropriate, a reflection and refraction survey of the site will be planned. The expected duration of this activity is three months.

This is a planning activity only. Decision to proceed with actual application of these methods is contingent on results of the evaluation, technical peer review and review of potential applications to Yucca Mountain Project needs.

8.3.1.17.4.7.2 Activity: Detailed gravity survey of the site area

Objectives

The objectives of this activity are to measure variations in mass of near-surface strata and surficial deposits, and to infer from this information the location of faults and continuity of rock units within the site.

Parameters

The parameters for this activity are gravity gradients and anomalies at the site.

Description

The gravity maps of the site currently available are based on gravity observations that are too widely spaced to be useful in discrimination of faults or demonstration of continuity of rock units. In this activity, a 1:24,000-scale map of the site will be constructed from gravity observation at stations spaced 200 ft apart along east-west lines spaced 500 ft apart (where topography permits). The expected duration of this activity is one year.

8.3.1.17.4.7.3 Activity: Detailed aeromagnetic survey of the site area

Objectives

The objectives of this activity are to measure variations in rock magnetism of surface strata and surficial deposits and to infer from this information the location of faults and continuity of rock units within the site.

Parameters

The parameters for this activity are magnetic gradients and anomalies at the site.

Description

The aeromagnetic maps of the site currently available are based on measurement of magnetic field along flight lines at one-fourth-mile spacing. These observations are too widely spaced to resolve ambiguities in fault continuity or to demonstrate the continuity of rock units. In this activity, a 1:12,000-scale map of the site will be constructed from measurement of the magnetic field along east-west flight lines spaced one-sixteenth mile apart. The survey will be draped over topography, maintaining a nominal terrain clearance of 400 ft. The expected duration of this activity is one year.

8.3.1.17.4.7.4 Activity: Detailed ground magnetic survey of specific features within the site area

Objectives

The objectives of this activity are (1) to measure variations in rock magnetism of surface strata and surficial deposits in the vicinity of specific faults, the shaft and surface facilities, drillholes, and aeromagnetic anomalies and (2) to infer from this information the location of faults and continuity of rock units at these locations.

Parameters

The parameters for this activity are magnetic gradients and anomalies at specified locations.

Description

In this activity, the magnetic field in the vicinity of specific features (Figure 8.3.1.4-9) will be measured from truck-mounted or hand-carried magnetometers. Observations will be semicontinuous (10- to 20-ft intervals). The classes of features at which these measurements will be made include (1) known and inferred structures, (2) vicinity of drillholes, (3) vicinity of shaft and surface facilities, and (4) vicinity of anomalies detected through aeromagnetic surveying (Activity 8.3.1.17.4.7.3). Not all such features will be surveyed. The number and location of those selected for investigation using this method will be determined by principal investigators as the need arises through evaluation of geologic and geophysical mapping.

8.3.1.17.4.7.5 Activity: Evaluate surface geoelectric methods and plan potential applications of these methods within the site area

Objectives

The objectives of this activity are to (1) evaluate previous attempts to use surface geoelectric methods at the site, (2) evaluate technology currently available, (3) evaluate the potential contribution of these methods to definition of subsurface geometry of faults, (4) review potential applications of these methods to Yucca Mountain Project needs, and (5) if appropriate, plan future applications of these methods at the site.

Parameters

The parameters for this activity are

1. Sensitivity and resolution of geoelectric field measurements.

2. Correlation of geoelectric measurements with faults and rock properties.

Description

Surface-based geoelectric investigations, including airborne electromagetic slingram, VLF, DC resistivity, electromagnetic soundings, tensor audio magnetotellurics, and telluric profiling have been applied to site and regional geologic problems (refer to the references in Table 8.3.1.17-7 and -8). Results of these investigations and the status of current technology will be reviewed and their potential application to structural and stratigraphic problems at the site evaluated. If appropriate, surface-based geoelectric investigations at site will be planned. Expected duration of this activity is three months.

This is a planning activity only. The decision to proceed with actual application of these methods is contingent on the results of the evaluation and a review of potential applications to Yucca Mountain Project needs.

8.3.1.17.4.7.6 Activity: Evaluate methods to detect buried faults using gamma-ray measurements, and plan potential application of these methods within the site area

Objectives

The objectives of this activity are (1)to evaluate the feasibility of using surface and airborne gamma-ray measurements to detect and discriminate faults at the site, (2) to review potential applications of these methods to Project needs, and (3) if appropriate, conduct an airborne radiometric survey for that purpose as an adjunct to the aeromagnetic survey of the site.

Parameters

The parameters for this activity are

1. Sensitivity and resolution of surface and airborne gamma-ray measurements.

2. Correlation of gamma-ray gradients and anomalies with faults and rock properties.

Description

The principal natural sources of gamma radiation are uranium, thorium, potassium, and radon gas. Because gamma-ray measurements (aerial or ground) detect gamma rays from the uppermost 50 cm of rock and soil, to be detectable buried faults must have a near-surface expression that is reflected in the near-surface distribution of the natural radioelements. In the site area, the Tiva Canyon and Topopah Spring members are potassium- and thorium-rich volcanic rocks. Gamma-ray spectral logs show typically 4 percent potassium, 6 ppm uranium and 30 ppm thorium for these rock units. Reconnaissance airborne gamma-ray surveys show that colluvium derived from these volcanic rocks, as along Fortymile Wash, has essentially the same signature as the rocks themselves.

To be detectable, buried faults must be reflected by near-surface radioelement distributions, perhaps arising through migration of uranium or potassium along the fault zone through percolation of meteoric water, or through percolation of radon from the fault to the surface in sufficient quantities to be detected by gamma-ray measurements.

In this activity, the possibility that buried faults can be detected will be evaluated through measurement of gamma rays using portable quantitatively calibrated gamma-ray spectrometers along several short (100 m long) traverses crossing buried extensions of the Paintbrush Canyon, Bow Ridge, Windy Wash, and Stagecoach Road faults. If results of these tests so warrant, an airborne radiometric survey will be conducted as an adjunct to the detailed aeromagnetic survey. Expected duration of this activity is three months.

This is a planning activity only. The decision to proceed with actual application of these methods is contingent on the results of the evaluation and a review of potential applications to Yucca Mountain Project needs.

8.3.1.17.4.7.7 Activity: Evaluate thermal infrared methods and plan potential applications of these methods within the site area

Objectives

The objectives of this activity are to evaluate current thermal infrared survey technology, evaluate its potential application to remote mapping of fractures and faults at Yucca Mountain, review potential applications of these methods to Project needs, and if appropriate, plan future applications of these methods at the site.

Parameters

The parameters for this activity are

1. Sensitivity and resolution of remote thermal infrared survey methods.

2. Correlation of thermal infrared signature with faults and fractures.

Description

Fractures and faults at Yucca Mountain are potential conduits for percolation of meteoric waters. Surface temperature variation associated with differing moisture content of near-surface material is detectable through thermal imaging from aircraft or satellites, and hence it may be possible to map the fault and fracture network at Yucca Mountain using remote thermal infrared sensing methods. In this activity, existing technology and its application to detection of faults and fractures, and water percolation pattern at the site will be evaluated. If appropriate, application of remote thermal infrared techniques to these problems will be planned. The expected duration of this activity is three months.

This is a planning activity only. The decision to proceed with the actual application of these methods is contingent on results of the evaluation and review of potential applications to Yucca Mountain Project needs.

8.3.1.17.4.7.8 Activity: Evaluate shallow seismic reflection (mini-sosie) methods and, if appropriate, conduct surveys of selected structures at and proximal to the site area

Objectives

The objectives of this activity are to evaluate the subsurface configuration of selected Quaternary faults and the lateral continuity and inclination of key beds within the Miocene volcanic sequence at the northeastern, eastern, and southwestern parts of the site area.

Parameters

The parameters for this activity are

1. Seismic reflections in the vicinity of selected faults.

2. Seismic reflections in the northeastern, eastern, and southwestern parts of the site.

3. Seismic velocity structure at and proximal to the site.

Description

Shallow seismic reflection (mini-sosie) has proved to be a rapid and economical method of defining subsurface geometry within the uppermost 1 km of the crust in some areas. However, previous attempts to use the method in the vicinity of the site have produced somewhat ambiguous results. The method has previously been used in defining the subsurface extent of the Beatty scarp and the Rock Valley fault, and field work has been completed on traverses crossing the Bare Mountain range front fault, and the central part of Crater Flat (Figure 8.3.1.4-8).

Nine additional profiles have been proposed (Figure 8.3.1.4-8), all but one of which are within the site area. Two of these (Jackass Flats and Fran Ridge traverses) are designated as preliminary traverses. Each begins and ends at drillholes, providing opportunity to tie the reflections to known beds. If acceptable results are achieved in the preliminary tests, the remaining profiles will be run.

The method uses portable instruments, 9.1-m source point (data stacked at common midpoints every 4.6 m at 12-fold, or every 9.1 m at 24-fold) with 12 geophones per group. The energy source is a battery of hand-held construction tampers.

This is an activity to evaluate the suitability of the technique. The expected duration of this activity is three months. The decision to proceed with full-scale application of the method is contingent on results of the evaluation.

8.3.1.17.4.8 Study: Stress field within and proximal to the site area

Objectives

The primary objective of this study is to provide data on the ambient stress at the site and its immediate vicinity that will aid in evaluating (1) the most favored orientation and nature of future movement on faults within the site area, (2) the stability of potential pathways for radionuclide travel controlled by or related to fracture aperture, (3) the stability of mined excavations, (4) the response of the rock mass to thermal loading, and (5) the applicability of tectonic models. A secondary objective is to evaluate the potential relevance of paleostress data to prediction of future stress orientations.

For convenience, the larger and smaller components of the principal stresses in the horizontal plane are referred to as S_H and S_h, respectively, and the component of the principal stresses in the vertical plane as S_v. At Yucca Mountain, the average direction S_h is approximately N.60°W., on the basis of in situ stress determinations (Stock et al., 1985). This direction is in reasonable agreement with the average orientation of the stress field in the Yucca Mountain region based on focal plane solutions of recent earthquakes and on in situ stress determinations at Rainier Mesa. However, to the west, in the Coso Volcanic Field, the average direction of S_h is approximately east-west (Walter and Weaver, 1980). The exact location and nature of the transition from N.60°W. at Yucca Mountain to east-west in the area west of Death Valley is unknown.

The in situ measurements at Yucca Mountain indicate the $S_h < S_H < S_v$, with the magnitude of S_h near the failure criterion for dip-slip failure on N.30°E.-trending faults and so low that the aperture of favorably oriented fractures is sensitive to hydrostatic pressure of the fluid column in boreholes (Ellis and Swolfs, 1983). However, most of the focal-plane solutions of recent earthquakes within the immediate region of Yucca Mountain indicate predominantly strike-slip movement on north-trending faults, suggesting that $S_h < S_v < S_H$. Additional study is required to verify the compatibility or lack of it for these two data sets and to evaluate their potentially conflicting implications pertaining to rupture, ground motion, and tectonic effects on hydrology.

Possibly the in situ measurements are only characteristic of a shallow part of the lithospheric crust, a part that is decoupled from deeper parts by one or more detachment faults. Such a zone of decoupling may distinguish active from inactive detachment faults. It follows that subsurface extensions of detachment faults forming the contact between Miocene and Paleozoic rocks north of Mercury, and at the northern flank of Bare Mountain, and at the southern edge of the Bullfrog Hills may be zones of mechanical decoupling between upper plate and lower plates. If so, stress regimes above and below

such zones may be quite distinct; this possibility will be evaluated in Activity 8.3.1.17.4.8.4

In addition to the possible complications of the regional stress pattern arising from the potential presence of detached plates, other complications may result from the apparent organization of the upper crust as a mosaic of structurally distinct blocks. The Yucca Mountain region appears to be an aggregation of such blocks, including for example, the blocks corresponding to the northern Amargosa Desert, the Bare Mountain, the Yucca Mountain, and the Little Skull Mountain areas. The orientation and degree of development of Neogene and Quaternary structures appear to vary from block to block.

The structural grain of some blocks, such as Little Skull Mountain, appears to be rotated 30 degrees clockwise from the regional trend, a feature known to be characteristic of bedrock terranes adjacent to the Walker Lane. The appearance of rotation probably reflects both a physical rotation about a vertical axis (the oroflexural bending of Albers, 1967) and, during the time the blocks were actively rotating, sharp curvature of stress trajectories crossing or curving into the Walker Lane. Investigation of ambient stress and paleostress at Yucca Mountain and vicinity should help evaluate the applicability of these and other tectonic models to the neotectonics of the site.

Activities planned for this study include (1) an evaluation of the effectiveness of shallow borehole hydrofrac and triaxial strain recovery methods for the determination of in situ stress and their potential application to determination of the stress field proximal to the site, (2) an evaluation of the present stress field at the site, (3) an evaluation of the published and unpublished data on paleostress orientation at and proximal to the site and an assessment of the relevance of this data to future stress orientations, and (4) an evaluation of theoretical stress distributions associated with potential tectonic settings (e.g., wrench fault, normal fault, and detachment fault setting) of the site.

Rationalization of the stress and stain at the site in relation to the plate-tectonic setting and applicable tectonic models will be performed in Study 8.3.1.17.4.12 (regional tectonic models and synthesis). In situ stress determinations will also be made in the exploratory shaft facility. Refer to Activity 8.3.1.4.3.1.1 for a description of these tests. Paleostress indicators in the form of fractures and slickenside lineations will also be evaluated in the exploratory shaft facility. Refer to Activity 8.3.1.4.2.2.4 for a description of this activity.

8.3.1.17.4.8.1 Activity: Evaluate present stress field within the site area

Objectives

The objective of this activity is to measure the vertical and lateral variation of in situ stress at the site. These measurements will include the variation of in situ stress within the vicinity of the steep hydrologic

gradient in the northwestern section of the site area, and in one borehole that is expected to intersect a postulated detachment fault and subjacent Paleozoic rocks below Yucca Mountain.

Parameters

The parameters for this procedure are

1. The magnitude of in situ stress.
2. The orientation of induced fractures and borehole breakouts.

Description

In situ stress measurements at the site have previously been made in drillholes USW G-1, USW G-2, USW G-3, and UE-25p#1 (Figure 8.3.1.4-5). These measurements suggest that the least principal horizontal stress (S_h) is oriented about N.60°W., and that at depths up to one kilometer $S_h < S_H < S_v$, indicating a normal faulting stress regime. On the basis of focal plane solutions for recent earthquakes, however, the deep (greater than 1-km depth) stress field in the region encompassing the site is believed to be characterized by strike-slip faulting. This is contrary to the general observation, reported in Chapter 1, that the stress field in the Great Basin province is characterized by a strike-slip regime near the surface and a normal faulting regime at depth (Vetter and Ryall, 1983).

This activity is designed to contribute to the characterization of in situ stress at the site through hydrofrac measurements and analysis of borehole breakouts in three boreholes (USW G-5, USW G-6 and USW G-7, Figure 8.3.1.4-5) to be drilled for other purposes. It is expected that borehole G-7 will pass through a postulated detachment and terminate in subjacent Paleozoic rocks. The in situ stress will also be measured in a fourth borehole, to be drilled for other purposes within the area of the steep hydrologic gradient in the northwestern sector of the site area, provided that these measurements will not compromise proposed hydrologic tests within this borehole. The duration is contingent on drilling schedule for these holes, but is estimated to be one to two years. Vertical variation of in situ stress will be evaluated through collection of hydrofrac measurements at 6 to 10 depth intervals within each well including, if feasible, one or more intervals within Paleozoic rocks.

8.3.1.17.4.8.2 Activity: Evaluate and test shallow borehole hydrofrac and triaxial strain recovery methods for the determination of in situ stress, and if appropriate, plan potential application of these methods within and proximal to the site

Objectives

The objectives of this activity are to

1. Evaluate the usefulness of shallow borehole hydrofrac and triaxial strain recovery methods for the determination of in situ stress.

2. Measure the lateral variation of in situ stress in areas proximal to the site.

3. Measure vertical variation in stress above and below the possible detachment between Miocene and Paleozoic rocks east of Yucca Mountain in the Little Skull Mountain or Striped Hills area.

Parameters

The parameters of this activity are

1. Magnitude of in situ stress.
2. Orientation of induced fractures and borehole breakouts.
3. Triaxial strain in oriented samples of drill core.

Description

The orientation and magnitude of the principal stresses at any particular place are apt to vary from the regional average as a result of location with respect to boundaries of structural blocks, zones of active dislocation, and possible differences in end loads and tractive forces at the base of the crustal blocks. For this reason, it is possible that in situ stress determinations could contain considerable information about the manner in which the upper crust in the vicinity of the site is deforming. However, the in situ stress at any point is also influenced by local elastic properties, topographic effects, local discontinuities, and previous history of deformation. The hydrofrac measurements must therefore be interpreted with caution, and several measurements at varying depth must be made to be confident of the result.

This activity is designed to examine the vertical variation in stress at two drillholes, one within the site area, the other east of the site in the Little Skull Mountain or Striped Hills area. Measurements at the site, using a shallow borehole (drilled for other purposes) will help evaluate existing hydrofrac measurements of in situ stress. Measurements at a location in the Little Skull Mountain or Striped Hills areas, using a shallow borehole (to be drilled for this purpose) will help evaluate vertical variation in stress near a possible detachment fault that projects toward Yucca Mountain in the subsurface. Locations of the two drillholes will be determined considering the structural and Quaternary tectonic setting of Yucca Mountain.

The two drillholes, 500 to 800 ft (165 to 260 m) deep, are to be continuously cored. Hydrofrac measurements will use standard procedures. The cores will be sampled at regular intervals, and elastic constants of the samples measured. In addition, the in situ stress in the cored intervals will be evaluated using the three-axis strain recovery technique. These measurements are intended to test the utility of the technique in the Yucca Mountain environment and evaluate whether additional in situ stress measurements are necessary to meet programmatic needs.

If the evaluation is favorable, a program to use these techniques to evaluate in situ stress in the structural blocks adjacent to the site will be planned.

This is an evaluation and planning activity only. Expected duration is six months. Larger scale application of the methods will depend on the results of the evaluation.

8.3.1.17.4.8.3 Activity: Evaluate published and unpublished data on paleostress orientation at and proximal to the site and assess the relevance of these data to Quaternary tectonics

Objectives

The objective of this activity is to establish successive orientations of principal horizontal components of stress in the vicinity of Yucca Mountain to evaluate the stability of stress through time and to provide a partial basis for determining the duration of the contemporary tectonic framework.

Parameters

The parameters of this activity are the orientation and age of paleostress indicators.

Description

Statistical summaries of movement directions of conjugate fault sets may be uniquely related to orientation and relative magnitude of principal stresses at the time of faulting. By noting relative ages of different fault sets, a sequential picture of changing stress orientation with time may be developed for a given area. The method has utility where ages of fault sets may be established within narrow limits, as is generally possible for faults cutting the Miocene and younger rocks at Yucca Mountain and vicinity. This activity seeks to relate these faults to the stress regime in which they were formed and to compare that stress regime with the present in situ stress field.

The orientation of fractures and associated slickensides in Miocene or younger rock has been studied in the south-central and southeastern parts of the Nevada Test Site by Frizzell and Zoback (1987) and by Dockery Ander (1984). These data will be merged with data being produced as a byproduct of shaft and mapping activities and the orientation of paleostress deduced using computer analysis.

Surface expressions of fracture displacements will be integrated with similar determinations obtained in subsurface core and exploratory shaft facility evaluations (Activity 8.3.1.4.2.2.4). Duration of this activity is expected to be three to six months.

8.3.1.17.4.8.4 Activity: Evaluate theoretical stress distributions associated with potential tectonic settings (wrench fault, normal fault, detachment fault setting, etc.) of the site

Objectives

The objectives of this activity are (1) to evaluate possible three-dimensional orientations of stress trajectories associated with potential tectonic settings of Yucca Mountain, including wrench fault, normal fault, and detachment fault tectonic models; (2) to evaluate the degree to which in situ stress data from Yucca Mountain and vicinity constrains applicability of these tectonic models to neotectonics of the site; and (3) to evaluate the potential relation between fracture aperture and in situ stress at Yucca Mountain.

Parameters

The parameters for this activity are

1. Measured magnitudes of principal stresses.
2. Measured orientation of stress trajectories.
3. Measured orientation and aperture of fractures at Yucca Mountain.

Description

Crustal stress measurements at Yucca Mountain will be compared with theoretical patterns, such as stress trajectory maps, unique to wrench-fault, detachment-fault, and normal-fault tectonic models to help assess the applicability of these models or their various permutations to the site. This activity will evaluate possible theoretical stress patterns associated with these and other tectonic models. The theoretical patterns will be chiefly drawn from published sources (e.g., Berger and Johnson, 1980; 1982; Savage and Smith, 1986) but modified where feasible to parallel potential geologic settings of the site. For example, stress distribution within the upper plate of a detachment fault is somewhat analogous to stress distribution within a glacier or a landslide. Mathematical solutions worked out for the case of landslide by Savage and Smith (1986) will be modified to fit a detachment analogue.

This activity will also evaluate the degree to which the data on stress distribution at Yucca Mountain and vicinity can be rationalized with one or more of the theoretical stress patterns. As part of this evaluation, consideration will be given to the inherent uncertainties in the degree to which the in situ measurements and focal plane solutions represent actual in situ stress at the point of measurement, and the degree to which that point represents some larger volume of rock. Consideration will also be given to potential effects of nontectonic factors, including topography and anisotropic elastic constants. The relation between fracture aperture, orientation, and in situ stress at Yucca Mountain will also be evaluated using either theoretical or empirical methods, as appropriate. Data on fracture aperture and orientation will be supplied by other activities (e.g., Activity 8.3.1.4.2.2.2). Results of this evaluation will be used by Activity

8.3.1.8.3.3.3 (assessment of the effects of stress or strain on hyrologic properties of the rock mass). The estimated duration of this activity is six months.

8.3.1.17.4.9 Study: Tectonic geomorphology of the Yucca Mountain region

Objectives

The objectives of this study are (1) to document the magnitude of Quaternary uplift and subsidence within the Yucca Mountain region and (2) to evaluate regional variation in the nature and intensity of Quaternary faulting.

The major premise of this study is that certain tectonic processes operating during the Quaternary have influenced the development of contemporary geomorphic features; hence, those features record information on the nature, rate, and localization of those processes. Those processes include faulting, uplift, and subsidence. Consideration of regional topography indicates that some areas within the Yucca Mountain region appear to be in the youthful stage of geomorphic development, with deeply incised drainages, V-shaped canyons, and steep mountain fronts. Other areas, in contrast, are characterized by worn-down remnants of old mountains, that are laced with alluviated washes reaching nearly to their summits. This could imply that some areas were, and perhaps still are, actively rising and others subsiding during late Pliocene and Quaternary time.

Planned investigations focus on evaluation of relative rates and location of uplift and subsidence (1) through definition of surfaces of long-lived stability, as gauged by age and degree of development of desert varnish; (2) through identification of subregional variation in range sinuosity and fan development; and (3) through evaluation of the development of the Amargosa drainage system. Variation in the nature and intensity of Quaternary faulting in the area within 100 km of Yucca Mountain will be evaluated through morphometric and morphologic analysis.

The data derived through this study will assist in evaluating the degree to which certain potentially adverse conditions are or are not present at the site and its immediate vicinity, including structural deformation such as uplift, subsidence, folding, or faulting during the Quaternary Period. The data will also be used to assist in formulation and validation of tectonic models (Study 8.3.1.17.4.12). Validation includes reconciling structural deformation within the site area with that outside the area, but within 100 km of the site.

The activities of this study are to (1) evaluate age and extent of tectonically stable areas at and near Yucca Mountain, (2) evaluate extent of areas of late Pleistocene and Holocene uplift and subsidence at and near Yucca Mountain, and (3) evaluate variation in the nature and intensity of Quaternary faulting in the area within 100 km of Yucca Mountain through morphometric and morphologic analysis.

8.3.1.17.4.9.1 Activity: Evaluate age and extent of tectonically stable areas at and near Yucca Mountain

Objectives

The objective of this activity is to evaluate the age and areal distribution of surfaces that appear to have been tectonically stable at and near Yucca Mountain through determination of the distribution and age of surfaces with substantial coatings of desert varnish.

Parameters

The parameters for this activity are the age and distribution of desert varnish.

Description

The age and thickness of coatings of desert varnish are a measure of prolonged exposure, which in itself is a measure of stability. The rock-varnish dating technique has recently been applied to dating of Late Cenozoic rocks, surficial deposits, and geologic surfaces in the Yucca Mountain region. Research at Los Alamos National Laboratory has shown that energy dispersive analysis by the scanning electron microscope is a very effective technique to determine the relative abundances of minor elements in rock varnish.

The age of rock varnish has been shown to influence strongly the ratio between soluble and insoluble cations (Dorn, 1983). The rock-varnish dating curve for the Nevada Test Site (NTS) has been extended to include older deposits and calibrated to several independently dated deposits. Yet to be completed are direct comparisons with the Dorn technique, study of chemical variations in varnish, and variation of cation ratios with varnish depth, and study of significance of varnish color (red versus black) on cation ratio.

The technique will be used to date surficial deposits and materials at Yucca Mountain and vicinity that are not datable by conventional isotopic techniques, including faulted surfaces, alluvial fans, stream terraces, pediment surfaces, bedrock surfaces, and hillslope deposits.

The application planned in this activity uses the cation-ratio dating technique to date "old" surfaces coated with desert varnish. Such surfaces are thought to be tectonically more stable than other areas where accumulation of desert varnish is precluded or interrupted because of rapid dissection or alluviation. Desert varnish has been shown to be highly reflective, producing bright spots in Thematic Mapper V satellite imagery. Hence, it is feasible to map such surfaces using the satellite imagery produced as a by-product of another activity (Activity 8.3.1.17.4.3.5).

Calibration of the cation-ratio dating technique (diffused-beam scanning electron microscope procedure) will be achieved by measuring cation ratios of rock varnish at well-dated localities in the NTS region. Cation ratios of samples from within the NTS will be compared with curves showing regional correlation of age with cation ratio. Surfaces with substantial coatings of desert varnish, as shown by maps produced from Thematic Mapper V satellite

imagery, will be dated. Desert varnish dates on geomorphic surfaces will be compared with the geomorphic development of each surface as determined through morphometric analysis (Dohrenwand, 1987). This activity is estimated to be 10 percent complete. The estimated future duration is two years.

8.3.1.17.4.9.2 Activity: Evaluate extent of areas of Quaternary uplift and subsidence at and near Yucca Mountain

Objectives

The objectives of this activity are to

1. Identify areas of rapid uplift by comparing volume of fan with the area of the associated drainage basin.

2. Identify areas of Quaternary subsidence and uplift, including Amargosa Desert, Crater Flat, Fortymile Wash, Rock Valley, and Ash Meadows, through an analysis of fluvial history of the Amargosa drainage system.

3. Complete a study of average or general rates of erosion and dissection in the southern Great Basin province.

Parameters

The parameters for this activity are the area of drainage basins, the volume of fans, the drainage pattern, the stream profiles, and the rates of degradation of constructional (volcanic) landforms.

Description

In this activity, areas of Quaternary uplift or subsidence will be defined through identification of basins and ranges within the Yucca Mountain region that show anomalously high rates of erosion or sedimentation, compared with adjoining areas and with province-wide averages. Regional rates of erosion will be documented through completion of a study of degradation and erosion of well-dated Quaternary constructional landforms. Local erosional or depositional anomalies will be determined through comparison of fan volume and drainage basin area, and through analysis of the fluvial history of the Amargosa River and its tributaries.

Alluvial fans and drainage basins will be correlated and delineated on maps. Area of fans and drainage basins in the area will be defined and measured using medium-scale (1:20,000) aerial photographs and topographic maps. Age of material in the fans will be established using Quaternary geologic maps and by field examination, supplemented by dating of fan deposits where required.

The Quaternary history of the Amargosa drainage system will be evaluated. Newly active areas of ponding or incision will be mapped as a means of identifying areas of Quaternary subsidence or uplift. Terraces,

shorelines, stream captures, and stream diversions within the Amargosa River drainage basin will be identified, mapped, and interpreted in terms of Quaternary tectonics.

The regional rate of erosion and dissection will be measured through analysis of erosion and degradation of well-dated constructional landforms and volcanic deposits at volcanic centers in the southern Great Basin. This activity is estimated to be 90 percent complete; the remaining work is primarily report publication.

8.3.1.17.4.9.3 Activity: Evaluate variations in the nature and intensity of Quaternary faulting within 100 km of Yucca Mountain through morphometric and morphologic analysis

Objectives

The objectives of this activity are to

1. Define morphotectonic domains in the area within 100 km of Yucca Mountain and relate them to areal variation in intensity or nature of faulting.

2. Improve the definition of morphologic indicators of shallow detachment faulting, wrench faulting, and basin-range type normal faulting, and to use those indicators to characterize the nature of faulting in morphotectonic domains within 100 km of Yucca Mountain.

3. Constrain tectonic models applicable to the site through evaluation of regional patterns of Quaternary deformation as expressed by distribution of morphotectonic domains.

Parameters

The parameters for this activity are

1. Structural and stratigraphic indicators, location, and timing of detachment faulting, basin-range faulting, and strike-slip faulting.

2. Regional morphometry of that part of the southwest Basin and Range within 100 km of the site; range spacing relief; total relief; range lengths, widths, and areas; basin lengths, widths, and areas; pediment widths and slopes; range-to-basin width ratios; depths of basin closure range front sinuosity.

Description

The planned activity will be divided into two phases: data gathering and comparative analysis, and interpretation. Data gathering and preliminary analyses will require about one half man-year. Interpretative work will begin late in the first year and progressively expand during succeeding years. Because the activity will provide a useful regional context for geologic and geophysical investigations, it is likely that much of the

interpretative work would be carried out in coordination with other investigations (perhaps as a predictive reconnaissance tool). This activity compliments Activity 8.3.1.17.4.3.2 (evaluate Quaternary faults within 100 km of Yucca Mountain) and Activity 8.3.1.17.4.6.1 (evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain).

At present, the relationships between geomorphology and tectonic activity are, at best, imperfectly understood. The most successful work to date has involved the use of range front morphometry and morphology to interpret general vertical tectonic activity (Bull and McFadden, 1977; Wallace, 1978; Bull, 1984). These approaches, however, do not clearly resolve differences between the timing and rate of differential vertical movement, and they are of relatively little use in assessing horizontal tectonic activity (e.g., strike-slip faulting, detachment faulting). Moreover, the timing, distribution, and relations between late Cenozoic shallow detachment faulting and basin-range faulting in the Basin and Range are also imperfectly understood. Analysis of the tectonic geomorphology of the area within 100 km of the site, therefore, will require improvement of existing indicators of vertical tectonic activity, identification and definition of new indicators of horizontal tectonic activity (particularly detachment faulting), and at least a general synthesis of what is presently known about the Quaternary tectonics of the region. To evaluate the relation between nature and intensity of Quaternary faulting and morphologic features this activity will

1. Compile available Quaternary structural, stratigraphic, and tectonic data for the southwest Basin and Range using existing summaries and reviews.

2. Describe the regional morphometry of the area within 100 km of the site.

3. Develop reconnaissance maps of piedmonts and Quaternary piedmont deposits for the area within 100 km of the site.

4. Develop and refine a suite of geomorphic indicators of shallow detachment faulting, wrench faulting, and normal faulting.

5. Synthesize and relate morphometric and morphologic characteristics to Quaternary tectonic development of the area within 100 km of the site.

This activity is estimated to be 30 percent complete. The expected duration of the remaining work is two years.

8.3.1.17.4.10 Study: Geodetic leveling

The primary objective of this study is to evaluate possible historical and contemporary vertical displacements across potentially significant Quaternary faults within 100 km of Yucca Mountain. A secondary objective is to characterize the historical rate of uplift and subsidence in the Yucca Mountain region, and evaluate the possible existence of tectonic boundaries, coinciding perhaps with the Walker Lane or with the Furnace Creek fault zone,

that separate domains with differing rates of uplift and subsidence. Geologic evidence suggests that a boundary of such a domain, however diffuse, lies somewhere toward the western edge of the region.

For the purposes of this study, the region is defined as the area bounded by Death Valley on the west, Crystal Springs Valley on the east, Warm Springs on the north, and Las Vegas on the south.

Three activities are planned: (1) releveling of base station network, Yucca Mountain and vicinity; (2) global positioning satellite survey of selected base stations, Yucca Mountain and vicinity; and (3) analysis of existing releveling data, Yucca Mountain and vicinity.

In evaluating the potential effectiveness of these activities, some consideration should be given to uncertainties in the measurements and the ability of the measuring techniques to resolve contemporary deformation. The magnitudes of potential displacements are likely to be proportional to the length of time between surveys. For periods of several years the displacements are likely to be difficult to detect with confidence. For example, repeated levelings across the Furnace Creek fault between 1970 and 1985 show no detectable offset, although levelings over this same time period across probable strands of the Death Valley fault indicate possibly 2 mm of vertical displacement across one strand (Artists Drive fault), and possibly 7 mm across another (Sylvester and Bie, 1986). Suitable baselines must be established, however, for possible periodic resurveying during the preclosure time period or for measurement of displacements after large earthquakes, should they occur.

Data developed in this study will be used in Study 8.3.1.17.4.12 (tectonic models and synthesis) to limit estimates of strain rates and contemporary fault displacements within 100 km of Yucca Mountain.

8.3.1.17.4.10.1 Activity: Relevel base-station network, Yucca Mountain and vicinity

Objectives

The objectives of this activity are (1) to evaluate the historic vertical displacement across potentially significant Quaternary faults and (2) to establish the locations and rates of uplift during historical times through measurement of the change in altitude of benchmarks since the last survey.

Parameters

The parameters for this activity are to determine the altitude of benchmarks.

Description

This activity includes biennial resurvey of existing first-order level lines across Yucca Mountain. The existing lines extend westward from Mercury, Nevada, crossing the Paintbrush Canyon, Bow Ridge, Solitario Canyon,

and Windy Wash faults at Yucca Mountain, thence through Crater Flat to the western terminus approximately 25 km west of Amargosa Valley. This line, plus quadrilateral nets across each of the faults listed above, was established in 1982-83.

The desirability of adding two additional surveys is to be evaluated with respect to potential contributions to site characterization and with respect to land access matters. The first of these includes two relatively short lines, one extending from Stovepipe Wells southeast to Death Valley Junction, the other from Death Valley southward along the Amargosa River and thence eastward through Jubilee Pass to Shoshone. This survey provides releveling across the Furnace Creek and southern Death Valley fault zones. The second survey includes the releveling of several earlier first and second-order lines north and east of the Nevada Test Site (NTS), forming a small circuit that immediately surrounds the NTS. The proposed route extends along an older first-order survey from Warm Springs southeastward along Nevada Highway 375 to Crystal Springs, southward along several older second-order lines along U.S. Highway 93 to about 15 km south of Alamo, and southwestward along a dirt road to Corn Creek Springs. This route crosses several Quaternary features of regional importance, including the northern part of the Death Valley-Pancake Range volcanic belt, the Pahranagat Range shear zone, and the Las Vegas Valley shear zone, and the Walker Lane belt. Decision to proceed with the two additional surveys is contingent on the results of the evaluation, and review of potential application to Project needs. Baseline surveys are to be completed within one year.

8.3.1.17.4.10.2 Activity: Survey selected base stations, Yucca Mountain and vicinity, using global positioning satellite

Objectives

The objective of this activity is to evaluate contemporary vertical displacement across potentially significant Quaternary faults and the contemporary rate of uplift and subsidence within 100 km of the site on the basis of altitude and position of selected base stations.

Parameters

The parameters for this activity are elevation and location of base stations.

Description

To more fully benefit from the relevelings undertaken as part of Activity 8.3.1.17.4.10.1, junction points and selected benchmarks will be observed periodically (annually and biannually) using the global positioning satellite (GPS). The observations will either be made as part of the National Geodetic Survey GPS program, or alternatively, using recently acquired USGS receivers. GPS vertical measurement precision (replication capability) scales linearly as a function of distance, and is currently on the order of 80 mm over a 50-km line. Comparisons with terrestrial measurements are indirect in the sense that GPS measures a geometrically defined

quantity, whereas leveling measures a geopotential difference between points. Accordingly, a gravity dependent correction will be made to bring terrestrial-based height differences into conformity with the GPS-based height differences. Baseline surveys are to be completed within one year.

8.3.1.17.4.10.3 Activity: Analyze existing releveling data, Yucca Mountain and vicinity

Objectives

The objective of this activity is to evaluate historical vertical displacement across potentially significant Quaternary faults, and possible historic uplift and subsidence within 100 km of Yucca Mountain through detection of changes in altitude as recorded by existing leveling data.

Parameters

The parameter for this activity is the altitude of base stations.

Description

This activity will review the results of releveling of the network of benchmarks in the Yucca Mountain region. The activity involves search of archives, and the collection, collation, and analysis of leveling data. No field work is planned. This activity is estimated to be 50 percent complete. The duration of the remaining work is six months.

8.3.1.17.4.11 Study: Characterization of regional lateral crustal movement

The objective of this study is to evaluate rates and orientations of historical and current lateral crustal movement based on analysis of existing data on seismicity, historical fault offset, and creep in the Basin and Range province.

Results of the evaluation will be used in Study 8.3.1.17.4.12 (tectonic models and synthesis) to constrain tectonic models applicable to Quaternary tectonics of the site, and in Study 8.3.1.17.4.1 (historical and current seismicity) to constrain probabilistic models of seismicity within 100 km of Yucca Mountain.

The characteristics to be evaluated include historical fault displacements, creep, historical seismicity, focal plane solutions, and seismic energy release.

8.3.1.17.4.11.1 Activity: Analyze lateral component of crustal movement based on historical faulting, seismicity, and trilateration surveys

Objectives

The objective of this activity is to evaluate rates and orientation of historical and current crustal strain in the Basin and Range province and the Yucca Mountain region.

Parameters

The parameters for this activity are historical fault displacements, creep, historical seismicity, focal mechanisms, seismic energy release, historical crustal strain, and changes in distances between benchmarks in the Yucca Mountain region.

Description

Data pertaining to historical seismicity, focal mechanisms, and seismic energy release will be supplied by Study 8.3.1.17.4.1 (historical and current seismicity). Data pertaining to fault displacements, creep, and crustal strain as measured by strain gauges and land surveys will be compiled. Surveys of the trilateration network at Yucca Mountain and vicinity will be repeated.

8.3.1.17.4.12 Study: Tectonic models and synthesis

The objectives of this study are (1) to synthesize data relevant to tectonics, (2) to develop a model or range of models that establishes the causal relation between application of tectonic forces and formation of structures observed at Yucca Mountain and vicinity, (3) to link observed rates of formation of those structures with regional rates of crustal strain, (4) to forecast changes in tectonic setting and the manner in which those changes will affect both the regional crustal strain rate and tectonic stability in the Yucca Mountain region, (5) to estimate the effect of those changes on rate and nature of crustal strain at Yucca Mountain and vicinity, and (6) to estimate the future rate of tectonic processes at Yucca Mountain.

A tectonic model or range of models will be developed or compiled to satisfy this investigation. Tectonic model is used here to mean a system of postulates, data, and inferences that explains the deformation of the earth's crust in the vicinity of the site, the forces involved in or producing such deformation, and the resulting geologic structures. Data relevant to faulting, magmatic activity, folding, and uplift and subsidence will be synthesized, including data on gravity residuals, magnetic residuals, seismic velocities, in situ stress, geologic structure and stratigraphy, and tectonic geomorphology.

The compilation or development of regional tectonic models will serve two purposes. The first purpose is to ensure that assumptions that are made about the local manifestation of tectonic processes are consistent with

current scientific understanding of tectonic processes acting in the region. For example, the determination of slip rate on the Paintbrush Canyon fault, from age dating of offset strata, will be checked for consistency with interpretive tectonic models that account for the style and rate of faulting throughout the site region. The second purpose of regional tectonic models is to document scientific uncertainty in the characterization of tectonic hazards so that it can be accounted for in evaluations of repository design and performance. This will be accomplished by developing or compiling a range of alternative models that represent the range of current scientific thinking about the tectonic processes that might affect the site.

Regional tectonic models are expected to be most germane to the characterization of the site's ground-motion potential (Investigation 8.3.1.17.3) because earthquake sources at regional distances can contribute to the ground-motion hazard at the site. Alternative tectonic models will be interpreted in terms of alternative, judgmentally weighted seismic source zones in a probabilistic seismic hazard analysis of the site (Study 8.3.1.17.3.6). In addition, tectonic models will provide context for interpretations of the local, preclosure surface faulting potential (Investigation 8.3.1.17.2) and the potential for faulting, folding, uplift, or subsidence to affect postclosure repository performance (Investigation 8.3.1.8.2).

The activities planned for this study are to (1) evaluate tectonic processes and tectonic stability at the site, (2) evaluate tectonic models, and (3) evaluate tectonic disruption sequences.

8.3.1.17.4.12.1 Activity: Evaluate tectonic processes and tectonic stability at the site

Objectives

The objectives of this activity are to

1. Synthesize gravity studies at Yucca Mountain and vicinity, and define regional variations in mass, and attribute them, as appropriate, to variations in crustal thickness, degree of melting, shallow intrusions, distribution of specific stratigraphic units, and faults.

2. Synthesize magnetic studies at Yucca Mountain and vicinity, and define areal variations in magnetic field, and relate them as appropriate to distribution of specific stratigraphic units, shallow intrusions, and subsurface configuration of faults.

3. Evaluate the regional extent of detachment faults, wrench faults, volcanic rocks belonging to the Death Valley-Pancake Range belt, evaluate the regional pattern of oroclinal bending (oroflexing), evaluate the regional extent of Miocene ash-flow tuffs and associated pyroclastic and epiclastic rocks, and evaluate regional extent of Paleozoic rocks known to be aquifers, aquitards, or to provide favored surfaces of detachment or thrusting.

4. Synthesize and evaluate information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain), constrain, if possible, the rate of offset and recurrence interval of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain), and evaluate the applicability of this information to geologic hazards at the site.

5. Synthesize and evaluate information pertaining to detachment faults at Yucca Mountain and vicinity, and constrain, if possible, the rate of displacement, subsurface configuration, and character of risk posed by this class of faults.

6. Synthesize and evaluate information pertaining to normal (and north-trending oblique and strike-slip faults) at the site and vicinity, and constrain, if possible, aggregate strain rate, subsurface configuration, recurrence interval, and character of risk posed by this class of faults.

7. Synthesize and evaluate information pertaining to the northeast-trending left-lateral strike-slip faults at the Nevada Test Site and vicinity, and constrain, if possible, slip rate, recurrence interval, and character of risk posed by this class of fault.

Parameters

The parameters for this activity are gravitational force, geomagnetic field, geologic structure, and stratigraphy.

Description

This activity includes compilation and interpretation of geologic, gravity, and magnetic maps of the Beatty 1:100,000 quadrangle, synthesis of geologic and geophysical studies, and preparation of topical reports on Quaternary wrench faulting, detachment faulting, normal faulting, and left-lateral strike-slip faulting. Information and interpretations supplied by these syntheses will form the basis for formulation of a tectonic model or models describing the way in which forces and bodies in the Yucca Mountain region interact to produce the geologic and tectonic framework of the proposed repository.

Maps (1:100,000 scale) of Bouguer gravity, residual gravity, and isostatic gravity will be compiled and amplified where necessary with additional gravity surveys. Data on density of geologic units will be collected and compiled. Filtered gravity maps (nominal passing wavelengths of 240 km) will be produced. Maxi spot or a comparable computer program will be used to identify and quantify gradient changes. Crustal models based on gravity and seismic velocity will be produced.

Maps (1:100,000 scale) of aeromagnetic data of the Nevada Test Site and vicinity will be compiled. Source models combining gravity data with magnetic signature of relevant anomalies will be calculated and compared.

Geologic maps (1:100,000 scale) of the Beatty 1 by 1/2° quadrangle will be compiled from published sources. Geologic cross sections showing inferred subsurface structural and stratigraphic geometry will be prepared. This activity is estimated to be 50 percent complete. The duration of the future work is estimated to be four years.

8.3.1.17.4.12.2 Activity: Evaluate tectonic models

Objectives

The objectives of this activity are to

1. Formulate a range of tectonic models that relate the nature and estimated rates (including bounding values of those estimated rates) of Quaternary processes (volcanism, faulting, uplift and subsidence, lateral strain, and possibly folding) of potential significance to design and performance of the repository at Yucca Mountain.

2. Evaluate temporal changes in tectonic activity and resulting changes in fractures and other structural features of potential hydrologic significance at and in the vicinity of Yucca Mountain. Relate tectonic cycle, if it exists, to tectonic model(s).

3. Ensure that assumptions, inferences, and conclusions concerning tectonic processes that are important to design and performance of the repository are consistent with tectonic models applicable to the site.

4. Ensure that uncertainty in the data, assumptions, and inferences concerning rates and nature of those tectonic processes that are important to design or performance of the repository is adequately reflected in conclusions about those processes.

Parameters

The parameters for this activity are recurrence rates, strain rates, ambient stress, boundary conditions, structural geology of the site area, structural geology of the area within 100 km of Yucca Mountain, location and geometry of Quaternary faults, fracture distributions and age of fracture-filling minerals in the site area, and age and location of basaltic volcanism within 25 km of Yucca Mountain.

Description

The various tectonic hypotheses that are potentially applicable to the neotectonics of Yucca Mountain include as end members the following: (1) the wrench fault hypothesis, which explains deformation at Yucca Mountain as resulting from right-lateral transform movement on an intracontinental shear zone (the Walker Lane) passing through or near the site area; (2) the detachment fault hypothesis, which explains deformation at Yucca Mountain as resulting from extension on subsurface detachment faults and the set of listric normal faults which merge with the detachment faults; and (3) the

basin-range normal fault hypothesis, which explains the Quaternary normal faults at Yucca Mountain as planar rotational faults extending to great depth. Quaternary volcanism in and south of Crater Flat could be attributed to (1) volcanism along a north-northeast-trending incipient rift zone (Death Valley-Pancake Range zone) or (2) volcanism at zones of extension developed between en echelon segments of northwest-trending wrench faults (leaky transform hypothesis). These and other potentially applicable tectonic hypotheses are listed in Tables 8.3.1.17-7 and -8. Each of these hypotheses, as stated, is consistent with some data and inconsistent with other data. There probably are, however, a set of models that include various elements of these hypotheses and that satisfactorily explain all or most of the data.

In this activity, data pertaining to tectonic cycles, including timing and localization of faulting, fracturing, and basaltic volcanism will be synthesized. Alternative conceptual tectonic models will be formulated, and the degree to which those models qualitatively and quantitatively incorporate and reconcile information on the parameters just listed will be evaluated. That information includes that gathered by other studies in tectonics and site geology. The tectonic models are expected to evolve as additional data are gathered, and hence this activity is expected to continue for the duration of the site characterization process. Preliminary models will be produced for use during site characterization.

8.3.1.17.4.12.3 Activity: Evaluate tectonic disruption sequences

Objectives

The objective of this activity is to evaluate disruption sequences involving faulting, folding, uplift and subsidence, and volcanism that are of potential significance to design or performance of the repository.

Parameters

The parameters for this activity are tectonic models, processes, and rates; probabilities of tectonic events; and physical consequences at the proposed repository site.

Description

The purpose of this activity is to evaluate disruption sequences involving faulting, folding, uplift and subsidence, and volcanism, acting either individually or in concert. Where possible, the probability of each sequence actually occurring in the future will be estimated and the range of geologic consequences described.

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8.3.2 REPOSITORY PROGRAM

This section summarizes the repository program and provides an overview of the research, development, and engineering activities required to ensure that the repository is capable of satisfying applicable technical criteria. Issue resolution strategies for Issue 1.11 (configuration of underground facilities), Issue 2.7 (repository design criteria for radiological safety), Issue 4.2 (nonradiological health and safety), and Issue 4.4 (preclosure design and technical feasibility) are presented in this section. Plans for the future work are based in large part on the current designs and the results of analyses completed to date; the current designs and analyses are presented in Chapter 6 (conceptual design of a repository).

8.3.2.1 Overview of repository program

The primary purpose of Section 8.3.2 is to describe the plans for completing the repository design work as it progresses through the sequence of design phases leading to construction of the repository. Those aspects of the design concerned specifically with site characteristics are discussed fully in this document. Other aspects, such as certain equipment designs and operations plan development (and supporting analyses and demonstrations), that do not rely heavily on site data are not discussed in detail. Rather, only enough information on these aspects is provided to define their role in issue resolution. A complete treatment of such aspects will be provided in the repository design plan (RDP). Thus, the RDP will describe fully all plans for completing the repository design work as it progresses through the sequence of design phases leading to construction of the repository, including work that relies directly on site data and that that does not. For example, substantially more detail will be provided in the RDP than in the SCP regarding the equipment development program and the nonsite-related aspects of radiological safety.

The plans described here in Section 8.3.2 are organized under four repository design issues that are part of the issues hierarchy. (Sections 8.1 and 8.2 list the issues and describe the general strategy and methodology for resolving them). Plans for completing the work necessary to resolve these four issues are discussed in the following four subsections:

Subsection	Issue	Issue short title
8.3.2.2	1.11	Configuration of underground facilities (postclosure)
8.3.2.3	2.7	Repository design criteria for radiological safety
8.3.2.4	4.2	Nonradiological health and safety
8.3.2.5	4.4	Preclosure design and technical feasibility

The work planned to resolve the four design issues is interrelated. Further, work described under several issues in other subsections of Section 8.3 is also tied closely to the work planned to be done under the four issues discussed here. Figure 8.3.2.1-1 graphically depicts the relationships between design-related issues by showing pathways along which information will be passed between the issues. Details about the information passed between issues are presented in the SCP sections in which the specific issues are discussed. As seen in the figure, the related issues include some performance issues as well as other design issues.

Numerous requirements and constraints are imposed on the overall repository design (i.e., on the work to be done under the repository design issues) because of the necessity for the repository to meet certain preclosure and postclosure performance requirements (i.e., by performance issues found in Section 8.3.5). For example, from the preclosure perspective, the repository must be designed, constructed, and operated in a manner that (1) preserves the option to retrieve waste until the license amendment for permanent closure is granted and (2) meets the requirements of radiological health and safety. Performance requirements involving retrievability (Section 8.3.5.2) and radiological health and safety (Sections 8.3.5.3 through 8.3.5.5) are developed in the preclosure subsections of Section 8.3.5

(performance assessment program) and communicated to the repository design issues. Also, for preclosure operations, the repository facilities must be designed to handle the waste and waste packages and to accommodate the waste package design requirements and constraints described under the waste package issues in Section 8.3.4 (waste package program). The requirements and constraints placed on the design issues by performance issues (and even other design issues) are usually accompanied by requests of the design to prepare certain specific products, the primary use of which is to help resolve the issue specifying the requirements. The output of many of the issues identified in Figure 8.3.2.1-1 consists of items like design activity and evaluation reports, equipment demonstration reports, design drawings and supporting analyses, operations plans, etc. These are often called products in the issues under which they are developed. These products may be requested by other issues (perhaps along with site parameters) as input to perform required tasks. The products are called "input items" by the requesting issue, to distinguish them from the products of that same issue (Figure 8.3.2.1-2). The input items needed by an issue are generally listed along with the site parameters in the appropriate tables within that issue.

From the postclosure perspective, the repository facilities must be designed to accommodate the performance requirements and constraints developed and described under the waste package, engineered barrier system, and total system performance issues in Section 8.3.5. In addition, the repository design must accommodate the emplacement of seals for the shafts, ramps, exploratory boreholes, and underground facilities, as described under Issue 1.12 in Section 8.3.3 (seal program).

In addition to the general relationships between issues indicated by the above discussion, there is an additional division of responsibility among the design-related issues shown in Figure 8.3.2.1-1. The following example concerning the topic of mined openings will serve to describe this division of responsibility. Issue 4.2 (Section 8.3.2.4) is concerned with the stability of mined openings as it relates to the nonradiological health and safety of workers. Issue 2.4 (Section 8.3.5.2) is concerned with maintaining stable openings for the entire period of retrievability in order to preserve access to the waste. Radiological safety issues 2.3 and 2.7 (Sections 8.3.5.5 and 8.3.2.3) are concerned with opening stability as it relates to potential initiating events for release of radionuclides into the environment of the workers and public. Issue 1.11 (Section 8.3.2.2) is concerned with the stability of those same openings after closure, because their long-term instability might create preferred pathways for water migration toward waste packages and compromise containment of the waste within the waste package. Finally, Issue 4.4 (Section 8.3.2.5) is concerned with providing stable mined openings large enough for moving equipment, personnel, materials, and ventilation air. With this spectrum of interest in the topic, it would be easy to perform duplicate work in resolving the different issues. To avoid such duplication, a careful division of responsibility between issues has been adopted. Issue 4.4 has been assigned the responsibility for the design of mined openings and for conducting the necessary stability analyses in support of the design. Other issues will impose design requirements or constraints upon Issue 4.4 pertinent to their needs, and will receive the design and other input items (e.g., supporting analyses) back from Issue 4.4. Under each issue the design and the supporting analyses will be evaluated to judge hether the requirements for mined opening stability have been satisfied.

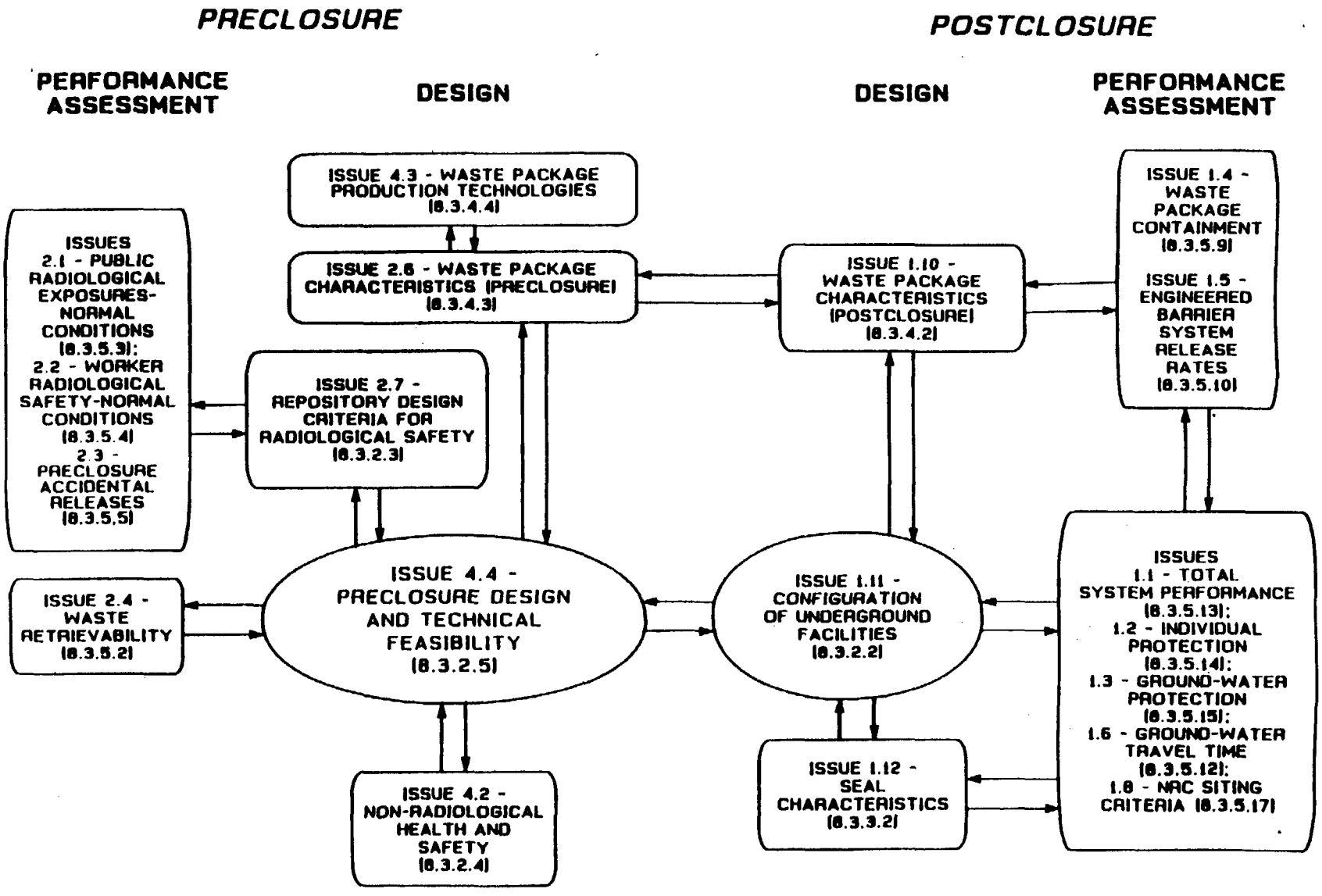

Figure 8.3.2.1-1. Relationships between design and performance related issues used directly in performance allocation

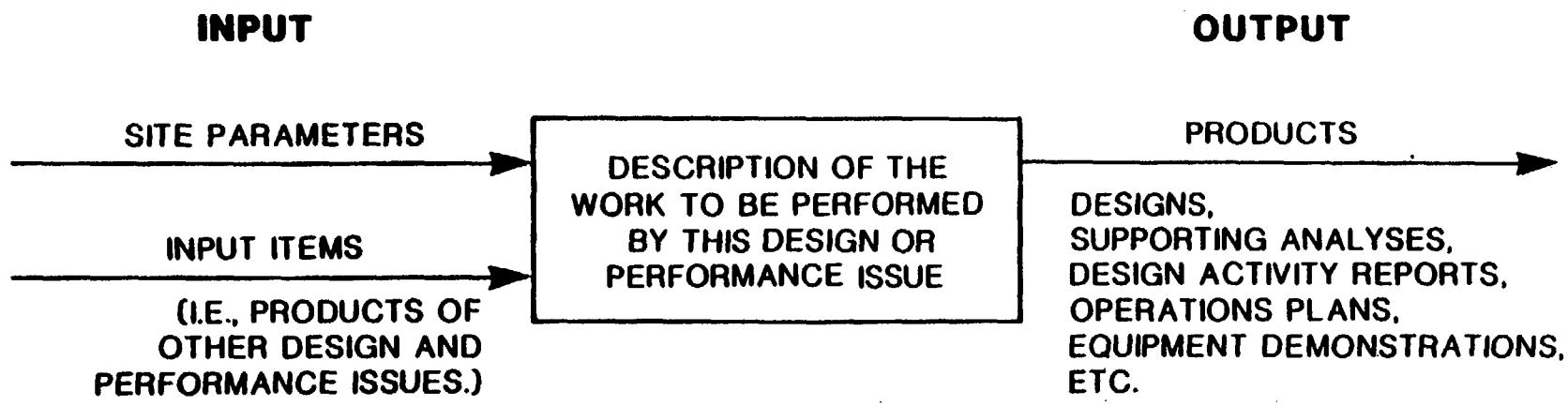

Figure 8.3.2.1-2. Schematic diagram of the input to and output from a design or performance issue.

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In a like manner, where Issue 4.4 shares similar design requirements with another issue on a particular facet of the repository design, Issue 4.4 has been assigned the responsibility for developing the design and providing the other three parts of the four-part design package (namely, the operating plan, supporting analyses, and any necessary demonstrations). The related issue(s) provide requirements and constraints (and requests for other input items) to Issue 4.4 and receive the design package in return from Issue 4.4. The logic diagram for Issue 4.4 illustrates these relationships. With this division of responsibility, Issue 4.4 is the issue that requests most of the data on site characteristics. This division of responsibility is also indicated in the logic diagrams and the supporting text and tables that discuss the design-related issues shown in Figure 8.3.2.1-1.

Figure 8.3.2.1-1 illustrates the interfaces by which design and performance issues exchange information. As the figure caption indicates, the specific design and performance issues portrayed in the figure are those that were used directly in the performance allocation process. Two general aspects of the figure are worth emphasizing. First, the figure was prepared primarily to illustrate the exchange of design criteria and design products between design issues. Accordingly, the figure does not provide specific detail about how the performance issues exchange information. The second general aspect of the figure worth noting is that not all of the design and performance issues in the issues hierarchy are portrayed on the figure.

Three of the issues absent from the figure are concerned with the higher level findings required by 10 CFR Part 960. These are Issues 1.9 (higher level findings--postclosure, Section 8.3.5.18), 2.5 (higher level findings--preclosure radiological safety, Section 8.3.5.6), and 4.1 (higher level findings--ease and cost of construction, Section 8.3.5.7). The primary reason for excluding higher level finding issues from the figure is that, at the current time, the resolution strategies for these issues do not require any data other than that requested for the resolution of the other design or performance issues. This is not expected to change, but if it should, an SCP progress report would be the vehicle to convey changes in the interrelationship diagram as well as changes to the preliminary performance allocation.

Issue 1.7 (performance confirmation, Section 8.3.5.16) is also absent from the figure because it is not considered possible at this time to develop a detailed, site-specific issue resolution strategy for performance confirmation. As site characterization progresses, however, the performance allocation for the Yucca Mountain site may change in response to a defined issue resolution strategy for performance confirmation. This information would also be reported in SCP progress reports.

The conceptual design of the repository is presented in Chapter 6 (and described in detail in the SCP Conceptual Design Report (SCP-CDR)) (SNL, 1987), along with extensive discussions that synopsize the analyses completed in support of the conceptual design. In Section 6.4 of this document, the analyses are discussed in the context of resolving the design issues and design-related performance issues (i.e., it provides a status of the work done to resolve the issues). Section 6.4 also provides background information for the additional work necessary to complete resolution of issues, as described in various subsections of Section 8.3. Site information used in the conceptual design and supporting analyses is reported in Chapters 1

through 5 of this SCP. (Those chapters also contain data that in some instances supersedes or postdates data used in the SCP-CDR.) Additional site data needed to support the design efforts will be acquired under the site program described previously in Section 8.3.1. Figure 8.3.2.1-1, however, does not show any ties to the site program; these ties were omitted in the interest of clarity in showing the ties between the design-related issues. The issue resolution logic diagrams, presented in each 8.3 issue-related section, however, do show the specific calls for data from the site program.

Before proceeding to the four design issues to be discussed in this section, the repository design phases are described, followed by a discussion of four specific subject areas:

1. Host rock environment (Section 8.3.2.1.1).
2. Coupled interaction tests (Section 8.3.2.1.2).
3. Design optimization activities and tests (Section 8.3.2.1.3).
4. Repository modeling (Section 8.3.2.1.4).

The design of the systems, components, excavations, structures, and barriers necessary to establish and demonstrate compliance with the performance objectives of 10 CFR Part 60 should be substantially completed at the time the license application is submitted to the NRC. To accomplish this, the DOE has divided the design of the repository as follows (DOE, 1985b):

1. Conceptual design phase.
   a. Conceptual design for the site characterization plan.
   b. Advanced conceptual design.

2. Title I and II design.
   a. License application design.
   b. Final procurement and construction design.

Design phases

Conceptual design for the site characterization plan

The SCP conceptual design phase is complete. This design phase concentrated on the surface and underground system, structure, and component designs that require site characterization data and provide the information to ensure that data-gathering plans relative to design will be adequate. Known site-specific data have been incorporated to help identify additional data needs, and sufficient design detail was developed to ensure that site data needs are identified and site-specific licensing issues related to site characterization have been identified. In addition, where available, data accuracy requirements have been identified. This design has been extensively referenced in Chapter 6.

Advanced conceptual design

The advanced conceptual design phase will be used to explore design alternatives and will firmly fix and refine the design criteria and concepts to be used in later design efforts. The project feasibility will be demonstrated, the life-cycle cost estimated, preliminary drawings prepared,

and a construction schedule developed as required in DOE Order 4700.1 (DOE, 1987d). The design will be developed with Project and configuration control as required by the DOE procedures for major system acquisitions and will comply with the configuration control program requirements of 10 CFR Part 50, Appendix B. This design will also identify any remaining design-related licensing issues not defined in the SCP conceptual design.

During the advanced conceptual design phase, the DOE objective is to develop appropriate solutions to all identified design-related licensing issues through consultation with the NRC as established by the Procedural Agreement between the U.S. Nuclear Regulatory Commission and the DOE identifying guiding principles for interface during site investigation and site characterization (NRC/DOE, 1983).

License application design

The license application (LA) portion of the Title I and Title II design phases will start after the completion of the advanced conceptual design (ACD) report; it will conclude with the development of an LA design report. The LA design phase will support 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. Therefore, sufficient design information will be developed during the LA design phase to meet the requirements of 10 CFR 60.21 for the license application. Design requirements resulting from detailed safety and reliability analyses will be fully integrated into the LA design and will form the basis for information required in the safety analysis report. The design of nonlicensing-related ancillary systems will be developed only to the extent necessary to ensure their proper function and adequate cost and schedule planning.

Final procurement and construction design

This portion of the Title I and II phases 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 the 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 construction and procurement schedules.

The DOE is currently initiating an effort to combine several program activities under a single System Engineering Development and Management (SEDM) contractor. In this approach, the SEDM contractor would prepare the ACD. Detailed plans for the design sequence under the SEDM contractor have not been developed. It is expected, however, that the design work to be accomplished under the plan described in this SCP will be the same, in total, as that performed under an SEDM contractor.

8.3.2.1.1 Verification or measurement of host-rock environment

Information from site explorations before the site characterization phase have permitted an understanding to be developed of the host-rock environment within which the underground facilities will be constructed. This understanding is described in detail in Chapters 1 through 7, in particular, (1) the geology, geophysics, seismicity, and tectonics of the site and surrounding area are described in Chapter 1 (geology); (2) the mechanical and thermal properties of the rock and soils at the site are described in Chapter 2 (geoengineering); (3) the hydrologic conditions and properties are described in Chapter 3 (geohydrology); and (4) the geochemical conditions and properties are described in Chapter 4 (geochemistry).

Plans to verify the current understanding and acquire necessary additional information about the host-rock environment are described here in Chapter 8. Section 8.3.1 (site program) describes the site investigations (studies, tests, and analyses) that will be conducted to acquire the additional site data. For convenience, the descriptions of the site investigations are grouped according to topical areas (e.g., geology program, rock characteristics program, and hydrology program).

Plans for completing the design of the repository facilities, the seals, and the waste packages are found in Section 8.3.2 (repository program), 8.3.3 (seal program), and 8.3.4 (waste package program), respectively. Similarly, plans for conducting assessments of the performance of the total mined geologic disposal system (MGDS) and the appropriate components are described in Section 8.3.5 (performance assessment program). These design and performance assessment plans are organized in accordance with the issues hierarchy described in Section 8.2. The site data needed to resolve each design and performance issue is defined within the discussion of the plans for resolution of the respective issue. The need for site data is then transmitted to the appropriate site program where the detailed plans for acquiring the data are described. No plans for acquiring site data are described within the design or performance issues themselves. These issues simply describe how the site data and other items of information will be used to resolve the issue. Correspondingly, only site data that are required to resolve a design or performance issue, or are needed to support another characterization program are acquired under the site program.

It is within this context that the topic of this section, verification or measurement of the host-rock environment, is addressed for design issues. The site data identified in the data chapters noted previously have been used to develop conceptual models of the host-rock environment within which the repository facilities will be constructed. These conceptual models and their influence on the conceptual design of the repository facilities are described in Chapter 6 (conceptual design of the repository). This conceptual design, the existing site data, the conceptual models, and the understanding they convey, taken together with the regulatory and other requirements upon the MGDS, form the basis for the plans for resolution of the design issues.

The role of the host-rock environment in the process can be divided into three phases or conditions: (1) pre-waste-emplacement environment (the host-rock conditions in the pre-excavation, pristine, in situ state); (2) post-subsurface-excavation environment (e.g., the conditions of rock stress and

deformation as a result of excavation); and (3) post-waste-emplacement environment (e.g., the conditions resulting from the combined effects of excavation and added heat from the emplaced waste). In the subsections that follow, topics of concern during each of the phases will be identified, and the reader will be directed to those design issues (and their respective SCP subsections) in which the topics are addressed. In addition, the specific site program will be identified from which site data are requested in order to resolve host-rock environment questions in the respective design issues.

8.3.2.1.1.1 Pre-waste-emplacement environment

Current knowledge of the pre-waste-emplacement geologic, geotechnical, hydrologic, and geochemical environment of the host rock has been used to develop models or descriptions of characteristics of the site in its pristine state. As noted in the previous section, the current description of the host-rock environment, together with some descriptive models, is found in Chapters 1 through 4. These data and models have assisted in identifying the site location, repository elevation, usable area, boundary conditions, and predicted response of the host rock to excavation and thermally induced loads. Further, during the site exploration phase of the characterization program, conceptual models were developed to assist in repository conceptual design as presented in Chapter 6 (preliminary performance assessments were also developed--refer to Section 8.3.5).

To conduct the design analyses and activities necessary to resolve the four design issues included in this section (8.3.2, repository program), additional site data pertaining to pre-waste-emplacement and preexcavation conditions are needed to

1. Confirm the three-dimensional model of the thermal and mechanical stratigraphy and structure of Yucca Mountain.

2. Develop a three-dimensional model for estimating the in situ stress state at Yucca Mountain.

3. Develop a three-dimensional model of the in situ temperature field at Yucca Mountain.

4. Evaluate mineability, fragmentation characteristics, dust characteristics, and potential excavation methods of the host rock.

5. Design and evaluate a ground support system for the underground facility and egresses.

6. Determine rock-mass deformation and estimate strength properties.

7. Determine the effects of confining pressure upon intact rock strength and fracture slip such that a strength and slip criterion, respectively, may be developed.

8. Determine the effects of time (the strain rate effect) upon intact rock strength.

9. Determine the sample size effect upon intact rock strength.

10. Determine the sensitivity of potential designs of system elements to material properties and their variability.

11. Provide pretest support of all mechanical, thermal, and thermo-mechanical experiments planned for the exploratory shaft facility.

12. Design a ventilation system for the repository facilities.

13. Evaluate the effects of radon gas emanation.

14. Evaluate the effect of structural features for standoff and special construction considerations.

15. Evaluate the potential for water inflow into the underground facilities.

Site data required to conduct these design analyses and activities will be acquired under the following specific site programs:

SCP section	Site program
8.3.1.4	Rock characteristics
8.3.1.6	Erosion
8.3.1.14	Surface characteristics
8.3.1.15	Thermal and mechanical properties
8.3.1.16	Preclosure hydrology

Further, to resolve Issue 4.4 (preclosure design and technical feasibility), additional site data are needed to

1. Validate predictive equations of ground motion at any point in the target horizon.

2. Validate methodology for predicting seismic hazards due to natural earthquakes for ground motion and surface rupture.

3. Determine fault activities at the site including total displacements, displacement rates, evidence of surface rupture, type, and orientation and age of recent activity of the faults in the site area.

4. Determine the attenuation of ground motion with depth (both for acceleration and frequency) as it applies to surface and subsurface facility design.

5. Determine the effects of wave propagation, amplitude, and direction upon surface and subsurface facility design.

Site data required to resolve these seismotectonic design questions will be acquired under the tectonics programs described in Sections 8.3.1.8 and 8.3.1.17.

8.3.2.1.1.2 Post-subsurface-excavation environment

The post-subsurface-excavation geologic and geotechnical environment considers the host-rock environment that reflects, for example, rock stress as a result of rock excavation. Models conceptualized and developed from the standpoint of pre-waste-emplacement, including material response, boundary conditions, and usable area, will be confirmed or modified to assist in resolving the issues identified previously. Certain of the analyses and tests identified for the post-subsurface-excavation condition are meant to continue through development and monitoring programs during the post-waste-emplacement phase (Section 8.3.2.1.1.3) of repository development in order to supplement or confirm earlier concepts.

To conduct the design analyses and activities necessary to resolve the four design issues included in this section (8.3.2, repository program), additional site data pertaining to post-subsurface-excavation conditions are needed to

1. Validate models that are intended to predict the response of the fractured rock mass to excavation loads.

2. Assess the state of stress and deformation at the emplacement borehole scale, drift scale, and repository scale as a result of excavation.

3. Assess the potential impact of rock mass creep upon state of stress and deformations around opening.

4. Evaluate potential excavation methods based on application of candidate methods during the underground exploration program.

5. Evaluate the planned ground support methods based on application of candidate methods to underground openings in the exploratory shaft facility.

6. Evaluate the mechanical response of the rock mass.

Site data required to conduct these design analyses and activities will also be acquired under the following specific site programs:

SCP section	SCP program
8.3.1.4	Rock characteristics
8.3.1.6	Erosion
8.3.1.14	Surface characteristics
8.3.1.15	Thermal and mechanical properties
8.3.1.16	Preclosure hydrology

8.3.2.1.1.3 Post-waste-emplacement environment

The post-waste-emplacement geologic and geotechnical environment considers the host-rock environment that reflects, for example, the combined effects of excavation and heat (from heat-generating waste). For this condition certain of the analyses and tests identified in Sections 8.3.2.1.1.1 (pre-waste-emplacement environment) and 8.3.2.1.1.2 (post-subsurface-excavation environment) are meant to continue through development and monitoring programs during this phase of repository development in order to supplement or confirm earlier results.

To conduct the design analyses and activities necessary to resolve the four design issues included in this section (8.3.2, repository program) and to resolve Issue 2.4 (waste retrievability, Section 8.3.5.2), additional site data pertaining to post-waste-emplacement conditions are needed to

1. Validate models that are intended to predict the response of the fractured rock mass to excavation and thermal loads.

2. Assess the temperature distribution as a function of time and position as a result of thermal loads from heat-generating waste. Analyses will be performed at the emplacement borehole scale, drift scale, and repository scale.

3. Assess the state of stress and deformation as a result of excavation and superposed thermal loads. Response will be predicted at the emplacement borehole scale, the drift scale, and the repository scale.

4. Assess the potential impact of rock creep (time-dependent deformation) upon state of stress and deformations around mined openings.

5. Determine the potential impact of changes in the orientation of the principal stress components upon the intact rock and rock-mass response (deformation and strength behavior).

6. Determine the thermomechanical response of intact samples and representative volumes of the rock mass.

Site data required to conduct these design analyses and activities will also be acquired under the following specific site programs:

SCP section	SCP program
8.3.1.4	Rock characteristics
8.3.1.6	Erosion
8.3.1.14	Surface characteristics
8.3.1.15	Thermal and mechanical properties
8.3.1.16	Preclosure hydrology

8.3.2.1.2 Coupled interaction tests

The design, construction, operation, and assessment of the future performance of a geologic repository must consider five general classes of phenomena. These are thermal, hydrologic, mechanical, chemical, and radiological phenomena. These phenomena may occur individually at a particular time or spatial location without affecting the other phenomena; often, however, the occurrence of one phenomenon may affect the behavior of another phenomenon and, therefore, couple the phenomena and the processes of which they are a part. The number of coupled processes that could exist under the various combinations of coupling the five general classes of phenomena is very large. It is not feasible to perform multivariable tests (i.e., coupled interaction tests) covering all these combinations. Testing will, therefore, occur only if it is relevant to licensing arguments.

Performing multivariable interaction tests is relevant to licensing arguments only if performing those tests is necessary to characterize behavior to show compliance with regulatory criteria. If the investigation of any particular combination of processes does not aid in showing compliance with at least one regulatory criterion, then that investigation is not relevant, and testing to determine the behavior and effects of those coupled processes is not necessary.

Regulatory criteria that must be satisfactorily addressed to receive a construction authorization are addressed within the issues hierarchy incorporated into this document (Section 8.2). Strategies to resolve all issues within the hierarchy, and thereby determine the level of compliance with the regulatory criteria, are addressed in Section 8.3.5 The approach used to determine the relevance of coupled behavior (as well as uncoupled behavior) follows the fundamental issue resolution strategy presented in Section 8.2 and used throughout Section 8.3.5. As a part of that strategy, those licensing arguments and concomitant tests that involve multivariable (i.e., coupled) effects are defined under the issues as information required to resolve those issues. To determine whether the consequences of certain coupled processes are significant, the performance allocated to the various system components is of major importance. It is inherent within the planning approach for site characterization that prior estimates be made to determine what parameters are important in showing regulatory compliance. These estimates of importance have been based upon previous laboratory and field data, performance analyses, and professional judgment.

From the performance allocation, parameters are derived that must be investigated during site characterization. No distinction within the issues is made among parameters that involve coupled interactions and those that do not; all are simply information required to resolve the issue using the approach stated under the particular issue. All the requirements for the parameters (whether involving coupled interactions or not), as well as the rationale for determining that the set of parameters are necessary and sufficient to show regulatory compliance, are discussed for each issue. Therefore, this section does not discuss a particular subset of tests (i.e., coupled interaction tests) or how the results of those tests are necessary and sufficient. In other words, the strategy for the approach to coupled interaction tests is to let the individual issues specify the parameters

necessary for resolving the issue and for showing compliance with the related regulatory criteria. The investigation of coupled interactions considers them not as a specific subset of data requirements, but merely as part of all the information needed to address the regulatory criteria. The tests (some with multivariable interactions and some without) that meet the parameter requirements are described under the appropriate characterization program.

Although no detailed description of coupled interaction tests is provided here, Table 8.3.2.1-1 shows the title of the study or activity involving investigation of multivariable effects, study or activity designation number, and an indication of the processes that will be investigated within the test or tests. The first three numbers of the study or activity designation number reflect the issue and information need under which the coupled interaction test is described.

Although the identification of which tests are considered as coupled interaction tests is somewhat subjective, Table 8.3.2.1-1 attempts to list all of the tests to be performed during site characterization that have a specific objective of investigating one or more processes that are directly interacting with another process. The tests listed in the table either are designed to test the interactions between two or more processes or to provide information to support evaluation of the effects of interactions between two or more processes. The reader should refer to the specific study or activity descriptions within the SCP, as well as the associated study plans and test procedures, for further details on the tests. There are other tests that have not yet been completely defined that will also investigate coupled interactions. These tests will be described in future SCP progress reports when the scopes of the tests are more completely defined.

Many processes involving multivariable phenomena are expected to be shown to be of secondary importance through analyses of their significance to determining the level of compliance with regulatory criteria. Those analyses must be performed under the individual issues because of the variety of regulatory criteria addressed by the issues and the subsequent variety of approaches used to determine the level of compliance. Like the strategy for dealing with multivariable interaction tests, the approach to multivariable interaction analyses is for each performance and design issue to call for the analyses it needs for its resolution. In this document, therefore, those analyses are described under the issues that call for them.

8.3.2.1.3 Design improvement activities and tests

Optimization implies improving or refining the design to better meet the goals or objectives of a system for a given set of conditions. This is achieved by defining the project as a system with components that meet specific objectives, appraising the performance of the system, and feeding back the information gained through the evaluation to improve the design and its performance. Successive iterations lead to an optimum design.

Table 8.3.2.1-1. Studies or activities for coupled interaction tests

Study or activity designation	Study or activity title	Processes investigated[a]
1.5.2.1.1	Dissolution and leaching of spent fuel (Section 8.3.5.10.2.1.1)	C-R-T
1.5.2.1.2	Oxidation of spent fuel (Section 8.3.5.10.2.1.2)	C-R-T
1.5.2.1.3	Corrosion of Zircaloy (Section 8.3.5.10.2.1.3)	C-H-R-T
1.5.2.1.4	Corrosion of and radionuclide release from other materials in the spent fuel waste form (Section 8.3.5.10.2.1.4)	C-H-R-T
1.5.2.1.5	Evaluation of the inventory and release of carbon-14 from Zircaloy cladding (Section 8.3.5.10.2.1.5)	C-R-T
1.10.4.1.1	Rock-water interaction at elevated temperatures (Section 8.3.4.2.4.1.1)	C-T
1.10.4.1.4	Dissolution of phases in the waste package environment (Section 8.3.4.2.4.1.4)	C-T
1.10.4.1.5	Effects of radiation on water chemistry (Section 8.3.4.2.4.1.5)	C-R-T
1.10.4.1.6	Effects of container and borehole liner corrosion products on water chemistry (Section 8.3.4.2.4.1.6)	C-T
1.10.4.2.1	Single-phase fluid system properties (Section 8.3.4.2.4.2.1)	C-H-T

Table 8.3.2.1-1. Studies or activities for coupled interaction tests (continued)

Study or activity designation	Study or activity title	Processes investigated[a]
1.10.4.2.2	Two-phase fluid system properties (Section 8.3.4.2.4.2.2)	C-H-T
1.10.4.4.1	Repository horizon near-field hydrologic properties (Section 8.3.4.2.4.4.1)	H-M-T
1.10.4.4.2	Repository horizon rock-water interaction (Section 8.3.4.2.4.4.2)	C-H-T
1.12.2.1.1	Detailed property determination of cementitious-based material suitable for a tuffaceous environment (Section 8.3.3.2.2.1.1)	C-H-M-T
8.3.1.2.2.4.1	Intact-fracture test in the exploratory shaft facility	C-H-M
8.3.1.2.2.4.4	Radial-borehole tests in the exploratory shaft facility	H-M
8.3.1.2.2.4.5	Excavation-effects test in the exploratory shaft facility	H-M
8.3.1.2.2.4.8	Hydrochemistry tests in the exploratory shaft facility	C-H
8.3.1.2.2.7.1	Gaseous-phase chemical investigations	C-H
8.3.1.2.2.7.2	Aqueous-phase chemical investigations	C-H
8.3.1.2.3.1.5	Testing at the C-hole sites with conservative tracers	C-H
8.3.1.2.3.1.6	Well testing with conservative tracers throughout the site	C-H

Table 8.3.2.1-1. Studies or activities for coupled interaction tests (continued)

Study or activity designation	Study or activity title	Processes investigated[a]
8.3.1.2.3.1.7	Testing at the C-hole sites with reactive tracers	C-H
8.3.1.2.3.1.8	Well testing with reactive tracers throughout the site	C-H
8.3.1.3.2.2.2	Smectite, zeolite, and glass dehydration and transformation	C-H-T
8.3.1.3.3.2.1	Kinetic studies of zeolite and related framework silicates	C-T
8.3.1.3.4.1.3	Sorption as a function of ground-water composition	C-H
8.3.1.3.5.1.1	Solubility measurements	C-H-R-T
8.3.1.3.5.1.2	Speciation measurements	C-H-R-T
8.3.1.3.6.1.1	Crushed tuff column experiments	C-H
8.3.1.3.6.1.2	Mass transfer kinetics	C-H
8.3.1.3.6.1.3	Unsaturated tuff columns	C-H
8.3.1.3.6.1.4	Fractured tuff column studies	C-H
8.3.1.15.1.3.2	Effects of variable environmental conditions on compressive mechanical properties	H-M-T
8.3.1.15.1.4.2	Effects of variable environmental conditions on mechanical properties of fractures	H-M-T
8.3.1.15.1.6.1	Heater experiment in unit TSw1[b]	H-M-T
8.3.1.15.1.6.2	Canister-scale heater experiment	H-M-R-T
8.3.1.15.1.6.3	Yucca Mountain heated block experiment	H-M-T

Table 8.3.2.1-1. Studies or activities for coupled interaction tests (continued)

Study or activity designation	Study or activity title	Processes investigated[a]
8.3.1.15.1.6.4	Thermal stress measurements	M-T
8.3.1.15.1.6.5	Heated room experiment	M-T

[a]The general classes of processes to be investigated include chemical (C), hydrologic (H), mechanical (M), radiation (R), and thermal (T). No degree of importance or test emphasis is implied by the listed order.

[b]TSw1 is the lithophysal portion of the Topopah Spring Member located above the potential repository horizon. In general tests at the site are in TSw2, the proposed repository horizon, unless otherwise indicated.

As the design changes, only a snapshot of it is available at any time before construction; hence, this document reflects that fact, and only the current design is presented. Improvements to the design will follow. Both the design and its detailing are refined as the design progresses through its various phases. The present design phase is conceptual, which includes the SCP conceptual design that accompanies this SCP and the advanced conceptual design (ACD). Future phases are the license application design, which is required to accompany license application to the NRC; the final procurement and construction design; and design revisions required during construction.

For large projects or systems requiring multiple interactions, the design progresses toward an optimum solution, but does not accomplish it in the mathematical sense. Therefore, the goal of the Yucca Mountain Project is not an optimum design solution, but a design that has been optimized to the point of providing an acceptable solution emphasizing certain characteristics. The desired characteristics or attributes of the system are discussed in the following paragraph.

The repository design and operation must be licensable by the NRC and be safe and cost effective according to the DOE. To facilitate addressing these overall system requirements, the design should be as simple as possible. Simple designs, the performance and reliability of which can be most readily predicted, will facilitate review and expedite licensing. The system will be described in the systems description document. The current repository design is discussed in Chapter 6. The requirements, by which the system will be evaluated, will be provided in the systems requirement and repository design requirement documents. These repository-specific documents will be useful in assessing the degree to which the desirable attributes are present in the Yucca Mountain mined geologic disposal system.

In arriving at a design with the preceding attributes, many tradeoff analyses will be required. The role of tradeoff analyses is to assess alternatives and provide the technical basis for making decisions that will improve the design and hence, system performance. Such studies are required when two or more design alternatives are considered and the most beneficial one is not obvious. The tradeoff analyses determine which design will be most favorable for meeting the system requirements. For example, technical feasibility or the probability of successfully constructing the design and achieving design goals may be tradeoffs in some design choices. Cost and performance may also be traded off for each of the design choices. The choice between alternatives may not always be clearly defined as the impact on each of the system elements must be assessed along with the resulting interactions. In Table 8.3.2.1-2, the ongoing and planned tradeoff analyses are listed along with their related issue. No special site data are required for design resolution other than that needed for the general underground facility design. Only those that significantly impact the design and performance of the system are listed. The many other analyses of less significant impact are not mentioned.

8.3.2.1.4 Repository modeling

This section identifies and describes the needs for numerical of models and codes for repository design analyses. These numerical models are derived from conceptual models of system and subsystem response of the host rock to excavation and waste emplacement.

The need for a particular conceptual model results from goals established through the issue resolution strategy. From these conceptual models, numerical models are developed.

This section addresses the models and codes intended to be applied to geomechanical, ventilation, seismic, and safety analyses. The testing and evaluation of these models and codes, including verification and validation, are discussed in Section 8.3.5.20.

For geomechanical analyses, loads imposed upon the rock mass from excavation and heat generating waste will be evaluated (Issue 1.11, configuration of underground facilities, Section 8.3.2.2). For ventilation analyses, design of the ventilation system will include equipment and worker health and safety considerations (Issue 4.2, nonradiological health and safety, Section 8.3.2.4). For seismic considerations, hazards due to ground and fault motion will be analyzed to determine the potential effects of underground nuclear events and earthquakes upon surface and subsurface facilities (Issues 4.4, technical feasibility Section 8.3.2.5, and 1.11). Safety analyses include both radiological concerns (Issue 2.7, repository design criteria for radiological safety, Section 8.3.2.3) and nonradiological concerns (Issue 4.2).

Table 8.3.2.1-2. Nevada Nuclear Waste Storage Investigations Project design tradeoff analyses

Design tradeoff analyses	Related issue
Horizontal versus vertical waste emplacement orientation (includes separate cost, performance, and technical feasibility analyses, as well as single-package short-hole and multipackage long-hole variants)	4.4 (Section 8.3.2.5)
Underground ventilation reversibility (use or not use)	4.2 (Section 8.3.2.4)
Selection of material handling method, hoist type, and waste transporter	4.4
Selection of repository orientation	1.11 (Section 8.3.2.2)
Underground emplacement of backfill	1.11
Selection of areal power density of emplaced waste	1.11
Selection of borehole spacing and length and waste standoff	1.11
Selection of excavating technique(s)	1.11, 4.4
Selection of excavation geometry and dimensions	4.4
Selection of underground rock support systems	4.4

8.3.2.1.4.1 Geomechanical analyses

Geomechanical analyses consider mechanical, thermal, and thermomechanical response of the rock mass through the emplacement and retrieval periods. Within the geomechanical area, the goals cited indicate the need to understand the response of the host rock to excavation and thermally induced loads. Excavation-induced loads depend primarily on the in situ stress field with additional stresses resulting from the geometry of the opening considered. Thermal loads depend primarily on magnitude of individual or combined heat sources. Heat is transmitted through the rock mass by considering the thermal properties of the rock and the heat transfer mechanism; thus, these loads vary with time and position. The effects of excavation-induced loads are first evaluated and then the effects of thermal loads are evaluated.

The current understanding of mechanical response is that, in general, the fractured rock mass can be treated as an elastic, elastic-plastic, or compliant-jointed medium (Section 6.4.2). Additionally, quasi-discrete and distinct-element models will be considered to evaluate the behavior of isolated joints, intersecting joints, and possibly rock-mass response. The current understandings of the mechanical response of the fractured tuff have been based on and supplemented by three integrated sources of data: (1) field studies of the local and regional geology of the site (Chapter 1), (2) laboratory and field data indicative of the mechanical and thermal response of the rock from Yucca Mountain (Chapter 2, Introduction), and (3) laboratory and field experiments data collected in situ at nearby Rainier Mesa (Section 2.3.3). The mechanical response considered in a given analysis or set of analyses may depend on the scale, loading, and boundary conditions of the problem or the purpose of the analyses.

The approach to understanding and predicting mechanical response has been to use progressively more complex models through the course of design, performance, and safety analyses. For example, standard engineering practices are often applied at the onset to provide initial guidance to developing repository design. This practice is qualified by data available before site characterization. The resultant preliminary design warrants evaluation and confirmation through use of boundary element and finite element methods.

Three types of analytical tools are being developed to provide perspectives of the rock mass mechanical response. These tools will be applied to address concerns of Issues 1.11 (configuration of underground facilities (postclosure), Section 8.3.2.2); 2.4 (retrievability, Section 8.3.5.2); 4.2 (nonradiological health and safety, Section 8.3.2.4), and 4.4 (preclosure design and technical feasibility, Section 8.3.2.5). The analytical tools are

1. Tunnel index methods (Barton et al., 1974a; Bieniawski, 1974) that are empirical methods that permit conclusions to be made regarding ground support requirements. As yet, these methods do not account for the effects of heat.

2. Calculations using boundary element techniques (numerical methods that treat the rock mass as an elastic media) will be used for an initial degree of confirmation or qualification to be placed on ground support requirements determined by the tunnel indexing methods. The effects of excavation and heat may be included in the analysis. Rock strength may be used to interpret results. These methods allow efficient parametric studies to be undertaken in which design tradeoffs and potential effects of parameter sensitivities to design can be evaluated through the predictions of deformations and stress at specific locations as a function of time. The usefulness of boundary element methods will be tested through comparison with closed-form analytic solutions, finite-element codes, and underground exploration.

3. The predominant calculational tool for planned license application analyses will probably be the finite-element method. Thus far, this method allows for modeling the most complex combinations of geometries, boundary conditions, and material behavior. Calculations by

this method, which treats the rock mass as an elastic, elastic-plastic, or compliant-jointed medium, will attempt to confirm or qualify the conclusions drawn from tunnel indexing and boundary-element methods based on the effects of excavation and heat predicted throughout the area of interest as a function of time. The finite-element method has the potential to consider rock strength, fracture slip, and fracture deformability either as part of the computation or as useful to interpret results. Also, ground-support (rock-support interactions including thermal effects) can be modeled using this method. Finite-element codes will be tested through comparison with closed-form analytic solutions, boundary-element codes, underground exploration, and laboratory and field testing.

Our current understanding is that the dominant heat transfer mechanism in the unsaturated tuff is temperature-dependent conduction. These understandings are based on a data base of laboratory and field tests and analyses (Section 2.5.3, relationship between intact rock and large-scale properties). The types of analytical tools being developed to provide perspectives of the rock mass thermal response to address Issues 1.11 (configuration of underground facilities (postclosure), Section 8.3.2.2), 4.2 (nonradiological health and safety, Section 8.3.2.4), and 4.4, (preclosure design and technical feasibility, Section 8.3.2.5), include

1. An analytic solution for heat conduction for finite cylinder heat sources with a decaying exponential source term with time and linear superposition of sources. This analytical tool will serve the purpose of making preliminary design assessments for the repository. This method will be tested using closed-form analytic solutions.

2. An analytic solution for the heat conduction for infinite line heat sources that may be constant or exponentially decaying with time. This analytical method is an integral part of the boundary-element method used to perform design and sensitivity analyses. This method will be tested using closed-form analytic solutions.

3. A numerical model capable of steady and transient linear and non-linear thermal conduction analyses in at least two dimensions. Possible boundary conditions include constant temperature at a node, constant or time-dependent temperature along a side, adiabatic surface, forced convection, natural convection, and thermal radiation. Material properties (densities, specific heats, and conductivity tensors) may be dependent on temperature. This method will be tested using closed-form analytic solutions, benchmarking activities (Section 8.3.5.20), and laboratory and field experiments. Heat transfer codes similar to the ones being considered have been successfully applied to analyses of heat transfer in salt (Waste Isolation Pilot Plant and Project Salt Vault), granite (Stripa and Spent Fuel Test-Climax), and tuff (SCP Sections 2.5.2.1.1 and 2.5.3). These codes will be tested to show their applicability to partially saturated tuff at the repository horizon because the currently existing studies are not sufficient. The results of these analyses are used as input for thermomechanical analyses.

Our current understanding of the combined contributions of the excavation and thermal effects upon rock-mass response (termed the thermomechanical response) is based on laboratory and field investigations of the thermomechanical response of rocks at the site (Section 2.5, thermal and thermomechanical properties--large scale). Based on this understanding, two methods are currently being applied to predict thermomechanical response. In the first, using boundary-element techniques, thermal stresses and displacements are calculated by treating the thermal stress and the initial stress as a time-varying boundary condition. In the second, using finite-element techniques, mechanical responses from excavation and thermal responses from the heat source are separately analyzed, and then the thermal results are input to the mechanical analysis to determine the thermomechanical response.

The types and scales of analyses being considered to address Issues 1.11, 4.2, and 4.4 include the following:

1. The state of stress and deformation in the vicinity of boreholes, rooms, access ways, shafts, ramps, and the repository will be studied to determine short- and long-term stability through analyses in which the thermomechanical response resulting from excavation and subsequent thermal loading is assessed.

2. Surface uplift and subsidence will be studied to determine repository scale manifestations of short- and long-term thermomechanical response resulting from excavation and subsequent thermal loading (e.g., to aid in establishing acceptable areal power densities).

3. The state of stress and deformation resulting from excavations and construction of the surface facilities will be studied to ensure structural integrity and safety of the facilities throughout the course of operations.

4. Rock-mass deformation properties (anisotropic elastic properties) will be calculated by applying state-of-the-art numerical techniques (compliant joint models) to the current data base of intact rock and fracture characteristics. Such anisotropic properties will be included in stability analyses as warranted.

8.3.2.1.4.2 Seismic analyses

For seismic considerations, hazards due to vibratory ground motion and surface fault rupture will be analyzed to determine the potential effects of underground nuclear events and earthquakes upon surface and subsurface facilities. Currently, to satisfy site characterization information needs for Design Issues 1.11 (configuration of underground facilities, Section 8.3.2.2) and 4.4 (preclosure design and technical feasibility, Section 8.3.2.5), as well as for Investigations 8.3.1.17.2 (fault movement) and 8.3.1.17.3 (seismicity); the phenomena being considered for analyses include

1. The attenuation of ground motion with depth (both for acceleration and frequency) as it applies to surface and subsurface facilities.

2. The effect of local geology upon seismic wave propagation and direction.

3. Fault activities at the site including total displacements, displacement rates, evidence of surface rupture, type and orientation, and age of recent activity of the faults in the site area.

4. Seismic hazards related to ground motion and surface rupture resulting from natural earthquakes.

5. Ground motion at any point in the repository horizon as a result of seismic loads, its effect on the state of stress and deformation, and the stability of underground openings.

8.3.2.1.4.3 Ventilation analyses

Ventilation analyses will be conducted initially to size and design the ventilation system and to assess its performance during the course of operations. Even in the unsaturated environment, removal of some water in the form of humidity will be accomplished by the ventilation system. The codes being considered for this work will be ones that have been used extensively in the past. Analyses may be attempted that could qualify these codes based on current applications of these codes at underground operations. Since the use of these codes in the past has not routinely included thermal effects to the extent expected for the repository, the codes should be qualified for that purpose. The types of analyses being considered to help address Issues 1.11 (configuration of underground facilities, Section 8.3.2.2), 2.7 (repository design criteria for radiological safety, Section 8.3.2.3), 4.2 (nonradiological health and safety, Section 8.3.2.4), and 4.4 (technical feasibility, Section 8.3.2.5), include

1. Analyses to ensure worker safety in the context of maintaining appropriate air quality for dust, humidity, radon daughter products, and temperature considerations.

2. Analyses to ensure that requirements for equipment operations are met.

8.3.2.1.4.4 Safety analyses

Safety analyses will be conducted in addressing Issues 2.7, repository design criteria for radiological safety, and 4.2, (nonradiological health and safety). For Issue 2.7, analyses will ensure that limits of radiological exposure of workers and the public are met. Important to these analyses are the source terms and configurations of the underground and surface facilities coupled with the operations plan for the facilities. Codes being considered for this work will be ones that have been proven through extensive past use in the nuclear industry.

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For Issue 4.2, analyses will be used to ensure worker health and safety in the daily course of operations. These analyses are similar to those listed in Sections 8.3.2.1.4.1 and 8.3.2.1.4.3.

8.3.2.2 Issue resolution strategy for Issue 1.11: Have the characteristics and configurations of the repository and repository engineered barriers been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.133 and (b) provide information for the resolution of the performance issues?

The postclosure design criteria of 10 CFR 60.133 addressed by this issue require that the underground facility and engineered barrier system be designed to

1. Contribute to containment and isolation.

2. Assist the geologic setting in meeting performance objectives.

3. Take into account the thermal and thermomechanical response and the need for sufficient flexibility to accommodate site-specific conditions.

This postclosure design issue provides the mechanism for identifying repository design characteristics and configurations important to the resolution of Key Issue 1, quantifying how these characteristics and configurations are in compliance with 10 CFR 60.133, and incorporating postclosure performance concerns into the design. Characteristics and configurations considered in developing the approach to this issue include repository depth, dip, orientation, geometry, layout, access location, thermal loading, drainage or moisture control, construction materials, backfill, excavation techniques, and opening stability.

The approach to resolving this issue will be to establish tentative performance goals through the issue resolution process and to develop reference postclosure designs of the repository that are in compliance with these goals. The impact of design characteristics and configurations on the postclosure performance of the repository will be documented in a series of topical reports. The reference postclosure design will be documented in the reference information base (RIB) (together with other components of the overall design) and in major design documents for use in postclosure performance assessments.

In practice, this issue will be resolved in step with the planned design stages. Specifically, preliminary assessments and design concepts are an integral part of the conceptual design summarized in Chapter 6. Updating of this information will continue through the advanced conceptual design and the license application design. Advancing from one step to the next in the design process requires that the goals of the issue be met or that there be reasonable expectancy that they will be met as detailed studies are completed in succeeding phases of the design.

The general approach used to determine compliance with 10 CFR 60.133 and to provide adequate information to support resolution of performance issues, which is summarized in Figure 8.3.2.2-1, is to

1. Apply the issue resolution process as a means of establishing the overall logic of Figure 8.3.2.2-1, specifically identifying the performance goals of the issue.

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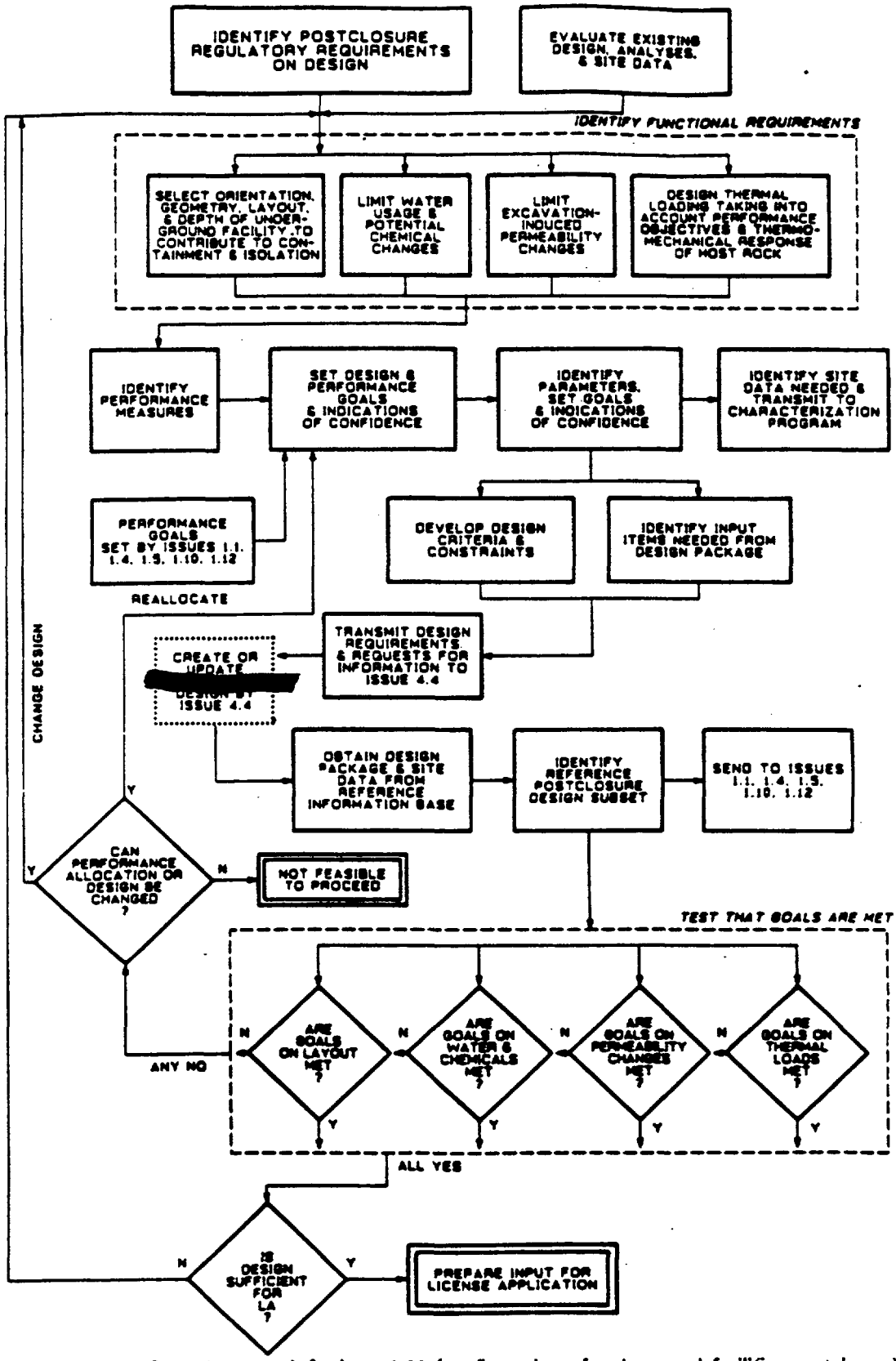

Figure 8.3.2.2-1a. General approach for Issue 1.11 (configuration of underground facilities–postclosure). See Figure 8.3.2.2-1b for legend. Section 8.3.2.1 describes the relationships and interfaces between design and performance issues.

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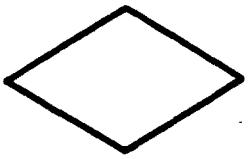
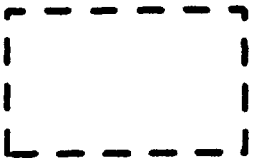
LEGEND

ACTIVITY PERFORMED TO RESOLVE ISSUE

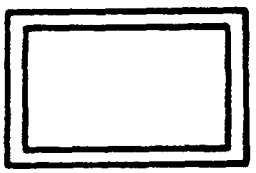


TEST TO DETERMINE SUBSEQUENT ACTIVITY

ACTIVITY PERFORMED BY INDICATED ISSUE



ACTIVITY WITH MULTIPLE SIMILAR ACTIVITIES OR TESTS



DECISION ABOUT ISSUE RESOLUTION

Y - YES N - NO LA - LICENSE APPLICATION

Figure 8.3.2.2-1b. Legend for Figure 8.3.2.2-1a.

2. Perform technical studies (design activities) to evaluate compliance with the goals, complete reference calculations for use by other issues and perform sensitivity studies that evaluate data needed for design (middle part of Figure 8.3.2.2-1).

3. Establish data requirements (accuracy and confidence) as guidance to data gathering, assimilate site and waste package data, and establish RIB inputs (data request and inputs on Figure 8.3.2.2-1).

4. Establish reference postclosure design as the basis for postclosure performance assessment of the repository.

The goals may be modified, extended, or eliminated as more detailed evaluations are completed.

A significant part of the role of this issue (1.11) in resolving Key Issue 1 is to provide the interface between postclosure performance and design (Figure 8.3.2.2-1). The design is produced by Issue 4.4 (Section 8.3.2.5). This issue provides the interface to postclosure performance issues by taking their performance goals and converting them into design requirements that can be used by Issue 4.4 to control the design through the repository design requirements document. Figure 8.3.2.2-1 shows Issue 1.11 as the bridge between the total system and Issue 4.4. The relationship between performance issues, this issue, and the design is embodied in the logic of Figure 8.3.2.2-1.

Regulatory basis for the issue

The parts of 10 CFR 60.133 that apply to postclosure performance and are addressed by this issue are listed in the following discussion. All parts of 10 CFR 60.133 not listed in the following discussion are considered preclosure criteria and are therefore addressed by other issues, specifically Issues 2.3 (accidental radiological releases, Section 8.3.5.4); 2.7 (repository design criteria for radiological safety, Section 8.3.2.3); 4.2 (nonradiological health and safety, Section 8.3.2.4); and 4.4 (preclosure design and technical feasibility, Section 8.3.2.5).

10 CFR 60 section	Subject applicable to Issue 1.11
133(a)(1)	Design layout and engineered barriers to contribute to performance
133(b)	Accommodate site-specific conditions
133(e)(2)	Design to reduce deleterious rock movement
133(f)	Select excavation methods that limit preferential pathways
133(h)	Assist performance of geologic setting in meeting the postclosure performance objectives
133(i)	Predict thermal and thermomechanical response

The general standard required for compliance with these regulations is "A reasonable assurance . . . that the objectives and criteria will be met" (10 CFR 60.101(a)(2)) based on predictive models" "supported by using an appropriate combination of such methods" (10 CFR 60.21(c)(1)(ii)(F)) (Section 8.3.2.2.4).

To understand the scope of these regulations and how they apply to this issue, some discussion is provided below on the work to be conducted under this and related issues.

The characteristics and configurations of the waste package and its interaction in the near-field environment are governed by 10 CFR 60.135, which is addressed by Issue 1.10 (waste package characteristics (post-closure) (Section 8.3.4.2), and hence is considered an interface to this issue. As such, Issue 1.10 places requirements on this issue that are reflected in the choice of processes, performance measures, and performance goals of this issue.

The NRC definition of the underground facility excludes ramps, shafts, boreholes, and seals for ramps, shafts, and boreholes but does not specifically exclude drift seals. Drift seals could be considered part of the underground facility, and, in turn, part of the engineered barrier system. However, they are explicitly addressed by Issue 1.12 (seals characteristics, Section 8.3.3.2), and governed by 10 CFR 60.134 and 10 CFR 60.112. Both their function and time of emplacement are very closely allied with the seals. Issue 1.12 established the requirements for sealing and how sealing will be accomplished. Thus, seals, including drift seals are considered to be an interface to this issue rather than a part of this issue. As such, Issue 1.12 places requirements on this issue that are reflected in the choice for processes, performance measures, and performance goals of this issue.

To provide the technical basis for meeting the higher level findings (Issue 1.9, Section 8.3.5.18), this design issue (1.11) must, in addition to compliance with 10 CFR Part 60, address the requirements of 10 CFR Part 960. This is done by using 10 CFR Part 60 to organize the issue resolution strategy while ensuring that the goals determined by the issue resolution approach include 10 CFR Part 960 requirements. Specific applicable parts of 10 CFR Part 960 include Subpart C, Sections 4-2-3 (Rock Characteristics) and 4-2-5 (Erosion).

Approach to resolving the issue

The issue resolution strategy for this issue started from the regulations and applied four steps: (1) functions, (2) processes, (3) performance measures, and (4) performance goals and confidence.

The "function" step is an expression of what must be done by the System Element 2.0, postclosure waste disposal system (Section 8.2.1). The functions for this issue were derived directly from 10 CFR 60.133 and provide the means for compliance of the design of the underground facility with the regulations. All the subsections of 10 CFR 60.133 noted under the regulatory basis are important to resolving this issue and are contained within these functions.

The "process" step describes how the function will be accomplished. Processes were assigned so that each function would be complete in its contribution to resolution of the issue. The processes identified for Issue 1.11 are closely related to the design activities for the issue. Because the system elements listed in the System Element 2.0 (postclosure waste disposal system) requirements are not currently defined to the level of detail of characteristics and configurations of the underground facility required by this issue, a separate checklist of such characteristics and configurations was prepared. This list was then used to guide selection of processes and was used in workshops on this issue to ensure that the list of processes was reasonable and essentially complete.

The "performance measures" step identifies the measure that will allow a determination of whether the process is being performed as required by the function. That is, to resolve the issue, the performance measure will serve as the indicator in determining how well the function is performed.

Each performance measure has an associated "goal and level of confidence" step. The goal is the value for the performance measure that will be adequate for the issue to be favorably resolved, and the level of confidence is an indication of the importance assigned to meeting the goal.

The assignment of these performance measures and associated performance goals and levels of confidence was based on professional judgment and peer reviewed in a series of workshops held in Albuquerque, New Mexico, in the spring of 1986. Completing this issue resolution completes the approach to resolving Issue 1.11 (configuration of underground facilities (postclosure)).

The results of the issue resolution approach for Issue 1.11, including each process, performance measure, and performance goal and associated confidence required, are discussed by function in the following paragraphs.

The four functions that the postclosure waste disposal System Element 2.0 (postclosure waste disposal system) must perform to resolve this issue are given in the following list together with the regulatory section they address. These functions were selected so that there is a direct correlation between the functions and the postclosure design criteria as expressed in 10 CFR 60.133.

1. Select orientation, geometry, layout, and depth of the underground facility to contribute to containment and isolation, taking into account flexibility to accommodate site specific conditions (10 CFR 60.133(a)(1) and 10 CFR 60.133(b)).

2. Limit water usage and potential chemical changes during construction and operations of underground facility so as to not adversely affect performance of natural and engineered barriers following permanent closure (10 CFR 60.133(a)(1) and 10 CFR 60.133(h)).

3. Limit potential for excavation-induced changes in rock mass permeability during construction of the underground facility so as to not adversely affect performance of natural and engineered barriers following permanent closure (10 CFR 60.133(f)).

4. Design thermal loading taking into account performance objectives and thermomechanical response of host rock (10 CFR 60.133(i), 10 CFR 60.133(e)(2), and 10 CFR 60.133(h)).

In this section, the specific processes contributing to each of the four functions are identified. Subsequently, one or more performance measures and corresponding performance goals are selected for each of the processes. The link between the processes, performance measures, and performance goals is illustrated by use of a series of tables in which the performance goals are expressed quantitatively whenever possible and appropriate. The tables are supported by descriptive text intended to provide a brief background and rationale for the tabulated material. The text and tables also identify interfaces with other issues. Such interfaces exist either when resolution of this issue contributes to resolution of another, or when resolution of another issue automatically satisfies performance measures identified here.

The tables identify two types of processes; namely, those upon which reliance is placed and those that provide additional, or backup, assurance that the function of the repository and its engineered components meet the postclosure performance criteria. The confidence with which the performance goals associated with each process need to be met at the license application stage are designated as high, medium, or low. Those designated as high are considered to be critical to providing reasonable assurance that the repository system will comply with the performance criteria. Definition of the approach to be used to meet the goals, with appropriate level of confidence, will ensure identification of the type and quality of the data required to support resolution of the performance issue.

Function 1: Select orientation, geometry, layout, and depth of the underground facility to contribute to containment and isolation, taking into account flexibility to accommodate site-specific conditions

To meet the requirements of 10 CFR 60.133(a)(1) and 10 CFR 60.133(b), the repository will be configured so that its orientation, layout, geometry, and depth contribute to or do not adversely affect containment and isolation. The primary system elements affected by function 1 are the disturbed zone (System Element 2.1.1) and the repository engineered barriers (System Element 2.2.2). Processes that contribute to meeting the function, and the related performance measures and goals are listed in Table 8.3.2.2-1. The following discussion treats the processes in three groups, which deal with the repository configuration, the environment for the waste containers, and the need for flexibility.

Repository configuration

The NWPA (1983) requires that there be sufficient space within the repository to accommodate the equivalent of 70,000 metric tons of uranium. As indicated in Table 8.3.2.2-1, this criterion must be met subject to goals relating to depth of overburden and an objective to stay above the water table in unsaturated, welded tuff of the Topopah Spring Member. Those goals were established to ensure compliance with containment and isolation performance criteria for the facility. They must be met during design through appropriate selection of the depth, dip, orientation, and lateral extent of

Table 8.3.2.2-1. Performance measures, goals, and needed confidence for selecting orientation, geometry, layout and depth of underground facility (postclosure design function 1)[a] (page 1 of 3)

Process: Possible	Process: Relied on	Performance measure		Tentative goal	Needed confidence
Vary depth, dip, orientation and lateral extent of underground facility to provide host rock with favorable containment and isolation characteristics	Yes	Usable area: Is usable area adequate for 70,000 metric tons of uranium (MTU) of waste?	1-A[b]	Area available >> area needed	High
				- >200 m overburden	High
				- stay in TSw2[c]	Medium
				- have disturbed zone stay >70 m above water table[d]	High
				- stay in primary area	Medium
				- areal power density (APD) <allowable far-field APD	High
				- probability <0.1 in 1,000 yr that >0.5% of waste packages will be breached by tectonic processes or events	High
				- offset from exploratory boreholes >15 m (cf. Issue 1.12)	High
Select emplacement borehole orientation and design to limit potential for adverse effects	Backup	Performance measures as defined by Issues 1.1, 1.6, and 1.10 will be used as part of choosing borehole orientation[e]	1-B	Performance goals as defined by Issues 1.1, 1.6, and 1.10 will be used as part of choosing borehole orientation	Medium
Limit the amount of water in contact with container to provide favorable isolation and containment environment	Yes	Regions of dehydration or condensation and drainage pattern	1-C	Design subsurface facility so that convection and natural drainage is away from containers and so that goals of Issues 1.10 and 1.12 can be met[f]	High
Skip and isolate unfavorable areas	Yes	Ground quality (technical feasibility performance measure)	1-D	Goals for determining technical feasibility of underground development considering local variability will be set by Issue 4.4	High

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Table 8.3.2.2-1. Performance measures, goals, and needed confidence for selecting orientation, geometry, layout and depth of underground facility (postclosure design function 1)[a] (page 2 of 3)

Process: Possible	Process: Relied on	Performance measure		Tentative goal	Needed confidence
Skip and isolate unfavorable areas (continued)		Extent of change in	1-E	Emplace in ground that satisfies	
		- saturation		- average saturation: 75%[g]	High
				- local saturation <90%[g]	Low
		- water chemistry		- water chemistry requirements established in Issue 1.10[h]	Medium
		Distance from ground with unfavorable properties	1-F	Stay far enough away to satisfy goals of 1-E above[i]	Medium
Adjust thermal load to accommodate local conditions	Yes	Temperature (to limit potential for adverse geochemical, etc. effects on the host rock)	1-G	Goals (4-O, 4-P, 4-R, 4-U, and 4-V) for determining allowable temperatures are set as part of function 4 (Table 8.3.2.2-4) of this issue	High
		Postclosure rock movements within acceptable limits under thermal loads	1-H	Goals (4-Q and 4-W) for determining if rock meets postclosure thermomechanical criteria will be set by function 4 (Table 8.3.2.2-4) of this issue	Medium

[a]The issues referenced in this table and its footnotes are addressed in the following sections: Issue 1.1 (total system performance, Section 8.3.5.13), Issue 1.6 (ground-water travel time, Section 8.3.5.12), Issue 1.10 (waste package characteristics-postclosure, Section 8.3.4.2), Issue 1.12 (seal characteristics, Section 8.3.3.2), and the climate program (Section 8.3.1.5).

[b]1-A indicates function 1 and goal A. This designator is carried over to Table 8.3.2.2-5 to associate data of that table with goals of this table.

[g]Goal is to stay in the TSw2 unit (low lithophysal Topopah Spring Member), but TSw1 (lithophysal Topopah Spring) may be considered. See Chapter 2 for complete description of units.

[i]The distance from the disturbed zone to the water table should be 70 m or more; preferably this should be 70 m of CHn (Calico Hills nonwelded unit).

[h]Design factors that will be considered in performance review of borehole orientation include drift size, extraction ratio, standoff distance, potential fault/fracture effects, borehole hydrology, liner effects, potential abnormal conditions, etc.

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Table 8.3.2.2-1. Performance measures, goals, and needed confidence for selecting orientation, geometry, layout and depth of underground facility (postclosure design function 1)[a] (page 3 of 3)

Footnotes (continued)

[f]Specific requirements of Issue 1.12 include (1) locate surface portals in nonflood prone areas; (2) restrict the number of shafts and ramps; (3) retain capability to emplace seals at base of shafts; (4) provide adequate storage capacity at base of shafts; (5) grade drifts to drain away from emplacement areas; (6) ensure drift floors can be reconditioned to enhance drainage; (7) provide adequate storage at low point of subsurface facilities before water enters emplacement drifts; and (8) establish drainage of shops, etc., toward exploratory shaft 1 (ES-1) and men and material (MM) shafts and of emplacement areas away from ES-1 and MM shafts. Specific requirements of Issue 1.10 include keeping containers dry through drainage and maintaining temperatures greater than the boiling point of water for more than 300 yr.

[g]Goal is to emplace waste in areas consistent with Issue 1.1 by requiring average emplacement saturation to be about 75% or less and local saturation around emplacement boreholes to be less than 90%. Intent of goal is to assure that perturbations to the site due to construction, operations, and the addition of heat will not cause saturated conditions.

[h]Water chemistry goals as set by Issue 1.10. Conditions should not be disturbed from predevelopment conditions by more than a specified amount.

[i]Actual standoff is determined by conditions around the ground with unfavorable properties by requiring that goal 1-E be met. Faults are explicitly incorporated into the design through goals 1-A, however, the anomalous conditions of concern in goal 1-E (saturation and geochemistry) are most likely to occur near faults. During conceptual design the offset of Ghost Dance (approximately 14 m) was used to estimate how much bigger the layout would be if such a standoff were incorporated (SCP-CDR Appendix M (SNL, 1987)). If ground with unfavorable properties is found within the ESF, a better estimate (than offset) of appropriate standoff can be made.

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the underground facility. Postclosure considerations are important to that design process because the areal power density (APD) must be selected so as to meet temperature, stress, and displacement criteria discussed under this issue. In addition, the repository layout and dip must be selected so as to assist drainage and contribute to maintaining the container environment goals established under Issue 1.10 (Section 8.3.4.2), waste package characteristics (postclosure).

The APD is an average figure for the repository. The thermal output of individual containers and their spacing and orientation become important when considering near-field performance criteria. Preliminary evaluations indicate that the orientations of the underground openings relative to the in situ stress and fracture geometry may not be primary design considerations (Section 6.4.2 of the Site Characterization Plan-Conceptual Design Report (SCP-CDR) (SNL, 1987). However, potential performance differences between the horizontal and vertical emplacement options will be evaluated. The selected option must meet isolation and containment requirements, and contribute to meeting the requirements of other issues, namely, Issues 1.1 (total system performance, Section 8.3.5.13), 1.6 (ground-water travel time, Section 8.3.5.12), 1.10 (waste package characteristics (postclosure), Section 8.3.4.2), and 4.4 (technical feasibility, Section 8.3.2.5). The final recommendation regarding the disposition of the waste will be documented in the reference postclosure design.

Container environment

A goal to limit the amount of water that will come in contact with the waste container is established in Issue 1.10 (Section 8.3.4.2), which is concerned with waste package design. Measures taken to meet this goal and thereby contribute to containment and isolation include location of the repository in an unsaturated host rock; development of an underground layout that enhances natural drainage away from the containers; and selection of a design basis thermal loading (APD) that maintains temperatures above the in situ boiling temperature of water at the container surface for the first 300 yr after repository closure. The use of seals to reduce the entry of water into the underground facility will also affect container environment; seals are addressed in Issue 1.12 (seals characteristics, Section 8.3.3.2).

In Table 8.3.2.2-1, a general requirement to define the regions of dehydration and condensation and the pattern of drainage within the underground facility is identified. The amount of moisture that is anticipated to come in contact with the containers during the postclosure period will be considered during design and will be the subject of performance assessment. Performance measures and goals relating to thermal environment of the canister are discussed further under function 4.

Flexibility

The design of the repository will be sufficiently flexible that there will be freedom to respond to conditions encountered underground during construction and emplacement. Two possible options for responding to adverse ground conditions are identified in Table 8.3.2.2-1. These are either to skip and isolate unfavorable areas or to adjust the thermal load locally.

Function 2: Limit water usage and potential chemical changes.

In conformance with the regulatory requirements stated in 10 CFR 60.133(a)(1) and 10 CFR 60.133(h), the engineered barriers will contribute to isolation and containment and will assist the geologic setting in meeting performance objectives. Two processes are identified as important to assuring that the engineered barriers (System Element 2.2.2) adequately satisfy those requirements. These are concerned with avoiding potentially adverse changes in the chemical environment and the degree of saturation of the host rock. These two processes and their related performance measures and performance goals and confidence are listed in Table 8.3.2.2-2.

Limit adverse chemical changes

Potentially adverse chemical effects may arise, either directly or indirectly, as a result of materials introduced to the site during construction, operation, and decommissioning. Primary factors in meeting this functional requirement are the control of materials entering the repository.

In Table 8.3.2.2-2, cement and organics are identified as materials that may need to be controlled, because they may adversely affect the pH and chemistry of the natural ground water. Goals with respect to pH and chemistry changes as they impact the waste package and waste isolation have been established by Issue 1.10 (Section 8.3.4.2), and Issue 1.1 (Section 8.3.5.13). This issue (1.11) (Section 8.3.2.2) will establish the allowable postclosure material quantities and impose these constraints on Issue 4.4 (Section 8.3.2.5). During design, particular attention has focused on the amount of cement used for all construction and operations, and in particular for the preparation of the emplacement boreholes, and any organics in the flushing fluid used during drilling. The goals of controlling the quantities of cement and organics, which are identified in Table 8.3.2.2-2, can be met with the required confidence by development and implementation of operating procedures for the underground facility.

Limit and control water used during construction

Control of water used during construction of the shafts, access ramps, and the excavations of the underground facility is identified as a process in Table 8.3.2.2-2, because of the desire to limit the changes in the degree of saturation of the host rock and the water reaching the containers. The degree of saturation of the rock in the immediate vicinity of the waste containers is a concern. As a result, it will also be important to limit and control the nature and quantity of the flushing medium used during drilling holes and the water used for drilling and dust control during construction of the other excavations of the repository.

The present design basis is that the emplacement boreholes will be drilled dry, using a vacuum chip removal system, and that criteria will be developed for control of any water used during construction, operation, and decommissioning. Other measures to be taken to control the amount of water that will come in contact with the containers are discussed under functions 1 and 4. These include, respectively, planning the repository so the natural

Table 8.3.2.2-2. Performance measures, goals, and needed confidences for limiting water usage and potential chemical changes (postclosure design function 2)

Process: Possible	Process: Relied on	Performance measure		Tentative goal	Needed confidence
Limit adverse chemical changes by using acceptable materials and fluids	Yes	Type, quantity, and location of materials (including materials for seals):	2-I[a]	Requirements specified by Issues 1.10 and 1.12 (Sections 8.3.4.2 and 8.3.3.2) applied here	
		Quantity of concrete		Limit cement in emplacement boreholes and drifts to that required for proper construction[b]	Medium
		Quantity of shotcrete		Limit shotcrete in drift and access linings to that required for proper construction	Medium
		Quantity of grout for bolt anchors		Limit grout used for bolt anchors to that required for proper construction	Medium
		Quantity of organics		Limit organics in drilling fluids and explosive residues from blasting	High
Limit the amount of water used in construction, operation, emplacement of seals, and decommissioning to provide favorable containment and isolation environment	Yes	Net water from operations that remains in host rock at emplacement	2-J	Water usage should be limited so that saturation at emplacement does not violate goal 1-E, Table 8.3.2.2-1	High
				Limit water to that required for dust control and proper equipment function	
				Remove all excess water	

[a]2-I indicates function 2 and goal I. This indicator is carried over to Table 8.3.2.2-5 to associate data of that table with goals of this table.

[b]Quantities and chemical composition may be impacted by requirements related to postclosure performance objective for the waste package.

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drainage is away from the waste containers, using seals to reduce the quantity of water that enters the repository, and maintaining container temperatures sufficiently high to maintain dry conditions around the waste containers during the first 300 yr following closure.

Function 3: Limit potential for excavation-induced changes in rock mass permeability

In conformance with requirements stated in 10 CFR 60.133(f) and 10 CFR 60.133(e)(2), the excavation method and the design of the underground openings of the repository will be selected so as to limit the potential for creation of preferential pathways to the accessible environment, particularly through deleterious rock movement and creation of new fractures in the rock mass. The system element contributing to satisfying this function is the disturbed zone (System Element 2.1.2). The disturbed zone is defined under Issue 1.6 (ground-water travel time, Section 8.3.5.12), as the region of the host rock in which there might be potentially adverse changes in the hydrologic properties (matrix permeability and porosity). Processes considered important to this function are identified in Table 8.3.2.2-3. Those processes are discussed individually in the following sections.

In addition to the potential for excavation-induced changes in rock mass permeability, thermal stresses can change fracture apertures and hence, fracture permeability. Goals controlling the potential for deleterious rock movement and preferential pathways that might result from thermal stresses have been established by performance allocation under function 4 (design thermal loading taking into account performance objectives and thermomechanical response of the host rock). Section 6.4.1 of the SCP-CDR (SNL, 1987) discusses the relationship of the current understanding of hydrologic processes in the unsaturated zone at Yucca Mountain to the goals established under function 4.

Permeability modification associated with excavation process

Damage to the rock mass that is associated with blasting can be limited through the use of appropriate blast control methods. Such procedures are important design concerns since they potentially impact support and maintenance (Issues 4.2 (Section 8.3.2.4), nonradiological health and safety, and 4.4 (Section 8.3.2.5), technical feasibility). Analyses in the SCP-CDR suggest that they are less important to postclosure performance concerns because movement of ground water is generally expected to be through the matrix rather than along fractures (see the Section 6.4.1 of SCP-CDR (SNL, 1987) for a complete discussion), and blast-induced fracturing typically extends only a short distance from an excavation compared with the distance to emplaced waste. Similarly, the use of drilling as the emplacement borehole construction method is important to preserving stability of the boreholes. Stable boreholes are important to maintaining the retrieval option during the preclosure period (Issue 2.4 (waste retrievability, Section 8.3.5.2)) and to meeting waste package criteria (Issue 1.10 (waste package characteristics--postclosure, Section 8.3.4.2)), as well as to minimizing block motion (caving) above the borehole that might result in adverse effects on waste package containment (Issue 1.10).

Table 8.3.2.2-3. Performance measures, goals, and needed confidences for limiting potential for excavation-induced changes in rock mass permeability (postclosure design function 3)

Process: Possible	Process: Relied on	Performance measure		Tentative goal	Needed confidence
Limit magnitude and extent of blast-induced permeability change by blast control	Backup	Permeability change due to blasting should not cause a change in disturbed zone boundary or unnecessarily complicate seal evaluation and emplacement	3-K[a]	Permeability change beyond 3 m should be less than one order of magnitude[b] (cf. Issue 1.6 (Section 8.3.5.12))	Medium
Limit potential for subsidence by limiting extraction ratio and drift size	Backup	Extraction ratio	3-L	Current design basis - Horizontal emplacement <10% - Vertical emplacement <30%	 High High
		Drift spans	3-M	<11 m	High
Backfill drifts at decommissioning	Backup	Amount of fill	3-N	Backfill to within 0.5 m of roof	Medium

[a]3-K indicates function 3 and goal K. This designator is carried over to Table 8.3.2.2-5 to associate data of that table with goals of this table.

[b]Drifts and emplacement boreholes; for description of constraints on shafts or seal areas see Issue 1.12 (Section 8.3.3.2).

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Limit potential for surface subsidence

Subsidence of the ground surface is observed to occur above mining excavations when a high proportion of the rock on a particular horizon is extracted. The possibility of subsidence can be reduced with a high degree of confidence, provided the span of any excavations is small and the pillars between excavations are large, and chiefly by minimizing the extraction ratio. For the repository, the requirements for containment and preservation of the retrieval option would be inconsistent with allowing significant roof falls or pillar damage. Hence, the potential for surface subsidence during the preclosure period must be excluded. In the longer term, the potential for subsidence will be limited by conservative pillar design and maintaining reasonably low extraction ratio. The role of backfilling is currently being investigated in subsidence control and creation of preferential pathways for water migration.

Limit postclosure drift collapse by backfilling

If the excavations of a repository are not backfilled before decommissioning, there is a potential for progressive collapse of at least portions of the underground excavations as the ground support system deteriorates. Whether such collapse constitutes a potentially adverse condition is addressed by this issue, by assessing if the potential for such collapse would cause the goals of performance issues to be violated (see function 4). The present design basis is that the underground excavations will be backfilled before closure of the underground facility.

Function 4: Design thermal loading, taking into account performance objectives and thermomechanical response of the host rock

As required by 10 CFR 60.133(i), the thermal loading of the repository will be selected so that the postclosure performance objectives will be met, taking into account the thermal and thermal-mechanical response of the host rock. In addition, there are performance objectives relating to environmental impacts at the ground surface above the repository. Because these are postclosure requirements, the repository engineered barriers (System Element 2.2.2) and the far-field (System Element 2.1.2) are identified as the most important to ensuring that these performance objectives are satisfied.

Table 8.3.2.2-4 identifies six processes that contribute to meeting this functional requirement. Of these six, three are directly concerned with the thermal field in the immediate vicinity of the waste package and below the underground facility, and two are related to potentially deleterious rock movement. The remaining process is concerned with surficial effects.

Limit temperature change in adjacent strata

The most credible path to the accessible environment is via the groundwater system. Because the repository is to be constructed in partially saturated material, this implies that the material between the underground facility and the water table below is important to the site performance. Some of the units below unit TSw2 (including the Calico Hills unit) are subject to mineralogic changes when they dehydrate. This may cause chemical and physical effects that could be detrimental to waste isolation. Accordingly,

Table 8.3.2.2-4. Performance measures, goals, and needed confidences for designing thermal loading taking into account performance objectives and thermomechanical response of host rock (postclosure design function 4) (page 1 of 2)

Process: Possible	Process: Relied on	Performance measure	Tentative goal	Needed Confidence
Limit temperature changes in selected barriers	Backup	Temperature	4-O[a] Limit temperature of CHn to <115C°[b]	Medium
			4-P Limit temperature of TSw3 to <115°[b]	Medium
Limit deleterious rock movement or preferred pathways	Backup	Potential for significant displacement (see Issue 1.1)	4-Q Relative motion <1 m at the top of TSw1[c] - No intact rock failure[d] - No continuous joint slip[e]	Medium
Limit impact on surface environment	Backup	Temperature	4-R Rise in surface temperature less than 6C°[f]	Low
		Surface uplift	4-S Surface uplift less than 0.5 cm per year[g]	Low
Vary borehole and drift spacing to control thermal loading and container temperature	Yes	Thermal loading	4-T Design basis thermal loading less than allowable thermal loading[h]	High
		Borehole wall temperature[i]	4-U Temperature <275°C	High
		Rock mass temperature[j]	4-V Temperature at 1 m from borehole <200°C[k]	High
Limit potential for borehole collapse	Yes	Stress, deformation, factor of safety, and potential rock fall	4-W Boreholes that do not load container beyond limits imposed under Issue 1.10 (Section 8.3.4.2)[l]	High
Limit corrosiveness of container environment	Yes	Time container is above boiling temperature of water (Issue 1.10)	4-X Majority of borehole walls above boiling temperature of water for >300 yr[m]	High

[a]4-O indicates function 4 and goal O. This designator is carried over to Table 8.3.2.2-5 to associate data of that table with goals of this table.

[b]Calculated with mean properties. See Issue 1.6 (Section 8.3.5.12) for a discussion of disturbed zone and basis for these goals.

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Table 8.3.2.2-4. Performance measures, goals, and needed confidences for designing thermal loading taking into account performance objectives and thermomechanical response of host rock (postclosure design function 4) (page 2 of 2)

Footnotes (continued)

[e]Issue 1.1 requirement is that the relative motion of the rock be less than 1 m (Section 8.3.5.13). To provide confidence that the goal is met, Issue 1.11 provides the additional constraints under goal 1-Q.

[d]Unconsolidated material and disturbed zone excluded from intact rock failure criteria.

[e]Continuous joint slip from surface to disturbed zone or from disturbed zone to water table.

[f]Unit evaluation goal retained in performance allocation process. Further evaluation of this goal is planned.

[g]Unit evaluation natural analogue goal retained and converted to rate in performance allocation process.

[h]Allowable thermal loading (APD) will be determined by goals (o) through (s). Current design basis is "equivalent energy density" through 2,000 yr to 10 yr old average burnup spent fuel emplaced at 57 kW/acre (as per unit evaluation).

[i]Borehole wall temperature chosen so that spent fuel waste temperature will not exceed 350°C using current canister designs (cf. Issue 1.10).

[j]To ensure as-built facility does not violate bounds of properties investigated in license application and to limit the potential for adverse stress conditions due to high temperature thermal expansion of the rock.

[k]200°C at 1 m may be replaced with some other measure of the volume of rock that may exceed the bounds of temperature for which the rock properties were investigated for license application.

[l]Goal is that borehole calculations using average properties (rock and waste) and design basis geometry will result in stresses, deformations, and factors of safety that are indicative of stable conditions for the average package. This will imply reasonable confidence that the goal is met.

[m]Goal is that borehole calculations using average properties (rock and water) and design basis geometry will result in the majority of the borehole walls being above boiling for more than 300 yr. This will imply reasonable confidence that the goal is met.

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a tentative performance goal of limiting the extent of those units that may be subject to dehydration due to increased temperature has been set. That goal, which is intended to minimize the extent of potentially adverse effects, should be dictated by performance assessment considerations, which are addressed under Issue 1.6 (ground-water travel time, Section 8.3.5.12).

Limit potential for deleterious rock movement or creating preferential pathways

During the postclosure period primary concern over deleterious rock movement or preferred pathways rests with maintaining the integrity of the natural barriers.

The thermomechanical effect most likely to affect natural barrier performance is permeability change. Away from the excavations, permeability change should be limited and occur primarily in existing fractures. Fracture permeability is not believed to be an important process in natural barrier performance (Section 6.4.1 of SCP-CDR) (SNL, 1987). The largest permeability changes will most likely be associated with rock movement around the emplacement boreholes, the emplacement drifts, or along faults. If the effects of such disturbances do not result in an extension of the disturbed zone, as described under Issue 1.6 (ground-water travel time), this should not impact the ability of the natural barrier to isolate the waste. Accordingly, limiting the potential for permeability changes is identified as a backup process.

An explanation of the relationship of thermomechanical effects to the current understanding of hydrologic processes in the unsaturated zone at Yucca Mountain is given in Section 6.4.1 of the SCP-CDR. Determination of the system performance goal (<1 m of relative motion of the rock) has been set by Issue 1.1 (total system performance, Section 8.3.5.13). If the goal does not adequately maintain the natural hydrologic processes at the site, then the potential exists to adversely affect system performance or releases to the accessible environment. This would most likely be associated with rock movement around the emplacement boreholes and drifts. Table 8.3.2.2-4 considers, as part of designing the thermal load, limiting the potential for deleterious rock movement and creating preferred pathways through controlling intact rock failure and continuous joint slip.

Limit surface impact

Temperature change and uplift are the plausible effects of the repository that may be detectable at the ground surface above the underground facility. A limit on the temperature change at the surface of 6 degrees Celsius has been selected. The performance goal for surface uplift, namely, that it should be comparable with natural analogues, is set so an analogy to naturally occurring rates of surface erosion can be made.

Limit near-field temperature changes

The temperature in the vicinity of the waste package is controllable, because it is dependent upon individual canister power generation and spacing and on overall thermal loading (areal power density (APD)). The spacing and

APD, which are in turn functions of the emplacement borehole spacing and the emplacement drift spacing, will be selected to satisfy the performance goals identified in Table 8.3.2.2-4.

For the immediate vicinity of the container, two performance goals are specified. These are the peak emplacement borehole wall rock temperature, which should be less than 275°C if the peak temperature criterion for the waste form is to be met (see also Issue 1.10, Section 8.3.4.2), and the volumetric limit on temperature rise, which ensures the design of the facility does not exceed the limits of properties measured. These goals are to be met subject to the additional constraint that the containers should be sufficiently hot, for the first 300 yr after emplacement, that the borehole walls should remain substantially dry. This constraint derives from a goal, defined under Issue 1.10, that the corrosiveness of the container environment be limited by ensuring that the containers remain dry.

Limit potential for borehole collapse

During the postclosure period, primary concern rests with the integrity of the waste package. The waste package is being designed considering loads during the preclosure and postclosure periods (Issue 1.10). The provisions for assurance that the design basis is not exceeded are discussed under function 1 and include skipping and isolating and locally adjusting the thermal load in regions that do not meet performance criteria. Such adjustments must be within the range of effects considered in the NRC license. If such measures do not adequately isolate the ground not meeting those criteria, then the potential exists for breaching containment. This would most likely be associated with rock movement around the emplacement boreholes. If the effects of such disturbances do not result in excessive loads on the waste package, this will not impact the ability of the repository to meet performance criteria.

Limit corrosiveness of container environment

This process is not derived directly from 10 CFR 60.133. Instead, it is a requirement placed on underground facility design by waste package design (Issue 1.10). The rationale for this requirement is discussed under that issue.

Interrelationships of the information needs

The seven information needs under this issue are

Information need	Subject
1.11.1	Site characterization information needed for design (Section 8.3.2.2.1)
1.11.2	Characteristics of waste package needed for design of the underground facility (Section 8.3.2.2.2)

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Information need	Subject
1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility that contribute to waste containment and isolation including flexibility to accommodate site specific conditions (Section 8.3.2.2.3)
1.11.4	Design constraints to limit water usage and potential chemical changes (Section 8.3.2.2.4)
1.11.5	Design constraints to limit excavation-induced changes in rock mass permeability (Section 8.3.2.2.5)
1.11.6	Repository thermal loading and predicted thermal and thermomechanical response of the host rock (Section 8.3.2.2.6)
1.11.7	Reference postclosure repository designs (Section 8.3.2.2.7)

As is shown on Figure 8.3.2.2-2, there is a direct relationship between the logic for issue resolution shown on Figure 8.3.2.2-1 and the information needs because the information needs were derived from what must be done for this issue to demonstrate compliance with 10 CFR 60.133. The information needs can be categorized as follows:

1. The first two (Information Needs 1.11.1 and 1.11.2) are collections of the information needed to resolve this issue and hence are closely related to the "parameter" step of performance allocation (Figure 8.3.2.2-2).

2. The next four (Information Needs 1.11.3 through 1.11.6) correspond to an issue resolution function of this issue (Figure 8.3.2.2-2).

3. The last (Information Need 1.11.7) is a summary of design information that will be provided by this issue to resolve performance assessment issues.

Data and analytical requirements for this issue are discussed in detail under the information needs. The data required to resolve this issue basically fall into one of three categories: (1) information from other issues, (2) site geologic data, and (3) rock properties data. The last two are discussed under the first information need in Section 8.3.2.2.1.

The first information need is satisfied by compiling all the site data requirements identified by Information Needs 1.11.3 through 1.11.6, addressing the question of how well these data need to be known and passing it to the site characterization issues.

The second information need (similar to the first) compiles a list of waste package data needed to resolve this issue. This information need interfaces with Issue 1.10 (waste package characteristics (postclosure)).

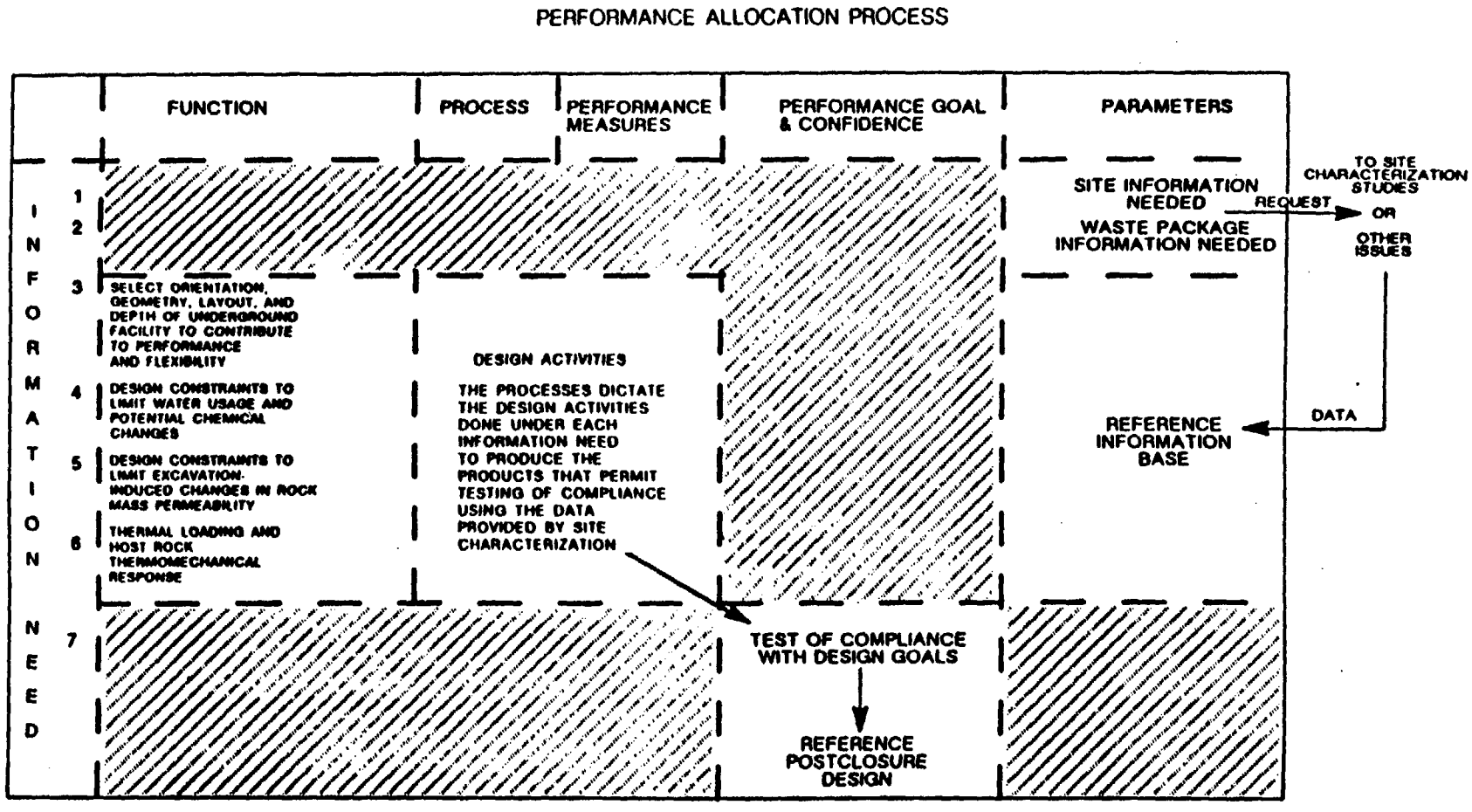

Figure 8.3.2.2-2. Relationship between subsumed information needs and issue functions and parameters for Issue 1.11, configuration of underground facilities (postclosure).

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Information Needs 1.11.3 through 1.11.6 discuss (1) the approaches (design activities) that will be used to ensure that performance goals are met with the appropriate level of confidence and (2) the data required by these approaches. The analytic techniques required to resolve this issue fall into one of two types: (1) the interactive graphics model or (2) geomechanical models. The first of these types is discussed in Information Need 1.11.3 and the second in Information Need 1.11.6.

The final information need under this issue documents the reference postclosure design and thereby provides the basis for satisfying Part b (provide information to support resolution of the performance issues) of the Issue (1.11).

The schedule information for Issue 1.11 (configuration of underground facilities) is presented in Section 8.3.2.2.8.

8.3.2.2.1 Information Need 1.11.1: Site characterization information needed for design

This information need does not correspond to an issue resolution function identified in the approach to resolving the issue discussion under Section 8.3.2.2. Rather, it summarizes the data requirements of other information needs of this issue and transmits these data requirements to the appropriate site characterization issues. This information need receives the experimental data from the characterization issues and then these data are properly converted from site measurements into reference information base (RIB) values that can be used by the other information needs of this issue and other issues. This information need will be satisfied by the following three products:

1. Data requirements list--identify site data needed from characterization issues (including how well data is needed to be known) to design the underground facility to contribute to containment and isolation.

2. Reference thermal/mechanical stratigraphy--document the three-dimensional thermal and mechanical stratigraphy of Yucca Mountain as contained in the interactive graphics information system as the reference basis for design and performance assessment.

3. Reference thermomechanical rock properties--conversion of measured data to reference data and transmission to the RIB for rock properties required by this issue.

Technical basis for addressing the information need

In the following subsections a link is established between this information need and the SCP technical data chapters and supporting documents. Specific site characterization parameters and the logic used in identifying how well they need to be known for resolution of this issue (1.11) are identified in this information need. Technical details of why a specific data

Link to the technical data chapters and applicable support documents

Existing design activities and results, which are the basis for the approaches proposed in the logic subsection, are discussed in Section 6.4.2 of this document and in Chapters 7 and 8 of the Site Characterization Plan-Conceptual Design Report (SCP-CDR) (SNL, 1987). The current design data base used in existing design activities and used for comparison to the data needs given in the parameters subsection is given in SCP Section 6.1.2. A more complete discussion of current data is found in Chapter 2 for site data and in Chapter 7 for waste package data. Test plans for gathering additional site data needed by this issue (1.11) can be found under the rock characteristics program (Section 8.3.1.4), the thermal and mechanical properties program (Section 8.3.1.15), the geohydrology program (Section 8.3.1.2), the geochemistry program (Section 8.3.1.3), the postclosure and preclosure tectonics programs (Section 8.3.1.8 and 8.3.1.17), and the climate program (Section 8.3.1.5).

Parameters

Data needs given in this section are listed by the performance allocation function and performance goal for which they are required. The rationale behind the required site data is given in the subsequent logic section and in the individual information needs. The data required are numbered by the function number followed by a dash and the goal letter. For example, 4-W indicates a data need for function "4" to satisfy goal "W." Where appropriate the data needs of individual functions and goals are grouped.

The data required for the design activities that determine if the goals of this issue are met are given in Table 8.3.2.2-5.

Logic

Inputs received from the other information needs of Issue 1.11 are used to compile an integrated list of site information and data to resolve this issue. The completeness of site information requirements needed to resolve Issue 1.11 will be checked by reviewing its processes and goals and by identifying the interactions and response of the site to the design (e.g., site-specific effects of excavation and release of heat by the waste); once the response of Yucca Mountain to the design is adequately described using site-specific data, the site information items needed to resolve this interaction will be deemed complete.

In the subsequent discussion, the logic behind the data needs is organized by products.

The area-needed determination (product 1.11.3-1) depends on site data through the allowable areal power density. Information Need 1.11.6 (Section 8.3.2.2.6) discusses the site data related to that parameter.

The usable area and flexibility evaluation (product 1.11.3-2) requires the use of the interactive graphics information system (IGIS). Information Need 1.11.3 (Section 8.3.2.2.3) explains how these data contribute to the product. Data required for the use of the IGIS include

Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 1 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
1-A	Layout	Drawing of underground facility location	Dimensions accurate to ±3 m	Medium	Dimensions accurate to ±0.5 m[e]	Medium	8.3.2.5
	Topography	Contour map of primary area and extensions	Contours accurate to ±7.5 m	Medium	Contours accurate to ±3 m	Medium	8.3.1.14
		Contour map of areas with minimum overburden	Contours accurate to ±3 m	High	Contours accurate to ±3 m	Medium	8.3.1.14
	Elevation of unit contacts for positioning underground facility[f]	Structure contour maps on upper and lower contact of TSw2 in primary area and extensions	Contours accurate to ±30 m	Medium	Contours accurate to ±30 m	Low	8.3.1.4
		Structure contour map on lower contact of TSw2 in areas of minimum overburden	Contours accurate to ±10 m	High	Contours accurate to ±10 m[e]	Low	8.3.1.4
		Structure contour map on upper contact of TSw2 in areas of minimum ground-water travel time	Contours accurate to ±10 m	Medium	Contours accurate to ±10 m[e]	Low	8.3.1.4
	Water table elevation	Contour map of water table in primary area and extensions	Contours accurate to ±7.5 m	Medium	Contours accurate to ±7.5 m[e]	Medium	8.3.1.2

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 2 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed	Expected value	Current confidence	Obtained from SCP section
1-A (continued)		Contour map of water table in areas with minimum ground-water travel time	Contours accurate to ±10 m	High	Contours accurate to ±10 m[e]	Medium	8.3.1.2
	Fault descriptions for positioning underground facility	Map of fault locations showing dip and displacement for primary area and extensions	Locations accurate to ±30 m[e]	High	Locations accurate to ±30 m	Medium	8.3.1.4
			Actual strike and dip ±10° for each fault	High	Average strike and dip ±10° for each fault[e]	Medium	8.3.1.4
			Displacement measurements accurate to ±2 m	Medium	Displacement measurements accurate to ±2 m[e]	Low	8.3.1.4
		Classification	Standard practice	Low	Standard practice	Low	8.3.1.4
		Recurrence time for 5 cm displacement	>1,000 yr	High	(h)	Low	8.3.1.8
	Exploratory borehole locations	Coordinates of position of boreholes	Coordinates accurate to ±3 m	High	Coordinates accurate to ±1 m[e]	Medium	8.3.3.2
1-B	Goals of Issues 1.1, 1.6, and 1.10	Performance objectives affected by emplacement borehole design	See Issues 1.1, 1.6, and 1.10	Not applicable	Not applicable	Not applicable	8.3.5.13, 8.3.2.12, 8.3.4.2
1-C	Hydrothermal model describing how moisture moves in host rock	Data of Issue 1.1	See Issue 1.1	High	(h)	Low	8.3.5.13

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 3 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
1-D	Results of rock mass classification work of Issue 4.4	Identification of acceptable rock mass classifications	See Issue 4.4	High	See Issue 4.4	Low	8.3.2.5
1-E 1-F	Saturation	During development around the excavations	<90%	High	65 to 85%	Low	8.3.1.2, 8.3.5.16
	Geochemistry	During development around the excavations	See Issue 1.10	Medium	See Issue 1.10	Low	8.3.1.3, 8.3.5.16
1-G	See function 4 for data required	Goal 1-G requires results of thermal calculations of function 4. Hence, data required (heat capacity, initial temperature, container output, etc.) are called for under that issue.					8.3.2.2
1-H	See function 4 for data required	Goal 1-H requires results of thermal calculations of function 4. Hence, data required (thermal properties, initial stress, strength, etc.) are called for under that issue.					8.3.2.2
2-I	Material inventory	Proposed inventory	See Issue 4.4	High	(h)	Low	8.3.2.5
	Geochemical effects	Effect of inventory	(i)	Medium	(h)	Low	8.3.4.2
2-J	Planned water usage	For mining operations	See Issue 4.4	High	(h)	Low	8.3.2.5
	Water usage in ESF	For mining operations	See Section 8.3.1.2	Medium	(h)	Low	8.3.1.2

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 4 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
	Goals of Issue 1.1	Allowable saturations	See Section 8.3.5.13	Medium	Not applicable	Not applicable	8.3.5.13
3-K	Excavation method	Proposed method	See Issue 4.4	Medium	See Issue 4.4	Medium	8.3.2.5
	Disturbed zone	Definition	See Section 8.3.5.12	Medium	Not applicable	Not applicable	8.3.5.12
	Blast-induced permeability change	Around excavations	±50% of in situ permeability	Medium	(h)	Low	8.3.1.15
3-L	Layout	Drawings of layout of underground facility	Dimensions accurate to ±0.5 m	High	Dimensions accurate to ±0.5 m	Medium	8.3.2.5
3-M	Layout	Excavation dimensions	Dimensions accurate to ±0.5 m	High	Dimensions accurate to ±0.5 m	Medium	8.3.2.5
3-N	Proposed backfill	Height of fill	Nonsite data	Medium	Nonsite data	NA	8.3.2.5
4-W	Peak ground acceleration from probability versus ground motion	For TSw2 in primary area and extensions	0.5 to 0.7g with >10,000-yr return period	Medium	(h)	Low	8.3.1.17
4-X 4-T 4-O 4-P 4-Q 4-R 4-S	Topography	Contour map of location of ground surface in primary area and extensions for use in thermal modeling	Contours accurate to ±30 m	Medium	Contours accurate to ±30 m	Medium	8.3.1.4

Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 5 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
4-X 4-T 4-O 4-P 4-Q 4-R 4-S	Geologic structure to water table (location of faults for thermal modeling)	Map of location of faults in primary area and extensions for use in thermal modeling	Location accurate to ±150 m	Medium	Location accurate to ±150m[e]	Low	8.3.1.4
4-X 4-T 4-O 4-P 4-Q 4-R 4-S	Geologic stratigraphy to water table (location of unit contacts for thermal modeling)	Structure contour maps on upper and lower contacts of TSw2 in primary area and extensions	Contours accurate to ±30 m	Medium	Contours accurate to ±30 m	Low	8.3.1.4
		Structure contour map on lower contact of TSw2 in areas with minimum overburden	Contours accurate to ±10 m	Medium	Contours accurate to ±10 m[e]	Low	8.3.1.4
		Structure contour map on upper contact of TSw2 in areas with minimum ground-water travel time	Contours accurate to ±10 m	Medium	Contours accurate to ±10 m[e]	Low	8.3.1.4
		Structure contour map on upper and lower contacts of other units in primary area and extensions	Contours accurate to ±60 m	Medium	Contours accurate to ±60 m[e]	Low	8.3.1.4

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 6 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
4-U 4-V 4-W 4-X	Emplacement geometry	Drawing locating boreholes and containers	Dimensions accurate to ±30 cm	High	Dimensions accurate to ±30 cm	Medium	8.3.2.5
		Drawing locating drifts	Dimensions accurate to ±3 m	Medium	Dimensions accurate to ±3 m	Medium	8.3.2.5
4-U 4-S 4-V 4-X	Container thermal output	Thermal output as a function of waste age and burnup	Nonsite data[j,k]	Not applicable	Nonsite data	Not applicable	8.3.4.2
4-W 4-O 4-P 4-Q	Container dimensions	(k)	Nonsite data[k]	Not applicable	Nonsite data	Not applicable	8.3.4.2
4-T 4-R	Waste inventory	(k)	Nonsite data[k]	Not applicable	Nonsite data	Not applicable	8.3.4.2
4-U 4-S 4-V 4-X	Initial temperature for thermal modeling	Of TSw2 in primary area and extensions	Temperature accurate to ±3°C[l]	Medium	Temperature = 23°C to 26°C ± 1.5°C[e]	Medium	8.3.1.15
4-W 4-O 4-P 4-Q 4-T 4-R		Mean annual air temperature for primary area	Temperature accurate to ±3°C	Medium	Temperature = 16°C to ±1°C[e]	Medium	8.3.1.12
4-W 4-Q 4-S	Initial stress state for primary area and extensions	Vertical stress and magnitude and direction of minimum and maximum horizontal stress	Vertical stress[m] accurate to ± 1 MPa	Medium	Vertical stress = weight of overburden	Low to medium	8.3.1.15

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 7 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
			Horizontal stress[m] accurate to ±2 MPa	Low	Horizonal/vertical stress ratio = 0.3 to 1 for TSw2	Low	8.3.1.15
4-U 4-S 4-V 4-X 4-W 4-O 4-P 4-Q 4-T 4-R	Heat capacity	TSw2[n] <275°C	Current mean[o] ±10%	High	See Table 6-16	Low to medium	8.3.1.15
		TSw3 and CHn1[n] <115°C	Current mean[o] ±10%	Medium	See Table 6-16	Low to medium	8.3.1.15
		Below CHn1[p] <100°C	Current mean[o] ±10%	Low	See Table 6-16	Low	8.3.1.15
		TSw1[n] <275°C	Current mean[o] ±10%	Medium	See Table 6-16	Low to medium	8.3.1.15
		Above TSw1[p] <50°C	Current mean[o] ±10%	Low	See Table 6-16	Low	8.3.1.15
4-U 4-S 4-V 4-X 4-W 4-O 4-P 4-Q 4-T 4-R	Thermal conductivity	TSw2[n] <275°C	Current mean[o] ±20%	High	See Table 6-16	Low to medium	8.3.1.15
		TSw3 and CHn1[n] <115°C	Current mean[o] ±20%	Medium	See Table 6-16	Low to medium	8.3.1.15
		Below CHn1[p] <100°C	Current mean[o] ±20%	Low	See Table 6-16	Low to medium	8.3.1.15
		TSw1[n] <275°C	Current mean[o] ±20%	Medium	See Table 6-16	Low to medium	8.3.1.15
		Above TSw1[p] <50°C	Current mean[o] ±20%	Low	See Table 6-16	Low to medium	8.3.1.15

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 8 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
4-W 4-Q 4-S	Coefficient of thermal expansion	TSw2 <275°C	Current mean[e] ±15%	High	See Table 6-16	Medium	8.3.1.15
		TSw3 and CHn1 <115°C	Current mean[e] ±15%	Medium	See Table 6-16	Low to medium	8.3.1.15
		Below CHn1 <100°C	Current mean[e] ±15%	Low	See Table 6-16	Low to medium	8.3.1.15
		TSw1 <275°C	Current mean[e] ±15%	Medium	See Table 6-16	Low to medium	8.3.1.15
		Above TSw1 <50°C	Current mean[e] ±15%	Low	See Table 6-16	Low to medium	8.3.1.15
4-W 4-Q 4-S	Young's modulus	TSw2 for 0-100 MPa	Current mean[e] ±15%	High	See Table 6-12	Medium	8.3.1.15
		TSw3 and CHn1[f]	Current mean[e] ±15%	Medium	See Table 6-12	Low	8.3.1.15
		Below CHn1[f]	Current mean[e] ±15%	Low	See Table 6-12	Low to medium	8.3.1.15
		TSw1 for 0-100 MPa	Current mean[e] ±15%	Medium	See Table 6-12	Medium	8.3.1.15
		Above TSw1[f]	Current mean[e] ±15%	Low	See Table 6-12	Low to medium	8.3.1.15
4-W 4-Q 4-S	Deformation modulus	TSw2 for 0-100 MPa	Current mean[e] ±15%	High	See Table 6-14	Low	8.3.1.15
		TSw3 and CHn1[f]	Current mean[e] ±15%	Medium	See Table 6-14	Low	8.3.1.15
		Below CHn1[f]	Current mean[e] ±15%	Low	See Table 6-14	Low	8.3.1.15
		TSw1 for 0-100 MPa	Current mean[e] ±15%	Medium	See Table 6-14	Low	8.3.1.15
		Above TSw1[f]	Current mean[e] ±15%	Low	See Table 6-14	Low	8.3.1.15

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 9 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
4-W 4-Q 4-S	Poisson's ratio	TSw2 for 0-100 MPa	Current mean[e] ±20%	Medium	See Table 6-12	Medium	8.3.1.15
		TSw3 and CHnl[g]	Current mean[e] ±20%	Low	See Table 6-12	Low to medium	8.3.1.15
		Below CHnl[g]	Current mean[e] ±20%	Low	See Table 6-12	Low to medium	8.3.1.15
		TSwl for 0-100 MPa	Current mean[e] ±20%	Low	See Table 6-12	Low to medium	8.3.1.15
		Above TSwl[g]	Current mean[e] ±20%	Low	See Table 6-12	Low	8.3.1.15
4-W 4-Q 4-S	Matrix unconfined compressive strength for units other than TSw2 and TSwl	In situ conditions and representative strain rate[f]	Current mean[e] ±20%	Medium	See Table 6-12	Low to medium	8.3.1.15
4-W 4-Q 4-S	Matrix angle of internal friction for units other than TSw2 and TSwl	In situ conditions and representative strain rate[f]	Current mean[e] ±20%	Medium	See Table 6-12	Low to medium	8.3.1.15
4-W 4-Q 4-S	Matrix cohesion for units other than TSw2 and TSwl	In situ conditions and representative strain rate[f]	Current mean[e] ±20%	Medium	See Table 6-12	Low to medium	8.3.1.15

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 10 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
4-W 4-Q 4-S	Rock compressive strength for TSw1 and TSw2	0-100 MPa and representative strain rate[g]	Current mean[e] ±20%	High	(h)	Medium	8.3.1.15
4-W 4-Q 4-S	Joint angle of internal friction for units other than TSw2 and TSw1	In situ conditions and representative strain rate	Current mean[e] ±15%	Medium	See Table 6-13	Low	8.3.1.15
4-W 4-Q 4-S	Joint cohesion for units other than TSw2 and TSw1	In situ conditions and representative strain rate	Current mean[e] ±15%	Medium	See Table 6-13	Low	8.3.1.15
4-W 4-Q 4-S	Large-scale joint strength for TSw1 and TSw2	0-30 MPa normal stress and representative strain rate	Current mean[e] ±20%	High	(h)	Low	8.3.1.15
4-Q 4-W	Joint normal stiffness	TSw2	See Table 6-13[e]	Medium	See Table 6-13[t]	Low	8.3.1.15
		TSw1, TSw3, and CHn1	See Table 6-13[e]	Low	See Table 6-13[t]	Low	8.3.1.15
	Joint shear stiffness	TSw2	See Table 6-13[e]	Medium	See Table 6-13[t]	Low	8.3.1.15
		TSw1, TSw3, and CHn1	See Table 6-13[e]	Low	See Table 6-13[t]	Low	8.3.1.15
	Joint spatial orientation	TSw2	See Table 6-15[e]	Medium	See Table 6-15	Low	8.3.1.4
		TSw1, TSw3, and CHn1	See Table 6-15[e]	Low	See Table 6-15	Low	8.3.1.4

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Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 11 of 12)

Related function and performance goal[b,c]	Performance parameter	Modifier	Tentative goal[d]	Needed confidence	Expected value	Current confidence	Obtained from SCP section
	Joint abundance	TSw2	See Table 6-15[e]	Medium	See Table 6-15	Low	8.3.1.4
		TSw1, TSw3, and CHn1	See Table 6-15[e]	Low	See Table 6-15	Low	8.3.1.4
	Joint persistence	TSw2	See Table 6-15[e]	Medium	See Table 6-15	Low	8.3.1.4
		TSw1, TSw3, and CHn1	See Table 6-15[e]	Low	See Table 6-15	Low	8.3.1.4
	Joint wall compressive strength	TSw2	See Table 6-15[e]	Medium	See Table 6-13	Low	8.3.1.15
		TSw1, TSw3, and CHn1	See Table 6-15[e]	Low	See Table 6-13	Low	8.3.1.15
	Joint roughness coefficient	TSw2	See Table 6-15[e]	Medium	See Table 6-13	Low	8.3.1.15
		TSw1, TSw3, and CHn1	See Table 6-15[e]	Low	See Table 6-13	Low	8.3.1.15

[a]Abbreviations used in this table are defined as follows: ESF = exploratory shaft facility; TSw1 = lithophysal portion of Topopah Spring welded unit; TSw2 = low lithophysal portion of Topopah Spring welded unit (preferred thermomechanical emplacement unit); TSw3 = basal vitrophyre Topopah Spring; CHn1 = tuffaceous beds of Calico Hills. See Chapter 2 for more complete description of units.

[b]Goals are ranked in judged order of importance of data item to issue resolution.

[c]1-A indicates function 1 and goal A. This designator is used to associate data requirements of this table with goals of Tables 8.3.2.2-1 through 8.3.2.2-4.

[d]Current mean is value given in current reference information (Tables 6-11 through 6-16).

[e]Expected value based on judgement.

[f]Elevation of the contacts of the thermal/mechanical unit TSw2 determined using data that already exists plus data to establish the top and bottom of unit TSw2 at the following approximate locations: (1) Midpoint of western ridge; (2) Northern extension of primary area: a) N775000 - E559000, b) N772500 - E560500, c) N773500 - E563500; and (3) Southeast extension of primary area: a) N760500 - E563000, b) N758500 - E561000, c) N757000 - E560000; and also by reevaluating existing borehole data: (1) Drill Hole Wash series; (2) H Hole series. Further lateral drifting from exploratory shaft will be used to (1) confirm contact between TSw1 and TSw2; (2) confirm fault locations at underground facility depth (for 2 or 3 faults, as intersected by lateral drifts); (3) confirm fault offsets in current structural model; and (4) provide drifting construction experience in faulted welded tuff.

Table 8.3.2.2-5. Performance parameters and tentative goals for Issue 1.11, configuration of underground facilities (postclosure)[a] (page 12 of 12)

Footnotes (continued)

[g]Averaged across the site, not accuracy at a given point.

[h]Inadequate information exists to establish expected value, but it is anticipated that a value satisfying the goal will be obtained.

[i]Accuracy determined by Issue 1.10 (Section 8.3.4.2).

[j]Calculations done to resolve this issue are based on power as a function of time (initial power and normalized decay function). As long as standard deviations of initial value and decay coefficients are no more than ten percent, calculations done to determine if goals of this issue are met should be valid.

[k]See Information Need 1.11.2 (Section 8.3.2.2.2) for details and accuracy.

[l]Existing data should be sufficient. Temperature could be a function of position in unit TSw2.

[m]Calculations are based on a vertical stress determined from the weight of the overburden and a horizontal to vertical stress ratio (K_o = 0.3 to 0.8). Calculations done to determine if the goals of this issue are met should be valid if the stresses so calculated are within the tentative goal specified for the in situ stress. Note: the tentative goal specified for the in situ stress is an estimate; if it can be shown with reasonable assurance that the minimum K_o is greater than 0.2, a lower accuracy for the tentative goal would be acceptable.

[n]Mean and standard deviation as a function of saturation.

[o]If the in situ rock at representative conditions has a distribution of property values which have the required confidences such that an adequate portion of the samples fall within the range prescribed by the current mean and percentage (percentage given in the table), then the calculations done to determine if the goals are met should be valid. If the distribution of property values does not meet this condition, then (1) the calculations will have to be reevaluated, (2) the calculations will have to be redone with new property values, (3) the design will have to be changed, (4) the accuracy of the data will have to be improved, or (5) the goal will not be met. Representative conditions are appropriate values of one or more of the following: saturation, stress, temperature, fracture, or jointing characteristics, etc., averaged over a representative volume.

[p]Mean and standard deviation representative at in situ saturation.

[q]At in situ conditions.

[r]Property representative of the volume of rock between dominate jointing.

[s]Sensitivity studies evaluating parameter range and goal have not yet been performed.

[t]These parameters can be calculated from values in Table 6-13.

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1. Stratigraphic data including strike, dip, thickness, and geographical location of distinct intervals (isopach data) and densities, orientations, and apertures of stratigraphically controlled fractures and lithophysae.

2. Structural data including locations, offsets, and widths of faults and fault zones; densities, orientations, and apertures of tectonic fractures.

3. Hydrologic model of Yucca Mountain including hydrologic flow paths, location of water table, and potential for perched water.

4. The potential for ground movement, which will be determined as described in Section 8.3.1.8.

How well the data that are input into this model need to be known has been determined by interactively using this model or by geometric figures representing the intersection of surfaces in this model to determine how much error in the data would result in a violation of the goal. For example, fault dips were varied to determine how much angular error in dip would result in unacceptable impacts on positioning of the underground facility and usable area.

The horizontal-versus-vertical emplacement decision (product 1.11.3-3) requires no site data beyond that required for the design of either mode (e.g., host rock physical and geomechanical properties, in situ principal stresses, fracture and fault geometry, and stratigraphy). This product draws on other issues (principally, Issue 4.4--preclosure design and technical feasibility) and depends on site data through those issues.

The drainage and moisture control plan (product 1.11.3-4) approach is still under development. For the design of the underground facility to contribute to waste containment and isolation, the drainage and moisture control plan will be based upon the performance assessment approach to system performance (Issue 1.1, Section 8.3.5.13). This performance assessment approach is still being documented. The approach to developing the drainage and moisture control plan is expected to apply basic engineering practice supplemented by simple thermal calculations (heat transfer by conduction) to identify regions of vaporization and condensation. This approach would require the same site data as that used for Information Need 1.11.6 (8.3.2.2.6) of this issue. However, computer codes that model how moisture migrates through the host rock under hydrothermal conditions would be useful to verify that this approach is correct. These models are being developed for performance assessment (see Issues 1.1, total system performance (Section 8.3.5.13), and 1.4, containment by waste package (Section 8.3.5.9)), and the site data required for these models is identified as part of those issues.

The criteria for the contingency plan (product 1.11.3-5) approach is still under development. For the design of the underground facility to contribute to waste containment and isolation, the contingency plan must be based on the performance assessment approach to system performance (Issue 1.1, total system performance (Section 8.3.5.13), and take into account the functions of each system element (e.g., the disturbed zone). The criteria for the contingency plan will consider ground quality and saturation

(Table 8.3.2.2-1). Ground quality will be determined by tunnel indexing methods discussed in Issue 4.4, technical feasibility (preclosure) (Section 8.3.2.5); the site data for those empirical engineering techniques are identified by that issue. The determination of the hydrologic processes important in the unsaturated zone at Yucca Mountain and the site data required to verify these processes are identified in Issue 1.4, containment by waste package (Section 8.3.5.9).

The material inventory criteria (product 1.11.4-1) and water usage criteria (product 1.11.4-2) do not depend directly on site; instead they depend on work for other issues. The Information Need 1.11.4 (Section 8.3.2.2.4) discusses these interfaces.

The extraction methods criteria (product 1.11.5-1) and long-term subsidence control strategy (product 1.11.5-2) require that the intrinsic permeability change be measured around the drifts to determine the extent of the blast-induced modified permeability zone. This requirement is needed to verify that the excavation technique (such as blast control) does not cause sufficient formation damage to extend the disturbed zone boundary. On the basis of Issue 1.6, ground-water travel time (Section 8.3.5.12), an order-of-magnitude permeability change and a factor-of-two porosity change have been chosen as significant. To satisfy the design performance goals, the permeability change beyond 75 percent of the distance to the boundary of the disturbed zone should be less than one order of magnitude (Section 8.3.5.12).

Thermal and thermomechanical modeling requires the following products:

1.11.6-1 Allowable areal power density.
1.11.6-2 Borehole spacing strategy.
1.11.6-3 Sensitivity studies.
1.11.6-4 Strategy for containment enhancement.
1.11.6-5 Reference calculations.

How well the data for thermal and thermomechanical modeling need to be known has been determined in a preliminary fashion by combining scoping sensitivity studies (included in Appendix N of the SCP-CDR (SNL, 1987)) and judgment. Properly controlled and documented sensitivity studies have been completed for the near-field (Ehgartner, 1987). When corresponding far-field work is completed, how well these data need to be known will be reviewed and possibly revised.

These sensitivity studies have evaluated the system response (temperature, stress, deformation, and factor of safety) to one standard deviation changes in model input parameters. By comparing system response to goals or failure criteria (unconfined compressive strength), the model input parameter value that results in unacceptable system performance was determined. Engineering judgment was then used to choose the acceptable range and confidence for each parameter.

Data are required to validate the models; however, that activity is conducted by Issue 4.4 (Section 8.3.2.5) and the validated models made available to this issue. Hence, this issue does not call for data to validate models.

8.3.2.2.1.1 Design Activity 1.11.1.1: Compile a comprehensive list of all the information required from site characterization to resolve this issue

Objectives

This activity summarizes in one place all the information requirements needed to resolve this issue. These requirements are given in the logic section of this information need. Subsequent revisions will include applicable statistical requirements for each item (e.g., acceptable error and level of uncertainty).

8.3.2.2.1.2 Design Activity 1.11.1.2: Determine adequacy of existing site data

Objectives

If existing site data are not sufficient for licensing, a determination will be made whether additional site data should be gathered or changes be made in design to accommodate the existing data base. This activity will use statistical methods to evaluate site data and compare them to data requirements. Based on the results, recommendations for further data acquisition or trade-off studies to determine if the underground facility should be redesigned to accommodate the updated data base will be made.

8.3.2.2.1.3 Design Activity 1.11.1.3: Document reference three-dimensional thermal/mechanical stratigraphy of Yucca Mountain

Objectives

Topical reports will be produced that describe the three-dimensional thermal and mechanical stratigraphy of Yucca Mountain. The description will rely on data collected from the site that will be analyzed using the interactive graphics information system (IGIS) and be recorded in the reference information base (RIB) to be used for subsequent analyses and studies.

8.3.2.2.1.4 Design Activity 1.11.1.4: Preparation of reference properties for the reference information base

Objectives

Topical reports will be produced giving properties and describing how these were determined from field and lab measurements. These reports will be compared to the requirements of this issue to assure the RIB contains the required data. This work includes rock characteristics, initial conditions (in situ stress and temperature), geology (stratigraphy and structure as reported in the three-dimensional graphics model of Yucca Mountain), and design data (e.g., areal power density and borehole spacing).

8.3.2.2.2 Information Need 1.11.2: Characteristics of waste package needed for design of the underground facility

This information need exists

1. To identify waste package information items needed in the reference information base by this issue (1.11).

2. To design the underground facility to contribute to containment and isolation and thus contribute to the resolution of this issue and Key Issue 1 (postclosure performance).

3. To decide how well each waste package input item needs to be known to provide reasonable assurance of compliance with any regulation addressed by this information need.

The waste package information stipulated in this information need is not provided by site characterization. The information is identified here because it (1) has a major impact on design of the underground facility and (2) is a major stimulus affecting the long-term response of the repository. These factors combine to make waste package characteristics a key element in the resolution of this issue.

This information need does not correspond to an issue resolution function identified in the overview of this section (8.3.2.2). Rather, the data needs summarized in this information need are derived from the approaches to satisfying the goals of the other information needs of this issue. This information need will be satisfied by the following product:

1.11.2-1 Waste package characteristics for design of underground facility.

These data will be obtained from Issue 1.10 (Section 8.3.4.2) and recorded in the subsystem design requirements document.

Technical basis for addressing the information need

In the following subsections, a link is established between this information need and the SCP technical data chapters and supporting documents. Specific waste package parameters and the logic used in identifying how well they need to be known for resolution of this issue (1.11) (Section 8.3.2.2) are identified in this information need. Technical details of why a specific data item is needed are documented in the information need that identifies the information item. Where appropriate, the means of obtaining those parameters is then addressed.

Link to the technical data chapters and applicable support documents

Existing design activities, which are the bases for the needed waste package data items identified in the subsequent logic subsection, are discussed in the SCP Sections 6.3 and 6.4 and in Chapters 3, 4, and 8 of the Site Characterization Plan-Conceptual Design Report (SCP-CDR) (SNL, 1987). The current design data base, used in existing activities and for comparison to the data needs given in the parameters section, is given in SCP Sec-

tion 6.1.2 and SCP-CDR Chapter 2. A complete discussion of current waste package data is found in SCP Chapter 7. The waste package data needed by this issue will be defined and transmitted to the reference information base by Issue 1.10, waste package characteristics (postclosure) (Section 8.3.4.2).

Parameters

The following waste package characteristics will be needed to resolve this issue (1.11):

Waste or waste package characteristics	Specific information needed	Accuracy or range
Thermal decay characteristics	Waste type	Not applicable
	Waste age	±1 yr
	Thermal power output as a function of burnup	±10 % for 0 to 5,000 yr after reactor
Waste package size	Length, overall	±1%
	Diameter	±1%
Waste package temperature constraints	Maximum allowable temperature of waste package surface	±1°C
Waste inventory	Metric tons uranium (MTU) per waste type	±5%
	MTU per assembly or container as a function of enrichment	±5%
	Receipt schedule (MTU each year by wastage and burnup)	Age ±1 yr Burnup ±5,000 MWd

Logic

Like Information Need 1.11.1, inputs received from the other information needs of this issue are used to compile an integrated list of waste package input items to resolve Issue 1.11. The completeness of input items needed to resolve this issue will be checked by reviewing the processes and goals of this issue and by identifying the interactions and predicted response of the site to the design (e.g., site-specific effects of excavation and release of heat by the waste). Once the response of Yucca Mountain to the design is adequately described, the waste package information items needed to resolve this interaction will be deemed complete.

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The thermal decay characteristics of the waste affect the allowed areal power density for waste emplacement, the host rock thermal response, and the placement of the waste. This information is needed as a function of waste type, age, and burnup to

1. Determine the total area required for the projected waste inventory and to develop the layouts for the underground waste emplacement area (Information Need 1.11.3, Section 8.3.2.2.3). The use of current information and status in resolving Issue 1.11 is described in Section 6.4.2.

2. Predict the thermal response of the host rock (Information Need 1.11.6, Section 8.3.2.2.6) for use in establishing the areal power density and borehole spacing. This prediction will depend on the time-dependent power output of the waste.

3. Calculate thermal history of the rock mass for input into analysis codes used for long-term opening stability analysis. The status of opening stability analysis is described in Section 6.4.2.

Waste package size will be needed to define the emplacement envelope and thermal loading of the host rock and to design the boreholes (Information Need 1.11.3).

Waste package temperature limits will be needed to determine the emplacement borehole spacing. Spacing determined by consideration of waste package temperature will be used to develop the underground repository layout. These temperature limits will be used to perform the analysis for resolution of Information Needs 1.11.3, design concepts for orientation, geometry, layout, and depth of the underground facility that contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions, and 1.11.6, repository thermal loading and predicted thermal and thermomechanical response of host rock. The methods for using this information to address these information needs are discussed in Chapter 6.

The following methods will be used to determine this information:

1. The thermal decay and thermal output of the waste will be calculated using codes like the Oak Ridge ORIGEN2 code, which is an isotope generation code that follows the decay chain of each specimen produced in the fission of uranium. This information will be used to define the specific decay and thermal characteristics for all waste types. Calculations will include the effect of fuel burnup.

2. The information needs pertaining to the waste package size and design will be based on the waste package functional criteria.

3. Waste package temperature will be limited by the maximum fuel-cladding temperature of spent fuel and the temperature of devitrification in defense high-level waste (DHLW).

8.3.2.2.2.1 Design Activity 1.11.2.1: Compile waste package information needed for repository design

Objectives

The objective of this activity is to determine what waste package information is needed for design of underground facility, obtain such data from Issue 1.10 (Section 8.3.4.2), and document it in the repository design requirements document.

8.3.2.2.3 Information Need 1.11.3: Design concepts for orientation, geometry, layout, and depth of the underground facility that contribute to waste containment and isolation including flexibility to accommodate site-specific conditions

The discussion under this information need extends the discussion of function 1, which was presented in the issue resolution strategy section for this issue (1.11). The approaches or methods to be used to calculate or otherwise establish that the anticipated or actual performance will meet the performance goals stated in Table 8.3.2.2-1 are described here. In many instances, the approaches, which follow in the logic section, require site data, performance information, or design information to make such an evaluation. The site data needs of this information need (1.11.3) are identified in the following parameters subsection. These needs are passed to the site characterization programs. Performance and design information needs are also identified in the following parameters subsection. In many instances, these performance and design information needs are the results or conclusions of work that depends on site data. The call for such site data is in the issue where the work is done and is not repeated here.

Table 8.3.2.2-1 identified five processes as contributing to meeting function 1. Each of these processes was related to one or more performance measures and their associated performance goals and desired confidences. The approaches and data needs discussed here are an extension of the horizontal relationships evident in that table.

This information need will be satisfied through five products that will be used to demonstrate that the performance goals of function 1 have been met. The products are the results of the design activities performed under this information need. The relationship of the five products to the five processes of function 1 is shown in Table 8.3.2.2-6.

These products may be delivered to other information needs under this issue or under other design or performance issues. In the following logic section, the products are used to group the approach and methods that will be used to show that the goals of this issue are met. Products are the results of the design activities and milestones identified later in this section.

Technical basis for addressing the information need

In the following subsection, the information needed by planned approaches for demonstrating that goals are satisfied is linked to data already available and plans for future data gathering. Specific parameters and the logic used to identify their importance to the resolution of Information Need 1.11.3 are then identified in subsequent subsections. The accuracy with which the parameters must be obtained is discussed under Information Needs 1.11.1 and 1.11.2 (Sections 8.3.2.2.1 and 8.3.2.2.2) where the site and waste package data needed to resolve this issue are consolidated.

Link to the technical data chapters and applicable support documents

The current design data base that has been used for existing design activities, and for comparison with data needs given in the following parameters subsection, is presented in the reference design data base in Section 6.1.2. A more detailed discussion of the current data in the reference design data base may be found in the data Chapters 1 through 5, and current waste package data are found in Chapter 7.

Data needed to resolve this issue already available are presented in Section 6.4.2. Section 6.4.2 provides the status of resolution of Issue 1.11 and also forms some of the bases for the approaches discussed in the following logic subsection.

Finally, Information Need 1.11.1 (Section 8.3.2.2.1) lists in detail the site data needs established in this information need, as well as for all other information needs under this issue. It also defines how well they need to be known to resolve the issue and identifies the site characterization issues under which the test plans for obtaining each site date need will be discussed.

Table 8.3.2.2-6. Relationship of Information Need 1.11.3 products to the processes associated with function 1 given in Table 8.3.2.2-1

	Product	Process
1.11.3-1	Area needed determination	Vary depth, dip, orientation, and lateral extent of underground facility to provide host rock with favorable isolation characteristics
1.11.3-2	Usable area and flexibility evaluation	
1.11.3-3	Vertical or horizontal emplacement orientation decision	Select emplacement borehole orientation that limits potential adverse effects and considers retrievability

Table 8.3.2.2-6. Relationship of Information Need 1.11.3 products to the processes associated with function 1 given in Table 8.3.2.2-1 (continued)

	Product	Process
1.11.3-4	Drainage and moisture control	Limit the amount of water in contact with container to provide favorable containment and isolation environment
1.11.3-5	Criteria for contingency plan[a]	Skip and isolate unfavorable areas Adjust thermal load to accommodate local conditions

[a]Contingency plan will be developed in Issue 4.4, technical feasibility (Section 8.3.2.5). Criteria developed here will relate to postclosure performance (e.g., fault standoff and thermal load adjustments).

Parameters

Parameters are those data and other information items listed in this section in Table 8.3.2.2-7 that are required to complete the activities and analyses necessary to develop the products identified in Table 8.3.2.2-6. Those activities and analyses will establish that the goals defined in Table 8.3.2.2-1 are met with the required level of confidence. The logic for identification of the products as being necessary to satisfy the information need, as well as the basis for identification of specific parameters and information items, is provided by the following subsection.

Table 8.3.2.2-7. Parameters and information required to satisfy Information Need 1.11.3

	Product	Parameters and input items
1.11.3-1	Area needed determination	Geometrical requirements Minimum allowable spacing between emplacement boreholes for equipment operation (Issue 4.4, Section 8.3.2.5)

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Table 8.3.2.2-7. Parameters and information required to satisfy Information Need 1.11.3

	Product	Parameters and input items
		Minimum allowable spacing between emplacement boreholes for meeting thermal response constraints (Information Need 1.11.6, Section 8.3.2.2.6)
		Waste handling equipment requirements placed on drift layout and design (Issue 4.4)
		Ventilation requirements placed on drift layout and design (Issue 4.4)
		Inventory of waste to be emplaced in the repository Total metric tons of uranium (MTU) and number of containers Thermal output per MTU as function of waste type, age, and burnup (Issue 1.10, Section 8.3.4.2)
		Sealing program requirements for underground layout (Issue 1.12, Section 8.3.3.2)
		Area requirements for nonwaste emplacement areas, including underground area for the exploratory shaft test facility (Issue 4.4)
		Typical panel layout, with borehole spacing and drift separations for all waste types, that will ensure waste and rock mass temperature criteria are met (Information Need 1.11.6)
		Allowable thermal loading of the underground facility (areal power density) by waste type (Information Need 1.11.6)
1.11.3-2	Usable area and flexibility evaluation	Site geologic data Stratigraphic data, including dip, thickness, and geographic locations of distinct intervals; densities, orientations, and apertures of stratigraphic controlled fractures and lithophysae
1.11.3-2	Usable area and flexibility evaluation	Structural data, including location, offsets, and widths of faults and fault zones; spatial frequencies, orientations, and apertures of tectonic fractures

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Table 8.3.2.2-7. Parameters and information required to satisfy Information Need 1.12.3 (continued)

Product		Parameters and input items
		Hydrologic model of Yucca Mountain, including hydrologic flow paths, location of water table, and potential for perched water Topographic data
		Contingency plan for accommodating unsuitable areas for development and/or waste emplacement (Issue 4.4)
		Anticipated occurrence of conditions necessitating implementation of the contingency plan
1.11.3-3	Vertical vs. horizontal emplacement orientation decision	Performance criteria identified in Issues 1.4 (Section 8.3.5.9), 1.5 (Section 8.3.5.10), 1.10 (Section 8.3.4.2), and 2.4 (Section 8.3.5.2)
		Near-field thermomechanical analyses of boreholes and emplacement drifts (completed under Information Need 1.11.6)
		Results of field demonstrations of borehole construction methods (Issue 4.4)
		Total system performance assessment (Issue 1.1, Section 8.3.5.13)
1.11.3-4	Drainage and moisture control plan	Proposed panel layout, for alternate waste types characteristics
		Near-field thermal analyses of borehole (completed under Information Need 1.11.6)
		Criteria from Issues 1.1, 1.4, and 1.10
		Propose ventilation system for the repository, including distribution, flow rates, temperature, and moisture content (Issue 4.4)
		Total system performance assessment (Issue 1.1)
1.11.3-5	Criteria for contingency plan	Criteria for ground quality that will satisfy Issues 1.1, 1.10, and 1.12 (Section 8.3.3.2).
		Criteria for technical feasibility of construction (Issue 4.4) retrieval (Issue 2.4)

Table 8.3.2.2-7. Parameters and information required to satisfy Information Need 1.12.3 (continued)

Product	Parameters and input items
	Standoff distance from ground with unfavorable properties, as constrained by Issue 1.1
	Thermal and thermomechanical analyses of excavations under normal and off-normal conditions (Information Need 1.11.6)

Logic

The major purpose of this information need is to identify underground facility design options and related decisions important to containment and isolation, and to describe the approaches and methods to be used to develop the products that satisfy the information need. The logic used in developing these approaches and methods is described in this subsection, which also provides the basis for the needed site data and other information listed previously. Specific activities that will be performed are identified in the following material. If such activities have been initiated already, their status is discussed in Section 6.4.2.

To satisfy the information need, it is necessary to determine the area needed for disposal of the waste (product 1.11.3-1) and the usable area (product 1.11.3-2). The usable area product must consider the necessity of incorporating sufficient flexibility in the design to allow adjustments to accommodate specific site conditions that may be identified through in situ monitoring, testing, or excavation. Design concepts that contribute to performance and flexibility may be impacted by the decision between vertical and horizontal boreholes for waste emplacement (product 1.11.3-3); thus, this decision must be made to satisfy this information need. Water drainage control requirements may also impact the design concepts that contribute to performance and flexibility, so an evaluation of such requirements is necessary to satisfy this information need (product 1.11.3-4). Criteria that will be used to establish whether actual site conditions are consistent with the design bases, as well as the measures that will be taken to accommodate any such departures, are discussed in the contingency plan (product 1.11.3-5).

Product 1.11.3-1: Area needed determination

For the waste emplacement areas, the area needed is the total thermal output of the waste divided by the allowable thermal load. In turn, the total thermal output is determined from the inventory of waste to be disposed, including the thermal output per metric ton of uranium as a function of waste type, age, burnup, and enrichment.

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At present, it is expected that the actual thermal output of individual waste packages may vary as much as one order of magnitude. Such variations will be dealt with on a local basis by possibly skipping some holes and, in the case of horizontal emplacement, flexibility in spacing of waste packages within an individual borehole. These adjustments would be made subject to other geometrical constraints, including such items as minimum spacing between boreholes to ensure proper shielding during emplacement and noninterference at borehole collars for the transporter. In addition, constraints imposed by retrieval, decommissioning, and performance requirements must also be accommodated.

A preliminary determination of the area requirement has been made (Mansure, 1985). Data needs identified in the parameters section are based upon the information actually used in that study.

Product 1.11.3-2: Usable area and flexibility evaluation

The usable area and amount of flexibility will be evaluated using an interactive graphics information system. This system uses a data base established from field data to produce a three-dimensional graphics model of Yucca Mountain. Displays of this model will then be used to identify areas of the mountain that satisfy all the performance goals identified in Table 8.3.2.2-1. Boundaries of the waste emplacement areas are thereby established. The boundaries are required to design a functional layout of the underground facilities and its relation with the surface facilities. Location of the waste emplacement area within the site permits a site-specific (location dependent) performance assessment of the underground facility to be undertaken.

A preliminary evaluation of subsurface waste emplacement areas and a preliminary location and shape for the underground facility has been determined (Mansure and Ortiz, 1984). Data needs identified in the parameters subsection are based upon the information used in that study.

Product 1.11.3-3: Vertical or horizontal emplacement orientation decision

Vertical emplacement uses boreholes drilled in the floor of the emplacement drifts, with one waste package placed in each borehole. This mode requires a relatively high mining extraction ratio compared to the horizontal emplacement mode. The design basis for horizontal emplacement boreholes allows multiple waste packages per borehole. Equipment development and proof-of-concept demonstrations for horizontal drilling and waste emplacement are described under Issue 4.4, technical feasibility (Section 8.3.2.5).

The selection of one of the two alternative emplacement modes will be based on performance considerations discussed under Information Need 1.11.6, (Section 8.3.2.2.6) as well as Issues 1.1, total system performance (Section 8.3.5.13), 1.10, waste package characteristics (postclosure) (Section 8.3.4.2), and 4.2, nonradiological health and safety (Section 8.3.2.4).

Product 1.11.3-4: Drainage and moisture control plan

The approach for meeting this goal is still under development since the approach to demonstrate performance by Issues 1.1, total system performance (Section 8.3.5.13) and 1.10, waste package characteristics (postclosure) (Section 8.3.4.2) is still being documented; however, it is expected that the approach of this information need will apply engineering practice supplemented with simple thermal calculations (heat transfer by conduction) to identify regions of vaporization and condensation so that the emplacement drifts and boreholes can be designed to control water migration. Seals will also be designed to control water migration (see Issue 1.12, Section 8.3.3.2). The system will be designed to promote the migration of moisture away from the containers.

Site data required to conduct these near-field thermal calculations are anticipated to be identical to the data required under Information Need 1.11.6 (Section 8.3.2.2.6) to calculate the thermomechanical response.

Product 1.11.3-5: Criteria for contingency plan

In siting and constructing shafts, ramps, drifts, or boreholes within Yucca Mountain, unexpected conditions such as small zones of perched water, localized heavy fractured zones, water recharge pathways, or localized heavily lithophysae-rich zones may be encountered. A contingency plan for the layout must be established to deal with these possibilities and to provide confidence that the repository, as constructed, will provide waste containment and isolation for the required repository capacity. The contingency plan must also establish the methods and related criteria that will be used to initiate its implementation. Administration of the contingency plan will be the responsibility of performance confirmation (Issue 1.7, performance confirmation (Section 8.3.5.16)).

Development of the contingency plan will begin with the assumption that all the target area will be considered acceptable, except for local regions identified as being unacceptable during the site characterization phase. Such known and similar anticipated regions will have been subtracted from the available area during the determination of the usable area, as discussed previously under product 1.11.3-2. An additional contingency will be provided to accommodate regions where specific local site conditions found during development of the underground facility are not within the ranges assumed in licensing review. The contingency plan will establish procedures to accommodate regions where specific site conditions are found to be off normal during development of the underground facility. The licensing of this plan will include the establishment of parameter ranges that will be used to decide what course of action will be implemented.

The repository design will be based on certain anticipated ranges of parameters and conditions. These ranges will be clearly defined for the licensing review. Since many of the parameters and conditions cannot be easily measured over the total site during site characterization, a set of simple procedures must be established for determining if the site conforms to the ranges defined in the licensing review. These procedures will have associated quantitative criteria to determine whether development can continue without modification. Failure to meet these criteria at any location would

result in a requirement for more detailed evaluation of the condition encountered. If such evaluation indicates that local conditions are not consistent with meeting performance objectives and regulatory requirements using the baseline design, then design modifications would be required. The procedures for implementing such modifications would be licensed as part of the contingency plan, implemented by the performance confirmation program, and reported to and reviewed with NRC. These might include

1. Continued development but with design revisions such as increased ground support and reduced thermal loading.

2. Skipping and isolating an area unfavorable for development.

In this approach, parameters that describe site conditions encountered can be considered to be in one of three ranges: (1) the range for which the baseline design applies, (2) the range for which the contingency plan describes how modifications must be made to the design, or (3) the range that falls outside that approved in licensing. It is the function of the contingency plan to reduce the potential for the last range resulting in adverse effects on isolation, containment, and cost.

That faults and other discontinuities will be encountered is implicit in the preceding discussion. By design, the major faults (e.g., Solitario Canyon fault) will be worked around. Minor faults and other discontinuities cannot all be avoided entirely and some will have to be crossed. Most are not expected to have undesirable characteristics and will not affect the repository design or layout; others may have associated characteristics that trigger implementation of the contingency measures such as those suggested previously.

Specific procedures for establishing the need to adopt contingency measures have not yet been defined. However, it is anticipated that extensive use will be made of existing empirical engineering procedures. For example, Rock Mass Quality Designation (Barton et al., 1974b) and Geomechanical Classification (Bieniawski, 1974) indices will be used to determine if the ground could be assigned an appropriate degree of ground support for preclosure operation. Based upon these indices, the ground support system may be changed or an area may be skipped. (Actual application of these tunnel indexing methods will be in Issue 4.4, technical feasibility (Section 8.3.2.5)). The postclosure implications of such actions, and other site conditions that might trigger remedial action, will be evaluated according to the criteria established in Issues 1.1, total system performance (Section 8.3.5.13) and 1.10, waste package characteristics (postclosure) (Section 8.3.4.2). This issue is concerned solely with ensuring that postclosure considerations are appropriately addressed in the contingency plan. This will involve establishing nonacceptance criteria and practical methods for identifying unacceptable conditions.

Development of the contingency plan requires that system performance of off-normal conditions be performed. Site data required to perform such assessments are the same as defined under product 1.11.3-1. In addition, a set of reasonable off-normal conditions that are consistent with the geologic

setting need to be developed. These may be as simple as extreme variations on material properties, but may include extensive brecciated zones, large pockets of lithophysal material, and perched water tables.

However, it is anticipated that part of the contingency plan will consider the mechanical stability of the rock mass and will use existing, and later modified (to account for thermal loading and site-specific conditions), empirical engineering procedures to initially qualify the stability of underground openings.

8.3.2.2.3.1 Design Activity 1.11.3.1: Area needed determination

The objective of this activity is to determine the area required for the underground facility (product 1.11.3-1). This determination will be revised as input data change (particularly data on waste inventory and allowable thermal loading). The technical basis part of the previous section discusses the approach for determining the area needed and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.3.2 Design Activity 1.11.3.2: Usable area and flexibility evaluation

The objectives of this activity are to

1. Analyze the three-dimensional structure and stratigraphy of Yucca Mountain to identify usable areas and ensure sufficient area is characterized to allow flexibility in design.

2. Produce graphic cross sections and maps that can be used to layout the drift arrangements.

3. Compare drift arrangements to ensure they fit the geology and structure.

4. Identify site geologic data requirements.

This work will result in a series of graphic products in the reference information base, inputs into the data requirements (Information Need 1.11.1, (Section 8.3.2.2.1)) and topical reports. The technical basis part of Section 8.3.2.2.3 discusses the approach for this evaluation and Section 8.3.2.2.1 discusses the data requirement for the activity.

8.3.2.2.3.3 Design Activity 1.11.3.3: Vertical and horizontal emplacement orientation decision

The objective of this activity is to provide the performance evaluation necessary to document this decision. The technical basis part of Section 8.3.2.2.3 discusses the approach to the orientation decision and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.3.4 Design Activity 1.11.3.4: Drainage and moisture control plan

The objective of this activity is to provide postclosure design requirements for the layout of the underground facility to be used in Issue 4.4, preclosure design and technical feasibility (Section 8.3.2.5). The design requirements will limit the amount of water in contact with the container so as to provide a favorable containment and isolation environment. The technical basis part of Section 8.3.2.2.1 discusses the approach to develop this plan and the models and data requirements for this plan.

8.3.2.2.3.5 Design Activity 1.11.3.5: Criteria for contingency plan

The objective of this activity is to provide criteria for the contingency plan developed by Issue 4.4, technical feasibility (Section 8.3.2.5). The technical basis part of Section 8.3.2.2.3 discusses the approach to developing the contingency plan and Section 8.3.2.2.1 gives the data requirements for this plan.

8.3.2.2.4 Information Need 1.11.4: Design constraints to limit water usage and potential chemical changes

The discussion under this information need extends the discussion of function 2, presented earlier in the issue resolution strategy section for the issue (1.11). The approaches or methods to be used to calculate or otherwise establish that the anticipated or actual performance will meet the performance goals stated in Table 8.3.2.2-2 are described here. In many instances, the approaches which follow in the logic subsection require site data, performance information, or design information to make such an evaluation. The site data needs of this information need (1.11.4) are identified in the following parameters section. These needs are passed to the site characterization programs. Performance and design information needs are also identified in the following parameters subsection. In many instances, the performance and design information needs are the results or conclusions of work that depends on site data. The call for such site data is in the issue where the work is done and is not repeated here.

Table 8.3.2.2-2 identified two processes necessary for meeting function 2. Each of these processes was related to one or more performance measures, and their associated performance goals and desired confidences.

The approaches and data needs discussed here are an extension of the horizontal relationship evident in Table 8.3.2.2-2.

This information need will be satisfied through two products that will be used to demonstrate that the performance goals of function 2 have been met. The products are the results of the design activities performed under this information need. The relationship of the two products to the two processes of function 2 is shown in Table 8.3.2.2-8.

These products will be delivered to other information needs under this issue, and to Issue 4.4, technical feasibility (Section 8.3.2.5) and Issue 1.1, total system performance (Section 8.3.5.13). In the following logic subsection, the products are used to group the approach and methods that will be used to show that the goals of this issue are met. Products are the results of the design activities and milestones identified later in this section.

Technical basis for addressing the information need

In the following subsection, the information needed by planned approaches for demonstrating that goals are satisfied is linked to data already available and to plans for future data gathering. Specific parameters and the logic used in identifying that they are important to resolution of Information Need 1.11.4 are then identified in subsequent subsections. The accuracy with which the parameters must be obtained is discussed under Information Needs 1.11.1 (Section 8.3.2.2.1) and 1.11.2 (Section 8.3.2.2.2) where the site and waste package data needed to resolve this issue are consolidated.

Link to the technical data chapters and applicable support documents

The current design data base that has been used for existing design activities and for comparison with data needs given in the following parameters subsection, is presented in the reference design data base Section 6.1.2. A more detailed discussion of the current data in the reference design data base may be found in the data Chapters 1 through 5, and current waste package data are found in Chapter 7.

The data needed to resolve this issue that are already available are presented in Section 6.4.2. Section 6.4.2 provides the status of resolution of Issue 1.11 and also forms some of the bases for the approaches discussed under the logic subsection.

Finally, Information Need 1.11.1 (Section 8.3.2.2.1), lists in detail the site data needs established in this information need, as well as for all other information needs under Issue 1.11. That information need also defines how well they need to be known to resolve the issue and identifies the site characterization issues under which the test plans for obtaining each site data need will be discussed.

Parameters

Parameters listed in this subsection (Table 8.3.2.2-9) are those site data and other input items required to complete the activities and analyses

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Table 8.3.2.2-8. Relationship of Information Need 1.11.4 products to the processes associated with function 2 (Table 8.3.2.2-2)

Product	Process
1.11.4-1 Material inventory criteria (total quantity, type, and location within the repository)	Limit adverse chemical effects by using acceptable materials
1.11.4-2 Water usage criteria (total and individual requirements)	Limit the amount of water used in construction, operation, emplacement of seals, and decommissioning to provide favorable containment and isolation environment

Table 8.3.2.2-9. Parameters and information items required to satisfy Information Need 1.11.4

Product	Parameters and input items
1.11.4-1 Material inventory criteria	Inventory of materials to be introduced into the repository site (from Site Characterization Plan-Conceptual Design Report and Issue 4.4, Section 8.3.2.5) Waste package environment constraints (from Issue 1.10, Section 8.3.4.2) Total system performance analysis (from Issue 1.1, Section 8.3.5.13)
1.11.4-2 Water usage criteria	Planned water usage (from Issue 4.4) Waste package environment constraints (from Issue 1.10) Total system performance analysis (from Issue 1.1)

necessary to develop the products that are identified in Table 8.3.2.2-8. Those activities and analyses will be performed so as to establish that the goals defined in Table 8.3.2.2-2 are met with the required level of confidence. The logic for identification of the products as being necessary to satisfy the information need, as well as the basis for identification of specific parameters and information items, is provided in the following subsection. For this particular information need none of the data identified in the table are site data.

Logic

To satisfy the information need, two sets of criteria will be developed for use in control of the repository design, construction, operation, and closure. The first set of criteria concerns the modification of the postclosure geochemical environment of the waste package as a result of all preclosure activities (product 1.11.4-1). The constraints on modification of that environment will be received from Issue 1.10 (Section 8.3.4.2) for waste package containment requirements and from Issue 1.1 (Section 8.3.5.13) for waste isolation requirements. The second set of criteria concerns changes in degree of saturation of the host rock as a result of all preclosure activities (product 1.11.4-2). Other criteria are established under Information Needs 1.11.3 and 1.11.5 (Sections 8.3.2.2.3 and 8.3.2.2.5).

Product 1.11.4-1: Material inventory criteria. Specific performance requirements are placed on the containment life of the waste packages. Design of a waste package that meets those performance requirements is based on assumptions regarding the geochemical environment to which it will be exposed during the preclosure and postclosure periods. Verification of the site performance, including any geochemical changes, is based on performance assessment analyses, requiring an accurate description of the chemistry of the host rock and the ground water. The extent to which the construction and operation of the repository will modify the geochemistry of the host rock and the ground water is, therefore, an important data need.

Issue 1.10, (Section 8.3.4.2) identifies changes in the pH and organic content of the ground water that might interact with the waste package, and influence containment and isolation. Further, Issue 1.10 specifies limits on these changes as constraints on the postclosure repository design. Potential causes of such changes have been identified, for example, as cement used for repository construction and operation (especially for the emplacement hole construction and preparation), in organic materials contained in any flushing medium during borehole construction (if the emplacement boreholes are not drilled dry as currently planned), shotcrete used for lining openings, and rock bolt anchor grouts or epoxies. Performance goals responsive to those concerns were set in Table 8.3.2.32-2. Repository design criteria and construction and operating procedures must be developed that will ensure all such goals are met.

Other changes to the geochemical environment, beyond those identified here, are identified in Issue 1.10, waste package characteristics (postclosure) (Section 8.3.4.2). Accordingly, the complete data need is identified as an inventory and distribution of all materials introduced into the site during repository construction and operation.

The responsibility of this information need is to establish design criteria for both the preclosure and postclosure periods based on the performance goals of Issues 1.1, total system performance (Section 8.3.5.13), and 1.10, waste package characteristics (postclosure) (Section 8.3.4.2). To do this (1) the potential impacts (pH changes, etc.) of a given quantity of materials must be assessed and (2) a plan must be developed to control the materials in the postclosure system so as to reasonably assure that performance goals will be met. The plan can meet the goals either by controlling the materials used during preclosure or by requiring the removal of materials during decommissioning. The design criteria will be an input into the decommissioning plan to be developed by Information Need 4.4.9 (Section 8.3.2.5.9).

Total system performance (Issue 1.1) should then analyze the plan to ensure that the repository would meet all performance requirements, given the proposed design and corresponding modification of the geochemical environment. Methods to control the materials inventory during construction and operation of the facility will be defined as part of the repository design, under Issue 4.4.7 (Section 8.3.2.5.7).

Product 1.11.4-2: Water management criteria. The current design basis for the waste container is that the surface of the container should remain substantially dry for at least 300 yr after closure. Measures taken to ensure that the design basis will be met include (1) location of the repository in unsaturated host rock, (2) design of an underground layout that will enhance the drainage of any free water away from the containers, and (3) maintaining of a near-container temperature that will be sufficient to evaporate most free water. Drainage and evaporation, as means to control the amount of water to which the waste containers will be exposed, are discussed under Information Needs 1.11.3 (Section 8.3.2.2.3) and 1.11.6 (Section 8.3.2.2.6). Under this information need the potential for significantly changing the degree of saturation of the low lithophysal portion of the Topopah Spring Member unit during construction, operation, and closure of the repository is addressed.

The most probable source of a sufficient quantity of water to cause a long-term change in the degree of saturation of the low lithophysal portion of the Topopah Spring Member unit would be water used as a flushing medium during drilling of emplacement boreholes. Accordingly, the current design basis is that an air flushing system should be used for borehole drilling. The appropriateness of this approach will be evaluated considering such factors as cost, worker safety, and available technology.

As for the materials inventory discussed previously, the responsibility under this information need is to establish realistic design criteria that, if met, would ensure that the postclosure performance goals will be met. Such criteria should be developed through analyses that consider the expected interactions, including fluid penetration, changes in the saturation level, and chemical interactions between the flushing medium and the rock mass.

The method of drilling the emplacement boreholes is particularly important because of the direct connection to the container environment. The design basis for construction of the ramps, shafts, access drifts, and emplacement drifts is that conventional mechanical mining methods will be

used. Appropriate amounts of water will be used during this construction for dust suppression. Measures for controlling the movement of such water through layout are discussed under Information Need 1.11.3 (Section 8.3.2.2.3). However, some water will enter the host rock. The quantity and distribution (e.g., points of application and method of application) of that water used in construction and operations will be investigated by this information need, and a water balance for the entire facility will be established. Associated operating procedures must then be developed to ensure that water entering the repository is managed appropriately. The responsibility under this information need is to determine reasonable water usage amounts, to develop tentative criteria for the repository design, and to define the performance assessment analyses needed to demonstrate compliance with postclosure performance goals.

8.3.2.2.4.1 Design Activity 1.11.4.1: Chemical changes resulting from the use of construction materials

The objective of this activity is to quantify the chemical changes (e.g., change in pH) that result from the use of a given quantity of construction material (e.g., cement). The technical basis part of the previous section discusses the role of this activity in Information Need 1.11.4, and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.4.2 Design Activity 1.11.4.2: Material inventory criteria

The objective of this activity is to establish appropriate limits on the inventory of the materials that will be used in construction and operation of the underground facility and write criteria for the appropriate limits on the inventory of materials that will be left in the openings after decommissioning including backfill. The technical basis part of the previous section discusses the role of this activity in Information Need 1.11.4, and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.4.3 Design Activity 1.11.4.3: Water management criteria

The objective of this activity is to establish appropriate limits on the amount of water that will be used for underground facility construction and operation, indicating amounts and locations for individual operations, and to convey those limits to Issue 4.4 (Section 8.3.2.2.5). The technical basis part of Section 8.3.2.4 discusses the role of these criteria in resolving Information Need 1.11.4, and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.5 Information Need 1.11.5: Design constraints to limit excavation-induced changes in rock mass permeability

The discussion under this information need extends the discussion of function 3, presented in the issue resolution strategy section for this issue (1.11). The approaches or methods to be used to calculate or otherwise establish that the anticipated or actual performance will meet the performance goals stated in Table 8.3.2.2-3 are described here. In many instances, the approaches, which follow in the logic section, require site data, performance information, or design information to make such an evaluation. The site data needs of this information need (1.11.5) are identified in the following parameters subsection. These needs are passed to the site characterization programs. Performance and design information needs are also identified in the following parameters subsection. In many instances, these performance and design information needs are the results or conclusions of work that depends on site data. The call for such data is in the issue where the work is done and is not repeated here.

Table 8.3.2.2-3 identified two processes as contributing to meeting function 3. Both of these processes were related to one or more performance measures and their associated performance goals and desired confidences. The approaches and data needs discussed are an extension of the relationships evident in Table 8.3.2.2-3.

This information need will be satisfied through two products that will be used to demonstrate that the performance goals of function 3 have been met. The products are the results of the design activities performed under this information need. The relationships of the two products to the three processes of function 3 are shown in Table 8.3.2.2-10.

These products will be delivered to Design Issue 4.4, technical feasibility (Section 8.3.2.5) and Performance Issue 1.1, total system performance (Section 8.3.5.13). In the logic subsection for this information need, the products are used to group the approach and methods that will be used to show that the goals of this issue are met. The products are the results of the design activities and milestones identified later in the section.

Technical basis for addressing the information need

In the following section, the information needed by planned approaches for demonstrating that goals are satisfied is linked to data already available and plans for future data gathering. Specific parameters and the logic used in identifying that they are important to resolution of this information need (1.11.5) are then identified in subsequent subsections. The accuracy with which the parameters must be obtained is discussed under Information Needs 1.11.1 and 1.11.2 (Sections 8.3.2.2.1 and 8.3.2.2.2) where the site and waste package data needed to resolve this issue are consolidated.

Link to the technical data chapters and applicable support documents

The current design data base that has been used for existing design activities, and for comparison with data needs given in the following parameters subsection, is presented in the reference design data base in Section 6.1.2. A more detailed discussion of the current data in the reference

Table 8.3.2.2-10. Relationship of Information Need 1.11.5 products to the processes associated with function 3 (refer to Table 8.3.2.2-3)

Product		Process
1.11.5-1	Excavation methods criteria	Limit magnitude and extent of blast-induced permeability change by blast control
1.11.5-2	Long-term subsidence control strategy	Limit potential for subsidence by limiting extraction ratio and drift size. Backfill drifts at decommissioning

design data base may be found in the data Chapters 1 through 5; current waste package data are found in Chapter 7.

Data needed to resolve this issue that are already completed are presented in Section 6.4.2. Section 6.4.2 provides the status of resolution of Issue 1.11 and also forms some of the bases for the approaches discussed under the following logic subsection.

Finally, Information Need 1.11.1, Section 8.3.2.2.1, lists in detail the site data needs established in this information need, as well as for all other information needs under Issue 1.11. Information Need 1.11.1 also defines how well they need to be known to resolve the issue and identifies the site characterization issues under which the test plans for obtaining each site data need will be discussed.

Parameters

Parameters are those data and other information items, listed in Table 8.3.2.2-11, that are required to complete the activities and analyses necessary to develop the products that were identified in Table 8.3.2.2-10. Those activities and analyses will be performed so as to establish that the goals defined in Table 8.3.2.2-3 are met with the required level of confidence. The logic for identification of products as being necessary to satisfy the information need, as well as the basis for identification of specific parameters and information items, is provided by the following section.

Logic

The main purpose of this information need is to ensure that appropriate criteria are provided as guidelines for repository design. These criteria will initially be developed with regard to present design concepts and on the basis of constraints developed under Issue 1.10, waste package character-

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Table 8.3.2.2-11. Parameters and information required to satisfy Information Need 1.11.5

Product	Parameters and input items
1.11.5-1 Excavation methods criteria	Proposed design of boreholes and drifts (Issue 4.4, Section 8.3.2.5)
	Description of proposed excavation methods (Issue 4.4)
	Estimates of the range of parameters defining damage due to excavation (Section 8.3.1.4)
1.11.5-2 Long-term subsidence control strategy	Repository layout (Information Need 1.11.3, Section 8.3.2.2.3)
	Drift and pillar stability analyses (Information Need 1.11.6, Section 8.3.2.2.6)
	Preliminary description of backfill (Issue 4.4)
	Extent of disturbed zone (Issue 1.6, Section 8.3.5.12)

istics (postclosure) (Section 8.3.4.2), and Issue 1.6, ground-water travel time (Section 8.3.5.12). The need to perform a total system performance assessment of a proposed design that conforms to these criteria is passed to Issue 1.1, total system performance (Section 8.3.5.13).

To satisfy the information need, two products that are driven by postclosure performance requirements will be developed. The first product will have limited and boundable postclosure affects. The second product will identify any measures that need to be taken to limit the potential for surface subsidence during the postclosure period. Other design criteria are established under Information Needs 1.11.3 and 1.11.4 (Sections 8.3.2.2.3 and 8.3.2.2.4).

Product 1.11.5-1: Excavation methods criteria. The process of creation of an underground excavation, whether a drift or borehole, involves the use of energy to fracture and comminute the rock mass to be removed. Some of this energy results in mechanical damage to the surrounding rock mass. This damage takes the form of opening of preexisting fractures, creation of new fractures, and movements, rotation, and loosening of structurally defined blocks of rock around the excavation. This damage can result in modification of the hydrologic environment of the host rock in the vicinity of the waste package or in the general underground facility area.

The current design basis for selection of excavation methods has been developed from the position that the potential for any modification of the properties of the host rock mass should be limited, as far as is reasonable, with currently available technology (Issue 4.4, technical feasibility (Section 8.3.2.5). On that basis, the current design of the repository incorporates construction of drifts using drill and blast methods (continuous mining is being considered, but has not yet been proved practical for welded tuff) and construction of emplacement holes using drilling methods.

Realistic criteria for establishing the suitability of these proposed construction methods must be developed based on performance assessment requirements. The current design, which is documented in the SCP-CDR (SNL, 1987), incorporates excavation techniques considering retrievability and worker health and safety concerns and meets the criteria for technological availability. Data requirements for incorporating such requirements are discussed under Issue 4.4. To perform the studies necessary to establish design criteria, it may be necessary to assume a range of characteristics of the damaged zone (not to be confused with the disturbed zone defined by the NRC): the extent and nature of new fracturing; the changes in permeability; and the shielding characteristics of the damaged zone.

Product 1.11.5-2: Long-term subsidence control strategy. Worker health and safety requirements, discussed under Issue 4.2, nonradiological health and safety (Section 8.3.2.4), and retrievability requirements, discussed under Issue 2.4, waste retrievability (Section 8.3.5.2), dictate that the excavation of the repository be usable throughout the operational period. These requirements preclude the possibility of subsidence before closure beyond that associated with predominantly elastic compression of the pillars between excavations. The responsibility under this information need is to ensure that ground movements in the vicinity of the excavations of the repository will not result in significant postclosure surface subsidence or the creation of preferred pathways for water migration.

Development of the long-term subsidence control strategy will be based on the results of drift and pillar stability analyses that are discussed under Information Need 1.11.6 (Section 8.3.2.2.6). Simple analyses will be used to estimate the possible extent and magnitude of loosening of the rock mass above a backfilled drift. Such analyses are expected to demonstrate with a high level of confidence that the potential for surface subsidence can be limited if current repository design concepts are implemented. Whether rock movements after closure may impact the system performance will be judged relative to the extent of the disturbed zone. If appropriate, the need for total system performance assessment analyses incorporating nonconservative estimates of permeability changes after closure will be defined.

8.3.2.2.5.1 Design Activity 1.11.5.1: Excavation methods criteria

The objective of this design activity is to identify any constraints to be placed on excavation methods because of postclosure performance considerations. The technical basis part of the previous section discusses the role of this activity in Information Need 1.11.5, and Section 8.3.2.2.1

discusses the requirements for excavation relative to induced permeability and porosity changes. Table 8.3.2.2-11 presents the excavation parameters and input required to satisfy this information need for this activity.

8.3.2.2.5.2 Design Activity 1.11.5.2: Long-term subsidence control strategy

The objectives of this design activity are to (1) develop a position regarding the potential for postclosure surface subsidence and the impact of postclosure ground movement on containment and isolation and (2) determine if current goals are adequate to limit potential for subsidence. The technical basis part of Section 8.3.2.2.5 discusses the role of this activity in Information Need 1.11.5, and Section 8.3.2.2.1 discuss the data requirements for this activity. Table 8.3.2.2-11 gives the long-term subsidence parameters and input required to satisfy this information need.

8.3.2.2.6 Information Need 1.11.6: Repository thermal loading and predicted thermal and thermomechanical response of the host rock

The discussion under this information need extends the discussion of function 4, which was presented in the issue resolution strategy section for this issue (1.11). The approaches or methods to be used to calculate or otherwise establish that the anticipated or actual performance will meet the performance goals stated in Table 8.3.2.2-4. In many instances, the approaches, which follow in the logic subsection for this information need, require site data, performance information, or design information to make such an evaluation. The site data needs of this information need (1.11.6) are identified in the following parameters section. These needs are passed to the site characterization programs. Performance and design information needs are also identified in the following parameters section. In many instances, these performance and design information needs are the results or conclusions of work that depends on site data. The call for such site data is in the issue where the work is done and is not repeated here.

Table 8.3.2.2-4 identifies six processes necessary for meeting function 4. Each of these processes was related to one or more performance measures and their associated performance goals and desired confidences. The approaches and data needs discussed here are an extension of the relationships evident in that table.

This information need will be satisfied through five products that will be used to demonstrate that the performance goals of function 4 have been met. The products are the results of the design activities performed under this information need. The relationship of the five products to the six processes of function 4 is shown in Table 8.3.2.2-12.

These products may be delivered to other information needs under this issue or under other design or performance issues. In the following logic subsection, the products are used to group the approach and methods that will be used to show that the goals of this issue are met. Products are the

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Table 8.3.2.2-12. Relationship of Information Need 1.11.6 products to the processes associated with function 4 (Table 8.3.2.2-4). (Asterisks indicate direct relationship between products and processes.)

Process	Product				
	Allowable APD[a]	Borehole spacing strategy	Sensitivity studies	Strategy for containment enhancement	Reference calculations[b]
Limit temperature changes in selected barriers	*		*		*
Limit deleterious rock movement or preferred pathways	*		*		*
Limit impact on surface environment	*				
Vary borehole and drift spacing to control thermal loading and container temperature	*	*	*	*	*
Limit potential for borehole collapse	*	*	*		*
Limit corrosiveness of container environment		*		*	

[a]APD = areal power density.
[b]Thermomechanical calculations in the reference information base for general Project reference and use.

results of the design activities and milestones identified later in the section.

Technical basis for addressing the information need

In the following subsection, the information needed by planned approaches for demonstrating that goals are satisfied is linked to data already available and plans for future data gathering. Specific parameters and the logic used in identifying their importance to resolution of this information need (1.11.6) are then identified in subsequent subsections. The accuracy with which the parameters must be obtained is discussed under Information Needs 1.11.1 and 1.11.2 (Sections 8.3.2.2.1 and 8.3.2.2.2) where the site and waste package data needed to resolve this issue are consolidated.

Link to the technical data chapters and applicable support documents

The current design data base that has been used for existing design activities, and for comparison with data needs given in the following parameters subsection, is presented in the reference design data base in Section 6.1.2. A more detailed discussion of the current data in the reference design data base may be found in the data chapters (1 through 5), and current waste package data are found in Chapter 7.

Data that are needed to resolve this issue and that are already completed are presented in Section 6.4.2. This section provides the status of resolution of this issue (1.11), and also forms some of the bases for the approaches discussed under the following logic subsection.

Finally, Information Need 1.11.1 (Section 8.3.2.2.1) lists in detail the site data needs established in this information need, as well as those for all other information needs under this issue. That information need also defines how well the data must be known to resolve the issue and identifies the site characterization issues under which the test plans for obtaining each site data need will be discussed.

Parameters

Parameters defined in this section are treated at two levels. At the first level (Table 8.3.2.2-13) the analyses and input items required to address this information need are identified. Specific parameters required to complete the analyses are identified at the second level (Table 8.3.2.2-14). This method of presentation has been adopted because there is considerable overlap between the types of analyses that will be performed to develop the five products identified under this information need. The iterative nature of the design process is also evident; for example, the borehole spacing documents require the use of container scale thermal analyses and those analyses require initial estimates of the borehole spacing. The analyses will be used to ensure that goals identified in Table 8.3.2.2-4 are met with an appropriate level of confidence. The logic for the identification of the products and the analyses required to prepare them are provided by the following subsection. Site parameters required to complete the analyses are determined by the input needs of the computer models and other analytical tools to be used.

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Table 8.3.2.2-13. Analyses and input items required to resolve Information Need 1.11.6

Product		Parameters and input items
1.11.6-1	Areal power density (APD)	Drift stability criteria (Issues 2.4 and 4.4, Sections 8.3.5.2 and 8.3.2.5) Constraints established by sealing program (Issue 1.12, Section 8.3.3.2) Far-field performance criteria, including limits on temperature change and permeability changes on adjacent strata Surface temperature change, and surface uplift limits Near-field limits on host rock temperature, as it influences container environment (Issue 1.10, Section 8.3.4.2) Far-field thermal and thermomechanical analyses (Table 8.3.2.2-14) Near-field thermal and thermomechanical analyses (Table 8.3.2.2-14)
1.11.6-2	Borehole spacing	Borehole stability criteria (Issues 2.4 and 4.4) APD Container and container environment constraints (Issue 1.10) Container scale thermal and thermomechanical analyses (Table 8.3.2.2-14)
1.11.6-3	Sensitivity studies	Container scale thermal and thermomechanical analyses (Table 8.3.2.2-14) Drift scale thermal and thermomechanical analyses (Table 8.3.2.2-14) Far-field thermal and thermomechanical analyses (Table 8.3.2.2-14) Ranges of feasible parameters defined in Table 8.3.2.2-14 Off-normal conditions scenario
1.11.6-4	Strategy for containment enhancement	Proposed water usage (Issue 4.4) APD and borehole spacing Waste package characteristics (postclosure) (Issue 1.10)
1.11.6-5	Reference calculation	Repository design Container thermal and thermomechanical scale analyses Drift thermal and thermomechanical analyses Far-field thermal and thermomechanical analyses

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Table 8.3.2.2-14. Parameters for thermal and thermomechanical analyses

Product	Parameters and input items
Container scale analyses	Borehole dimensions and spacing Waste package description Container dimensions Container thermal output Container thermal decay characteristics Liner and overpack specification Geologic description of site Stratigraphy Jointing orientation, frequency, distribution Rock mass thermal and thermomechanical properties TSw2 and adjacent units Saturation Thermal conductivity Heat capacity Thermal expansion coefficient Rock mass deformation modulus Rock mass strength In situ stress Rock matrix elastic modulus Rock matrix Poisson's ratio Rock matrix strength Joint orientation Joint spacing Joint strength Joint normal stiffness Joint shear stiffness
Drift scale analyses	Areal power density Waste decay characteristics (See listing under container scale analyses) Drift dimensions and spacing Waste emplacement configuration Geologic description of site Stratigraphy Rock mass thermal and thermomechanical properties of TSw2 and adjacent units (see listing under container scale analyses) Rock support measures

Table 8.3.2.2-14. Parameters for thermal and thermomechanical analyses (continued)

Product	Parameters and input items
Far-field analyses	Areal power density Waste decay characteristics (see listing under container scale analyses) Repository layout Geologic description of site Stratigraphy Topography Fault locations and properties Jointing orientation, frequency, distribution Rock mass thermal and thermomechanical properties of all units, including overburden (see listing under container scale analyses)

Logic

The burden of ensuring that the repository facilities will meet all applicable performance objectives lies with this information need. Other information needs under this issue are primarily concerned with establishing the design bases (such as available space) and constraints that must be placed upon the design as a consequence of postclosure performance concerns. This information need is also concerned with the development of reference calculations that provide a consistent set of predictions of the behavior of the repository for performance assessment.

Five products have been identified as needed to satisfy this information need: (1) the areal power density, (2) the emplacement borehole spacing, (3) sensitivity studies, (4) strategy for containment enhancement, and (5) reference calculations. Developing these products involves consideration of multiple processes (Table 8.3.2.2-12) and the application of the appropriate analyses (identified in Table 8.3.2.2-13). The following discussion treats first the products and then the analyses upon which they rely.

Product 1.11.6-1: Areal power density. The areal power density (APD) is the single most important characteristic of the repository since it can be directly related to the capacity of the site, the repository layout, and the extent to which the original characteristics of the site are modified as a consequence of waste emplacement. The method of development of the APD involves performing thermal and thermomechanical analyses. The results of those analyses are compared with constraints or goals established under other design issues and the performance issues. Given waste with a particular set of characteristics, the average thermal loading is varied until the larger scale performance criteria are met. Analyses of drifts, and possibly of

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boreholes, are then performed to ensure that near-field criteria are also satisfied for the selected APD and the given thermal power decay characteristics of the waste form.

Product 1.11.6-2: Borehole spacing. The borehole spacing is very closely related to the areal power density (APD), and when the APD is being determined it may be necessary to perform drift or borehole scale calculations that assume a particular spacing. Borehole spacing is an important design factor because (1) there may be several different arrangements of waste (different borehole spacings), each with the same APD, that meet constraints; and (2) the considerable variability of the thermal output of the waste will require that the borehole spacing be a variable. This product must develop the strategy for selecting borehole spacing based on an approach that considers thermomechanical interaction between boreholes and between drifts and boreholes, and equipment constraints on borehole construction or waste emplacement. These analyses will provide detailed assessment of the temperatures near the emplacement boreholes. These assessments will be compared to criteria established under Issues 1.10, waste package characteristics (postclosure) (Section 8.3.4.2); 2.4, waste retrievability (Section 8.3.5.2); and 4.4, technical feasibility (Section 8.3.2.5).

Product 1.11.6-3: Sensitivity studies. Sensitivity studies will be performed to evaluate the effects of uncertainty in the description of the waste form and the geologic setting. At present it is assumed that such studies will rely on repeated analyses incorporating realistic parameter variations. The results of these analyses may be expressed quantitatively as sensitivity coefficients and incorporated within a finalized methodology of uncertainty analysis.

Product 1.11.6-4: Strategy for containment enhancement. Under the discussion of the borehole spacing product, it was noted that more than one spacing may meet all constraints; however, these different ways to distribute the waste may not all perform equally. This product will document what has been done to make sure that the significant alternatives or ways of enhancing performance have not been overlooked. For example, one goal is to keep the container dry by maintaining temperatures above boiling for 300 yr; however, at the edges of the underground facility, temperatures will not be as high as at the middle. This product will investigate increasing the waste loading at the edges of the underground facility to maintain higher temperatures there. This product will rely primarily on container scale thermal calculations and is intended to respond to the requirements of Issue 1.10, waste package characteristics (postclosure) (Section 8.3.4.2).

Product 1.11.6-5: Reference calculations. The repository design as shown in Chapter 6 was developed in support of the site characterization plan. The design is expected to be refined as the site investigation proceeds, and after field evaluation at the exploratory shaft facility. These refinements will be documented as part of the advanced conceptual design and license application design activities. At every stage it is important to have a complete set of referenceable predictions of the behavior of the repository system. Such predictions provide a basis on which to assess the suitability of the proposed design and are important

considerations when developing the needs for supporting laboratory and field investigations. These predictions (or reference calculations) will be based on progressively better designs and site data of improving quality.

Analysis of thermal and thermomechanical response. Before discussing the specifics of analyses it is important to emphasize an assumption upon which the subsequent discussion relies. The assumption is that responsibility for ensuring that the retrieval option is maintained until the time of closure rests with Issues 4.4, technical feasibility (Section 8.3.2.5), and 2.4, waste retrievability (Section 8.3.5.2). Accordingly, it is assumed that necessary steps will be taken to validate the approach used to ensure that reasonable maintenance requirements and retrieval will be met under those issues. Achieving that assurance will necessarily require that the damaged zone around the boreholes and drifts, as it exists at the time of closure, will be reasonably characterized. For the postclosure period it remains to be demonstrated that the container integrity will not be violated and that the disturbed zone is not extended as a consequence of the changing thermal stress field.

The terms near-field and far-field are often used when discussing analyses on different scales. Here it is more convenient to subdivide the near-field into the container scale and the drift scale, on the basis that analyses on those two scales may be conducted independently. (That is likely to be true for horizontal emplacement, but it may be more difficult to separate the two for the vertical emplacement option.) The following paragraphs discuss the scope of the analyses anticipated to be performed on these three scales and the types of models to be used. Further, the need for supporting activities and field studies to validate these models is addressed.

Validation of the computer models to be used to verify the design of the waste emplacement configuration is discussed under Issue 4.4, technical feasibility (Section 8.3.2.5). No additional validation of the finite-element models discussed there is considered necessary, because there will be no significant change in the conditions that they seek to analyze. As such, this issue does not call for site data to validate the models.

Container scale analyses. In Table 8.3.2.2-5 performance goals are defined for the waste container and the adjacent rock. Thermal and thermomechanical modeling will be used to ensure that these goals continue to be met beyond closure of the underground facility. The design parameters that may be selected to ensure that the goals are met are the waste package spacing and the areal power density. In general, the analyses will be identical to those performed for the preclosure period. Namely, either two- or three-dimensional analyses will be performed using finite-element models that incorporate a description of jointed rock behavior. Selection of a three-dimensional idealization, as opposed to two-dimensional, will be based on the geometry of the waste emplacement configuration. However, two-dimensional analyses are expected to be adequate for evaluation of horizontal emplacement boreholes, while three-dimensional analyses may be required for vertical boreholes. (For vertical emplacement, the waste packages may be too close to the emplacement drift to allow the assumption of symmetry necessary to use two-dimensional analysis techniques.)

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Because the emplacement borehole liner is expected to have a limited life, the analyses should not include the possible beneficial effect of rock support during the early postclosure period. In the absence of any such support it is possible that blocks of rock will become detached from the borehole wall and come in contact with the waste container. Prediction of the size of those blocks and the loads that could be imposed on the container are considered important in view of load constraints defined under Issue 1.10, waste package characteristics (postclosure) (Section 8.3.4.2). The finite-element models currently under development within the Yucca Mountain Project do not address block failure. Hence, it will be necessary to apply other techniques to evaluate the loading, such as wedge analysis, key block analysis, and use of models based on application of the distinct element method. These other methods should incorporate realistic descriptions of the geometry of the rock surrounding the emplacement borehole and include the effects of thermal loading. The thermal load history (boundary condition) used in the wedge or key block analysis may be obtained from thermomechanical analyses performed to evaluate goals for the waste container and adjacent rock.

Drift scale analyses. The objective of drift-scale analyses of the postclosure period is to ensure that no new paths to the accessible environment, or extension of the disturbed zone, will occur. The potential for such effects can be mitigated by backfilling the emplacement drifts before closure. Good drift maintenance performed during the preclosure period, the amount of void space around the drift, the compaction characteristics of the backfill, and the bulking factor of the host rock will limit the amount of rockfall in the case of localized rock failure. The possible implications of such disturbance can be evaluated using performance assessment models based on assumptions about the distribution of void space around the drift. It is also recommended that such evaluations be supported by thermal and thermomechanical analyses intended to evaluate the behavior under the applied thermal loading.

Data for the postclosure drift analyses will include a description of the drift at the time of closure, with particular emphasis placed on definition of the extent of damage and a description of the backfill. The finite-element models described under Issue 4.4, technical feasibility (Section 8.3.2.5), will be used to perform analyses. The only additional component of the models will be the backfill. Because primary reliance will be placed on performance assessment to evaluate the acceptability of the system, detailed validation of thermomechanical models of the backfilled drifts is not considered necessary.

Far-field analyses. Far-field thermal and thermomechanical analyses of the postclosure repository configuration will be performed to confirm that the far-field performance goals continue to be met. The tools for these analyses will be the same as those used for container and drift-scale analyses, namely, finite-element, thermomechanical analyses of representative cross sections of the repository. There are no new physical processes to be analyzed and there are no additional bases for evaluating the potential for deleterious rock movements or creation of preferred pathways other than the potential effects of faulting. Faulting should be included in the far-field thermomechanical models to assess their potential effects. The far-field analyses of the repository system require the same data and techniques as

other thermomechanical analyses. Temperature-induced displacements in the rock mass will be examined and will consider the possibility of movement along preexisting features such as faults. If movement on features that intersect the repository facility is possible, the analyses described in Section 8.3.2.5 will be extended to examine possible effects. Seismically induced movements will be considered in conjunction with temperature-induced effects.

8.3.2.2.6.1 Design Activity 1.11.6.1: Thermal loading for underground facility

The objective of this design activity is to establish the allowable thermal loading as a function of waste age and burnup. Determination will start with far-field calculations and consider near-field effects to ensure practical waste distribution exists that meets near-field constraints. The technical basis part of the previous section discusses the approach to determining the allowable APD, and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.6.2 Design Activity 1.11.6.2: Borehole spacing strategy

The objective of this design activity is to establish strategy for choosing borehole spacings as a function of waste thermal output as affected by waste type, age, and burnup. Strategy will be designed to ensure that spacings chosen will satisfy all near-field constraints. The technical basis part of Section 8.3.2.2.6 discusses the approach to establishing a borehole spacing strategy, and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.6.3 Design Activity 1.11.6.3: Sensitivity studies

The objective of this design activity is to determine predicted repository thermal and thermomechanical response to variations in model input data. This information will be used to evaluate adequacy of data gathered and to determine goals have been met with proper confidence. The technical basis part of Section 8.3.2.2.6 discusses this approach to sensitivity studies, and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.6.4 Design Activity 1.11.6.4: Strategy for containment enhancement

The objective of this design activity is to document how design of underground facility has taken into account containment, in particular, the goal for Issue 1.10 (Section 8.3.4.2) of keeping the containers dry for 300 yr. The technical basis part of Section 8.3.2.2.6 discusses the approach to this strategy, and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.6.5 Design Activity 1.11.6.5: Reference calculations

The objective of this design activity is to provide a consistent set of calculations with proper quality assurance of thermal and thermomechanical response of host rock that can be used by performance assessment issues. The technical basis part of Section 8.3.2.2.6 discusses the approach to these calculations, and Section 8.3.2.2.1 discusses the data requirements for this activity.

8.3.2.2.7 Information Need 1.11.7: Reference postclosure repository design

This information need does not correspond to an issue resolution function identified in the issue resolution strategy (Section 8.3.2.2) for this issue (1.11). Nor does it require the acquisition of site data. Rather, this information need will be satisfied using data acquired under other information needs, as well as results of analyses conducted under other information needs.

This information need will be satisfied by two products:

1. Reference postclosure design provides the reference postclosure design of the repository, which will form part of the basis for the postclosure performance assessment of the repository (to satisfy part 2 of this issue).

2. Documentation of compliance will demonstrate compliance of the postclosure design with the requirements of 10 CFR 60.133 (satisfying part 1 of this issue). This product will be documented in the advanced conceptual design and license application design reports.

Technical basis for addressing the information need

In the subsequent subsections a link is provided to other sections of the SCP and supporting documents, including reference to documentation of the current status of satisfying this information need as found in Section 6.4. The reference postclosure design will be documented in the reference information base. An explanation of the logic of what is required to satisfy this information need is also given.

Link to the technical data chapters and applicable support documents

The current design concepts and drawings are documented in Section 6.2 and in Chapters 3 and 4 of the SCP-CDR (SNL,1987). The reference design drawings that result from this information need will be part of the basis for postclosure performance assessment of the repository by the following issues:

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Issue	Short title	SCP section
1.1	Total system performance	8.3.5.13
1.3	Ground-water protection	8.3.5.15
1.4	Containment by waste package	8.3.5.9
1.5	Engineered barrier system release rates	8.3.5.10
1.6	Ground-water travel time	8.3.5.12
1.8	NRC siting criteria	8.3.5.17
1.9	Higher level findings--postclosure	8.3.5.18

Parameters

The following information needs or investigations will furnish information necessary to develop the postclosure design of the underground facility:

Information need or investigation	Subject
1.11.3	Underground facility orientation and layout (Section 8.3.2.2.3)
1.11.4	Design constraints to limit water usage (Section 8.3.2.2.4)
1.11.6	Thermomechanical effects on postclosure design (Section 8.3.2.2.6)
1.12.2	Seal materials (Section 8.3.3.2.2)
1.12.3	Emplacement methods for seals (Section 8.3.3.2.3)
1.12.4	Reference seal designs (Section 8.3.3.2.4)
4.4.7	Design analyses for technical feasibility (Section 8.3.2.5.7)
8.3.1.4.1	Integrated drilling program (stratigraphy, structure, rock properties)
8.3.1.9.1	Degradation of surface markers and monuments

Logic

This information need will evaluate criteria for reference design and construction drawings and transmit these criteria to Issue 4.4, technical feasibility (Section 8.3.2.5). Specific drawings that result will be supplied, as they are available, to the reference information base during the advanced conceptual design and license application design phases.

The information that must be documented as part of the reference postclosure underground facility design is as follows:

1. The location of underground openings including their preclosure size and shape and their drainage pattern.

2. The anticipated postclosure state of the openings including backfill and reasonable degradation. The boreholes on the average are expected to be stable and meet containment requirements; however, drifts that will remain stable for some period after repository closure will not be relied on to be open and may be backfilled.

3. The documentation of location, function, and design of the seals for ramps, shafts, drifts, and exploratory drill holes. This documentation will be produced by Issue 1.12, seal characteristics (Section 8.3.3.2). Documentation of this information will be included in the reference postclosure design.

4. The criteria for dismantling of the underground structures and facilities including statement of materials that will be left in place (plan for decommissioning will be in Issue 4.4, technical feasibility, Section 8.3.2.5).

5. Documentation of surface monuments, if any (Issue 1.12).

8.3.2.2.7.1 Design Activity 1.11.7.1: Reference postclosure repository design

The objective of this design activity is to establish what information will constitute the reference postclosure design for use in performance assessment and document this information in the advanced conceptual design and license application design reports. The previous section discusses the role of the activity in resolving Issue 1.11.

8.3.2.2.7.2 Design Activity 1.11.7.2: Documentation of compliance

The objective of this design activity is to document that the issue has been resolved by determining if the postclosure design complies with the design goals of this issue and to document this compliance in the advanced conceptual design and license application design reports.

8.3.2.3 Issue resolution strategy for Issue 2.7: Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.130 through 60.133 and (b) provide information for the resolution of the performance issues?

This issue is concerned with the features (i.e., characteristics and configurations) of the repository that relate to radiological safety. These features consist of a subset of the total set of engineered systems and components that make up the repository. The features also address some aspects of the natural setting (i.e., the site) by accounting for the impact of these aspects on the engineered systems and components. For example, the shielding properties of the host rock and their effect on radiation levels in areas occupied by workers should be considered in the design of equipment for handling the waste package in the underground facility.

The role of this issue in addressing the features of the repository related to radiological safety must be placed in context with the roles of other issues. Figure 8.3.2.1-1, Section 8.3.2.1, shows the relationships between several design and performance assessment issues. To be more specific about the relationship of Issue 2.7 to the other issues with which it is directly tied, only Issues 2.7 (this issue), 4.4 (Section 8.3.2.5), and 2.1 through 2.3 (Sections 8.3.5.3 through 8.3.5.5) are shown in Figure 8.3.2.3-1. The figure defines the ties between these issues by indicating what major items of information are passed between them. The figure also illustrates the connection of all these issues with the site characterization program. The scope of an issue is indicated by its size with respect to other issues in this figure. Note that Issue 4.4 is the largest in scope, and the other issues, including this issue branch out from Issue 4.4, reducing the scope to more specific areas. A strong tie between Issue 2.7 and Issue 4.4 is indicated and, in particular, the reliance of this issue upon Issue 4.4 for development of the design and supporting analyses.

In the discussion that follows in this section, the regulatory basis for addressing Issue 2.7 is described, the approach to resolving the issue is defined, and the relationship of this approach with the information needs within this issue is discussed.

Regulatory basis for the issue

As indicated in this issue statement, the regulatory bases for this issue arise primarily from two sources. First, 10 CFR Part 60 provides the repository design criteria in Sections 60.131 through 60.133. In addition, 10 CFR 60.111(a) and 10 CFR Part 20 are pertinent to this issue. Performance Issues 2.1, 2.2, and 2.3, which address radiological exposures to the workers and public under normal and accident conditions, impose criteria upon the design of the repository as a result of EPA and NRC imposed limits on the exposures to the public and workers. These two bases for Issue 2.7 will be treated individually and in detail in the discussions that follow.

In 10 CFR Part 60 the NRC has laid out design criteria for the geologic repository and the waste package. These criteria are found in Sections 60.130 through 60.135. In addition to the brief statement of the general scope of the design criteria given in section 60.130, the sections of

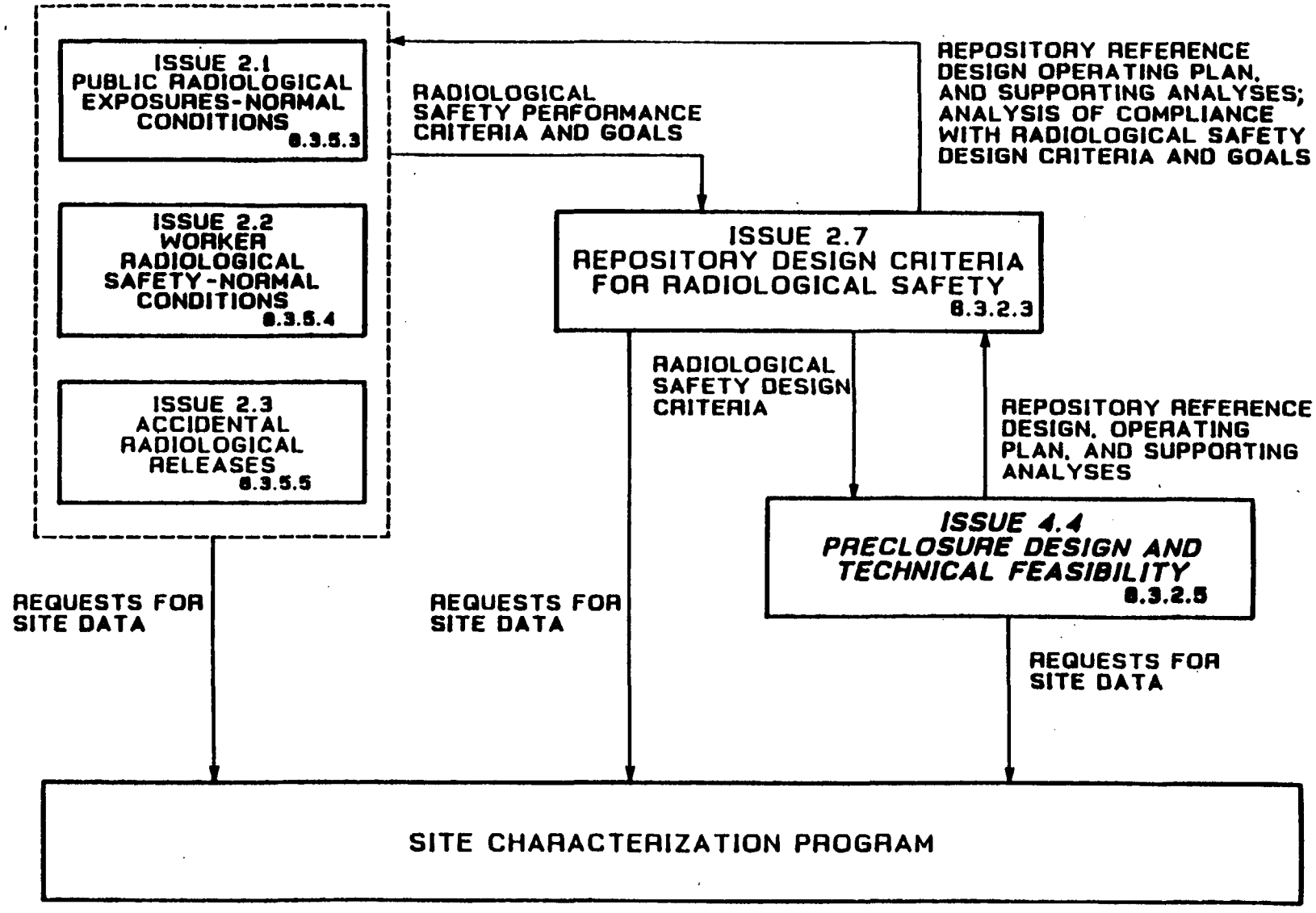

Figure 8.3.2.3-1. Relationship of Issue 2.7 (repository design criteria for radiological safety) to other issues and the site characterization program.

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particular importance to repository design aspects of radiological safety are 60.131 through 60.133. (Section 60.134 addresses seals and is treated in Section 8.3.3, seals systems. Section 60.135 is treated in Section 8.3.4 under Issue 2.6, waste package characteristics--preclosure.) General design criteria for the geologic repository operations area (GROA) are given in 10 CFR 60.131. This section contains two main topics: (1) methods of radiological protection and (2) systems, structures, and components important to safety. Additional design criteria for the surface facilities are given in 60.132, and additional design criteria for the underground facilities are given in 60.133.

Not all the design criteria spelled out in these sections are related to radiological safety; therefore, not all these design criteria are addressed in Issue 2.7. The division of responsibility and relationships between the design issues are described in Section 8.3.2.1 (Figure 8.3.2.1-1), and the specific issue responsible for addressing each criterion stated in 10 CFR 60.131 through 60.133 is presented in Table 8.3.2.3-1. In addition, the table also indicates which of the criteria result in the need for site parameters in order to accomplish the design and analyses necessary to address the criteria. Only those criteria that result in the need for site data will be addressed in detail in the SCP. All criteria, as well as the plans to account for those criteria in the design of the repository, will be addressed in the plans for repository design.

Approach to resolving the issue

Licensing strategy overview

This issue requires that the repository design incorporate the general design criteria specified in 10 CFR 60.131 through 60.133 such that the preclosure performance objectives identified in 10 CFR 60.111 can be met. The general objective of these criteria is to ensure that the geologic repository operations area (GROA) is designed in such a way that the general public and repository workers are adequately protected from both routine and accidental releases of radioactive material during repository operation, including retrieval operations. The primary means of resolving this issue is by reflecting the preclosure design criteria of 10 CFR 60.131 through 60.133 in the design of the GROA and by performing analyses that will demonstrate that the performance objectives of 10 CFR 60.111 will be met.

As stated in 10 CFR 60.130, the design criteria specified in 10 CFR 60.131 through 60.133 are a minimum set. Other design criteria may be specified that are consistent with and complement the criteria in 10 CFR 60.131 through 60.133. As can be seen in Table 8.3.2.3-1, the information needed to resolve this issue is primarily design related. Site data that are required pertain mainly to the identification of design-basis accidents and to the use of the site properties to help design features enhance radiological safety. The resolution of Issue 2.7 will be complete when it has been demonstrated that each item listed in 10 CFR 60.131 through 60.133 has been adequately addressed in the license application design. The analysis of additional design features will provide added assurance of radiological safety beyond the regulatory requirements. It is important to note that under this issue,

Table 8.3.2.3-1. Design criteria for the geologic repository operations area (page 1 of 8)

Design criteria of 10 CFR 60.131 through 60.133	Issue that addresses the criterion[b]	Are the site data needed to address the criterion?
60.131 GENERAL DESIGN CRITERIA FOR THE GEOLOGIC REPOSITORY OPERATIONS AREA		
(a) Radiological protection. The geologic repository operations area shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in restricted areas within the limits specified in Part 20 of this chapter. Design shall include -		
(1) Means to limit concentrations of radioactive material in air;	2.7	Yes
(2) Means to limit the time required to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation;	2.7	No
(3) Suitable shielding;	2.7	Yes
(4) Means to monitor and control the dispersal of radioactive contamination;	2.7	Yes
(5) Means to control access to high radiation areas or airborne radioactivity areas; and	2.7	No
(6) A radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity released in effluents. The alarm system shall be designed with provisions for calibration and for testing its operability.	2.7	Yes
(b) Structures, systems, and components important to safety.		
(1) Protection against natural phenomena and environmental conditions.	2.7	Yes
The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the geologic repository operations area will not interfere with necessary safety functions.		

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Table 8.3.2.3-1. Design criteria for the geologic repository operations area (page 2 of 8)

Design criteria of 10 CFR 60.131 through 60.133	Issue that addresses the criterion[b]	Are the site data needed to address the criterion?
60.131 GENERAL DESIGN CRITERIA FOR THE GEOLOGIC REPOSITORY OPERATIONS AREA (continued)		
(2) Protection against dynamic effects of equipment failure and similar events.	2.7	No
The structures, systems, and components important to safety shall be designed to withstand dynamic effects such as missile impacts, that could result from equipment failure, and similar events and conditions that could lead to loss of their safety functions.		
(3) Protection against fires and explosions.		
(i) The structures, systems, and components important to safety shall be designed to perform their safety functions during and after credible fires or explosions in the geologic repository operations area.	2.7	Yes
(ii) To the extent practicable, the geologic repository operations area shall be designed to incorporate the use of noncombustible and heat resistant materials.	4.4	No
(iii) The geologic repository operations area shall be designed to include explosion and fire detection alarm systems and appropriate suppression systems with sufficient capacity and capability to reduce the adverse effects of fires and explosions on structures, systems, and components important to safety.	2.7	Yes
(iv) The geologic repository operations area shall be designed to include means to protect systems, structures, and components important to safety against the adverse effects of either the operation or failure of the fire suppression systems.	2.7	No
(4) Emergency capability.		
(i) The structures, systems, and components important to safety shall be designed to maintain control of radioactive waste and radioactive effluents, and permit prompt termination of operations and evacuation of personnel during an emergency.	2.7	No

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Table 8.3.2.3-1. Design criteria for the geologic repository operations area (page 3 of 8)

Design criteria of 10 CFR 60.131 through 60.133	Issue that addresses the criterion[b]	Are the site data needed to address the criterion?
60.131 GENERAL DESIGN CRITERIA FOR THE GEOLOGIC REPOSITORY OPERATIONS AREA (continued)		
(ii) The geologic repository operations area shall be designed to include onsite facilities and services that ensure a safe and timely response to emergency conditions and that facilitate the use of available offsite services (such as fire, police, medical, and ambulance service) that may aid in recovery from emergencies.	4.4	No
(5) Utility services.		
(i) Each utility service system that is important to safety shall be designed so that essential safety functions can be performed under both normal and accident conditions.	2.7	Yes
(ii) The utility services important to safety shall include redundant systems to the extent necessary to maintain, with adequate capacity, the ability to perform their safety functions.	2.7	No
(iii) Provisions shall be made so that, if there is a loss of the primary electric power source or circuit, reliable and timely emergency power can be provided to instruments, utility service systems, and operating systems, including alarm systems, important to safety.	2.7	No
(6) Inspection, testing, and maintenance.	2.7	No
The structures, systems, and components important to safety shall be designed to permit periodic inspection, testing, and maintenance, as necessary, to ensure their continued functioning and readiness.		
(7) Criticality control.	2.7	Yes
All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated		

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Table 8.3.2.3-1. Design criteria for the geologic repository operations area (page 4 of 8)

Design criteria of 10 CFR 60.131 through 60.133	Issue that addresses the criterion[b]	Are the site data needed to address the criterion?
60.131 GENERAL DESIGN CRITERIA FOR THE GEOLOGIC REPOSITORY OPERATIONS AREA (continued)		
effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation.		
(8) Instrumentation and control systems.	2.7	Yes
The design shall include provisions for instrumentation and control systems to monitor and control the behavior of systems important to safety over anticipated ranges for normal operations and for accident conditions.		
(9) Compliance with mining regulations.	2.7, 4.2	Yes
To the extent that DOE is not subject to the Federal Mine Safety and Health Act of 1977, as to the construction and operation of the geologic repository operations area, the design of the geologic repository operations area shall nevertheless include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended functions. Any deviation from relevant design requirements in 30 CFR, Chapter 1, Subchapters D, E, and N will give rise to a rebuttable presumption that this requirement has not been met.		
(10) Shaft conveyances used in radioactive waste handling.	NA[b] - all waste will be transported underground using a ramp[c]	NA
(i) Hoists important to safety shall be designed to preclude cage free fall.		
(ii) Hoists important to safety shall be designed with a reliable cage location system.		NA
(iii) Loading and unloading systems for hoists important to safety shall be designed with a reliable system of interlocks that will fail safely upon malfunction.	NA	NA

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Table 8.3.2.3-1. Design criteria for the geologic repository operations area (page 5 of 8)

Design criteria of 10 CFR 60.131 through 60.133	Issue that addresses the criterion[b]	Are the site data needed to address the criterion?
60.131 GENERAL DESIGN CRITERIA FOR THE GEOLOGIC REPOSITORY OPERATIONS AREA (continued)		
(iv) Hoists important to safety shall be designed to include two independent indicators to indicate when waste packages are in place and ready for transfer.	NA	NA
60.132 ADDITIONAL DESIGN CRITERIA FOR SURFACE FACILITIES IN THE GEOLOGIC REPOSITORY OPERATIONS AREA		
(a) Facilities for receipt and retrieval of waste.	2.7	Yes
Surface facilities in the geologic repository operations area shall be designed to allow safe handling and storage of wastes at the geologic repository operations area, whether these wastes are on the surface before emplacement or as a result of retrieval from the underground facility.		
(b) Surface facility ventilation.	2.7	Yes
Surface facility ventilation systems supporting waste transfer, inspection, decontamination, processing, or packaging shall be designed to provide protection against radiation exposure and offsite releases as provided in 60.111(a).		
(c) Radiation control and monitoring.		
(1) Effluent control.	2.7	Yes
The surface facilities shall be designed to control the release of radioactive materials in effluents during normal operations so as to meet the performance objectives of 60.111(a).		
(2) Effluent monitoring.	2.7	No
The effluent monitoring systems shall be designed to measure the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirement for effluent control. The monitoring systems shall be designed to include alarms that can be periodically tested.		

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Table 8.3.2.3-1. Design criteria for the geologic repository operations area (page 6 of 8)

Design criteria of 10 CFR 60.131 through 60.133	Issue that addresses the criterion[b]	Are the site data needed to address the criterion?
60.132 ADDITIONAL DESIGN CRITERIA FOR SURFACE FACILITIES IN THE GEOLOGIC REPOSITORY OPERATIONS AREA (continued)		
(d) Waste treatment.	2.7	No
Radioactive waste treatment facilities shall be designed to process any radioactive wastes generated at the geologic repository operations area into a form suitable to permit safe disposal at the geologic repository operations area or to permit safe transportation and conversion to a form suitable for disposal at an alternative site in accordance with any regulations that are applicable.		
(e) Consideration of decommissioning.	4.4	No
The surface facility shall be designed to facilitate decontamination or dismantlement to the same extent as would be required, under other parts of this chapter, with respect to equivalent activities licensed thereunder.		
60.133 ADDITIONAL DESIGN CRITERIA FOR THE UNDERGROUND FACILITY		
(a) General criteria for the underground facility.		
(1) The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall contribute to the containment and isolation of radionuclides.	1.11	Yes
(2) The underground facility shall be designed so that the effects of credible disruptive events during the period of operations, such as flooding, fires, and explosions will not spread through the facility.	4.4	No
(b) Flexibility of design.		
The underground facility shall be designed with sufficient flexibility to allow adjustments where necessary to accommodate specific site conditions identified through in situ monitoring, testing, or excavation.	1.11	Yes

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Table 8.3.2.3-1. Design criteria for the geologic repository operations area (page 7 of 8)

Design criteria of 10 CFR 60.131 through 60.133	Issue that addresses the criterion[b]	Are the site data needed to address the criterion?
60.133 ADDITIONAL DESIGN CRITERIA FOR THE UNDERGROUND FACILITY (continued)		
(c) Retrieval of waste.	2.4, 4.4	Yes
The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of 60.111.		
(d) Control of water and gas.	4.4	Yes
The design of the underground facility shall provide for control of water or gas intrusion.		
(e) Underground openings.		
(1) Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained.	2.4, 4.2, 4.4	Yes
(2) Openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock.	1.11	Yes
(f) Rock excavation.	1.11	Yes
The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water or radioactive waste migration to the accessible environment.		
(g) Underground facility ventilation.		
The ventilation system shall be designed to -		
(1) Control the transport of radioactive particulates and gases within and releases from the underground facility in accordance with the performance objectives of 60.111(a).	2.7	Yes
(2) Assure continued function during normal operations and under accident conditions.	2.7, 4.2, 4.4	Yes
(3) Separate the ventilation of excavation and waste emplacement areas.	2.7,4.4	No

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Table 8.3.2.3-1. Design criteria for the geologic repository operations area (page 8 of 8)

Design criteria of 10 CFR 60.131 through 60.133	Issue that addresses the criterion[b]	Are the site data needed to address the criterion?
60.133 ADDITIONAL DESIGN CRITERIA FOR THE UNDERGROUND FACILITY (continued)		
(h) Engineered barriers.	1.11	Yes
Engineered barriers shall be designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure.		
(i) Thermal loads.	1.11	Yes
The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, ground-water system.		

[a]The SCP sections addressing the issues listed in this column are as follows: Issue 1.11, configuration of underground facilities (postclosure) (Section 8.3.2.2); Issue 2.4, waste retrievability (Section 8.3.5.2); Issue 2.7 (this section); Issue 4.2, nonradiological health and safety (Section 8.3.2.4); and Issue 4.4, preclosure design and technical feasibility (Section 8.3.2.5).

[b]NA = not applicable.

[c]The Yucca Mountain Project has a ramp instead of a hoist, which will be used to transport waste underground in transporters. Accidents involving the transport of waste underground, such as a runaway transporter, are being investigated.

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assurance will be provided that radiation safety design criteria are met while Performance Issues 2.1 through 2.3 will address compliance with regulatory limits. (Note that there are currently no regulatory dose limits for repository accidents.)

Application of the issue resolution strategy

The logic to be used in the resolution of this issue is illustrated in the logic diagram shown in Figure 8.3.2.3-2. This diagram depicts how the generic approach to issue resolution described in Section 8.1 and 8.2 is to be applied to this issue. The first step of this process, identifying regulatory requirements, has already been discussed previously under "regulatory basis for the issue." The following discussions will explain each of the remaining steps shown in the logic diagram for the resolution of this issue.

Identification of functional requirements. To allocate performance to the engineered systems of the Yucca Mountain mined geological disposal system (MGDS), the functions of the MGDS with respect to this issue must be identified. These functions of the MGDS may be taken from Table 8.3.2.3-1. These functions and what might be called subfunctions are listed below with some elaboration on each. The portion of 10 CFR 60.131 through 60.133 that the function or subfunction is intended to address is also listed in parentheses.

Function 1: Radiological protection. The first function of the repository is to maintain radiation doses, levels, and concentrations of radioactive material in restricted areas within the limits specified in 10 CFR Part 20. This function is intended to produce a design that will protect the radiological health and safety of both the repository workers and the public. Radiological protection involves many activities; therefore, it has been subdivided into 11 subfunctions. These subfunctions are labeled with letters that correspond to the designators used in the performance goal and parameters tables presented later in this section and are as follows:

A. Limit concentration of radioactive materials in air (10 CFR 60.131(a)(1)).

B. Limit time required to perform work in the vicinity of radioactive materials (10 CFR 60.131(a)(2)).

C. Provide suitable shielding where necessary (10 CFR 60.131 (a)(3)).

D. Monitor and control the dispersal of radioactive contamination (10 CFR 60.131(a)(4)).

E. Control access to high radiation areas (10 CFR 60.131(a) (5)).

F. Provide radiation alarm systems for worker protection (10 CFR 60.131(a)(6)).

G. Monitor and control radioactive materials in repository effluents (10 CFR 60.132(c)).

H. Provide radiation alarm systems for repository effluents (10 CFR 60.131(a)(6)).

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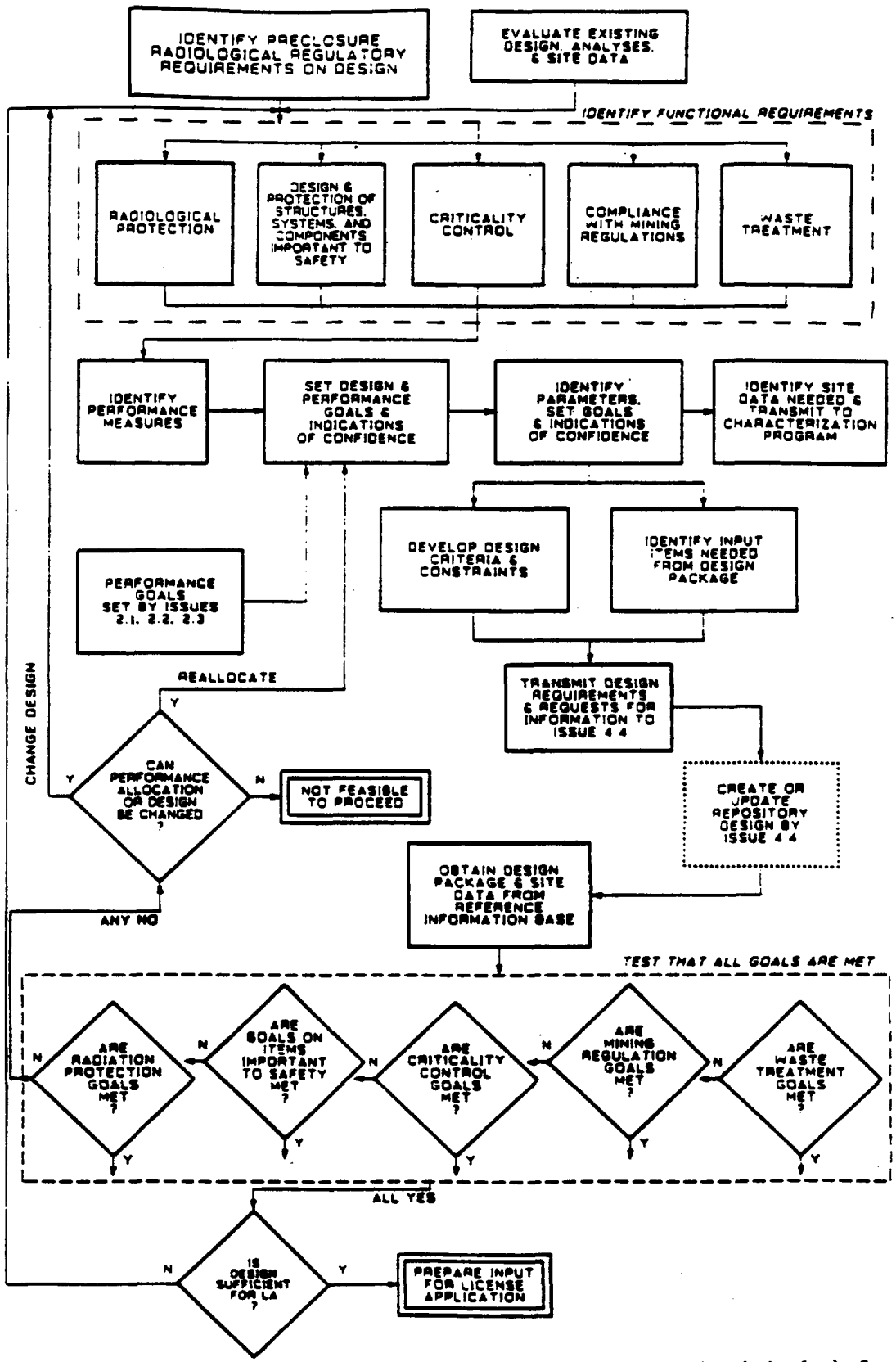

Figure 8.3.2.3-2a. Logic diagram for Issue 2.7 (repository design criteria for radiological safety). See Figure 8.3.2.3-2b for legend. Section 8.3.2.1 describes the relationships and interfaces between design and perfromance issues.

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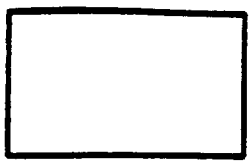
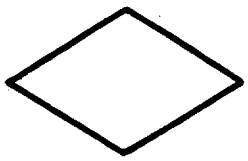
LEGEND

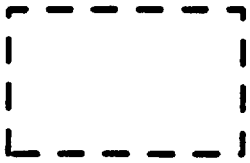


ACTIVITY PERFORMED TO RESOLVE ISSUE



TEST TO DETERMINE SUBSEQUENT ACTIVITY

ACTIVITY PERFORMED BY INDICATED ISSUE



ACTIVITY WITH MULTIPLE SIMILAR ACTIVITIES OR TESTS

DECISION ABOUT ISSUE RESOLUTION

Y - YES N - NO LA - LICENSE APPLICATION

Figure 8.3.2.3-2b. Legend for Figure 8.3.2.3-2a.

I. Provide safe handling and storage of waste whether awaiting emplacement or being retrieved (10 CFR 60.132 (a)).

J. Provide repository facility ventilation systems that will protect against radiation exposure (10 CFR 60.132 (b) and 10 CFR 60.133 (g)).

K. Assure the continued function and separation of ventilation systems during normal operations and under accidents conditions (10 CFR 60.132(b) and 10 CFR 60.133(g)).

Function 2: Design and protection of structures, systems, and components (SS&C) important to safety (ITS). This function is intended to produce a design that provides assurance that radiation safety design features will operate effectively when they are needed. This function also involves many activities and has been subdivided into eight subfunctions. These eight subfunctions are also labeled with the letter designators used later in this section and are as follows:

L. Protect structures, systems, and components important to safety against natural phenomena and environmental conditions (e.g., rockburst) (10 CFR 60.131(b)(1)).

M. Protect structures, systems, and components important to safety against dynamic effects of equipment failure and similar events (10 CFR 60.131(b)(2)).

N. Protect structures, systems, and components important to safety against fires and explosions (10 CFR 60.131(b)(3)).

O. Ensure that structures, systems, and components important to safety will maintain control of radioactive materials, permit prompt termination of operations, and allow evacuation of personnel during an emergency (10 CFR 60.131(b)(4)(i)).

P. Ensure that utilities important to safety will continue their safety functions during emergencies (10 CFR 60.131(b)(5)).

Q. Ensure that structures, systems, and components important to safety will facilitate inspection, testing, and maintenance (10 CFR 60.131(b)(6)).

R. Provide timely backup power when needed and during emergencies (10 CFR 60.131(b)(5)).

S. Provide instrumentation and control systems to monitor and control structures, systems, and components important to safety for all anticipated ranges of operation (10 CFR 60.131(b)(8)).

Function 3: Criticality control. This function will provide assurance that all systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive material are designed to ensure that a criticality accident is not credible (10 CFR 60.131(b)(7)).

Function 4: Compliance with mining regulations. This function will ensure that requirements of 30 CFR Chapter I, Subchapters D, E, and N that are applicable to protection of workers who perform a safety function will be incorporated into the design of the repository (10 CFR 60.131(b)(9)).

Function 5: Waste treatment. This function will ensure that waste treatment facilities are designed to permit safe offsite disposal of site-generated waste in accordance with applicable regulations (10 CFR 60.132(d)).

Allocation of performance. The next four steps after the identification of functional requirements include the bulk of the performance allocation process. In these steps, performance measures, performance goals, and needed parameters are developed. The results of these steps are in Tables 8.3.2.3-2 and 8.3.2.3-3.

The functions that organize these tables were derived directly from 10 CFR 60.131 through 60.133. Performance measures developed for each function provide the means to measure success in performing the required functions. Performance goals were developed such that if the goals are met, the function is satisfactorily completed. The parameters listed in Table 8.3.2.3-3 for each performance goal are those site data needed to calculate the performance measure to be compared with the performance goal.

Development of design criteria and constraints. This issue develops design objectives and criteria to be used by Issue 4.4 (preclosure design and technical feasibility) in designing the repository. These design objectives are listed as performance goals in Table 8.3.2.3-2. In general, the basis for developing numerical performance goals has been to assume one-fifth of the limits specified in DOE Order 5480.1, Chapter XI (DOE, 1980). Of all these performance goals, a few stand out as the major design objectives for radiological safety. The first of these comes out of the shielding function and establishes that radiation fields in all normally occupied areas (or areas to which workers have free access) shall be less than 0.5 mrem/h. Any areas of the repository with radiation fields that cannot be reduced to below 0.5 mrem/h shall have controlled access and other procedural controls to limit doses to workers. Another design objective is that concentrations of airborne radionuclides (including radon and short-lived radon daughters) shall be as low as reasonably achievable (ALARA) below a design objective of one-fifth the values listed in 10 CFR 20, Appendix B, Table I, Column I. (Since radon is a naturally occurring radionuclide, it is not strictly within the scope of 10 CFR Part 20 or Subpart A of 40 CFR Part 191; however, radon releases are considered within the scope of this issue.) A third important design objective is the requirement to maintain releases of radioactive materials in repository effluents below levels that would result in offsite individual 50-yr whole-body dose equivalents of 25 mrem/yr (40 CFR 191.03). This value is considered to embody the ALARA principle (Kathren et al., 1980). A final design objective is to maintain combined annual individual worker doses from all sources of radiation to less than 1 rem if consistent with NRC ALARA requirements. To be consistent with the ALARA principle, lower levels of radiation will be achieved if it is reasonable to do so. It should be noted that based on International Committee on Radiation Protection, Publications 26 and 30 (ICRP, 1977; 1978), current regulations are undergoing changes that may require changes in these design criteria.

Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 1 of 13)

Subfunction	Process or activity	Performance measure	Tentative goal	Needed confidence	Site data?
			RADIOLOGICAL PROTECTION (FUNCTION 1)		
A Limit concentrations of radioactive materials in air	Monitor concentrations of radioactive materials in repository airstreams	Concentrations of radioactive materials in repository airstreams	A1 Concentrations of radioactive materials in normally occupied areas do not exceed 20% of the values listed in in 10 CFR 20, Appendix B, Table 1, Column 1	(a)	No
			A2 Concentrations of non-naturally occurring radioactive materials in controlled access areas do not exceed the values listed in 10 CFR 20, Appendix B, Table 1, Column 1	High	Yes
			A3 Concentrations of naturally occurring radon and short-lived radon daughters such that annual exposure is less than 4 Working Level Months as defined in 30 CFR 57.2	High	Yes
	Filter exhaust air from potentially contaminated areas	Concentrations of radioactive materials in repository airstreams	See A1, A2, and A3 above	High	Yes
	Maintain gaseous radionuclides in repository airstreams below acceptable levels	Concentrations of radioactive materials in repository airstreams	See A1, A2, and A3 above	High	Yes

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 2 of 13)

Subfunction	Process or activity	Performance measure	Tentative goal	Needed confidence	Site data?
		RADIOLOGICAL PROTECTION (FUNCTION 1) (continued)			
B Limit time required to perform work in the vicinity of radioactive materials	Limit time of occupancy for tasks in radiation fields greater than 0.5 mrem/h	Time required to perform tasks in radiation fields greater than 0.5 mrem/h	B1 Time limited such that the as low as reasonably achievable (ALARA) principle is met	(a)	No
			B2 Combined annual individual worker dose less than 1 rem by as much as reasonable	(a)	No
	Provide remote handling capability for long-term task in radiation fields greater than 0.5 mrem/h	Dose reduction due to use of remote handling equipment	B3 Dose reduction enough to justify use of remote handling equipment	(a)	No
C Provide suitable shielding materials	Provide shielding to reduce radiation fields to below 0.5 mrem/h in normally occupied work areas	Radiation fields in normally occupied work areas	C1 Radiation fields less than 0.5 mrem/h by as much as is reasonable	(a)	No
	Utilize shielding properties of the host rock in limiting exposure of workers to direct radiation	Dose reduction factor attributable to host rock shielding properties	C2 Dose reduction factor properties similar to concrete	Medium	Yes
D Monitor and control the dispersal of radioactive contamination	Monitor contamination by using				
	- Stationary radiation monitoring systems	Contamination levels outside contamination areas	D1 Doses due to contamination insignificant	(a)	No

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 3 of 13)

Subfunction	Process or activity	Performance measure	Tentative goal	Needed confidence	Site data?
		RADIOLOGICAL PROTECTION (FUNCTION 1) (continued)			
D Monitor and control the dispersal of radioactive contamination (continued)	- Portable radiation monitors	Contamination levels outside contamination areas	D2 Doses due to contamination insignificant	High	Yes
	- Personnel dosimetry	Contamination on personnel	D3 Doses due to contamination insignificant	(a)	No
	Control dispersal of contamination by				
	- Providing access control to potential contamination areas	See subfunction E, performance measures	D4 See subfunction E, goals	(a)	No
	- Providing ventilation control and cleanup of airstreams	See subfunction J, performance measures	D5 See subfunction J, goals	High	Yes
	- Decontamination of contaminated items and equipment	Residual contamination	D6 Use Regulatory Guide 1.86 (NRC, 1974), methods and meet goals	(a)	No
	- Collection of site-generated waste	Residual contamination due to site-generated waste	D7 No residual contamination	(a)	No

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 4 of 13)

Subfunction	Process or activity	Performance measure		Tentative goal	Needed confidence	Site data?
RADIOLOGICAL PROTECTION (FUNCTION 1) (continued)						
E Control access to high radiation areas	Provide signs and personnel barriers to prevent access by unauthorized personnel	Visibility of signs	E1	Compliance with 10 CFR 20.203	(a)	No
			E2	Adequate visibility	Medium	No
		Distribution and location of signs	E3	Compliance with 10 CFR 20.203	(a)	No
			E4	Adequate distribution	(a)	No
		Effectiveness of personnel barriers	E5	Adequate barrier effectiveness	(a)	No
	If necessary, provide guards to prevent access by unauthorized personnel	Effectiveness of guard	E6	No unauthorized access	(a)	No
	Provide procedural requirements to control access to high radiation areas	Effectiveness of procedures	E7	Adequate procedures to control access	(a)	No
F Provide radiation alarm systems for worker protection	Provide visual alarm systems to alert workers if radiation levels exceed established design levels	Visibility of alarm system	F1	Adequate visibility	(a)	No
		Accuracy and reliability of alarm system	F2	Adequate accuracy and reliability of alarm system	(a)	No

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 5 of 13)

Subfunction	Process or activity	Performance measure	Tentative goal	Needed confidence	Site data?
RADIOLOGICAL PROTECTION (FUNCTION 1) (continued)					
F Provide radiation alarm systems for worker protection (continued)	Provide audible alarm systems to alert workers if radiation levels exceed established design levels	Loudness and noticeability of alarm system	F3 Consistency with Regulatory Guide 8.5 (NRC, 1981b)	(a)	No
		Accuracy and reliability of alarm system	F4 Adequate accuracy and reliability of alarm system	(a)	No
G Monitor and control radioactive materials in repository effluents	Detect radioactive materials in repository effluents streams	Ability to detect radioactive materials in repository effluent streams	G1 Adequate detection of significant radionuclides in repository effluents	(a).	No
			G2 Detection precision consistent with industry standard and adequate to demonstrate compliance with goals	(a)	No
	Control radioactive materials in repository effluent streams	Ability to control radioactive materials in repository effluent streams	G3 Adequate control of significant radionuclides in repository effluents	(a)	No
			G4 Maintain releases of radioactive materials at or below levels that would result in offsite individual 50-yr dose equivalents of 25 mrem/yr (see page 8.10 of ALARA guide; Kathren et al., 1980)	High	Yes
H Provide radiation alarm systems for repository effluents	Provide visual alarm systems to alert workers if radiation levels in effluents exceed established design levels	See subfunction F, performance measures	H1 See subfunction F, goals	(a)	No

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 6 of 13)

Subfunction	Process or activity	Performance measure	Tentative goal	Needed confidence	Site data?
RADIOLOGICAL PROTECTION (FUNCTION 1) (continued)					
H Provide radiation alarm systems for repository effluents (continued)	Provide audible alarm systems to alert workers if radiation levels in effluents exceed established design levels	See subfunction F, performance measures	H2 See subfunction F, goals	(a)	No
I Provide safe handling and temporary storage of waste whether awaiting emplacement or being retrieved	See subfunction B, limit work time in vicinity of radioactive materials	See subfunction B, performance measures	I1 See subfunction B, goals	(a)	No
	See subfunction C, provide suitable shielding	See subfunction C, performance measures	I2 See subfunction C, goals	High	Yes
	Maintain combined individual worker doses from all sources of radiation below annual design objective	Combined annual individual worker doses from all sources of radiation	I3 Combined annual individual worker doses from all sources of radiation less than 1 rem and ALARA	(a)	No
J Provide repository facility ventilation systems that will protect against radiation exposure	Maintain airflow in direction from areas of lower contamination potential to areas of higher contamination potential	Pressure differentials between radiation zones	J1 Between 0.1 and 0.5 in. WG	High	Yes
		Potential for accidental flow reversals	J2 Accidental flow reversal precluded	(a)	No
		Flow rate in highly contaminated areas	J3 Adequate room changes per hour in areas of highest contamination per hour (e.g., isolation zones and hot cells)	(a)	No

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 7 of 13)

Subfunction	Process or activity	Performance measure		Tentative goal	Needed confidence	Site data?
		RADIOLOGICAL PROTECTION (FUNCTION 1) (continued)				
J Provide repository facility ventilation systems that will protect against radiation exposure (continued)	Separate ventilation systems of surface waste-handling areas from other surface areas	Leakage between systems	J4	Very low leakage	(a)	No
		Pressure differential between separate systems	J5	Between 0.1 and 0.5 in. WG	(a)	No
	Separate ventilation systems of underground waste-handling and emplacement areas from mining development areas	Leakage between systems	J6	Very low leakage	(a)	No
		Pressure differential between separate systems	J7	Between 0.1 and 0.5 in. WG	(a)	No
	Provide close-capture ventilation exhaust systems when necessary	System capture efficiency	J8	Adequate capture efficiency	(a)	No
	Filter airstream and exhausts when necessary	Decontamination factor	J9	Adequate decontamination factor	High	Yes
		Number of filter banks	J10	Single stage available for normally clean areas	High	Yes
			J11	Two stage in service for expected contamination areas	(a)	No
	Flow pattern of ventilation should direct potential contamination away from personnel	Flow patterns of ventilation systems	J12	Potential contamination always directed away from personnel and to filterable exhausts	(a)	No

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 8 of 13)

Subfunction	Process or activity	Performance measure	Tentative goal	Needed confidence	Site data?
DESIGN AND PROTECTION OF STRUCTURES, SYSTEMS, AND COMPONENTS IMPORTANT TO SAFETY (FUNCTION 2)					
K Protect structures, systems, and components important to safety against natural phenomena and environmental conditions	House structures, systems, and components important to safety in buildings designed to withstand credible natural phenomena and environmental conditions	Effects of credible natural phenomena and natural conditions on structures, systems, and components important to safety	K1 Structures, systems, and components function as designed to meet radiological dose limits	High	Yes
L Protect structures, systems, and components important to safety against dynamic effects of equipment failure and similar events	House structures, systems, and components important to safety in structures designed to withstand dynamic effects of equipment failures and similar events	Response of structures, systems, and components important to safety to dynamic effects of equipment failure and similar events	L1 Structures, systems, and components function as designed to meet radiological dose limits	(a)	No
M Protect structures, systems, and components important to safety against fires and explosions	House structures, systems, and components important to safety in structures with fire and explosion detection/suppression equipment	Effects of fires, explosions, and suppression systems on structures, systems, and components important to safety	M1 Structures, systems, and components function as designed to meet radiological dose limits	(a)	No

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 9 of 13)

Subfunction	Process or activity	Performance measure	Tentative goal	Needed confidence	Site data?
DESIGN AND PROTECTION OF STRUCTURES, SYSTEMS, AND COMPONENTS IMPORTANT TO SAFETY (FUNCTION 2) (continued)					
N Ensure that structures, systems, and components important to safety will maintain control of radioactive materials, permit prompt termination of operations, and allow evacuation of personnel during emergencies	Design structures, systems, and components important to safety to maintain control of radioactive material during emergencies	Maintenance of control of radioactive material during design-basis accidents	N1 Control of radioactive material maintained such that dose limits are met	(a)	No
	Design structures, systems, and components important to safety to permit prompt shutdown of nonsafety related operations during an emergency	Time to shutdown nonsafety related operations during design-basis accidents	N2 Prompt shutdown of nonsafety related operations during design-basis accidents	(a)	No
	Design structures, systems, and components important to safety so that they facilitate the evacuation of the repository during emergencies	Effects of structures, systems, and components important to safety on evacuation during an emergency	N3 Minimal effect of structures, systems, and components important to safety on evacuation of personnel	(a)	No
O Ensure that utilities important to safety will continue their safety function during emergencies	Design utilities important to safety to continue their safety functions during conditions anticipated during an emergency	Ability of utilities important to safety to continue to perform safety functions during design-basis accidents	O1 Utilities important to safety continue to perform safety functions during design-basis accidents	High	Yes

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 10 of 13)

Subfunction	Process or activity	Performance measure		Tentative goal	Needed confidence	Site data?
DESIGN AND PROTECTION OF STRUCTURES, SYSTEMS, AND COMPONENTS IMPORTANT TO SAFETY (FUNCTION 2) (continued)						
P Ensure that structures, systems, and components important to safety will facilitate inspection, testing, and maintenance	Design structures, systems, and components important to safety to facilitate inspection, testing, and maintenance	Complexity of inspection operations for structures, systems, and components important to safety	P1	Inspection of structures, systems, and components important to safety relatively simple	(a)	No
		Complexity of testing operations for structures, systems, and components important to safety	P2	Testing of structures, systems, and components important to safety relatively simple	(a)	No
		Complexity of maintenance operations for structures, systems, and components important to safety	P3	Maintenance of structures, systems, and components important to safety relatively simple	(a)	No
Q Provide timely backup power to structures, systems, and components important to safety when needed and during emergencies	Design power systems with backup power capability (diesel generators or other suitable means)	Capacity of backup power supply	Q1	Sufficient capacity to operate all structures, systems, and components important to safety	(a)	No
		Time for backup power supply to become operable	Q2	Response time adequate to serve structures, systems, and components important to safety	(a)	No
R Provide instrumentation and control systems to monitor and control structures, systems, and components important to safety for all anticipated ranges of operation	Design structures, systems, and components with instrumentation and control systems	Range of operation of monitoring instrumentation	R1	Monitors operable for anticipated ranges of system operation, including design-basis accident conditions	High	Yes
		Range of operation of control instrumentation	R2	Control systems operable for anticipated ranges of system operation, including design-basis accidents	High	Yes

Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 11 of 13)

Subfunction	Process or activity	Performance measure		Tentative goal	Needed confidence	Site data?
DESIGN AND PROTECTION OF STRUCTURES, SYSTEMS, AND COMPONENTS IMPORTANT TO SAFETY (FUNCTION 2) (continued)						
R Provide instrumentation and control systems to monitor and control structures, systems, and components important to safety for all anticipated ranges of operation (continued)		Ability to control structures, systems, and components important to safety	R3	Adequate control of essential functions of structures, systems, and components important to safety	High	Yes
CRITICALITY CONTROL (FUNCTION 3)						
S Criticality control	Maintain control of geometry of waste configurations in all phases of waste handling and disposal	Geometry of waste storage arrays	S1	Geometries unfavorable to nuclear criticality	(a)	No
		Geometry of waste package configurations	S2	Geometries unfavorable to nuclear criticality	(a)	No
		Geometry of emplaced waste	S3	Geometries unfavorable to nuclear criticality	(a)	No
		Possibility of accidental disruption of waste geometry leading to unfavorable configurations	S4	Very low probability	High	Yes
	Maintain subcritical assemblies and masses of fissile material in all phases of waste handling and disposal	Mass and fissile content of waste storage arrays	S5	Masses and fissile contents subcritical (see goal S13)	(a)	No
		Mass and fissile content of waste package configurations	S6	Masses and fissile contents subcritical (see goal S13)	(a)	No
		Mass and fissile content of emplaced waste	S7	Masses and fissile contents subcritical (see goal S13)	(a)	No

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Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 12 of 13)

Subfunction	Process or activity	Performance measure		Tentative goal	Needed confidence	Site data?
		CRITICALITY CONTROL (FUNCTION 3) (continued)				
S Criticality control (continued)		Possibility of accidental disruption of waste leading to unfavorable concentrations of fissile materials	S8	Very low probability	High	Yes
	Control the introduction of any neutron moderating materials to waste containing areas	Moderating materials in or around waste storage arrays	S9	No significant moderating materials	(a)	No
		Moderating materials in or around waste package configurations	S10	No significant moderating materials	(a)	No
		Moderating materials in or around emplaced waste	S11	No significant moderating materials	High	Yes
		Possibility of accidental introduction of moderating materials into areas containing waste	S12	Very low probability	High	Yes
	Neutron multiplication	K_{eff} of fissile materials	S13	K_{eff} <0.95 as specified in 10 CFR 60.131(b)(7)	High	Yes
		COMPLIANCE WITH MINING REGULATIONS (FUNCTION 4)				
T Comply with mining regulations	Protection of workers who perform assigned safety function	Ability of workers to perform assigned safety functions	T1	Workers perform their assigned safety functions	(a)	No

Table 8.3.2.3-2. Functions, performance measures, and performance goals for Issue 2.7 (repository design criteria for radiological safety) (page 13 of 13)

Subfunction	Process or activity	Performance measure		Tentative goal	Needed confidence	Site data?
		WASTE TREATMENT (FUNCTION 5)				
U Treat waste	Collect secondary site-generated radioactive waste from waste handling areas	Fraction of site-generated waste collected	U1	Site-generated waste collected	(a)	No
	Treat and stabilize or recycle secondary site-generated waste collected	Fraction of site-generated waste treated and stabilized or recycled	U2	Site-generated waste treated and stabilized or recycled	(a)	No
	Package treated and stabilized secondary site-generated waste for disposal offsite	Fraction of treated and stabilized site-generated waste packaged	U3	Treated and stabilized site-generated waste packaged	(a)	No

[a]Needed confidence for nonsite related data will be provided in the plans for repository design.

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Table 8.3.2.3-3. Parameters required for Issue 2.7 (repository design criteria for radiological safety) (page 1 of 6)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
A1, D2, G2, J1, J9, J10	Dust and particle size distributions	Underground and at site	1 to 10 micron, normal	High	Data not available	Data not available	(c)
A3	Radon emanation rate from tuff	TSw2 unit[b]	(d)	High	0.48 pCi per square meter per second	Low	8.3.1.15, (c)
C2, I2, S13	Bulk density of host rock	TSw2 unit	(d)	High	2.26 to 2.32 g/cc	Medium	8.3.1.15
C2, I2, S11, S13	Elemental composition of host rock	TSw2 unit	Normal composition for tuffs	High	Normal composition for tuffs	Medium	8.3.1.3
C2, I2, S11, S13	Water content of host rock as a function of temperature and time	TSw2 unit	(d)	High	65% saturation	Medium	8.3.1.2
G4	Wind speeds	80 km radius	(d)	High	See Figures 5-3 to 5-7, and Tables 5-6 and 5-7	Medium	8.3.1.12
G4	Wind direction	80 km radius	(d)	High	See Figures 5-3 to 5-7, and Tables 5-6 and 5-7	Medium	8.3.1.12
G4	Atmospheric stability	80 km radius	(d)	Medium	See Table 5-11	Medium	8.3.1.12
G4	Mixing layer depth	80 km radius	(d)	Medium	(e)	Medium	8.3.1.12

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Table 8.3.2.3-3. Parameters required for Issue 2.7 (repository design criteria for radiological safety) (page 2 of 6)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
G4	Average ambient temperature	80 km radius	(d)	Medium	See Tables 5-2 and 5-3	Medium	8.3.1.12
G4	Atmospheric moisture	80 km radius	(d)	Medium	See Tables 5-2 and 5-5	Medium	8.3.1.12
G4	Precipitation: type, amount, intensity, etc.	80 km radius	(d)	Medium	See Tables 5-2 and 5-4	Medium	8.3.1.12
G4	Barometric pressure	80 km radius	(d)	Medium	See Table 5-2	Medium	8.3.1.12
G4	Size and distance of topographic features from release points	80 km radius	Topographic features beneficial to dispersion	Medium	See U.S. Geological Survey topographic maps	High	Literature
G4	Bioaccumulation of radionuclides in terrestrial flora	80 km radius	(d)	Medium	1×10^{-28} to 1×10^{-14} Ci/kg[f]	Medium	(c)
G4	Bioaccumulation of radionuclides in terrestrial fauna	80 km radius	(d)	Medium	1×10^{-25} to 1×10^{-15} Ci/kg[g]	Medium	(c)
G4	Types of crops raised	80 km radius	(d)	Medium	(h)	Medium	(c)
G4	Amounts of crops raised	80 km radius	(d)	Medium	1×10^{4} to 1×10^{7} kg/yr[i]	Medium	(c)
G4	Types of crops consumed	80 km radius	(d)	Medium	(j)	Medium	(c)

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Table 8.3.2.3-3. Parameters required for Issue 2.7 (repository design criteria for radiological safety) (page 3 of 6)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
G4	Amounts of crops consumed	80 km radius	(d)	Medium	1×10^4 to 1×10^5 kg/yr	Medium	(c)
G4	Types of animals raised	80 km radius	(d)	Medium	(k)	Medium	(c)
G4	Amounts of animals raised	80 km radius	(d)	Medium	1×10^1 to 1×10^5 kg/yr	Medium	(c)
G4	Types of animals consumed	80 km radius	(d)	Medium	(l)	Medium	(c)
G4	Amounts of animals consumed	80 km radius	(d)	Medium	1×10^4 to 1×10^6 kg/yr	Medium	(c)
G4	Animal consumption of forage	80 km radius	(d)	Medium	1×10^1 to 1×10^4 kg/yr	Medium	(c)
G4	Forage storage time	80 km radius	Goal is values given in Reg. guide 1.109 (NRC, 1977a)	Medium	Data not available	Data not available	(c)
G4	Grazing yield and period	80 km radius	(d)	Medium	75 to 100% of the year	High	(c)
G4	Radius of crop and animal area	80 km radius	(d)	Medium	50 km to bulk of cropland and farms (W to SW)	High	(c)

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Table 8.3.2.3-3. Parameters required for Issue 2.7 (repository design criteria for radiological safety) (page 4 of 6)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
G4	Volumetric flow of surface water to water bodies	80 km radius	Little or no surface run-off	Medium	Environmental assessment, Section 3.3.1 (DOE, 1986b)	Medium	(c)
G4	Recreational uses of water bodies	80 km radius	Very little recreational use of water	Low	(m)	(m)	(c)
J1	Repository design ventilation pressure drop conditions	Underground	See Section 8.3.2.5	High	See Section 8.3.2.5	See Section 8.3.2.5	8.3.2.5
D5, J9, J10, K1, O1, R1, R2, R3, S4, S8, S12	Frequency and magnitudes of						
	- Tornadoes	At facility	(d)	High	See Section 5.1.1.6[a]	Medium	8.3.1.12
	- Cloud-to-ground lightning strikes	At facility	(d)	Medium	About 18 per year, magnitude unknown	Medium	8.3.1.12
	- Sandstorms/windstorms	At facility	(d)	High	See Table 5-8, and Section 5.1.1.6	Medium	8.3.1.12
	- Snowfall/ice storms	At facility	Rare, low magnitude	High	Rare, low magnitude	Medium	8.3.1.12
	- Repository surface flooding	At facility	PMF[o]	High	PMF[o]	Medium	8.3.1.16

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Table 8.3.2.3-3. Parameters required for Issue 2.7 (repository design criteria for radiological safety) (page 5 of 6)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
	- Surface and subsurface seismic events	In region	(d)	High	(p)	(p)	8.3.1.17
	- Fault movement within the repository	Surface and subsurface	(d)	High	See Section 1.5.2	Medium	8.3.1.17
D5, J9, J10, K1, O1, R1, R2, R3, S4, S8, S12	- Drift roof fall/ collapse/ failure	Underground	(q)	Medium	Data not available	Data not available	8.3.2.4
	- Landslides	At facility	(q)	Medium	Data not available	Data not available	8.3.1.14
	- Volcanic ash fall	At facility	(q)	Medium	Data not available	Data not available	8.3.1.17
	- Nearby brush fires	Near facilities	(q)	Low	Data not available	Data not available	8.3.1.13
	- Aircraft crashes	At facility	(q)	High	1×10^{-5} to 1×10^{-7} per year	Medium	8.3.1.13
	- Criticality events	In surface and subsurface facilities	Criticality events precluded	High	Not credible	High[c]	8.3.5.5
	- Other potential accidents	Natural or site-related	(s)	High	(s)	(s)	PRAM Program[c]

[a]The letters in this column key the performance parameters to the tentative goals in Table 8.3.2.3-2.
[b]TSw2 unit is the nonlithophysal Topopah Spring unit (repository horizon).

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Table 8.3.2.3-3. Parameters required for Issue 2.7 (repository design criteria for radiological safety) (page 6 of 6)

Footnotes (continued)

[c]Collection of these data are part of the environmental program planned activities and is addressed in the Radiological Monitoring Plan discussed in Section 8.3.1.13 (offsite installations).
[d]Tentative goal is to have further measurements of this parameter verify the range of expected values listed here.
[e]See Quiring (1968).
[f]This range covers all flora for which data is now available, specific values are flora and radionuclide specific.
[g]This range covers all fauna for which data is now available, specific values are fauna and radionuclide specific.
[h]Crops include wheat/grains, corn, apples, potatoes, alfalfa, alfalfa seed, hay, silage, peppers, melons, berries, pecans, leafy vegetables, and honey.
[i]Specific values depend on available crops, crop areas, and crop densities.
[j]Includes all crops listed in footnote h except alfalfa, hay, and silage.
[k]Includes beef cattle, dairy cattle, goats, hogs, sheep, and poultry.
[l]Includes quail, freshwater fish, duck, geese, rabbit, and deer, plus those listed in footnote k.
[m]Very limited use of Crystal Reservoir; swimming pool data not yet available.
[n]Probability at Yucca Mountain is approximately 7.5×10^{-4} in any given year; magnitude is F-0 on Fujita tornado scale (very weak).
[o]PMF = probable maximum flood; the PMF is still under investigation.
[p]Information on seismic events may be found in Section 8.3.1.17.
[q]Parameter goal to be evaluated in terms of frequency and consequence.
[r]Design will preclude criticality accidents per 10 CFR 60.131(b)(7).
[s]Other accident-specific goals to be evaluated as appropriate under preclosure risk assessment methodology (PRAM).
[t]PRAM = preclosure risk assessment methodology.

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Specific design products from Issue 4.4 required as input items for this issue are also transmitted from this issue; however, at this time no specific design products or input items other than the repository reference design, operating plan, and supporting analyses have been identified. After design criteria and requests for specific products have been transmitted to Issue 4.4, the repository design is created or updated and placed in the reference information base. The repository reference design, operating plan, and supporting analyses are then available to Issue 2.7 and the performance issues for evaluation.

Test that all goals are met. Once the repository reference design, operating plan, and supporting analyses are ready for evaluation, an assessment will begin of the design against its design objectives. This issue will use the most current site data to perform its assessment of the design; therefore, if site data in the reference information base has been updated since the repository design for the current phase was completed, it is possible that the design of the repository may need to be updated on the basis of the assessment under Issue 2.7. Issues 2.1, 2.2, and 2.3 will perform performance assessments of the repository design against applicable performance criteria after the design evaluation.

The design evaluation consists of a comparison of the design with the design criteria and objectives. If any objectives are not satisfied, both the design and the unsatisfied objectives will be examined to develop the appropriate solution. The solution may involve (1) changing the design of the repository or (2) changing a radiation safety design objective that has been shown to be unreasonable or unattainable. Necessary and reasonable objectives will not be altered. If the design cannot be corrected to meet necessary and reasonable objectives, then an unfavorable resolution of this issue has occurred. If the design can be corrected, then the corrected design is reassessed against the design objectives.

Part of the design assessment is an evaluation of whether the ALARA principle has been satisfied. This will require cost-benefit analyses and tradeoff studies. Most of these studies will have been performed before taking the design into the advanced conceptual design phase; however, it may prove necessary to perform more of these analyses if new alternatives are developed after the design is substantially complete.

Upon satisfactory completion of the design assessment by this issue (i.e., all design objectives have been met and the ALARA principle has been adequately addressed), the final question to be asked is: Is the design sufficient for license application? If the answer to this question is no, then another iteration of the design process is performed and the design is improved and more details are developed. If the answer to the question is yes, then a favorable resolution of Issue 2.7 has been achieved.

Interrelationships of information needs

The question asked by this issue addresses the design criteria listed in 10 CFR 60.131 through 60.133. These design criteria cover a wide range of topics; however, this issue is only concerned with those design criteria that have radiological protection as their basis. In the preceding discussion,

those design criteria that have radiological protection as their basis were grouped into five functions. Those five functions form the basis for the following information needs:

Information need	Subject
2.7.1	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to radiological protection have been met.
2.7.2	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to the design and protection of structures, systems, and components important to safety have been met.
2.7.3	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met.
2.7.4	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to compliance with mining regulations have been met. (This issue does not require site data and so is not discussed in the SCP).
2.7.5	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to waste treatment have been met. (This issue does not require site data and so is not discussed in the SCP).

Information Need 2.7.1 calls for a determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to radiological protection have been met. This might be misleading because all the criteria (performance goals) under this issue pertain to radiological protection in one way or another. In this instance, those criteria pertaining to radiological protection are those that arise in the performance allocation for this issue under the function "radiological protection." These are shown in Table 8.3.2.3-2. This information need will evaluate the reference repository design, operating plan, and supporting analyses to assess compliance with these design criteria and objectives.

Information Need 2.7.2 calls for a determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to the design and protection of structures, systems, and components important to safety have been met. The additional design objectives (performance goals) for this information need are in Table 8.3.2.3-2 under the function "design and protection of structures, systems, and components important to safety." The evaluation will involve the analysis of design-basis accidents and other less severe accidents that might

affect structures, systems, and components important to safety. Many of these analyses will have been performed as part of the design process; these will be available for use in the Issue 2.7 evaluation.

Information Need 2.7.3 calls for a determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met. The additional design objectives (performance goals) for this information need are in Table 8.3.2.3-2 under the function "criticality control." Evaluation of these design criteria and design objectives will entail the assessment of operating plans as well as repository equipment. When suggesting corrections to any problems that may be discovered, major emphasis will be placed on using simple design features rather than operating procedures to control criticality.

Information Need 2.7.4 calls for a determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to the required compliance with mining regulations have been met. The additional design objectives (performance goals) for this information need are in Table 8.3.2.3-2 under the function "compliance with mining regulations." Compliance with the mining regulations is required for those design criteria in 30 CFR Chapter I, Subchapters D, E, and N relevant to the design of structures, systems, and components important to safety. This information need will evaluate the reference repository design, operating plan, and supporting analyses to assess compliance with those design criteria in 30 CFR that are relevant to this issue.

Information Need 2.7.5 calls for a determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to the waste treatment have been met. The additional design objectives for this information need are in Table 8.3.2.3-2 under the function "waste treatment." The only regulatory design objective for waste treatment in 10 CFR Part 60 is for site-generated waste to be treated and packaged in a form suitable for onsite or offsite disposal. The current design basis is for offsite disposal. All additional design objectives (performance goals) are based on this choice. This information need will evaluate the reference repository design, operating plan, and supporting analyses to assess compliance with those design criteria and objectives.

These evaluations performed under Information Needs 2.7.1 through 2.7.5 will be performed in conjunction with each other. No single information need performs the final resolution of this issue. The final product of all the above information needs is a report that addresses each of the design criteria and design objectives and discusses the compliance or noncompliance of the repository design. This report will constitute the resolution of Issue 2.7 in the final design stages.

To answer the information needs, both design and site information is needed; however, only three of the information needs require site data: Information Needs 2.7.1, 2.7.2, and 2.7.3. Information Need 2.7.1 requires site data to evaluate the design against design criteria and performance goals dealing with concentrations of radon and daughter products, use of host rock properties in providing shielding, and releases of radioactive materials to the environment. Information Need 2.7.2 requires site data to evaluate the design of structures, systems, and components important to safety with

respect to protection from site-related accidents. Finally, to evaluate criticality control, Information Need 2.7.3 requires the same site data as Information Need 2.7.2. In the following sections discussing the information needs (i.e., Information Needs 2.7.1 in Section 8.3.2.3.1, and 2.7.2 and 2.7.3 in Section 8.3.2.3.2), only those information needs that require site data are addressed, and only those aspects of the information needs concerning site data are discussed.

8.3.2.3.1 Information Need 2.7.1: Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to radiological protection have been met

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Chapter 3 contains discussions about the present state of the knowledge on the site hydrology, including uses of surface water and ground water. Section 4.1.2.6 (background radioactivity of repository ground water) discusses what is known about the radionuclide content of repository ground water to date. Chapter 5 contains discussions about the present state of knowledge on the meteorology of the site and surrounding region. Background radiation levels are discussed in Section 3.4.7 of the environmental assessment (DOE, 1986b). Further discussions on the subject of radiological protection of the public and the workers may be found in Sections 6.1.1.4.1 (radiological protection design requirements), 6.4.4 (Issue 2.1: public radiological exposures--normal conditions), 6.4.5 (Issue 2.2: worker radiological safety--normal conditions), 6.4.6 (Issue 2.3: accidental radiological releases), and 6.4.7 (Issue 2.7: repository design radiological criteria for safety. Section 8.3.5.1 contains discussions of the preclosure risk assessment methodology (PRAM) program. The PRAM program includes radiological risk to the workers during normal operations as part of its scope. Sections 2.5 (radiological protection), 6.1 (radioactive releases during normal operations), and 6.2 (releases under abnormal conditions) of the Site Characterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987) also contain discussions relevant to this issue.

Parameters

As can be seen in Table 8.3.2.3-2, this information need requires mostly design information; therefore, the discussions here related to site data will be brief. The site parameters required by this information need are those needed to (1) determine concentrations of naturally occurring radon and short-lived daughters in the repository airstreams, (2) make use of the shielding properties of the host rock, and (3) quantify the transport of radioactive materials to the workers and to the public. The site data required by this information need along with the SCP section providing the information are listed in the following table.

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Data requirement	SCP section
REPOSITORY ROCK AND GROUND-WATER DATA	
Radon emanation rate from the tuff	8.3.1.15.1
Elemental composition of the host rock	8.3.1.3.2
Bulk density of the host rock	8.3.1.15.1
Water content and saturation of the host rock as a function of temperature and time	8.3.1.2.3
METEOROLOGICAL DATA	
Wind speeds in the region	8.3.1.12.2
Prevalent wind directions	8.3.1.12.2
Atmospheric stability of the area	8.3.1.12.2
Atmospheric mixing layer depth of the area	8.3.1.12.2
Average ambient temperature of the area	8.3.1.12.2
Atmospheric moisture of the area	8.3.1.12.2
Area precipitation, including type, amount, intensity, etc.	8.3.1.12.2
Dust and particle size distributions underground and on the site	(a)
Size and distance of major topographic features from release points	8.3.1.14.1
AGRICULTURAL AND CULTURAL DATA	
Bioaccumulation of radionuclides in the terrestrial flora	(a)
Bioaccumulation of radionuclides in the terrestrial fauna	(a)
Types and amounts of crops raised	(a)
Types and amounts of crops consumed	(a)
Types and amounts of animals raised	(a)

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Data requirement	SCP section
Types and amounts of animals consumed	(a)
Animal consumption of forage	(a)
Forage storage time	(a)
Grazing yield and period	(a)
Radius of the crop and animal area	(a)
Volumetric flow of surface water to water bodies	(a)
Recreational uses of area water bodies	(a)

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

Logic

Among the design objectives developed for this issue is a performance goal limiting the concentration of naturally occurring radon, a performance goal for the shielding properties of the host rock, and a performance goal limiting releases of radioactive materials based on eventual exposure of the workers and public. Site data that characterizes the radon source term is needed both for the creation of the design and for the evaluation of the effectiveness of the design in limiting the radon concentration. This data is listed in the previous table. To evaluate the shielding properties of the host rock, site data is needed that will allow the computation of neutron and gamma cross sections. Data of this type are composition, density, and saturation data and are also listed in the previous table. These data should reflect the rock properties before, during, and after emplacement. To evaluate the effectiveness of the repository in limiting releases of radioactive materials to acceptable levels, data are needed that will characterize the transport of any released radionuclides in the environment. These data include information on the short- and long-term pathways. In this instance, the short-term pathways are dominated by atmospheric transport. The meteorological data needed to characterize the atmospheric transport of radionuclides are listed in the table above. Long-term pathways include ingestion of radionuclides deposited on plants, contained in drinking and recreation waters, and deposited in animals that are consumed. Again, the data needed to assess these pathways are listed above.

The only activities under this issue are evaluations of the design at each design phase. This is actually supporting design by providing feedback to the designers to be used in the next phase of design or in modifying the

current design. Section 8.3.2.5 (preclosure design and technical feasibility) contains a complete listing of design activities, including those to be performed in support of radiological safety.

8.3.2.3.1.1 Design Activity 2.7.1.1: Design evaluation for compliance with radiological safety design criteria and performance goals

Objectives

The objective of this activity is to evaluate the repository design against the radiological safety design criteria and performance goals at each phase of the design and provide feedback to the designers on needed corrections or modifications.

Parameters

The site parameters needed to perform this activity are all those listed in the technical basis section for this information need.

Description

This activity will consist of a complete radiological safety design analysis and performance goal assessment of the reference repository design, operating plan, and supporting analyses at each phase of design. Much of the analysis for this evaluation will be performed as part of the design process and will be supplied for review as part of the supporting analyses. Other analyses required for this evaluation will be performed in parallel with performance assessment analyses required by Issues 2.1, 2.2, and 2.3 (Sections 8.3.5.3 through 8.3.5.5). These issues will supply their results to Issue 2.7 for a determination that design criteria and performance goals have been met.

8.3.2.3.2 Information Needs 2.7.2 and 2.7.3: (1) Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to the design and protection of structures, systems, and components important to safety have been met, and (2) Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met

Technical basis for addressing the information need

Link to the technical data chapters and other support documents

The only site data that these two information needs require are data that characterize site-related accidents. This information is needed to assess the performance of structures, systems, and components important to safety. Most of this information is related to meteorology or seismic concerns. Chapter 5 contains discussions about the present state of the know-

ledge on the meteorology of the site and surrounding region. Discussions of the site seismology are contained in Section 8.3.1.17. Further discussions of the subject of radiological protection of the public and workers may be found in Section 6.1.1.4.1 (radiological protection design requirements), 6.4.4 (Issue 2.1: public radiological exposures--normal conditions), 6.4.5 (Issue 2.2: worker radiological safety--normal conditions), 6.4.6 (Issue 2.3: accidental radiological releases), and 6.4.7 (Issue 2.7: repository designation for radiological safety). Section 8.3.5.1 contains discussions on the preclosure risk assessment methodology (PRAM) program. Sections 2.5 (radiological protection), 6.1 (radiological releases during normal operations), and 6.2 (releases under abnormal conditions) of the Site Characterization Plan-Conceptual Design Report (SCP-CDR) (SNL, 1987) also contain discussions relevant to this information need. Finally, two appendices of the SCP-CDR have information especially relevant to this information need. These are Appendix F (preclosure radiological safety analysis), which is a preliminary analysis of accidents at the Yucca Mountain repository prepared to support the development of the preliminary Yucca Mountain Project Q-list, and Appendix L (items important to safety and retrievability), which contains a discussion of the method used and results of the preliminary Q-list.

Parameters

As can be seen in Table 8.3.2.3-2, this information need requires mostly design information. The site parameters required by this information need are those required to determine the characteristics and frequencies of site-related accidents. Below is a list of site data required by this information need along with the SCP section providing the information.

Data requirement	SCP section
Frequency and characteristics of	
Tornadoes	8.3.1.12.4
Cloud-to-ground lightning strikes	8.3.1.12.4
Sandstorms	8.3.1.12.4
Snow fall	8.3.1.12.4
Ice storms	8.3.1.12.4
Repository surface flooding	8.3.1.16.1, 8.3.1.16.3
Repository flooding from ground-water inflow	8.3.1.16.1, 8.3.1.16.3
Surface and subsurface seismic events	8.3.1.17.3

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Data requirement	SCP section
Fault movement within the repository	8.3.1.17.2
Drift roof fall, collapse, or failure	8.3.2.4.1
Surface landslides	8.3.1.14.1
Volcanic ash fall	8.3.1.17.1
Nearby forest or brush fires	8.3.1.13.1
Aircraft and helicopter crashes in the area of the surface facilities	8.3.1.13.1
Other potential accidents	Preclosure risk assessment methodology (PRAM) program 8.3.1.13.2

Logic

Both of the information needs included in this section involve the protection of structures, systems, and components important to safety. Information Need 2.7.2 addresses the design of such items, and Information Need 2.7.3 addresses compliance with mining regulations concerning such items. The only site data needed to design structures, systems, and components important to safety or to assess the design of these items are data concerning site-related accidents against which these items are to be protected. These are listed in the previous parameters subsection.

There are no specific activities planned under these information needs; however, there are activities planned for the issue as a whole. These activities are discussed in the logic section for Information Need 2.7.1 (Section 8.3.2.3.1).

8.3.2.4 Issue resolution strategy for Issue 4.2: Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues?

Regulatory basis for the issue

In addition to the radiological safety requirements for workers, the NRC also specifies that DOE should comply with mining regulations (10 CFR 60.131(b)(9)). The NRC points out that the design of the geologic repository operations area should include provisions for worker protection adequate to ensure that structures, systems, and components important to safety can perform their intended functions.

Resolution of this issue requires that designs and operating procedures that ensure worker nonradiological health and safety during the preclosure period be selected and implemented. Certain aspects of the designs must also be demonstrated to verify that the design approach produces designs that are safe. Design aspects that must be demonstrated are related to the designs of the underground system elements located within the underground areas heated by the emplaced waste; this heating presents a unique design environment. The overall design process is described in Issue 4.4, preclosure design and technical feasibility (Section 8.3.2.5). The relationship of Issue 4.2 to Issue 4.4 is graphically described in Figure 8.3.2.1-1 of Section 8.3.2.1. The role of this issue is to define these aspects of the overall design that impact worker health and safety, to prescribe design requirements necessary to meet the regulatory requirements and to transmit the design requirements to Issue 4.4 for incorporation into the overall design. When each phase of the design process, advanced conceptual design, license application design, etc., is completed, the design package developed under Issue 4.4 is reviewed by this issue to evaluate whether all of its goals are met. The logic of this process, from the viewpoint of Issue 4.2 is depicted in the diagram of Figure 8.3.2.4-1.

The goal of Issue 4.4 is to ensure that the design, construction, and operation of the repository can be accomplished with reasonably available technology. The implication of Issue 4.4 is that the repository will be able to draw upon an existing experience base in the design and the development of procedures for ensuring worker nonradiological health and safety. To this end, this issue will draw upon regulatory requirements to establish goals for the design and operation to ensure worker health and safety. These goals will be imposed on Issue 4.4 in the form of requirements and constraints on the overall design and operating procedures. In the SCP, the goals are generally restricted to those that may require data from site characterization.

From the standpoint of worker nonradiological health and safety, the designs and procedures for the repository must consider at least the following factors:

1. The ability to identify unacceptable or marginal areas of ground.

2. The ability of the repository construction to adapt to constraints imposed by rock characteristics (Section 8.3.1.15).

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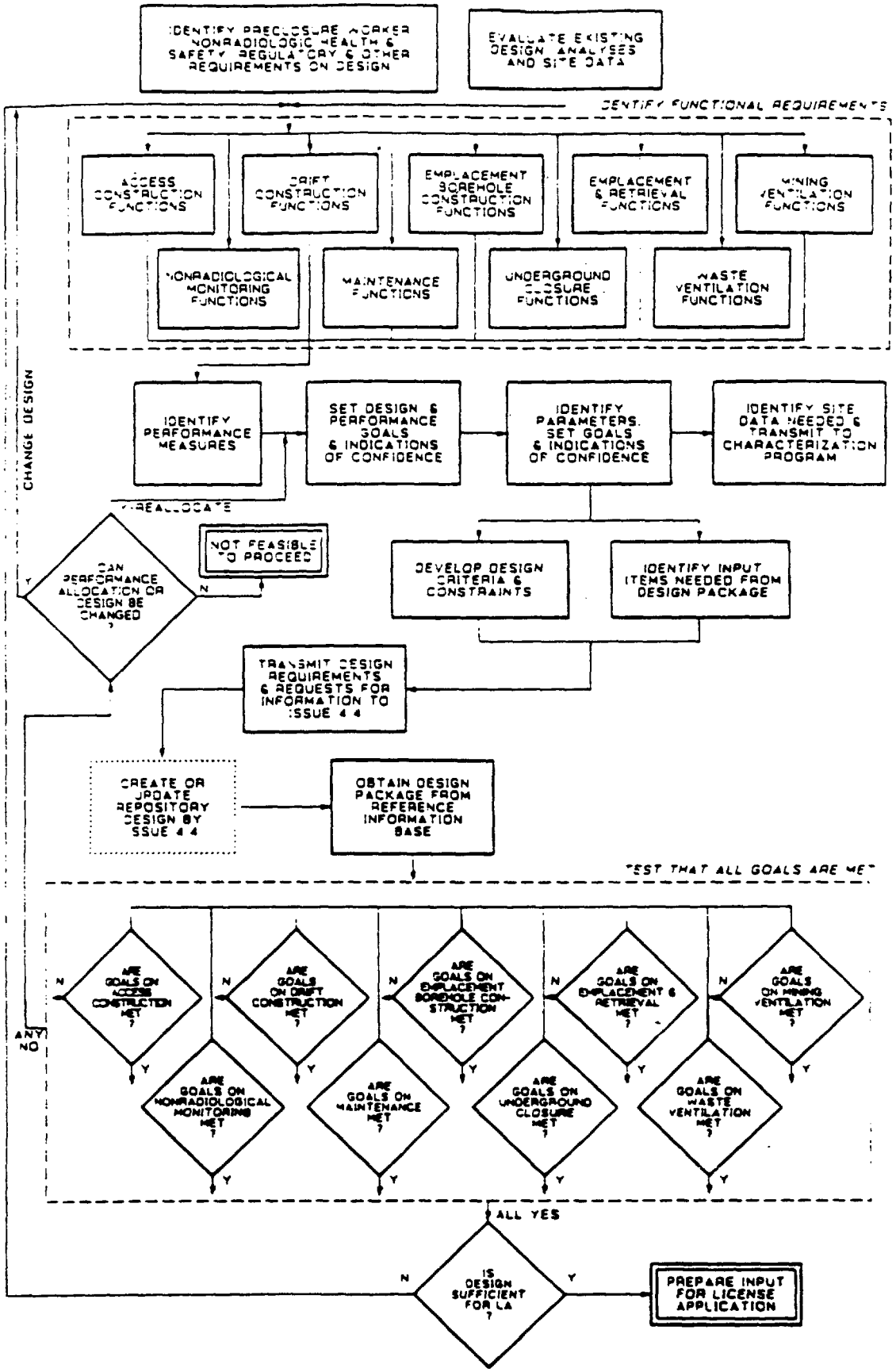

Figure 8.3.2.4-1a. Logic diagram for Issue 4.2 (nonradiological health and safety). See Figure 8.3.2.4-1b for legend. Section 8.3.2.1 describes the relationships and interfaces between design and performance issues.

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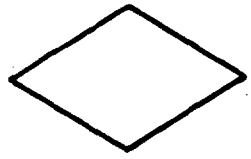
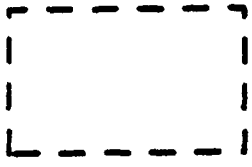
LEGEND

ACTIVITY PERFORMED TO RESOLVE ISSUE



TEST TO DETERMINE SUBSEQUENT ACTIVITY

ACTIVITY PERFORMED BY INDICATED ISSUE



ACTIVITY WITH MULTIPLE SIMILAR ACTIVITIES OR TESTS

DECISION ABOUT ISSUE RESOLUTION

Y - YES N - NO LA - LICENSE APPLICATION

Figure 8.3.2.4-1b. Legend for Figure 8.3.2.4-1a.

3. Use of reasonably available technology (Issue 4.4, Section 8.3.2.5).

4. Maintenance of underground openings during repository operation and closure (Issue 2.4, Section 8.3.5.2).

5. The development of rigorous maintenance procedures and schedules for all repository facilities and operating equipment.

6. Phenomena such as thermally induced fracturing, hydration, or dehydration.

7. Stratigraphic or structural features that could compromise worker safety.

8. Potential for roof falls (drift and access stability during construction and repository operation).

9. Rock support requirements.

10. Air quality (potential for natural gases such as radon or methane, high concentrations of equipment exhaust gases, and harmful dusts).

11. Working temperature.

12. Potential for equipment-related accidents. (This is not a site-related factor unless site conditions restrict the size of openings or corner radii.)

The major factors that impact worker safety are associated with the underground facilities. These factors are opening stability and ventilation. At the Yucca Mountain site, ground-water inflow sufficient to cause a worker safety problem is not anticipated (Section 8.3.1.16). The natural rock temperature at Yucca Mountain does not present a concern, but the rock temperatures and hence the worker environment during retrieval could be of concern. Equipment-related accidents are not expected to be caused by restrictive site conditions. Accesses and drifts will be sized to allow adequate room for maneuvering of equipment without endangering personnel. Rock stability requires that the characteristics of the rock be known and that a design procedure is established to accommodate conditions expected in construction, waste emplacement, and waste retrieval.

Approach to resolving the issue

The approach used to resolve this issue is graphically depicted in Figure 8.3.2.4-1 and is briefly described by the following steps:

1. The "system elements" pertinent to the issue are identified; only the preclosure system elements as presented in DOE (1986c) are considered since workers are present only during the preclosure period of the repository. Additionally, it is judged that worker nonradiological health and safety is imperiled only by operational or construction activities. Applying this criteria eliminates the waste emplacement package and the site elements. The remaining element is the repository. The subelements under the repository

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element that are considered are mining, waste handling, decommissioning, and support. The elements under each repository subelement are evaluated individually to determine if (1) they are pertinent to the nonradiological health and safety of the repository workers and (2) they will require site data for analysis.

For the purpose of resolving this issue, the activities presented in SNL (1987, Appendix P) are replaced by the physical facilities in which the activities are performed, (e.g., access construction (System Element 1.2.1.1) is considered to be the "accesses" to the underground facilities of the repository).

Note: Those system elements not requiring site data for design and assessment of nonradiological health and safety will not be considered beyond the system element identification step. These elements will be addressed in the plans for repository design.

2. The functions that are performed within the system elements identified as pertinent to worker nonradiological health and safety are specified. The functions are selected using the following criteria: (1) is there a potential for failure of the structure in which the function is performed and (2) is there a potential for failure of the equipment used to perform the function? An example function is "ventilation supply and exhaust" for System Element 1.2.1.1 (access construction).

3. The processes or activities accomplished within the system elements selected are listed in conjunction with the functions. The listing is not all inclusive, but it does note those significant processes that can impact worker nonradiological health and safety.

4. The required performance (performance measure) of the system element in accomplishing its functions is specified. Under System Element 1.2.1.1, access construction, an example of a performance measure is "usable access over 100 years."

5. The final step of the issue resolution strategy specifies the tentative performance goals and needed confidence. Performance goals are a statement of what the system element must do or provide to ensure worker safety. Needed confidence is a measure of the importance assigned to achieving the goal set for the system element. An example of a performance goal and confidence assignment from System Element 1.2.1.1, access construction, for the function of ventilation supply and exhaust is a goal of at least 60 ft/min for air velocity during construction; this goal has been established by industry as adequate to ensure a safe working environment. This minimum air flow velocity is set to ensure good mixing and sweeping to avoid stagnant air pockets. A needed confidence assignment of "high" implies that the ability to supply adequate air to the underground is essential for worker health and safety.

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Reasonable assurance that the repository design and operating procedures will ensure worker nonradiological health and safety (i.e., the resolution of this issue) will result from the following:

1. Assignment and implementation of appropriate design safety factors.

2. Establishment of design criteria that mandate compliance with regulations governing health and safety requirements.

3. Evaluation of design to assure compliance with the required regulations.

4. Establishment of training and safety programs.

The types of design analyses that will be used to design the system elements identified are specified in Information Need 4.2.1 (Section 8.3.2.4.1). Implementation of these analyses requires both site and nonsite information (data). The types of site information required are specified in Information Need 4.2.1. Detailed descriptions of the site information required are provided in Section 8.3.2.5, Tables 8.3.2.5-1 through 8.3.2.5-12.

The Yucca Mountain mined geologic disposal system elements and subelements that have an impact on the nonradiological health and safety of the work force and visitors include System Elements 1.2.1 (mining), 1.2.2 (waste handling), 1.2.4 (decommissioning), and 1.2.5 (support). The system subelements that require site-specific data for design and the development of operational procedures to ensure worker nonradiological health and safety are the following:

System subelement	Subject
1.2.1.1	Access construction
1.2.1.2	Drift construction
1.2.1.3	Borehole construction
1.2.1.6	Mining ventilation
1.2.2.5	Retrieval
1.2.2.7	Waste ventilation
1.2.4.1	Underground closure
1.2.5.6	Maintenance
1.2.5.9.2	Nonradiological monitoring

Those subelements of the Yucca Mountain mined geologic disposal system that affect worker nonradiological health and safety but do not require site data for analysis or design are the following:

System subelement	Subject
1.2.1.4	Rock handling
1.2.2.1	Receiving
1.2.2.2	Preparation
1.2.2.3	Storage
1.2.2.4	Emplacement
1.2.2.6	Shipping
1.2.4.2	Surface facility decommissioning
1.2.5.2	Administration

Note that construction and inspection are included under the System Element 1.2.1.3, borehole construction, and, therefore, are not included under System Element 1.2.2.4, emplacement. Thus, no site data are needed for emplacement.

The functions, processes performed, performance measures, performance goals, and needed confidence for achieving the stated performance goals for each system element identified as pertinent to Issue 4.2 are given in Tables 8.3.2.4-1 through 8.3.2.4-9. Those elements selected that do not require site data as input to determine that worker health and safety are achieved are not included.

Interrelationships of information needs

The information needs subsidiary to this issue are as follows:

Information need	Subject
4.2.1	Site and performance information needed for design (Section 8.3.2.4.1)
4.2.2	Potential nonradiological hazards to personnel (not addressed in the SCP)
4.2.3	Design measures for avoiding or mitigating hazards to personnel (not addressed in the SCP)

Table 8.3.2.4-1. Performance measures, goals, and needed confidences for System Element 1.2.1.1 (access construction) pertinent to Issue 4.2, nonradiological health and safety (page 1 of 4)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Underground facility access and egress	Safe access to underground facilities (usable access for 100 yr)	Limit rock damage	
		- Overbreak <6 in. average	Medium
		- Blast-induced fracture extent into intact rock <3 m average	Medium
	Access closure (combined performance of rock and opening support)	Access closure	
		- Closure rate <1 mm/yr in shafts and ramps	Medium
		- Total closure in ramps <6 in. in 100 yr	Medium
		- Total closure in shafts <3 in. in 100 yr	Medium
		Rockfall	
		- <5 ton average/1,000 ft/yr (ramps)	Medium
		- Maximum rock or slab size <2 tons	Medium
		- Rockfall in ramps contained by support system	Medium
		- Rockfall or average liner spall <1/2 ton/1,000 ft/yr (shafts)	Medium

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Table 8.3.2.4-1. Performance measures, goals, and needed confidences for System Element 1.2.1.1 (access construction) pertinent to Issue 4.2, nonradiological health and safety (page 2 of 4)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Underground facility access and egress (continued)		- All rockfall or liner spall to be retained (by supplemental support or liner system) (shafts)	Medium
	Acceptable maintenance frequencies	Maintenance	
		- Inspection and minor maintenance will be done on a continuing basis	Medium
		- Major maintenance frequency >25 yr	Medium
	Access sizes and grades compatible with requirements for personnel, material transport, and utility routing	Grades	
		- Waste ramp grade <10%	High
		- Tuff ramp grade <20%	High
		Size	
		- Men and materials shaft 20 ft minimum diameter	Medium
		- Waste transport ramp roadway width 5 ft greater than waste transporter (minimum clearance between and ramp or ramp equipment equipment >2 ft)	Medium

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Table 8.3.2.4-1. Performance measures, goals, and needed confidences for System Element 1.2.1.1 (access construction) pertinent to Issue 4.2, nonradiological health and safety (page 3 of 4)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Underground facility access and egress (continued)		- Tuff ramp diameter adequate for tuff conveyor movement of major construction equipment and utilities (20 ft)	Medium
Removal of broken rock	Compliance with 30 CFR Part 57	Adequate clearance for rock removal equipment	Medium
		Safety systems (conveyors)	High
		- Barriers and guards	
		- Heat sensors	
		- Slack sensors	
		- Back run preventers	
		Dust suppression	High
Ventilation supply and exhaust	Pressure drops in accesses	Accesses sized to limit air velocities and to accommodate future changes in air demands	
		- <3,000 ft/min in shafts	Medium
		- <1,500 ft/min in ramps	Medium
		- >60 ft/min in all accesses	Medium

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Table 8.3.2.4-1. Performance measures, goals, and needed confidences for System Element 1.2.1.1 (access construction) pertinent to Issue 4.2, nonradiological health and safety (page 4 of 4)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Emergency egress	Compliance with 30 CFR Part 57	Accesses designed to provide safe egress during emergencies	High

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

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Table 8.3.2.4-2. Performance measures, goals, and needed confidences for System Element 1.2.1.2 (drift construction) pertinent to Issue 4.2, nonradiological health and safety (page 1 of 3)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Underground facility access	Safe and usable access for 100 yr	Limit rock damage	
		- Overbreak <6 in. average	Medium
		- Blast induced fracture extent into intact rock <3 m average	Medium
	Drift closure (combined performance of rock and opening support system)	Drift closure	Medium
		- Rate of closure <1 mm/yr in main and access drifts	Medium
		- Rate of closure <3 mm/yr in waste emplacement drifts	Medium
		- Total closure <6 in. in 100 yr	Medium
	Rockfall quantity and retention	Rockfall retention	Medium
		- <5 ton/1,000 ft/yr	
		- Maximum rock or slab size <2 tons	
		- Rockfall retained by support system	Medium
	Acceptable maintenance frequencies	Maintenance	
		- Inspection and minor maintenance will be performed on a continuing basis	Medium

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Table 8.3.2.4-2. Performance measures, goals, and needed confidences for System Element 1.2.1.2 (drift construction) pertinent to Issue 4.2, nonradiological health and safety (page 2 of 3)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Underground facility access (continued)		- Major maintenance frequencies >25 yr	Medium
	Drift size and grades for personnel and material transport and utility routing	Drift size 6 ft wider than equipment size	High
		Drift grades <8%	High
Removal of broken rock	Compliance with 30 CFR Part 57	Adequate clearance	High
		Safety systems (conveyors)	High
		- Barriers and guards	
		- Heat sensors	
		- Slack sensors	
		Dust control and suppression	High
Ventilation supply and exhaust	Pressure drop in drifts	Drifts adequately sized to limit air velocities and to cover changes in future air needs	
		- Velocities in supply mains 2,000 ft/min	Medium
		- Velocities in returns <2,000 ft/min	Medium
		- >60 ft/min in all occupied drifts	High

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Table 8.3.2.4-2. Performance measures, goals, and needed confidences for System Element 1.2.1.2 (drift construction) pertinent to Issue 4.2, nonradiological health and safety (page 3 of 3)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Emergency egress	Compliance with 30 CFR Part 57	Ventilated emergency escapeways	High

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

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Table 8.3.2.4-3. Performance measures, goals, and needed confidences for System Element 1.2.1.3 (borehole construction) pertinent to Issue 4.2, nonradiological health and safety

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Construct borehole	Compliance with 30 CFR Part 57 and ACGIH[b] (1986)	Air quality requirements same as specified for System Element 1.2.1.6 (mining ventilation)	High

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

[b]ACGIH = American Conference of Governmental Industrial Hygienists.

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Table 8.3.2.4-4. Performance measures, goals, and needed confidences for System Element 1.2.1.6 (mining ventilation) pertinent to Issue 4.2, nonradiological health and safety

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Provide adequate quantity of air to all work areas	Air quality, compliance with 30 CFR Part 57	125 CFM/horsepower of diesel equipment used for mining and mining support	High
		210 CFM/underground worker	High
		Minimum air velocity of 60 ft/min in all active work areas	High
Provide quality air to all work areas	Air quality, compliance with 30 CFR Part 57 and Threshold Limit Values (TLVs) and bioindices specified in ACGIH[b] (1986)	SiO_2 <0.1 mg/m^3	High
		O_2 concentration >19.5 vol%	
		CO <50 ppm time weighted average (TWA); short term exposure limit (STEL) <400 ppm	High
		Radon daughter concentration <1.0 working level (WL) in active work areas	High
		Personnel exposure to radon <4 working level months (WLM) annually	High
		Air cooling power >300 watts/m^2 at 45°C (dry bulb)	High

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

[b]ACGIH = American Conference of Governmental Industrial Hygienists.

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Table 8.3.2.4-5. Performance measures, goals, and needed confidences for System Element 1.2.2.5 (retrieval) pertinent to Issue 4.2, nonradiological health and safety (page 1 of 2)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Provide access to emplacement borehole	Temperature in retrieval area	Surface rock temperature in shafts and ramps <35°C	High
		Temperature in access drifts <50°C (SRT)[b]	High
		Air temperature during retrieval <40°C	High
	Rock movement	Rock/support movement in accesses <1 mm/yr	Medium
		Rock movement in access drifts <1 mm/yr	Medium
		Rock movement in emplacement drifts <3 mm/yr	Medium
		Total closure in shafts <3 in. in 100 yr	Medium
		Total closure in ramps and drifts <6 in. in 100 yr	Medium
		Rockfall in ramps and drifts <5 ton/1,000 ft/yr	Medium
		Maximum rock or slab size <2 ton	Medium
		Rockfall in shaft <1/2 ton/1,000 ft/yr	Medium
		All rockfall (accesses and drifts) to be retained by support system (rock size >2 in. diameter)	High

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Table 8.3.2.4-5. Performance measures, goals, and needed confidences for System Element 1.2.2.5 (retrieval) pertinent to Issue 4.2, nonradiological health and safety (page 2 of 2)

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Provide access to emplacement boreholes	Maintenance	Inspection and minor maintenance will be done on a continuing basis	Medium
		Major maintenance frequency >25 yr	Medium

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

[b]SRT = Standard room temperature.

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Table 8.3.2.4-6. Performance measures, goals, and needed confidences for System Element 1.2.2.7 (waste ventilation) pertinent to Issue 4.2, nonradiological health and safety

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Functions/processes and goals for waste ventilation are the same as those specified for System Element 1.2.1.6 (mining ventilation) except for the requirements for air cooling power and drift cooldown, which are specified below.			
Air quality	Air cooling power	Air cooling power required for inspection or light maintenance in waste emplacement area to be 300 watts/m^2 at 45°C (dry bulb)	
		Air cooling power required for heavy maintenance or retrieval (emplacement drifts) to be 500 watts/m^2 at 40°C (dry bulb)	
Cooldown of rock for reentry of emplacement drifts to perform heavy maintenance or retrieval	Rock surface temperature	Surface rock temperature <50°C	

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

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Table 8.3.2.4-7. Performance measures, goals, and needed confidences for System Element 1.2.4.1 (underground closure) pertinent to Issue 4.2, nonradiological health and safety

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Backfill of drifts and installation of postclosure seals	Temperature	Air cooling power >500 watts/m^2 at 40°C (dry bulb)	High
		Rock surface temperature <50°C	Medium
		Air temperature <40°C	High
	Compliance with 30 CFR Part 57 and ACGIH[b] (1986)	SiO_2 concentration <0.1 mg/m^3	High
		O_2 concentration >19.5 vol%	
		CO <50 ppm time weighted average (TWA); short term exposure limit (STEL) <400 ppm	High
		Radon daughter concentration <1.0 working level month (WLM) in active work areas	High
		Personnel exposure to radon <4 working level months (WLM) annually	High

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

[b]ACGIH = American Conference of Governmental Industrial Hygienists.

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Table 8.3.2.4-8. Performance measures, goals, and needed confidences for System Element 1.2.5.6 (maintenance) pertinent to Issue 4.2, nonradiological health and safety

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Access (shaft and ramps) maintenance	Closure and rockfall	Rock movement	
		- <1 mm/yr	Medium
		- <3 in. total in shaft (100 yr)	Medium
		Rockfall	
		- <5 ton/1,000 ft/yr (ramp)	Medium
		- Maximum rock or slab size <2 tons	Medium
		- <1/2 ton/1,000 ft/yr (shaft)	Medium
		All rockfall >2 in. diameter retained by support system	Medium
Drift maintenance	Usability for 100 yr	Inspection and maintenance will be done on a continuing basis	Medium
		Major maintenance frequency >25 yr	Medium

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

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Table 8.3.2.4-9. Performance measures, goals, and needed confidences for System Element 1.2.5.9.2 (nonradiological monitoring) pertinent to Issue 4.2, nonradiological health and safety

Function/process	Performance measure	Tentative goal[a]	Needed confidence
Monitor usability of shafts, ramps, and drifts during construction, operation, retrieval, closure, and decommissioning	Items important to operational safety monitored and displayed in repository control center	Continuous monitoring of - Temperature - Rock movement - Rock support system (visual) - Air quality - Water inflow - Seismic activity	High

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

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Information Needs 4.2.2 and 4.2.3 do not result in the need for site data because they directly place constraints on Issue 4.4 where the data is collected (Section 8.3.2.5), and consequently, only the role of Information Need 4.2.1 will be addressed in the site characterization plan. The information specified as required by Information Need 4.2.1 will be used to resolve the issue of personnel safety related to design features and procedures that depend on site characteristics for analysis and assessment. Information Need 4.2.1 identifies the elements of the repository that present a potential safety hazard and outlines the analysis required to develop designs that will eliminate the potential hazard. The design techniques and the resulting designs are evaluated to determine that the goals specified by the issue resolution strategy are met. If the goals are met, then the issue is resolved.

8.3.2.4.1 Information Need 4.2.1: Site and performance assessment information needed for design

Technical basis for addressing the information need

Issue 4.2 requires that the design and operating procedures be developed and demonstrated and that these procedures support resolution of the performance issue. Information Need 4.2.1 requires that the information needed to implement those procedures and develop the design be identified. To satisfy both the issue and information need, a two-part approach is proposed. Part 1 will address the issue of development and documentation of the design and operating procedures that are unique to repository design and require site-specific demonstration. Part 2 will identify the information needed to implement those procedures for the repository design, construction, and operation.

For Part 1, the development and documentation of the design and operating procedures, the following activities will be completed before license application: (1) initial designs and operating procedures will be developed and documented concurrently with the construction of the exploratory shaft facility (ESF), (2) the construction of the ESF will be monitored, (3) field experience and data collected during construction will be compared with design predictions for the range of conditions encountered in the ESF, and (4) the adequacy of the designs and operating procedures will be investigated. There will be some aspects of the repository design and operating procedures, particularly those related to worker health and safety during the potential retrieval, the closure, and the decommissioning phases, that cannot be demonstrated in the ESF; full-scale demonstrations of these aspects will be deferred to the performance confirmation area of the repository. The critical thermomechanical aspects of the design will be demonstrated by phenomenological and scaled tests in the ESF. The demonstrations and tests planned to verify the adequacy of the design and operating procedures will be addressed in the planned design activities section that follows the parameters section.

For Part 2, the information needed to implement the design and operating procedures is presented in the parameters section. Many of these parameters are the same as those identified for Issue 4.4, (preclosure design and technical feasibility, Section 8.3.2.5).

Link to the technical data chapters and applicable support documents

Chapter 6 describes the current repository conceptual design including excavation, development, and ground support (Section 6.2.6.1); ventilation (Section 6.2.6.3); and summarizes the status of this issue in Section 6.4.7. The information needed to address preclosure health and safety for the license application design (LAD) is identified in this section and in Issue 4.4 (Section 8.3.2.5). The establishment of the repository design and operating procedures will depend on observations and measurements made at the ESF. Performance Issue 4.1 (Section 8.3.5.7) dictates performance goals that must be addressed in this issue. Characterization programs 8.3.1.14, 8.3.1.15, 8.3.1.16, and 8.3.1.17 provide the parameter values required to address this issue.

Parameters

The parameters for this information need are as follows:

1. Information needed to design ground support in accessways and drifts. Parameters used to design the accessways and drifts and the design methods that use these parameters are presented in Information Need 4.4.7 (Section 8.3.2.5.7). Issue 4.4, Tables 8.3.2.5-1 through 12 indicate how well we need to know these parameters, which will be acquired from the ESF as well as other locations at the site. The ranges for parameter values listed in Issue 4.4 are compatible with the ranges required to resolve this issue. To ensure usability of the accesses and drifts during the potential retrievable phase and during decommissioning, an inspection and maintenance program will be maintained. Parameters listed in Issue 4.4 that relate to this issue include thermal, mechanical and thermomechanical properties of the intact rock, the joints and the rock mass, as well as the parameters for application of the empirical methods (such as rock quality designation, joint set number, joint roughness). The areal power density (APD) of the installed waste as well as the waste emplacement configuration will have a significant impact on the required maintenance program and consequently on worker safety. The information on APD and installed configuration of the waste will be obtained from Information Needs 1.11.3 and 1.11.6 (Sections 8.3.2.2.3 and 8.3.2.2.6), and the referenced preclosure design Information Need 4.4.5 (Section 8.3.2.5.5).

2. Information needed to design access ramps and drifts for safe movement of equipment, material, and personnel. A major consideration in safe movement of equipment, material, and personnel is the grades that must be negotiated. The following parameters are used in the determination of the repository design and hence the grades in the access ramps, main haulageways, access drifts, and emplacement drifts:

a. Site surface topography in the vicinity where surface facilities will be located.

b. Location of the upper and lower contacts for candidate disposal horizon. The location of the upper and lower contacts of the candidate disposal horizon should be established in areas where uncertainty exists that the thickness of the densely welded Topopah Spring Member (unit TSw2) is sufficient for safe construction and operation. The thickness of the unit TSw2 necessary to provide sufficient flexibility in selecting the depth of the underground facility has been established as 50 m. Consideration must also be given to the 200-m overburden requirement; the location of the unsaturated tuffs above the water table; the location of the contact between the relatively lithophysae-free and lithophysae-abundant tuff; stratigraphic zones of poor rock quality; and the location of the lower contact between the densely welded tuff and the basal vitrophyre.

c. Disposal horizon orientation (effective strike and dip). The disposal horizon effective strike and dip will be determined from the upper and lower contacts obtained from borehole data and data gathered during construction of the ESF.

d. Site surface geology. The site surface geology will be used to locate the portal for access shafts and ramps. The principal data needed is the location of exposed or near surface rock.

e. Location of site geologic structures. The geologic structures need to be identified for use in determining the location of shaft and ramp portals.

3. Information needed to plan safe construction techniques. The construction techniques and procedures to be used at the repository will be based on the characteristics of the repository site (e.g., the construction of drifts can be by conventional drill and blast methods or by mechanical mining machines); the method chosen will impact the procedures required to ensure worker safety. The information needed, with the required quality requirements, follows:

a. Rock properties needed to select mining methods, to size openings, and to design tunnel support. The properties required have already been identified under the design parameters needed for design of accessways and drifts (Issue 4.4, Section 8.3.2.5).

b. Formation water quantities. The presence of perched water reservoirs within the stratigraphic column penetrated by the shafts and ramps and within the disposal horizon could be a concern for worker safety. The site geology and existing data base do not suggest that significant perched reservoirs are located within the repository site at Yucca Mountain.

c. Potential for generation of hazardous respirable particulates. Actual types of particulates (e.g., silicates and asbestos form fibers) must be determined. Particulate sizes and quantities produced by various activities such as mining, crushing, drilling, and conveying must be determined. Size determination must quantify particulates that are equal to or smaller than the maximum size that can be carried or entrained by the repository ventilation flows.

4. Information needed to design the ventilation system (including data quality requirements) for dilution of natural, toxic, or hazardous gases. Gases in the mining horizons should be analyzed qualitatively and the actual gas types that may be encountered such as radon and methane should be determined. Worker safety information needs associated with radon are addressed in Issue 2.2 (worker radiological safety--normal conditions, Section 8.3.5.4). Existing data suggest that the occurrence of methane or other naturally occurring hazardous gases is unlikely and so no parameters specific to this need are identified.

   The occurrence of hazardous gases from underground operating equipment will impact the ventilation system. The qualification and typing of these gases does not require site data; thus, no parameters are required from the site.

5. Information needed to design the ventilation to provide adequate cooling to allow drift inspection, maintenance, waste retrieval, and decommissioning. A major worker safety concern during potential retrieval is the temperature of the working environment. In some instances it may be necessary to cool the drifts before retrieval or decommissioning operations to ensure a safe environment. The data required to design the necessary cooling system along with the requirement for data quality are as follows:

   a. Thermal conductivity of the rock.

   b. In situ temperature in the disposal horizon.

   c. Site meteorology. The diurnal and seasonal variations of the site relative humidity and temperature at the ventilation inlet and outlet locations are required.

   d. Moisture release rate from the drift and accessway surfaces.

   e. Ventilation airstream pressure loss as a function of drift length.

Logic

At this time it is possible to identify but not fully quantify all parameters needed to develop designs and operating procedures that will ensure worker nonradiological safety. Quantifying these parameters is an iterative process that begins with information obtained from preliminary investigations at the site. This preliminary information will be verified or revised as

dictated by new information obtained from tests conducted in the ESF. The information obtained from the ESF will be adjusted as required during construction of the repository to include additional data obtained on conditions not encountered in the limited extent of the ESF.

The following sections identify the subsurface activities that will be conducted during construction and subsequently in the repository to verify that the adopted design and operating procedures are adequate to protect worker health and to provide safe working conditions.

Two categories of tests and studies are identified: (1) those related to access and drift usability and (2) those related to ventilation and air quality. These two categories cover the major site data requirements related to nonradiological worker health and safety.

8.3.2.4.1.1 Design activity to verify access and drift usability

The methods and data used to develop the conceptual design of the repository are preliminary. The ESF offers an opportunity to verify these design techniques and to substantiate or provide the basis for adjustment of the design techniques used. The lateral extent of the ESF is expected to be sufficient to ensure that the demonstrated design techniques, the data obtained, and the test results will generally be applicable throughout the subsurface facilities with only minor modifications.

To demonstrate in the ESF that the design and operating procedures are adequate for repository design, the following demonstrations and tests will be conducted:

1. Demonstration of construction methods for accesses and drifts in tuff with emphasis on different lithophysae abundance, vitrification, and structural characteristics.

2. Characterization of the exposed rock. This characterization will be done to gain experience in the characterization methods proposed and to develop a data base that can be used to classify visually the rock encountered in the construction of the repository. The classification of the rock is the basis on which a particular ground support system will be specified during repository construction.

3. Demonstration of ground support installation for the various types of ground support proposed. The design of the ground support systems will include a number of types (e.g., rock bolts, rock bolts with wire mesh, shotcrete, and reinforced concrete). The types of support planned, based on currently available information, will be demonstrated.

4. Rock and support monitoring. Measurements of drift closure and support system loads will be made for the various rock types encountered and for the different support systems used. These measurements in the exploratory shaft test facility will, in addi-

tion to providing beneficial data, be used to develop the measurements techniques and select instrumentation systems for use in the repository.

5. Test to compare ground support performance with performance predictions.

6. Test to simulate thermal/mechanical interactions to evaluate long-term ground support behavior.

7. Tests to validate the design models used to predict the performance of accessways and drifts.

The first five tests or demonstrations will verify the adequacy of the design and operating procedures for the construction of the repository; the last two tests address long-term considerations for ground support during waste emplacement, monitoring, maintenance, retrieval, closure, and decommissioning. These long-term considerations are difficult to evaluate by full-scale demonstration in the ESF; consequently, they may require a combination of laboratory tests, scaled field tests, model validation tests, and monitoring in the repository.

Additional details of the seven demonstrations and tests proposed for verification of the design and operating procedures are provided in the following:

1. Demonstration of construction methods. An evaluation of the influence of construction methods on worker safety and ground support requirements will be made. The evaluation will assess the effects of the selected and other candidate mining methods such as smooth-wall blasting and mechanical mining on the extent of the damaged zone, over-break, and support requirements. Tests will include the evaluation of the effects of blast hole pattern design, powder loading, and blasting agent type on safety and ground stability. Results of the blasting tests will be used to develop specifications and operating procedures for blasting in the repository. Monitoring of vibration effects due to blasting and the effect of the vibration on the ground support system will also be needed. The evaluation of the excavation techniques will be repeated for each significantly different ground classification.

2. Characterization of rock. Characterization of the rock will be performed in areas of the ESF where ground support system performance is monitored and where construction methods are evaluated. Characterization includes rock-quality designation, fracture spacing, fracture orientation, roughness, infill characteristics, intact rock compressive strength, internal-friction angle, tensile strength, moisture condition, permeability, and in situ stress as a function of distance from the excavated surfaces. These parameters will be evaluated for the various rock types encountered (provided the rock type dictates a revised support requirement). This information will be used to develop a catalog of rock types versus the required support for use in repository construction.

3. Support installation. The procedures for assessing ground conditions and selecting and installing the required ground support should be demonstrated during ESF construction. Those ground conditions for which the timing of ground support installation is critical should be identified.

4. Evaluation of the ground support system performance. The ground support systems should be monitored by observation, passive methods, and active instrumentation to evaluate performance. Rock bolt load history, shotcrete and concrete stress development, rock displacement, and rock stress changes should be monitored. Regions of rock stress relaxation and joint slip should be identified to assess the loads carried by the support system. The support systems should be monitored for all rock types encountered that dictate different support designs.

5. Comparison of ground support performance and design predictions. Design predictions will be based on empirical, analytical, and numerical techniques. Comparison of support performance and design predictions will involve site-specific modeling and the development of criteria for comparison and acceptance for both the analytical and empirical methods.

6. Simulation of thermal and mechanical interactions to evaluate long-term support behavior. Tests will be required to evaluate corrosion of ground support hardware, bolt anchor capacities at high temperatures, bonding characteristics between concrete or shotcrete and rock at high temperatures, and life expectancy of ground support systems for projection of maintenance requirements. A number of these tests could be conducted in a testing laboratory, while others will need to be done in scaled or full-sized test chambers in the ESF.

7. Tests to validate design models. Many aspects of the preclosure repository design associated with worker safety, specifically drift usability before closure, are based on the level of thermally induced stresses around the openings. Real-time demonstration of the design adequacy based on thermal effects in the repository will not be practical in the ESF. The fundamental basis for the design model, however, can be demonstrated by controlled full-size or scaled tests. Such tests would include

   a. Determination of the equivalent rock mass modulus, thermal expansion coefficient, and rock mass strength for the range of expected rock qualities.

   b. Determination of the influence of temperature on the rock mass properties in item a.

   c. Evaluation of large-scale joint properties such as joint stiffness (shear and normal), joint strengths (cohesion and friction angle), and the evaluation of the effects of temperature on these properties.

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d. Demonstration of thermally induced rock deformation around canister and room configurations. These tests would be conducted in all significantly different rock types. The data from these tests would be compared with the results from the calculations based on the design models to develop confidence that the design procedures are correct.

8.3.2.4.1.2 Design activity to verify air quality and ventilation

Studies are required to assess the impact of site characteristics on the ventilation requirements necessary to provide a safe working environment. Site characteristics will determine dust quantities produced during construction, in situ gas types and quantities, and the wall roughness required for the ventilation flow calculations.

The influence of the construction method on dust generation and dust control methods can be evaluated during construction of the ESF. The drift roughness can be a function of the construction method, the rock quality, and the support system. Worker safety would be impaired if the factors contributing to surface roughness prevent the delivery of sufficient air to the working areas of the repository. Excessive roughness factors could dictate the need for larger drifts and the need for additional or larger ventilation supply and exhaust shafts. The parameters needed to properly design the ventilation system are as follows:

1. Air resistance factors as a function of wall roughness for the different rock types, construction methods, and support systems.

2. The in situ moisture in the rock. This will determine the water burden imposed on the ventilation system. The potential for dewatering versus temperature and the heat and moisture transfer into the ventilation system should be evaluated. The dehydration temperatures for the various rock types should be evaluated.

3. Formation gas types should be identified. Surface emission rates for the various types of gases present should be determined as a function of time after emission surface exposure and temperature.

4. Dust generation rates need to be determined for the different construction methods used and for the different types and qualities of rock encountered.

8.3.2.5 Issue resolution strategy for Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established for the resolution of the performance issues?

Regulatory basis for the issue

Issue 4.4 (preclosure design and technical feasibility) questions whether the repository can be designed, constructed, operated, and closed using reasonably available or proven technology or if it will be necessary to extrapolate beyond current technologies in order to perform the functions identified by this issue. Many other constraints are imposed on this issue by other design or performance issues, including retrieval, postclosure design, and nonradiological health and safety concerns. Figure 8.3.2.1-1 in the overview section (8.3.2.1) depicts the relationship between this issue and the other design-related issues.

To avoid duplication, a careful division of responsibility between issues has been adopted. Issue 4.4 has been assigned the responsibility for the design of surface facilities and mined openings. Other issues will impose design requirements or constraints upon Issue 4.4 pertinent to their needs, and will receive the design and other input items (e.g., supporting analyses) back from Issue 4.4.

In a like manner, where it shares similar design requirements with another issue on a particular facet of the repository design, Issue 4.4 has been assigned the responsibility for developing the design, and providing the other three parts of the four-part design package (namely, the operating plan, supporting analyses, and any necessary demonstrations--see Figure 8.3.2.5-1). The related issue(s) provide requirements and constraints (and requests for other input items) to Issue 4.4 and receive the design package in return from Issue 4.4. Note that with this division of responsibility, Issue 4.4 requests most of the data on site characteristics. This division of responsibility is indicated in the logic diagrams and the supporting text and tables of the SCP sections discussing the design-related issues shown in Figure 8.3.2.1-1.

The regulatory basis for addressing this issue and the subsidiary information needs is contained in 10 CFR 60.133 and 10 CFR Part 960. Most of the parts of 10 CFR 60.133 that relate to the repository location, layout, and postclosure performance are addressed directly in Issue 1.11 (configuration of underground facilities (postclosure), Section 8.3.2.2). Some provisions of 10 CFR 60.133 relate to preclosure concerns, however. For example, 10 CFR 60.133(b) states that "the underground facility shall be designed with sufficient flexibility to allow adjustments when necessary to accommodate site-specific conditions identified through in situ monitoring, testing or excavation." Some of the "adjustments" might be required because of technology limitations such as the ability to predict rock behavior over the long life of the repository. Such limitations might result in a preclosure constraint from a postclosure criterion. Similarly, 10 CFR 60.133(f) states that "the design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential path for ground water or radioactive waste migration to the accessible environment."

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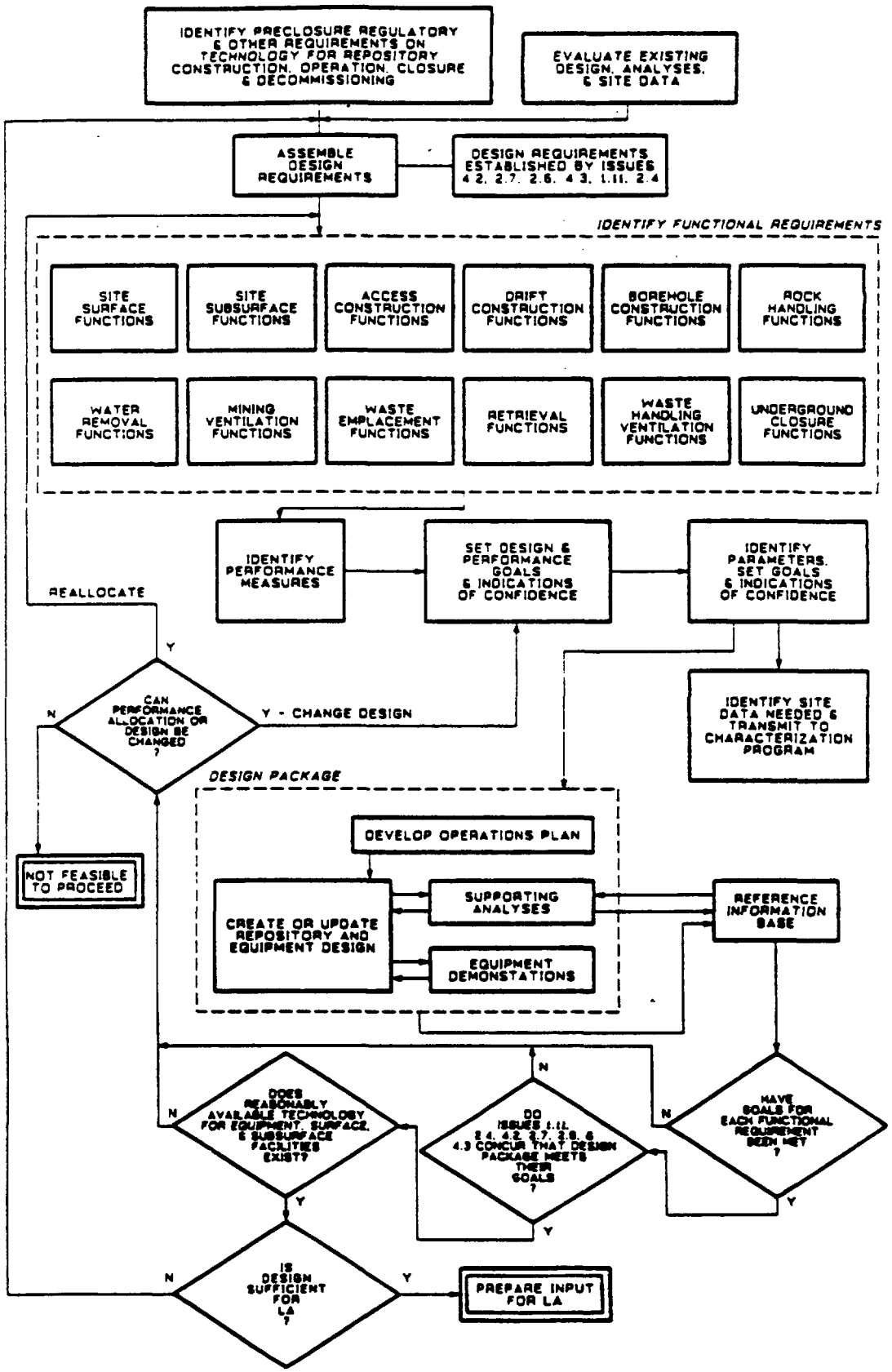

Figure 8.3.2.5-1a. Logic diagram for Issue 4.4 (preclosure design and technical feasibility). See Figure 8.3.2.5-1b for legend. Section 8.3.2.1 describes the relationships and interfaces between design and performances issues.

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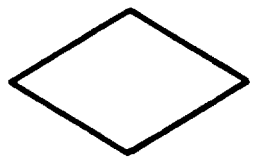
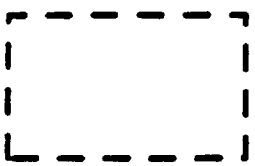
LEGEND

ACTIVITY PERFORMED TO RESOLVE ISSUE

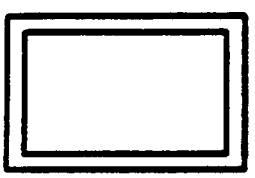


TEST TO DETERMINE SUBSEQUENT ACTIVITY

ACTIVITY PERFORMED BY INDICATED ISSUE



ACTIVITY WITH MULTIPLE SIMILAR ACTIVITIES OR TESTS



DECISION ABOUT ISSUE RESOLUTION

Y - YES N - NO LA - LICENSE APPLICATION

Figure 8.3.2.5-1b. Legend for Figure 8.3.2.5-1a.

This requirement places a potential constraint on the construction methods and could impact this issue. The viability of these potential limitations and constraints will be determined during construction and subsequent testing in the exploratory shaft facility.

Other regulatory bases are contained in 10 CFR 60.131(b)(10), which applies to shaft conveyances used for waste transportation. These requirements will be applied as appropriate to features in the waste transport ramp that will be used to enhance safety.

The preclosure siting guidelines in 10 CFR Part 960 identify the potentially adverse condition, "In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility." This condition is addressed directly in this issue. This issue also covers the design questions related to the preclosure technical guidelines for surface and rock characteristics, hydrology, and tectonics.

Approach to resolving the issue

The approach used in resolving this issue is shown graphically in Figure 8.3.2.5-1. The approach, as it is applied to this issue, follows these steps:

1. The "system elements" of the Yucca Mountain mined geologic disposal system (MGDS) that are pertinent to the issue are selected from the total list of system elements given in Section 8.2. For Issue 4.4, only the preclosure elements are considered pertinent. Issue 4.3 (Section 8.3.4.4) addresses the technology requirements for waste package production, and so this element will not be considered in this issue. The site elements, surface and subsurface, could potentially require the use of advanced technology; consequently, they are considered in this issue. The elements, mining, waste handling, and decommissioning, are considered as potential candidates for the use of advanced technology in that they contain the bulk of the construction and operational activities. The performance confirmation and support system elements of the repository are not considered to require advanced technology; thus, they are not considered in this issue.

   Only System Elements 1.1.1 (surface) and 1.1.2 (subsurface) are physical items; the remaining system elements are activities. For this section, the remaining elements will be replaced by physical eatures in which the identified activities are performed (e.g., drift will be substituted for drift construction). For system elements such as retrieval the system element is used to identify limitations or goals for the performance of repository elements such as drifts and boreholes.

2. The functions and processes of the elements considered pertinent to design and to assessment of technical feasibility are identified. For these elements, the functions listed are those things that the element must do or provide for the repository to meet its required operational and functional goals. The list of functions is not all-

inclusive. Only those functions that establish the technology requirements within the specific system elements and require site-specific data to assess the need for new technology or technology development are identified. The criteria for whether a function plays a role in establishing technology requirements are as follows: (1) has the function been repeatedly demonstrated in normal industrial practices, (2) does the function depend only on engineered structures and equipment of predictable capabilities, and (3) does the function have a potential impact on worker health and safety?

3. The performance measure step identifies the required performance for the system element. Typical performance measures are temperature, rock movement, air flow, and maintenance frequency.

4. This step in the issue resolution strategy specifies the tentative performance goals and confidence needed in order to meet the performance measures. Performance goals are established to provide design guidelines. The goals are not always regulatory requirements; they are, however, based on meeting the applicable regulations.

5. The last step identifies the parameters needed to perform the analyses to determine if the performance goals can be met. It includes a tentative goal and an indication of expected values, needed confidence, and direct confidence.

The information needed to resolve this issue will be derived from the site or will be based on nonsite performance requirements. The criteria applied to distinguish those elements, and their included functions and processes, that require site data for the analysis of technology requirements are as follows:

1. Does the performance of the element depend on site environmental inputs (e.g., seismic and meteorological)?

2. Does the design of the element depend on site physical characteristics (e.g., topography, soil and rock strengths, and hydrology)?

Those elements that may require technology development but do not require site-specific data will be addressed in the repository design plan. The site data required for the analysis of the level of technology required will be defined in the information needs under this issue. These information needs will also establish the data quality requirements.

System elements

The Yucca Mountain mined geologic disposal system elements that were selected from the total set of elements listed in Section 8.2, as pertinent to this issue, are given in the following list. The elements that will be evaluated before the conclusion can be made that the repository can be constructed, operated, closed, and decommissioned using currently available technology are as follows:

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System element	Name
1.1	Site
1.1.1	Surface
1.1.2	Subsurface
1.2	Repository
1.2.1	Mining
1.2.1.1	Access construction
1.2.1.2	Drift construction
1.2.1.3	Borehole construction
1.2.1.4	Rock handling
1.2.1.5	Water removal
1.2.1.6	Mining ventilation
1.2.2	Waste Handling
1.2.2.1	Receiving
1.2.2.2	Preparation
1.2.2.3	Storage
1.2.2.4	Emplacement
1.2.2.5	Retrieval
1.2.2.6	Shipping
1.2.2.7	Waste handling ventilation
1.2.2.8	Contamination control
1.2.4	Decommissioning
1.2.4.1	Underground closure
1.2.4.2	Surface facility decommissioning

The functions or processes for each of these elements are given in Tables 8.3.2.5-1 through 8.3.2.5-12. System elements 1.2.2.1 (receiving), 1.2.2.2 (preparation), 1.2.2.3 (storage), 1.2.2.6 (shipping), 1.2.2.8 (contamination control), and 1.2.4.2 (surface facility decommissioning) are not represented in tables but will be discussed in the repository design plan. These tables also include the performance measures used to evaluate performance in each element, the tentative performance goals, the needed confidences, and the performance or design parameters required to evaluate the technology requirements. Tentative goals, current confidences, needed confidences, and expected values are also provided for each performance or design parameter.

Interrelationships of information needs

The information needs for this issue identify the site parameters and the approach to integrating these parameters into designs and studies that demonstrate reasonable assurance of compliance with the performance goals and the regulatory requirements. Table 8.3.2.5-13 lists the information needs associated with this issue and the system elements addressed in each information need. Information Need 4.4.1 (Section 8.3.2.5.1) generally describes the parameter requirements developed in the other information needs under this issue.

Table 8.3.2.5-1. Preliminary performance allocation for System Element 1.1.1, surface (page 1 of 6)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value
Provide sufficient area for surface facilities	Space to accommodate surface facilities (with contingency)	>100 acres for central surface facility	High	Surface topography at facility locations	Topographic maps with 1 m contours	Medium	Medium	1 m contours
		>50 acres for mined material storage	High	Surface topography at candidate mined material storage area	Topographic maps with 2 m contours	Medium	Medium	2 m contours
		>10 acres for each underground access location	Medium	Topography at underground access locations	Topographic maps with 1 m contours	Medium	Medium	1 m contours
		Minimum cut and fill	Medium	Topograpy of surface facility sites	Topographic maps with 1 m contours	Medium	Medium	1 m contours
Provide usable access for waste delivery vehicles	Grades for rail and truck delivery	<6% road grades <2% road grades	High	Surface topography on access routes	Topographic maps with 2 m contours	Medium	Medium	1 m contours
Provide facility sites (including underground accesses) that are not jeopardized by natural or manmade phenomena	Location relative to floodplain	Above floodplain	High	Topography at facility locations	Topographic maps with 1 m contours	High	Medium	1 m contours
				Surface hydrology for 5, 25, 50, 100, 500, yr flood and probable maximum flood (PMF)				
				Area of inundation	Inundation maps with elevation of inundation area to within ±2 m	High	Low	Area map with elevation of inundated area within ±2 m
					Secondary quantities used to derive area of inundation			
					Topography of drainage area 2 m contours	Medium	Medium	2 m contours
					Debris quantity and category	Low	Low	Cannot be estimated with currently available data
	Locations for surface facilities	Facilities important to safety (FITS) not located over potentially active geological structures	High	Identification of any fault within 100 m of FITS with greater than 1 chance in 100 of producing more than 5 cm of surface displacement in 100 yr	Determine existence	High	Low	No such faults are expected to be found

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Table 8.3.2.5-1. Preliminary performance allocation for System Element 1.1.1, surface (page 2 of 6)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value
Provide facility sites (including underground accesses) that are not jeopardized by natural or manmade phenomena (continued)				If determined to exist, establish				
				Location at surface	Actual location to accuracy of ±5 m	High	Low	Location within 5 m
				Orientation at surface	Actual orientation to accuracy of ±10°	High	Low	Orientation to 10°
				Probability of exceeding 5 cm displacement under FITS	Probability of 5 cm displacement under FITS <.01 in 100 yr	High	Low	Probability <.01 in 100 yr
		Acceptable potential for vibratory ground motion	High	Design basis ground motion time histories and corresponding response spectra	Time histories and response spectra representative for exceptional earthquakes on nearby faults and underground nuclear explosions (for frequencies between 0.5 and 33 Hz)	Medium to high	Low	0.4-0.6g peak acceleration
				Potential for exceeding design basis ground motion at FITS	<0.1 probability in 100 yr	Medium to high	Low to medium	Probability <0.1 in 100 yr
				Probability vs. peak ground acceleration, peak ground velocity, and peak velocity response at selected frequencies at surface FITS locations	Values estimated for annual probability ranging from 10^{-2} to 10^{-6} per yr	Medium to high	Low	Cannot be estimated based on current data
		Acceptable potential for volcanic eruption at surface facilities	High	Probability of volcanic eruption that would disrupt surface facilities	Probability <.0001 in 100 yr	High	Medium to high	Probability <.0001 in 100 yr
		Design basis ash fall thickness at surface facility locations (including shaft and ramp portals)	Medium	Design basis ash fall thickness	<0.1 probability of exceeding design basis ash fall in 100 yr	Low to medium	Low	Probability <0.1 in 100 yr

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Table 8.3.2.5-1. Preliminary performance allocation for System Element 1.1.1, surface (page 3 of 6)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value
Provide facility sites (including underground accesses) that have acceptable soil and rock conditions	Soil and rock conditions	Stable foundations on soil and rock under static load conditions	Medium	Allowable foundation bearing load pressure for soil considering shear failure and settlement (total and differential)	Allowable bearing pressure >0.2 MPa	Medium	Low to medium	0.2-0.4 MPa
				Allowable foundation bearing load pressure for rock considering shear failure and settlement (total and differential)	Allowable bearing pressure >14 MPa	Medium	Low to medium	21 MPa
		Stable retaining walls on soil and rock under static load conditions	Medium	Active and passive soil pressures for flexible and rigid structural walls	Earth pressure coefficient active >0.25 passive >3.4	Medium	Low	 0.27 3.70
				Active and passive rock pressure for flexible and rigid structural walls	Earth pressure coefficient active >0.25 passive >3.4	Medium	Low	 0.27 3.70
		Stable slopes for static and dynamic loading conditions	Medium to high	Factor of safety for an identified mechanism of potential slope failure in soil for static and dynamic loading conditions	For slopes potentially impacting FITS F.S.[b] >1.5 (static) F.S. >1.2 (dynamic)	High	Low	Cannot be estimated based on current data
					For slopes potentially impacting other structures F.S. >1.3 (static)	Medium	Low	Cannot be estimated based on current data
				Factor of safety for an identified mechanism of potential slope failure in rock for static and dynamic loading conditions	For slopes potentially impacting FITS F.S. >1.5 (static) F.S. >1.2 (dynamic)	High	Low	Cannot be estimated based on current data

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Table 8.3.2.5-1. Preliminary performance allocation for System Element 1.1.1, surface (page 4 of 6)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value
Provide facility sites (including underground accesses) that have acceptable soil and rock conditions (continued)					For slopes potentially impacting other structures F.S. >1.3 (static)	Medium	Low	Cannot be estimated based on current data
		Suitable hydraulic related soil conditions considering infiltration/runoff characteristics and erosion potential	Medium	Favorable infiltration: runoff ratio	See Section 8.3.1.2 (geohydrology)	High	Low	See 8.3.1.2
				Favorable hydraulic induced soil erosion characteristics	Scour around bridge piers <13 m in 100 yr	Medium	Low	See 8.3.1.6
					Bed erosion <5 m in 100 yr	Medium	Low	Cannot be estimated based on current data
					Sheet erosion <1 m in 100 yr	Medium	Low	Cannot be estimated based on current data
		Stable foundations on soil and rock for dynamic loading conditions (for FITS)	High	Favorable soil-structure interaction considering displacements and degree of yielding in soil beneath base of building[c]	Total displacement <3 in.	High	Low	Cannot be estimated based on current data
					Percentage of soil that has yielded beneath base of building <10%	High	Low	Cannot be estimated based on current data
				Favorable rock-structure interaction considering displacements and degree of yielding in soil beneath base of building[c]	Total displacement <3 in.	High	Low	Cannot be estimated based on current data
					Percentage of rock that has yielded beneath base of building <10%	High	Low	Cannot be estimated based on current data
		Stable retaining walls on soil and rock under dynamic loading conditions (for FITS)	High	Favorable soil-structure interaction considering displacements and degree of yielding in soil beneath base of building	Total displacement <6 in.	High	Low	Cannot be estimated based on current data
					Percentage of soil that has yielded beneath base of building <10%	High	Low	Cannot be estimated based on current data

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Table 8.3.2.5-1. Preliminary performance allocation for System Element 1.1.1, surface (page 5 of 6)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value
Provide facility sites (including underground accesses) that have acceptable soil and rock conditions (continued)				Favorable rock-structure interaction considering displacements and degree of yielding in soil beneath base of building	Total displacement <2 in.	High	Low	Cannot be estimated based on current data
					Percentage of rock that has yielded beneath base of building <10%	High	Low	Cannot be estimated based on current data
		Soils not subject excessive volume change	Medium	Magnitude and rate of time dependent settlement in soils below earthfills[d]	Total settlement <4 in.	Medium	Low	Settlement <4 in.
				Magnitude of swell in subgrade soils below roads[d]	Total swell <1 in.	Medium	Low	Swell <1 in.
				Magnitude of soil collapse below surface facilities (foundations, earthfills, and roads) due to saturation and/or loading[d]	Total collapse <2%	Medium	Low	Cannot be estimated based on current data
					In situ density >90% of maximum dry density	Medium	Low to medium	Cannot be estimated based on current data
				Favorable soil liquifaction potential for saturated low density soils under dynamic loading conditions[d]	In situ density >85% of maximum dry density	Medium	Low to medium	Density >93.5%
					Well graded soil	Medium	Low to medium	Poorly graded gravel or silty gravel
Protection and confinement of operational activities	Facilities adequate to withstand natural weather phenomena without damage to functional capability	Facilities not damaged by weather extremes	High	Design wind load at surface facility locations (normal winds)	80 mph	Medium	Medium	80 mph
				Design basis tornado Probability of occurrence	$<1 \times 10^{-7}$ per yr	Medium	Low	$<1 \times 10^{-7}$ per yr
				Maximum wind speed	180 mph (combined translational and rotational velocity)	High	Medium	<180 mph
				Maximum atmospheric pressure drop	0.7 psi	High	Low	0.7 psi

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Table 8.3.2.5-1. Preliminary performance allocation for System Element 1.1.1, surface (page 6 of 6)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value
Protection and confinement and operational activities (continued)				Design snow load at surface facility locations	10-16 in.	High	Medium	14 in.
				Design precipitation rate at surface facilities	2-4 in./h	High	Medium	3 in./h
Provide proper environment for personnel and equipment	Proper environment for personnel and equipment under normal weather extremes	Heating and cooling design values	High	Heating and air conditioning design values	No site characterization data is required. Existing data from near vicinity locations is adequate if normalized to Yucca Mountain sites. Values will be developed and presented in the repository design plan.			
		Site location	Medium	Site locations	Coordinates of facility locations	Medium	High	Coordinates within ±5 m
		Site elevation	Medium	Site elevation	Elevations of surface facilities	Medium	High	Elevations within ±5 m

[a]Tentative goals, including ranges, for performance or design parameters are based on current reference values used to repository conceptual design and supporting analyses (Tables 6-11 through 6-16), and limited sensitivity analyses reported in Appendix I of the Site Characterization Plan-Concenptual Design Report (SNL, 1987) and its references and in Ehgartner (1986).

[b]F.S. = factor of safety.

[c]If the alluvium or rock adjacent to the foundation has shear velocities greater than 3,500 ft/s, then a soil-structure interaction analysis will probably not be necessary.

[d]The need for these design and performance parameters or characterization parameters is contingent on the soil and rock conditions encountered. On the basis of the preliminary soil and rock data from the site, these parameters are not currently required.

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Table 8.3.2.5-2. Preliminary performance allocation for System Element 1.1.2, subsurface (page 1 of 5)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value[b]
Provide adequate area for distributing waste (with contingency) and required overburden	Area for 70,000 metric tons of waste and overburden >200 m	Goal for needed area established in Issue 1.11 (see Section 8.3.2.2 for needed site parameters)	High		See Issue 1.11, Section 8.3.2.2			
Provide underground sites (including accesses) that are not jeopardized by natural or manmade phenomena	Ability to continue preclosure operations and retrieve waste	Underground facilities not located in areas with a high probability of disruption by faulting	High	Identification and characterization of significant Quaternary faults in the repository block	Determine existence	High	Low	No such faults are expected to be found in repository, but two such faults bound block
				If determined to exist, establish				
				Location at repository level projected from surface data	Actual location to accuracy of ±20 m	High	Low	Cannot be estimated based on current data
				Orientation (strike and dip)	Actual orientation to accuracy of ±10°	High	Low	Cannot be estimated based on current data
				Probability of exceeding 7 cm displacement in areas of waste emplacement	Probability of 7 cm displacement in waste emplacement area <1 chance in 10 in 100 yr	Medium	Low	Probability <0.1 in 100 yr
		Acceptable potential for vibratory ground motion	High	Design basis ground motion time histories, and corresponding spectra at underground facility	Time histories and response spectra representative of 10,000-yr cummulative-slip earthquakes on nearby faults and underground nuclear explosions (for frequencies between 0.5 and 33 Hz)	Medium to high	Low	0.2-0.3g peak acceleration (subsurface)
			High	Combined potential for vibratory ground motion at underground facility locations	<1 chance in 10 of exceeding design basis ground motion in 100 yr	Medium to high	Medium to low	Probability <0.1 in 100 yr

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Table 8.3.2.5-2. Preliminary performance allocation for System Element 1.1.2, subsurface (page 2 of 5)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value[b]
Provide adequate area for distributing waste (with contingency) and required overburden (continued)		Acceptable potential for volcanic eruption through underground facility	High	Probability of volcanic eruption through area of waste emplacement	Probability $<1 \times 10^{-6}$ per yr	High	Low	Probability $<1 \times 10^{-6}$
Provide host rock thickness for drift construction and waste emplacement	Thickness for drift construction and waste emplacement	Host rock thickness >50 m	High	Stratigraphic contacts for top and and bottom of the TSw2 formation within candidate areas for repository	Determine elevation of stratigraphic contacts at selected points within candidate repository area to accuracy of ±10 m (Note: goal is to determine potential usable extent of acceptable area based on this and other criteria)	High	Low	Thickness of TSw2 within area meeting other selected guidelines for repository horizon defined in Issue 1.11 (Section 8.3.2.2)
Provide physical properties adequate for construction and operation of stable (safe) underground accesses, drifts, emplacement boreholes, and support facilities for normal and credible abnormal conditions	Usable openings of required sites	Accessways and drifts usable for 100 yr	High	Rock properties in primary area Poisson's ratio (intact rock)	TSw1 0.20-0.30 (NL)[c]	Low	Low to medium	0.20-0.30
					0.13-0.19 (L)[d]	Low	Low	0.13-0.19
					TSw2 0.19-0.29	Medium	Medium	0.19-0.29
				In situ stress (rock mass)	Vertical 6.3-7.7 MPa (average) value for 300 m)	Medium	Low to medium	6.3-7.7
					Minimum horizontal stress ratio 0.3-0.8	Medium	Low	0.3-0.8
					Maximum horizontal stress ratio 0.3-1.0	Medium	Low	0.3-1.0
					Bearing of minimum horizontal stress between N 50 E-N 65 E	Medium	Medium	N 50° W-N 65° W
					Bearing of maximum horizontal stress between N 25 E-N 40 E	Medium	Medium	N 25° E-N 40° E
				Initial temperature (rock mass)	TSw2 23-25°C	Medium	Medium	23-25°C
				Coefficient of thermal expansion (rock mass)	TSw1 current mean ±15% (NL and L)	Medium	Low to medium	12×10^{-6}/K
					TSw2 current mean ±15%	Medium	Medium	9×10^{-6}/K

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Table 8.3.2.5-2. Preliminary performance allocation for System Element 1.1.2, subsurface (page 3 of 5)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value[b]
Provide physical properties adequate for construction and operation of stable (safe) underground accesses, drifts, emplacement boreholes, and support facilities for normal and credible abnormal conditions (continued)				Thermal conductivity (rock mass)	TSw1 current mean ±20% (NL) (Dry)	Medium	Low to medium	1.2 W/m-K
					TSw1 current mean ±20% (L) (Dry)	Medium	Low	0.8 W/m-K
					TSw2 current mean ±20% (Dry)	Medium	Low to medium	1.4 W/m-K
				Young's modulus (intact rock)	TSw1 12-54 GPa (NL)	Medium	Medium	19-44 GPa
					14-17 GPa (L)	Medium	Low	15.5 GPa
					TSw2 29-33 GPa	Medium	Medium	31 GPa
				Deformation modulus (rock mass)	TSw1 12-20 GPa (NL)	Medium	Low	12-20 GPa
					4-11 GPa (L)	Medium	Medium	4-11 GPa
					TSw2 11-19 GPa	Medium	Low	11-19 GPa
				Heat capacity	TSw1 current mean ±10% (NL) (saturated)	Medium	Low to medium	2.1 J/m³-K
					current mean ±10% (NL) (dry)	Medium	Low to medium	2.0 J/m³-K
					current mean ±10% (L) (saturated)	Medium	Low to medium	1.9 J/m³-K
					current mean ±10% (L) (dry)	Medium	Low to medium	1.4 J/m³-K
					TSw2 current mean ±10% (saturated) (dry)	Medium	Low to medium	2.2 J/m³-K
				Unconfined compressive strength (intact rock)	TCw current mean ±20%		(see footnote e)	
					PTn current mean ±20%		(see footnote e)	
					TSw1 54-207 MPa (NL)	Medium	Medium	67-172 MPa
					13-19 MPa (L)	Medium	Medium	16 MPa
					TSw2 121-175 MPa	Medium	Medium	148 MPa
				Cohesion of rock and angle of internal friction -- intact rock (compressive strength as a function of confining pressure) fining pressure)	TCw cohesion, current mean ±20%	Medium	Low	30-70 MPa
					Angle of internal friction, current mean ±20%	Medium	Low	45°
					PTn cohesion, current mean ±20%	Medium	Low	4-12 MPa
					Angle of internal friction, current mean ±20%	Medium	Low	8-5°

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Table 8.3.2.5-2. Preliminary performance allocation for System Element 1.1.2, subsurface (page 4 of 5)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value[b]
Provide physical properties adequate for construction and operation of stable (safe) underground accesses, drifts, emplacement boreholes, and support facilities for normal and credible abnormal conditions (continued)					TSw1 cohesion, current mean (NL & L) ±20%	Medium	Low	11-36 MPa
					Angle of internal friction, current mean (NL&L) ±20%	Medium	Low	12-35°
					TSw2 cohesion, current mean ±20%	Medium	Low	35 MPa
					Angle of internal friction, current mean ±20%	Medium	Low	24°
				Joint normal and shear stiffness properties (fractures)	TSw2		(see footnote e)	
				Joint wall compressive (fracture surfaces)	TSw2		(see footnote e)	
				Joint roughness coefficient (fracture surfaces)	TSw2		(see footnote e)	
				Cohesion and coefficient of friction (fractures)	TSw2 cohesion, current mean ±20%	Medium	Low	0.1 MPa
					Coefficient of friction, current mean ±20%	Medium	Low	0.54
				Number of joint sets	TSw2 2-3	High	Medium	2-3 sets
				Frequency and spacing	TSw2 20-40/m³	Medium	Medium	20-40/m³
				Joint orientation	TSw2 identify joint sets and orientation	Medium	Medium	Cannot be estimated based on current data
				Joint roughness and condition of joints	TSw2 discontinuous to smooth undulating	Medium	Medium	Rough, undulating
				Rock quality designation	TSw2 80-35	Medium	Medium	80-35
				Joint alteration	TSw2 softening or low friction with clay mineral coatings	Medium	Medium	Unaltered to slightly altered

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Table 8.3.2.5-2. Preliminary performance allocation for System Element 1.1.2, subsurface (page 5 of 5)

Function or process	Performance measure	Tentative Goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value[b]
Provide physical properties adequate for construction and operation of stable (safe) Underground accesses, drifts, emplacement boreholes, and support facilities for normal and credible abnormal conditions (continued)				Construction method	No site data required			
				Presence of swelling or squeezing ground	Not present based on current data			
				Water inflow	Quantify water inflow	Medium	High	Not expected
				Expected seismic loading	0.2-0.3g acclera-tion	Medium	Low	0.2-0.3g (underground)
				Description and frequency of abnormal conditions in rock-mass	TBD	TBD	TBD	TBD
				Fault properties (subsurface)				
				Location	Actual location to accuracy of ±5 m	High	Low	Location within 5 m
				Orientation	Actual orientation to accuracy of ±10°	Medium	Medium	Orientation to within 10°
				Physical, thermal, and mechanical properties of major faults	Offset ±2 m Spacing ±1 m Fill characteristics	High	Low	Cannot be estimated based on current data
Dissipate heat from emplaced waste	Waste package temperature	Centerline temperature of waste package <350°C	High	Initial formation temperature	See values specified under rock properties in primary area			
				Thermal conductivity of rock	See values specified under rock properties in primary area			
				Heat capacity of rock	See values specified under rock properties in primary area			
Provide adequate water for repository operations	Available water	Water availability >400 acre-ft per yr	High	Sustained yield of pumped water source for operational support	400 acre ft/yr	Medium	Medium	>400 acre ft/yr

[a]Where the goal is indicated as a percentage of the current mean value, the goal is to show that the distribution of the new data is similar to that of the current data and that the mean value of the new data lies within the range specified as percentage of the current mean value. The goals are based on current values used for repository conceptual design and supporting analyses (Tables 6-11 through 6-16) and limited sensitivity analyses reported in Appendix I of the Site Characterization Plan-Conceptual Design Report (SNL, 1987) and in Ehgartner (1986).

[b]In general the expected value is provided to indicate the range of typical values measured to date. This column is not intended to identify the limits of all values measured to date nor is it intended to indicate that the design would be invalid if future values obtained differ from the values presented.

[c]NL denotes properties for nonlithophysal.

[d]L denotes properties for lithophysal.

[e]Existing data are insufficient to establish goals or expected values.

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Table 8.3.2.5-3. Preliminary performance allocation for system element 1.2.1.1, access construction (page 1 of 4)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Underground facility access for personnel, support materials, waste handling systems during construction, operation (including retrieval), and decommissioning	Accesses (shafts and ramps) usable for 100 yr with reasonable maintenance	Access to construct, emplace, and retrieve waste, close, and decommission for 100 yr	High	The parameters required, the tentative goals, and confidence required for these parameters are the same as those listed under System Element 1.1.2 subsurface, under rock properties in primary area				
	Compliance with 10 CFR 60.133f	Limit rock damage during construction		The parameters required, the tentative goals, and confidence required for these parameters are the same as those listed under System Element 1.1.2 subsurface, under rock properties in primary area				
		Overbreak <6 in. average	Medium					
		Extent of fracturing of intact rock <3 m average	Medium					
	Access closure (combined performance of rock and opening support system)	Extent of closure		The parameters required, the tentative goals, and confidence required for these parameters are the same as those listed under System Element 1.1.2 subsurface, under rock properties in primary area				
		<1 mm/yr in accesses (shafts and ramps)	Medium					
		Total closure <6 in. in 100 yr (ramps)	Medium					
		Total closure <3 in. in 100 yr (shafts)	Medium					
	Rockfall	Rockfall		The parameters required, the tentative goals, and confidence required for these parameters are the same as those listed under System Element 1.1.2 subsurface, under rock properties in primary area				
		<5 ton (average) per 1,000 ft of length per yr (ramps)	Medium					
		Maximum size of rock or slabfall <2 tons	Medium					
		Rockfall contained by support system (ramps)	Medium					
		No rockfall to disrupt or damage waste transporter (ramp)	Medium					

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Table 8.3.2.5-3. Preliminary performance allocation for system element 1.2.1.1, access construction (page 2 of 4)

Function or process	Performance measure	Tentative Goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Underground facility access (continued)		Rockfall or liner spall in shafts <1 ton (average) per 1,000 ft/yr	Medium					
		All rockfall or liner spall in shaft to be retained (by supplemental support system, supplemental liner or other methods)	High					
	Maintenance frequency	Inspection and maintenance frequency		The parameters required, the tentative goals, and confidence required for these parameters are the same as those listed under System Element 1.1.2 subsurface, under rock properties in primary area				
		Inspection and minor maintenance done on continuing basis	Medium					
		Major maintenance frequency <25 yr	Medium					
	Access sizes and grades compatible with requirements for personnel and material transport and utility routing	Size:			No site characterization data required			
		20 ft clear diameter man and material shaft to accommodate man and material cage of required capacity and utilities	Medium					
		19 ft diameter waste ramp roadway width 5 ft > width of waste transporter. Minimum vehicle clearance >2 ft	Medium					

Table 8.3.2.5-3 Preliminary performance allocation for system element 1.2.1.1, access construction (page 3 of 4)

Function or process	Performance measure	Tentative Goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Underground facility access (continued)		20 ft diameter tuff ramp clearance adequate for tuff conveyor, movement of major construction equipment and utilities	Medium					
		Grades		Elevation at ramp entry ramps	Topographic maps with 1 m contours	Medium	Medium	1 m contours
		Waste ramp grade <10%	High					
		Tuff ramp grade <20%	Medium					
Ventilation routing (supply and exhaust)	Pressure drop in shafts and ramps	Shafts and ramps of sufficient size to limit flow velocities. Size sufficient to provide contingency to cover changes in future air quantity requirements		Pressure drop per unit length of drift	Site data required will be pressure drop measurements made in shafts and ramps constructed in different types of rock. Measurements wills be repeated for each construction method and liner type used.			
		Ramp velocities <1,500 ft/min	Medium					
		Shaft velocities <3,000 ft/min	Medium					
Sealing	Shafts and ramps compatible with requirements for repository sealing	Materials used compatible with sealing requirements	High		Parameters (information needed) have been identified under Issue 1.12, Table 8.3.3-9.			
		Construction methods compatible with sealing requirements	High		No site characterization data required			
		Shaft liner capable being removed at time of closure	High		No site characterization data required			

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Table 8.3.2.5-3. Preliminary performance allocation for system element 1.2.1.1, access construction (page 4 of 4)

Function or process	Performance measure	Tentative Goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Sealing (continued)	Water storage capacity at base of ramps/shafts to be 150 m^3	High			No site characterization data required			

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Table 8.3.2.5-4. Preliminary performance allocation for System Element 1.2.1.2, drift construction (page 1 of 2)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Underground facility access for personnel, support materials, waste handling systems during construction, operation (including retrieval), and decommissioning	Drifts usable for 100 yr with reasonable maintenance	Access to construct, emplace and retrieve waste, close and decommission for 100 yr	High	The parameters required for these performance goals for System Element 1.2.1.2 are the same as specifed under rock properties in primary areas under System Element 1.1.2 (subsurface)				
	Compliance with 10 CFR 60.133f	Limit rock damage during construction		The parameters required for these performance goals for System Element 1.2.1.2 are the same as specified under rock properties in primary areas under System Element 1.1.2 (subsurface)				
		Overbreak <6 in. average	Medium					
		Extent of fracturing in intact rock <3 m	Medium					
	Drift closure (combined performance of rock and rock support system)	Extent of closure		The parameters required for these performance goals for System Element 1.2.1.2 are the same as specified under rock properties in primary areas under System Element 1.1.2 (subsurface)				
		<1 mm/yr in main and access drifts	Medium					
		<3 mm/yr in waste emplacement drifts	Medium					
		Total closure <6 in. in 100 yr for all drifts	Medium					
	Rock fall (performance of rock support system)	Rockfall		The parameters required for these performance goals for System Element 1.2.1.2 are the same as specified under rock properties in primary areas under System Element 1.1.2 (subsurface)				
		<5 ton (average) per 1,000 ft of drift per yr	Medium					
		Rockfall contained by support system	High					
		Maximum size of rock or slab fall <2 tons	Medium					
		No rockfall sufficient to disrupt or damage waste transporter	Medium					
	Acceptable maintenance frequency	Frequency		The parameters required for these performance goals for System Element 1.2.1.2 are the same as specified under rock properties in primary areas under System Element 1.1.2 (subsurface)				
		Inspection and minor maintenance will be done on a continuing basis	High					

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Table 8.3.2.5-4. Preliminary performance allocation for System Element 1.2.1.2, drift construction (page 2 of 2)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Underground facility access (continued)		Major maintenance frequency >25 yr	High				Medium	
	Drift sizes and slopes compatible with requirements for personnel and material transport and utility routing	Drift cross-section 6 ft greater than maximum mobile equipment width	Medium		No site characterization data required			
		Drift grades <8%	High	Upper and lower contact elevations for the TSw2 formation over the entire repository area	Upper and lower contact elevations for the TSw2 within 20 m	Medium		Elevations accurate to ±20 m
Ventilation routing (supply and exhaust)	Pressure drop in drifts	Drifts of sufficient size to limit air velocities to <2,000 ft/min	Medium		No additional site characterization data required. Site data requirements related to nonradiological health and safety are identified in Table 8.3.2.5-8 under System Element 1.2.1.1, mining ventilation			
Sealing	Drifts (underground layout) compatible with repository sealing	Underground drift layout and grades should provide water drainage from waste emplacement to designated nonemplacement drifts	High	Upper and lower contact elevations for the TSw2 formation within the potential repository area	Upper and lower contact elevations for the TSw2 within 20 m	Medium	Medium	Elevations accurate to ±20 m
		Drift layout and and grades within the exploratory shaft facility should drain to the ES-1 shaft	High	Upper and lower contact elevations for the TSw2 formation within the potential repository area	Upper and lower contact elevations for the TSw2 within 20 m	Medium	Medium	Elevations accurate to ±20 m

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Table 8.3.2.5-5. Preliminary performance allocation for System Element 1.2.1.3, borehole construction

Function/ process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal[a]	Needed confidence	Current confidence	Expected value
Provide for emplacement	Constructability of usable borehole for waste disposal envelope	25 ft deep x 29 in. diameter vertical borehole	High	Abrasiveness of rock	Reasonable cutter life	Medium	Medium	Cannot be estimated based on current data
		363 ft long x 36 in. diameter horizontal borehole	High	The additional parameters required to access constructability of usable boreholes are the rock parameters identified under System Element 1.1.2 (subsurface)				
Provide waste emplacement envelope	Installation of borehole liner	Ability to install vertical hole liner	High	Mechanical systems---No additional site characterization data required				
		Ability to install up to 363 ft of horizontal hole liner	High	Mechanical systems---Because the longitudinal boreholes are lined as they are drilled, no additional site characterization data required				

[a]Tentative goals, including ranges, for performance or design parameters are based on current reference values used for repository conceptual design and supporting analyses (Tables 6-11 through 6-16), and limited sensitivity analyses reported in Appendix I of the Site Characterization Plan-Conceptual Design Report (SNL, 1987) and its references and in Ehgartner (1986).

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Table 8.3.2.5-6 Preliminary performance allocation for System Element 1.2.1.4, rock handling

Function/ process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Removal of mined rock	Ability to remove mined rock at rate of generation	3,000 tons/day	Medium	Size range of blast-fractured rock	Maximum rock size	Low	Low	<12 in.
				Angle of repose of fractured rock piles	Actual angle of repose ±5°	Low	Low	25-30°

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Table 8.3.2.5-7. Preliminary performance allocation for System Element 1.2.1.5, water removal

Function/ process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Removal of process water	All process water removed	Removal capacity >600 gph	Medium	Quantity of process water	(a)			
Removal of natural water	Removal rate equal to rate of inflow	Removal capacity >50 gpm	Medium	Natural water inflow	Actual inflow rate to accuracy of ±10 gpm	Medium	Low	<50 gpm
Removal of water resulting from condensation in ventilation returns (potential during operations)	Removal rate equal to rate of condensation	Removal capacity > potential rate of condensation	Medium	Condensate quantity	(b)			

[a]No site characterization data required. Values will be developed in the plan for repository design.
[b]Condensate potential and quantities will be determined using parameters specified in System Elements 1.1.2 (subsurface), 1.2.1.6 (mine ventilation), and 1.2.2.7 (waste handling ventilation).

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Table 8.3.2.5-8. Preliminary performance allocation for System Element 1.2.1.6, mining ventilation (page 1 of 2)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Supply quality air to working area (considering: temperature, humidity, dust content, and other pollutants)	Compliance with 30 CFR Part 57	125 ft^3/min per unit diesel horsepower in use	High	In situ temperature of host rock	TSw2 23-25°C	Medium	Medium	23-25°C
	Compliance with threshold limit values and biological exposure indices specified in ACGIH[a] (1986)	Normal operation air cooling power = 300 w/m^2 at 45°C (dry bulb)	High	Diurnal temperature and humidity variation of ambient air at intake and exhaust locations	Temperature/humidity vs. time-of-day plots for year (based on historical data)	No site characterization data required. Existing data sufficient when normalized to site		
		210 ft^3/min per worker	High	Seasonal temperature and humidity variation of ambient air at intake and exhaust locations	Temperature/humidity vs. time-of-day plots for year (based on historical data)	No site characterization data required. Existing data sufficient when normalized to site		
		60 ft/min minimum air velocity in work areas	High					
				Surface topography at intake and exhaust locations	Topographic maps with 1 m contours	Medium	Medium	1 m contours
				Pressure drop/unit length of accesses or drifts	Actual pressure drop for rock exhibiting different surface characteristics and for each method of construction	Low	Low	(b)
		Silicon dioxide particulate concentration <0.1 mg/m^3	High	Rock chemistry	Potential for SiO_2	Medium	Medium	SiO_2 content of rock
				Dust generation potential for mining and drilling operations	Particulate size and quantity data	Medium	Medium	(c)
		Oxygen concentration >19.5 volume percent	High	Equipment type and utilization times	No site characterization data required			
		Radon daughter concentration <1.0 working level (WL) in active working area (Issues 2.2 and 2.7)	High	Potential for radon	Rock uranium content	Medium	Medium	(c)
				Radon emission rate from rock	Radon emission rate	Medium	Medium	(c)

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Table 8.3.2.5-8. Preliminary performance allocation for System Element 1.2.1.6, mining ventilation (page 2 of 2)

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Supply quality air to working area (considering: temperature, humidity, dust content, and other pollutants) (continued)		Personnel exposure to radon daughters <4 WL months (Issues 2.2 and 2.7)	High	Potential for radon	Rock uranium content	Medium	Medium	(c)
				Radon emission rate from rock	Radon emission rate	Medium	Medium	(c)
Provide flexibility to allow changes in air quantities and routing	System design flexibility to allow changes in air quantities and routing	Flexibility in design of layout and flow control features (regulators and stoppings)	High	Underground design	No site characterization data required			
Provide safe escape routes for work force	Ventilated escape routes available for all active work areas	Ventilated escape routes provided by design	High	Underground design operation plan	No site characterization data required			
Provide independence between ventilation systems	Compliance with 10 CFR 60.133(g)	Drift layout and contructed features (bulkheads, airlocks, etc.) designed to ensure independence of systems	High	Underground design	No site characterization data required			
		Leakage to be from mining ventilation to waste emplacement ventilation system	High	Permeability of disturbed rock	Permeability of rock affected by mining operations (blasting)	Low	Low	(c)
				Pressure differentials between systems	No site characterization data required			

[a]ACGIH - American Conference of Governmental Industrial Hygienists.
[b]No estimate available. Values used to this point for ventilation calculations have been based on handbook information.
[c]Cannot be estimated based on currently available data.

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Table 8.3.2.5-9. Preliminary performance allocation for System Element 1.2.2.4, emplacement

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Transport waste to emplacement location	Ability to transport the required number of waste packages per day using methods that will ensure personnel safety	Transport 10 packages per day	High	Mechanical activity--no site characterization data required				
		Nonradiological safety (Issue 4.2)	High	Parameters pertinent to nonradiological safety that are dependent on site characteristics are presented under System Element 1.2.1.1 (access construction) and System Element 1.2.1.2 (drift construction)				
	Compliance with ALARA[a] Compliance with other requirements relating to worker radiation dose[b]	Radiological safety (see Issue 2.7 for radiological safety goals, Issue 2.2 for normal conditions, and Issue 2.3 for accident conditions)	High	Parameters pertinent to radiological safety that are dependent on site characteristics are presented under System Element 1.2.2.5 (retrieval)				

[a]ALARA = as low as reasonably achievable.
[b]The goals and parameters required to develop assurance of worker radiological safety are discussed and presented in detail in Sections 8.3.5.4, 8.3.5.5, and 8.3.2.3.

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Table 8.3.2.5-10. Preliminary performance allocation for System Element 1.2.2.5, retrieval

Function or process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Retrieval of emplaced waste	Access to emplacement borehole	Access available for 100 yr with reasonable maintenance of accesses and drifts	High	Access to the emplaced waste for retrieval will be ensured by setting the goals for rock damage, closure, and rockfall stipulated in Systems Elements 1.2.1.1 (access construction) and 1.2.1.2 (drift construction). The parameters needed to predict performance of the accesses and the drifts are specified in System Element 1.1.2 (subsurface)				
	Access to waste package	Rock temperature at borehole wall <275°C	Medium	Access to the emplaced waste for retrieval will be ensured by meeting the goals for rock damage, closure, and rockfall stipulated in Systems Elements 1.2.1.1 (access construction) and 1.2.1.2 (drift construction). The parameters needed to predict performance of the accesses and the drifts are specified in System Element 1.1.2 (subsurface)				
		Borehole liner deformation <2 in. vertical emplacement, <3 in. for horizontal emplacement (in 100 yr)	Medium	Access to the emplaced waste for retrieval will be ensured by meeting the goals for rock damage, closure, and rockfall stipulated in Systems Elements 1.2.1.1 (access construction) and 1.2.1.2 (drift construction). The parameters needed to predict performance of the accesses and the drifts are specified in System Element 1.1.2 (subsurface)				
		Liner corrosion <1/2 liner thickness in 100 yr	Medium	Water and formation chemistry	Quantitative and qualitative analysis of formation and water	Medium	Medium	Cannot be estimated based on current data
Waste retrieval	Retrieval time	Retrieval time < emplacement time plus construction time	Medium	Operations plan	No site characterization data required			
	Operator safety	Radiation dose rate for retrieval operations personnel <1 rem/yr	High	Radiation shielding characteristics of rock	Attenuation factors for neutron and gamma radiation	Medium	Medium	Cannot be estimated based on current data
Waste transport	Operator safety	Radiological safety[a]	High	Radiation shielding characteristics of rock	Attenuation factors for neutron and gamma radiation	Medium	Medium	Cannot be estimated based on current data
		Nonradiological safety[a]	High	Operations plan	No site characterization data required			

[a]The goals and parameters needed to develop assurance of worker radiological safety are identified and discussed in detail in Sections 8.3.5.4, 8.3.5.5, and 8.3.2.3.

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Table 8.3.2.5-11. Preliminary performance allocation for System Element 1.2.2.7, waste handling ventilation

Function/ process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Supply air to waste disposal areas during emplacement and retrieval	The performance measures, goals, and needed confidences for this function are the same as for System Element 1.2.1.6 (mining ventilation) except for the addition of cooling requirements to provide for retrieval of waste packages from heated drifts, the additional requirement is			Site data required for this System Element is the same as the data required by System Element 1.2.1.6				
	Air cooling power for retrieval or preparation	Air cooling power for retrieval or retrieval preparation = 500 W/m^2 at 40°C (Dry Bulb)	High					
Radiological safety	Detection of airborne radioactive material	Immediate detection of airborne radioactive materials	High					
	Reduction and redirection of vent flows in the event that airborne radioactive particulate is detected	Reduction of ventilation flow by 50%	High					
		Diversion of ventilation flow to filter system	High					
Provide flexibility to allow changes in air quantities and routing necessary to accommodate changes in requirements	Performance measures and goals are the same as System Element 1.2.1.6 (mining ventilation)							
Provide safe escape routes for work force	Performance measures and goals are the same as System Element 1.2.1.6 (mining ventilation)							
Provide independence between ventilation systems	Performance measures and goals are the same as System Element 1.2.1.6 (mining ventilation)							

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Table 8.3.2.5-12. Preliminary performance allocation for System Element 1.2.4.1, underground closure

Function/ process	Performance measure	Tentative goal	Needed confidence	Performance or design parameter	Tentative goal	Needed confidence	Current confidence	Expected value
Removal of repository structures	Compliance with requirements for decommissioning	Decommissioning operations and designs compatible with postclosure requirements	High	Parameters needed are identified in System Elements 1.1.1 (surface) and 1.1.2 (subsurface). Requirements will be identified in the decommissioning section of the operations plan and the repository design plan				
Installation of seals	Compliance with requirements for postclosure seals	Preclosure designs compatible with requirements for postclosure seal installation	High	Parameters required are identified in System Elements 1.1.2 (subsurface), 1.2.1.1 (access construction), and 1.2.1.2 (drift construction), and Issue 1.12, Table 8.3.3-8				
		Preclosure and decommissioning materials compatible with postclosure seals	High	Parameters required are identified in System Elements 1.1.2 (subsurface), 1.2.1.1 (access construction), and 1.2.1.2 (drift construction), and Issue 1.12, Table 8.3.3-8				
		Seals installed per requirements of sealing program	High	Parameters required are identified in System Elements 1.1.2 (subsurface), 1.2.1.1 (access construction), and 1.2.1.2 (drift construction), and Issue 1.12, Table 8.3.3-8				
Installation of surface markers	Marker permanence	Marker lifetimes equal to requirements	Medium	Parameters needed are identified in System Elements 1.1.1 (surface) and 1.1.2 (subsurface). Requirements will be identified in the decommissioning section of the operations plan and the repository design plan				
Construction of diversion structures or water flow barriers	Construction according to sealing requirements	Lifetime and material requirements met	Medium	Parameters needed are identified in System Elements 1.1.1 (surface) and 1.1.2 (subsurface). Requirements will be identified in the decommissioning section of the operations plan and the repository design plan				
Installation of backfill	Filling of all underground openings	Openings filled with materials acceptable to waste package performance requirements	High	Parameters required are identified in System Elements 1.1.2 (subsurface), 1.2.1.1 (access construction), and 1.2.1.2 (drift construction), and Issue 1.12, Table 8.3.3-8				
		Openings filled with materials meeting sealing requirements	High	Parameters required are identified in System Elements 1.1.2 (subsurface), 1.2.1.1 (access construction), and 1.2.1.2 (drift construction), and Issue 1.12, Table 8.3.3-8				

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Table 8.3.2.5-13. System elements for the Yucca Mountain mined geologic disposal system addressed by each information need (page 1 of 2)

Information need	Short title	System elements
4.4.1	Site and performance assessment information needed for design	ND[a]
4.4.2	Waste package information needed for design	Addressed in repository design plan (RDP)
4.4.3	Plans for repository operations	ND
4.4.4	Repository design requirements	ND
4.4.5	Reference preclosure repository design	1.1.1 Surface 1.1.2 Subsurface
4.4.6	Equipment development and demonstration	Addressed in RDP
4.4.7	Design analyses	1.1.1 Surface 1.1.2 Subsurface 1.2.1.5 Water removal
4.4.8	Technology for surface facility	1.1.1 Surface
4.4.9	Technology for underground facilities	1.1.2 Subsurface 1.2.1.1 Access construction 1.2.1.2 Drift construction 1.2.1.3 Borehole construction 1.2.1.4 Rock handling 1.2.1.5 Water removal

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Table 8.3.2.5-13. System elements for the Yucca Mountain mined geologic disposal system addressed by each information need (page 2 of 2)

Information need	Short title	System elements
4.4.9 (continued)		1.2.1.6 Mining ventilation 1.2.2.4 Emplacement 1.2.2.5 Retrieval 1.2.2.7 Waste-handling ventilation 1.2.4.1 Underground closure
4.4.10	Technology seals emplacement	1.2.4.1 Underground closure

[a]ND = no data available.

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The site parameters will be acquired through characterization programs for rock characteristics (Section 8.3.1.4), surface characteristics (Section 8.3.1.14), thermal and mechanical rock properties (Section 8.3.1.15), hydrology (Section 8.3.1.16), and tectonics (Section 8.3.1.17).

The determination of whether the repository can be constructed, operated, closed, and decommissioned using reasonably available technology will be based on the technology requirements for each system element. The technology requirements will be developed by a design process for the element that includes configuration determination, design analysis (requiring site and nonsite data) and material selection to meet the performance goals for that element. The assessment that the technology is reasonably available will be based on the following criteria:

1. Have the proposed construction techniques been successfully used in other applications?

2. Have similar performance goals been met in other subsurface facilities with thermal conditions, hydrologic conditions, and rock characteristics like those predicted for the repository?

3. Have the operations required for the repository been used and proved at other installations?

4. Can the technology for construction, prediction of performance, and operation of the repository be demonstrated before license application to ensure its successful application in the repository?

5. Can a combination of empirical, observational, and analytical techniques be used that will give reasonable assurance that the design will meet the performance goal?

The exploratory shaft facility can be used to demonstrate technology. A further demonstration of technology will be possible in the initial phases of repository construction and in the performance confirmation area of the repository.

8.3.2.5.1 Information Need 4.4.1: Site and performance assessment information needed for design

This information need summarizes the site-related parameters identified as being required by the remaining information needs under this issue. Specifically, the required information is derived from the design analyses, reference design development, equipment program needs, operations plan, subsystems design requirements, and assessments of reasonably available technology. Both surface and underground data and parameters that have potentially significant effects on design and performance will be included. Tables 8.3.2.5-1 through 8.3.2.5-12 provide specific information regarding these parameters, including an indication of the confidence needed in the parameter values.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Section 6.1 of this document summarizes the design basis for the repository, including the design requirements, reference design data base, and approaches and tools used for design. Section 6.2 describes the current design of the repository. In addition, Section 6.4 documents the current status of analyses completed to date that use much of the data. On the basis of these sections, the following observations can be made:

1. Properties of surface material and rock at or near the surface can have an impact on the design of surface facility structural foundations.

2. Soil and rock conditions, as well as topographic relief, can influence the specific locations selected for the surface facilities and underground entrances.

3. Repository surface and subsurface facilities must be designed to withstand ground motion associated with earthquakes and underground nuclear tests that might occur at the site vicinity during their operational lifetime. The facilities will be designed to withstand ground motion associated with a natural earthquake with a recurrence time greater than 1,000 yr. Such ground motion is expected to be larger than that resulting from underground nuclear testing. The ground motion resulting from underground nuclear testing is, therefore, expected to be bounded by a design based on the larger ground motion associated with natural seismicity. In addition, because of the presence of a number of faults in the site vicinity, the potential for surface rupture during the operational period will be considered in choosing the final location for the surface facilities.

4. Rock characteristics can impact construction and operation affecting stability, mineability, and the operating environment (e.g., humidity, drift temperatures, and air quality).

The SCP Conceptual Design Report (SCP-CDR) (SNL, 1987) summarizes the design bases in Chapter 2, provides a detailed description of design and operations in Chapters 3, 4, and 5, and, for convenience, reproduces the SCP discussions (See 6.4) regarding the status of resolving Issue 4.4 in Chapter 8.

Parameters

The parameters needed to address this information need have been identified in detail and are listed in Tables 8.3.2.5-1 through 8.3.2.5-12 according to the applicable system element.

Logic

This section briefly presents the justification for specifying the parameters identified in Section 8.3.2.5, Tables 8.3.2.5-1 through 8.3.2.5-12.

The surface facilities must be located where the underlying soil and rock conditions provide adequate strength without undue settlement of structural foundations. Hence, soil and rock mechanical properties are needed for the foundation design.

Soil-structure interaction can significantly affect the seismic forces on the surface structures. To determine these effects, the shear wave velocity profile, shear modulus, damping, and Poisson's ratio data are needed.

Topographic, local meteorological, and upland drainage data, together with soil and rock characteristics, alternative locations, and right-of-way, etc., will be combined to determine flooding potential at the site, acceptable configuration of the facilities, problems to the site, and cut and fill estimates. Meteorological data are also required to design the underground ventilation system.

Ground motion at the site from man-made and natural seismic events is important in the location and design of surface facilities. Information about potential igneous activity, ground motion, and fault movements that could result in surface rupture is important for evaluating the design of both the surface and underground facilities. Any active faults that are close to the repository will be evaluated for their potential to produce ground motions and possible rupture during the operational period. The surface and subsurface facilities will need to be designed to tolerate these ground motions, and the effects of surface rupture will need to be considered.

The properties and behavior of the host rock, surrounding strata, and ground-water systems are very important for the preclosure and postclosure period design requirements of the underground facilities. Rates and magnitudes of igneous activity at the site are important for the postclosure period to determine potential impacts on containment and isolation of radioactive wastes. Hydrologic characteristics at the site are also very important for seal designs.

The mineability of the rock units at Yucca Mountain is being investigated through a series of mining demonstrations. The exploratory shaft and test facilities will be used to demonstrate mineability. Site data to satisfy this part of the information need is the mineability demonstration. Results of the demonstration will establish data on mining and drilling rates that can be used to evaluate cost effectiveness and technical feasibility.

Factors important for working environment considerations in design that depend upon rock characteristics are (1) drift rock wall temperature, (2) drift wall wetness factor, (3) any water inflow into the drift, and (4) air quality (dust, radon, etc.). Air quality is investigated in other information needs and is not considered under this information need. Dust is addressed in Information Need 4.2.1 (site performance information needed for design, Section 8.3.2.4.1), and the potential for radon emanation from the host rock is addressed in Information Need 2.2.1 (natural radiological environment, Section 8.3.5.4.1).

Data for water inflow into the drift will be used to design the drainage and pumping systems. Although significant inflows are not expected, the underground facility will be designed to accommodate anomalous conditions. The drainage system will control the flow of water so that water will not collect at places such as emplacement boreholes (a condition that would be adverse to performance). The pumping system will remove any excess water accumulating at collection points and move it to the surface. This information need merely identifies this data requirement and passes it to the water supply investigation described in Section 8.3.1.16.3.

Drift wall wetness factor is required for ventilation system design because it reflects humidity in the drift. An assumed value is currently being used, and analysis of the environment of the exploratory shaft facility (ESF) areas will allow an assessment of whether the assumed value correctly predicted the amount of water vapor that enters the drift. This will require monitoring air flows and humidity within ESF areas.

There are no planned design activities for this information need. Data required to satisfy this information need are identified in Section 8.3.2.5.7. Related design activities will be discussed in the discussions of the other information needs under this issue. An updated set of reference values is planned for issuance at or near the start of each major design phase (advanced conceptual design, license application design, and final procurement and construction design). Designers will use the reference values or justify why other than reference values have been used.

For the field testing, technical procedures will be developed using control methods similar to those of NRC Regulatory Guides and American Society for Testing and Materials standards. Quality assurance requirements to be used will be consistent with the DOE Quality Assurance Program, as described in Section 8.6.

8.3.2.5.2 Information Need 4.4.2: Characteristics and quantities of waste and waste packages needed for design

This information need serves as an important interface between the waste package design and the repository design. No site data are required to satisfy this information need. The information is identified here for completeness and because the waste information has a major impact on the surface and underground facilities of the repository. The data identified in the information need is used throughout this issue.

This information need is considered satisfied when waste package-repository interface requirements have been finalized and passed to the subsystems design requirements document for use by designers and analysts. Updates of this information are planned for each successive phase of the design process.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The reference design of the waste package is discussed in Chapter 7. In Section 6.1, the waste and waste package information used in conceptual design of the repository is identified.

Parameters

The following is a listing of the waste-related parameters needed for the design of the repository. The source for obtaining these parameters is identified and discussed in the section that follows.

1. Waste quantities, including

   a. Spent fuel--number of disposal canisters, disposal packages, individual fuel elements, and quantities of waste hardware if consolidation is performed.

   b. Defense high-level waste--number of waste packages.

   c. West Valley waste--number of waste packages.

2. Thermal and radiation output plus thermal and radiation decay characteristics of waste forms.

3. Waste package design, size, weight, material, wall thickness, and the configuration of internal structures.

4. Waste package design restrictions for temperature, static and dynamic loading, and materials compatibility.

Logic

The conclusion that the repository can be constructed, operated, closed, and decommissioned using available technology will be developed by design analyses. A major factor affecting the design and the analyses is the quantity and character of the waste. The waste package quantities and characteristics are required to establish facility and equipment shielding requirements, to assess the potential of damage to materials or alteration of materials by radiolysis, and to determine the thermal input to the repository. Waste package quantities and receipt rates are required to estimate the size of the waste handling facilities, to determine the amount of waste handling equipment needed, to prepare the waste for emplacement, and to emplace and retrieve the waste.

The logic supporting the selection of the specific parameters identified in the previous section is as follows:

1. Waste quantities are required to size the surface and underground facilities and to determine the need for waste preparation and handling equipment.

2. The thermal decay characteristics of the waste form affect the allowed areal power density (APD) for waste emplacement. This information will be used to

   a. Determine the total area required for the projected waste inventory and to develop the layouts for the underground waste emplacement area (Information Need 1.11.3, underground facility orientation and layout, Section 8.3.2.2.3). The use of this information is described in Section 6.4.5.

   b. Predict time-dependent temperatures and stresses for Information Need 1.11.6 (Section 8.3.2.2.6) and design analyses for Information Need 4.4.7.

3. Thermal output of the waste package will be used as an input to predict thermal and thermomechanical response of the host rock, surrounding strata, and ground-water system (Information Need 1.11.6). These information needs will provide rock temperatures which will be used to

   a. Establish inspection procedures and instrumentation for inspecting emplaced waste.

   b. Establish ventilation requirements for the repository operational period and for retrieval.

   c. Calculate rock-mass stresses and displacements as a part of opening stability analyses. These analyses will be used as a part of the basis upon which retrievability can be ensured starting at any time up to 50 yr after waste emplacement operations are initiated (Information Need 2.4.6 (compliance with retrieval requirements, Section 8.3.5.2.6)). Opening stability analysis is described in Information Need 4.4.7.

   d. Determine the moisture load on the ventilation system due to in situ moisture migration caused by the rock thermal gradient. This moisture migration will affect ventilation design (Information Need 4.4.7).

   e. Evaluate the potential for corrosion on the various elements of the waste emplacement envelope (liner, shield plug, closure).

   f. Set temperature criteria for design of the hardware and equipment used to support waste emplacement and retrieval.

4. Radiation output of the waste package will be needed to

   a. Establish emplacement hole depths so that adequate rock is available to provide sufficient shielding to limit operational personnel dose rates to design values. This need contributes to Information Need 2.7.1 (radiological protection, Section 8.3.2.3.1).

b. Provide input to material radiation damage analyses and studies related to radiolysis of materials.

5. Waste package size will be needed to define the emplacement envelope and to design the waste package handling equipment (Information Need 4.4.6). The waste emplacement envelope consists of the emplacement borehole and borehole liner, the shield plug, the hole closure, and any materials used external to the liner for liner strength enhancement or corrosion retardation.

6. Waste package material will dictate to a significant extent the materials used in construction of the underground facility. The waste package material will preclude the use of materials in the vicinity of the waste package that may have a significant deleterious effect on the waste package. Items potentially affected are the borehole liner, liner grout, and concrete used in the preparation of the emplacement site. This information will also be an input to design Information Need 1.10.3 (reference emplacement configuration, Section 8.3.4.2.3), Information Need 1.4.2 (material properties of containment barrier, Section 8.3.5.9.2), and Information Need 1.4.3 (scenarios and models needed, Section 8.3.5.9.3).

7. Waste package design information will be used to

   a. Evaluate the ability of the waste package to withstand loads imposed by emplacement and normal or abnormal retrieval conditions (Information Need 4.4.6).

   b. To size the equipment used underground to support emplacement and retrieval (Information Need 4.4.6).

   c. To evaluate scenarios for breaching the reference waste package (Information Need 1.4.3).

8. Waste package temperature limits will be used to determine the emplacement borehole spacing. Spacings determined by consideration of waste package temperature will then be used to develop the underground repository layout for Information Need 1.11.3 and in Information Need 1.11.6. The methods for using this information to address these information needs are in Section 6.4.2.

9. Methods and information sources used to develop the required parameters include the following:

   a. The waste quantities will be provided by the DOE in the generic requirements document. These quantities are based on a compilation of the current waste inventories and projections of future fuel usage.

   b. The thermal decay and thermal output of the waste will be calculated using codes like the Oak Ridge ORIGEN II code, which is an isotope generation code that follows the decay chain of each

specimen produced in the fission of uranium. This information will be used to define the specific decay and thermal characteristics for all waste types. Codes will include the effect of fuel burnup.

c. The radiation output of the waste package will be determined by analyses that consider the waste package geometry, the waste package design, and waste characteristics such as type, burnup, and age. Analyses of this type are typically done using codes that apply Monte Carlo techniques. No specific codes have yet been identified.

d. The information pertaining to the waste package size, material, and design will be obtained from Information Need 1.10.2 (reference waste package designs).

e. The waste package temperature will be limited by the maximum fuel cladding temperature for spent fuel and by the temperature of devitrification for defense high-level waste.

Analyses will be performed to update the information required by this information need as the repository design proceeds through the planned design phases and as more up-to-date information is obtained relating to waste quantities, waste characteristics, and waste package designs.

8.3.2.5.3 Information Need 4.4.3: Plan for repository operations during construction, operation, closure, and decommissioning

A plan for repository operations is needed to effectively design and evaluate the preclosure performance of a waste repository. This information need will produce such a plan. No site data not already required by another information need is required for this plan; hence, the operations plan will only be briefly discussed in the SCP and will be more thoroughly described in the repository design plan (RDP).

Preliminary design and waste package information are combined with equipment concepts to produce flow diagrams and time-line diagrams that form the basis for the operations plan for conceptual designs. In each succeeding design phase, more detail becomes available for each required operation. The operations plan is updated to reflect the added detail and to reflect design decisions during each design phase (i.e., advanced conceptual design, license application design, and final procurement and construction design). The plan and the accompanying staffing levels and quantities of required equipment become an important part of the basis for completing safety analyses, cost estimates, environmental impact analyses, retrievability evaluations, and equipment design.

This information need is considered to be satisfied when successive versions of the operations plan are published for use as design guidance.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Chapter 6 describes most of the repository operations. In Section 6.1, general requirements (e.g., amounts and types of incoming wastes, and receipt rates) for the repository are identified; the operations for waste emplacement and retrieval are identified in Section 6.2; and Section 6.4.8 identifies the progress made to date on the operations plan development.

In the SCP conceptual design report (SCP-CDR), the design bases are given in Chapter 2 and the repository operations are discussed in Chapter 3 and parts of Chapter 4. Chapter 8 of the SCP-CDR provides a brief synopsis of the operations plans published to date.

Parameters

The principal information that serves as input to the development of a plan for repository operations is as follows:

1. Waste-related information (Information Need 4.4.2, waste package information needed for design).

   a. Quantities.
   b. Receipt rates.
   c. Manufacturing processes.
   d. Inspection procedures.
   e. Reference transportation cask designs.

2. Reference repository design.

   a. Preclosure (Information Need 4.4.5, reference preclosure repository design).

   b. Postclosure (Information Need 1.11.7, reference postclosure underground designs, Section 8.3.2.2.7).

3. List of equipment and their performance (design) requirements (Information Need 4.4.6, equipment development and demonstration).

4. Abnormal conditions anticipated for repository operations (Information Need 4.4.3, plans for repository operation).

Logic

The starting point for development of an operations plan is a description of the material (nuclear waste) to be handled, the receipt rate for this material, and how the material will be delivered to the facility (reference transportation packages or shipping casks). This information is then coupled with concepts for the facility (reference designs of surface and underground facilities) and concepts for the handling equipment (receiving equipment, packaging equipment, transporter, and support equipment) to produce block flow diagrams for waste-related operations. These basic waste flow diagrams

are then combined with similar diagrams for numerous repository support systems (mining, muck removal, monitoring, etc.) to produce overall repository material flow diagrams.

Time-line diagrams are then developed that can be used along with the flow diagrams to (1) determine important operational information (amount of equipment, normal throughput, maximum capacity, etc.); (2) develop tradeoff studies to assess what system operational flexibility is gained by various combinations of waste receipt, available equipment, and operations sequences; (3) determine staffing levels for the repository; and (4) provide input for accident and cost analyses.

After the list of planned operations is developed for normal conditions, the differences in operations needed for specific scenarios that define abnormal conditions can be added. This assessment of operations under credible abnormal conditions often leads to the identification of needs for special equipment or procedures to be used.

The operations plan becomes more detailed with each successive design phase (advanced conceptual design, license application design, final procurement and construction design) as more and more information is available and as design decisions are made concerning both facilities and equipment.

A major revision of the operations plan will therefore be needed for each design phase. These major revisions comprise the two planned activities to be completed under this information need.

8.3.2.5.3.1 Design Activity 4.4.3.1: Operations plan to accompany the advanced conceptual design

Objectives

The objective of this design activity is to produce an operations plan to accompany the advanced conceptual design (ACD).

Description

This version of the operations plan will be published during ACD. The principal focus for the plan will be the waste handling operations (including retrieval) since these operations will be detailed as input to preliminary safety evaluations and to the establishment of scenarios for credible abnormal conditions.

8.3.2.5.3.2 Design Activity 4.4.3.2: Operations plan to accompany the license application design

Objectives

The objective of this design activity is to produce an operations plan to accompany the license application design (LAD).

Description

This version of the operations plan will be published during LAD. It will contain the results of design decisions made during ACD and will contain operations only for the selected emplacement option. This version will contain sufficient detail for all repository operations to allow both radiological and nonradiological safety analyses to be conducted.

8.3.2.5.4 Information Need 4.4.4: Repository design requirements for construction, operation, closure, and decommissioning

Design requirements or criteria are needed to guide the repository design. These requirements must reflect guidance from regulations, program level guidance, project level guidance, and site-specific information. As indicated in Figure 8.3.2.5-2, regulations applicable to a nuclear waste repository and guidance from the DOE have been combined to produce program level guidance in the form of a generic requirements document (DOE, 1986c). Project level guidance in the form of system requirements follow from the generic requirements. At the designer level, repository design requirements (RDR) are developed. The content of these requirements documents and the hierarchical relationship between them is shown schematically in Figure 8.3.2.5-2.

This information need is considered to be satisfied by the publication and control of the RDR applicable to each phase of the design of the repository. Controlled assumptions and the baseline design configuration will be clearly documented and maintained in the RDR.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Section 6.1 identifies the design basis used to develop the SCP conceptual design report (SCP-CDR) (SNL, 1987). Section 6.2 shows the design resulting from this basis, and Section 6.4 indicates the status of work completed to date that establishes the requirements in the RDR. Chapter 2 of the SCP-CDR contains a more detailed discussion of the bases for the SCP conceptual design.

Parameters

The following requirements in the following lists will be considered in the generation of the RDR for use by repository designers.

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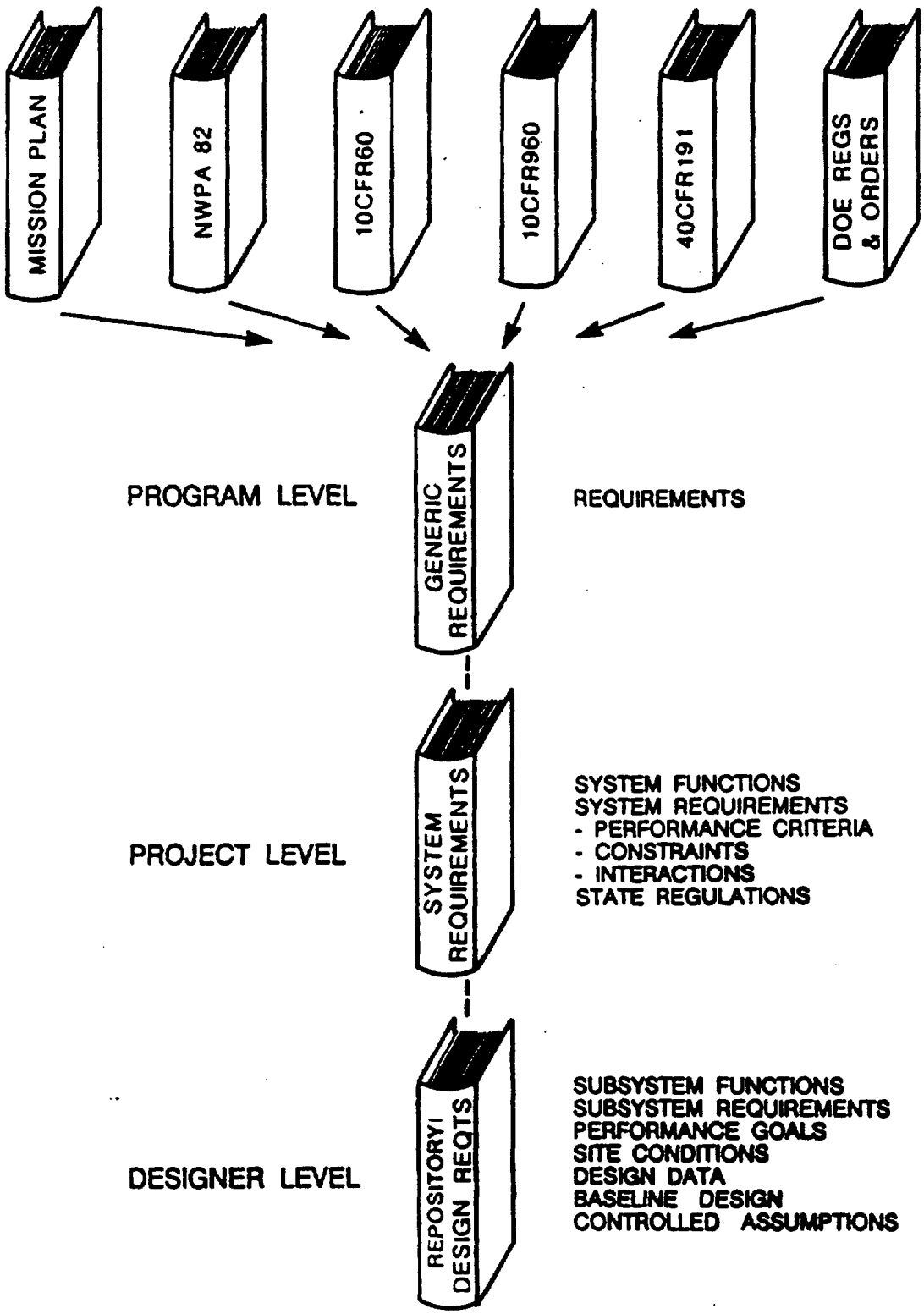

Figure 8.3.2.5-2. Hierarchical relationships of requirements documents.

Federal government requirements include

1. Nuclear Waste Policy Act of 1982 (NWPA, 1983).

2. Mission Plan (DOE, 1985b).

3. NRC, DOE, EPA, U.S. Department of Transportation (DOT), Mine Safety and Health Administration (MSHA) Code of Federal Regulations examples include

   a. 10 CFR Part 60.
   b. 10 CFR Part 960.
   c. 40 CFR Part 191.
   d. 30 CFR Part 57.
   e. 49 CFR Parts 171 through 177.
   f. CFR Part 20.

4. DOE order examples include

   a. "General Design Criteria," DOE Orders 4700.1, 6430.1, and 4300.1B.

   b. "Environmental Protection, Safety, and Health Protection Standards," DOE Orders 5480.4, 5480.1B, and 5480.1A.

The State of Nevada regulations to be considered include

1. Water quality standards.
2. Air quality standards.
3. Safety standards.
4. Mining regulations.

The program and project guidance documents are

1. Generic requirements (DOE, 1986c).
2. System requirements (DOE, 1986f).

The site-specific information to be considered are

1. Reference information base data on site properties.

2. Performance goals from related issues.

3. Reference design configurations and baseline design information from Issue 1.11, (configuration of underground facilities, Section 8.3.2.2) and this issue.

Logic

The RDR document provides site-specific instructions (design criteria) that will be used to develop a mined geologic disposal system (repository), consistent with the requirements set forth in the system requirements and the generic requirements. The basis for the RDR is a statement of the functions that the repository systems must perform and a specific statement of the

functional parameters that the repository must meet. The current RDR will be further developed during each succeeding design phase. A technical change control system will be an integral part of the RDR updating process and the RDR will aid in controlling the scope of each repository design phase. As the design progresses to increasing levels of detail and design decisions are baselined, the SDR will also progress in increasing level of detail.

The repository design criteria contained in the RDR are derived from numerous Federal-government-related sources (Figure 8.3.2.5-2). These sources include the Nuclear Waste Policy Act of 1982, the Code of Federal Regulations (CFR), and DOE orders. The CFR includes regulations developed by the NRC, DOT, Mine Safety and Health Administration (MSHA), and the EPA. Applicable State of Nevada regulations are also included. The RDR also includes requirements generated by determining the (physical) elements of the Yucca Mountain mined geologic disposal system, their functions, and their associated requirements. Subsystem functions and requirements have also been identified to aid the designer, and are supplemented by the use of performance goals determined in issue resolution strategies being used in various design and performance issues. In addition, design basis assumptions (i.e., use of backfill, container content, and one- or two-stage construction) and baseline design information (number and location of shafts and ramps, and reference emplacement configuration) are also included as guidance to designers and to limit the scope of the design studies. Finally, reference site conditions and reference design data to be used by the designers are identified.

The RDR is organized according to the physical subsystem structure. Sixteen major sections and supporting appendices follow an introduction that provides insight into the regulatory background for the document and its organization. The content of the various sections is indicated in Table 8.3.2.5-14. Sections 5 through 11 directly follow the work breakdown structure used in the Yucca Mountain Project as the basis for planning work and monitoring costs.

Changes to the RDR will be evaluated and authorized through the use of a technical change control system. As each new phase of design is entered, a major revision of the RDR will be needed. These major revisions make up the planned design activities to be completed under this information need.

Table 8.3.2.5-14. Organization of repository design requirements

Section	Content
1	Introduction--regulatory background and document organization
2	Site
3	General design requirements

Table 8.3.2.5-14. Organization of repository design requirements (continued)

Section	Content
4	Waste descriptions
5	Surface systems and utility systems
6	Surface facilities
7	Shafts and ramps
8	Underground excavations
9	Underground service and utility systems
10	Seals
11	Exploratory shaft facility
12	Special equipment design
13	Operations and maintenance
14	Permanent closure
15	Performance confirmation
16	Retrievability
Appendices	

8.3.2.5.4.1 Design Activity 4.4.4.1: Repository design requirements (RDR) for license application design

Objectives

The objective of this activity is to develop the design requirements for the repository for use in the license application design (LAD).

Description

The update to the RDR covered in this activity will be published before the initiation of the LAD. It will contain substantially more detail regarding surface and underground waste handling operations, a single emplacement orientation, and the results of numerous design decisions documented during advanced conceptual design (ACD).

8.3.2.5.5 Information Need 4.4.5: Reference preclosure repository design

At any specific time the reference preclosure design is the result of a progressive, iterative design process. This process will result in refinements in design configurations between now and the start of construction. The reference preclosure design is the current design that reflects the most current design criteria, results from completed studies, and the available site data. The currently identified designs that will be produced before license application, along with a brief description of their intent are described in the repository program overview (Section 8.3.2.1). The designs are briefly described in the following paragraphs.

The Site Characterization Plan-Conceptual Design Report (SCP-CDR) is the reference design of the repository at this time. It is based on the criteria, studies completed, and site information available before the start of exploratory shaft construction. This design is used as the basis for a preliminary assessment of design feasibility and includes a preliminary description of planned repository operations. A cost estimate and construction schedule has also been developed for this design.

The advanced conceptual design (ACD) will be an expansion and extension of the SCP-CDR. Expansion will primarily concentrate on those elements of the repository that are important to public and worker radiological safety. One of the main objectives will be to identify and define design concepts that will be carried forward into the license application phase. This design will incorporate results from additional data, refined calculations, additional tradeoff studies, and updated criteria. Repository costs and construction schedules will be updated for this design. A detailed operations plan will be prepared for this design.

The license application design (LAD) will be used as the basis for the license application. It will be highly detailed for those items classed as being important to safety and waste isolation and will include all items of the repository. This design will be evaluated by detailed analysis and calculations based on the refined, expanded data base resulting from additional site characterization work performed in the exploratory shaft facility or obtained by other means such as exploratory borings.

The products of this information need will be the major design reports that detail the design. These reports will be supported by topical reports, tradeoff studies, analyses, and operational plans created in this or related information needs. Major design reports will also be supplemented by the continual use of configuration control. Configuration control will allow design changes to be continuously monitored and documented and will also provide reference information usable for design analyses needed for tradeoff and sensitivity studies. At any specific time, the reference configuration will appear in the reference information base (RIB). More and more detail will be controlled in the RIB as the design progresses toward the LAD configuration. The final procurement and construction design will be developed after submittal of the license application as the basis for repository construction, and will not be discussed here. This information need will provide the input to all analyses, calculations, and studies that are sensitive to the repository configuration and operational procedures. The reference

design also provides the basis for repository construction and operational cost estimates and schedules.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The current repository design is shown in Section 6.2. The basis for this design is provided in Section 6.1; site data supporting the current design are given in Chapters 1 through 5, and the waste package configuration is given in Chapter 7. Chapters 3, 4, and 5 of the SCP-CDR contain an expanded description of the repository design and planned operations.

Parameters

The site parameters needed to develop the reference preclosure design and to complete the studies identified in a subsequent paragraph under this information need are identified in other information needs. The major categories of parameters needed are (1) parameters related to waste quantities and characteristics, (2) mechanical properties of the disposal horizon, (3) thermal properties of the disposal horizon, and (4) the surface characteristics of the site.

Logic

The reference preclosure design is developed through an iterative process. It will become more complete and more detailed with each iteration as a result of the availability of more data and the completion of additional analyses. The number of design alternatives decreases with each design stage until, in the final design, the only alternatives still available are those contingent on anticipated variations of the geology. The analysis supporting the reference design becomes more definitive as the design progresses.

Numerous design activities are planned preceding and during advanced conceptual design. These activities include evaluations of the chosen design and tradeoff evaluations conducted to evaluate design options or alternatives. Some design activities will require site data and some will not. The currently planned design activities that require site data are detailed below; in addition, examples for those required activities that do not require site data are also given.

Supporting activities requiring site data

The following supporting activities require site data:

1. Repository orientation evaluation: An evaluation that assesses the design impact of the repository orientation relative to the in situ principal stresses, fracture and fault geometry, and stratigraphy.

2. Construction contingency plan: A plan for contending with local anomalies (such as bad ground) that may be encountered in the construction of the repository.

3. Underground facility boundary evaluation: An evaluation that will determine the boundary for the underground facilities.

4. Probable maximum flood determination: This determination will be used in conjunction with surface topography for designing flood protection barriers for the surface facilities and underground accesses and will be used in locating both the surface facilities and the entrances for the underground accesses.

5. Retrieval environment prediction: A prediction of the environment that may be encountered during retrieval as a function of the time after emplacement. Drift temperature will be predicted as well as drift condition for both normal and abnormal conditions.

6. Backfill evaluation: A topical report that examines the systems required to install backfill, the impact of the backfill installation operation on worker safety, and the expected properties of the installed backfill, and expected results on postclosure performance.

7. Analysis of the ventilation system: A comprehensive analysis of the ventilation system for the underground portion of the repository. This analysis will develop quantity requirements, pressure requirements, and flow velocities, and will also contain a cooling analysis to predict the times required for cooling to allow maintenance or retrieval. The hardware and construction features will be identified and schematically designed as a part of this document. Radon gas and moisture loss or gain will also be addressed in this analysis. Similar analyses for establishing the filter configuration for the emplacement exhaust air are planned.

8. Underground seismic considerations: An evaluation of the effect of seismic events to determine the impact on the underground facility. Analysis will include ground support systems and emplacement boreholes as well as constructed features such as portals and shaft linings.

9. Surface seismic considerations: An evaluation of the effect of seismic events to determine the impact on surface facilities.

10. Foundations for surface facilities: A determination of the foundation requirements for surface facilities. Analysis will be made based on bearing capacity of soils, and building loads, including determinations of dynamic behavior of the foundation soil in order to include the soil-structure interaction effects due to seismic loads.

Supporting activities not requiring site data (given for example only)

The following types of supporting activities do not require site data:

1. Repository options evaluation: An evaluation to examine the impact of a single- or two-stage repository and fuel consolidation on repository cost, schedule, and function.

2. Operations plan: See Information Need 4.4.3 (plans for repository operations, Section 8.3.2.5.3) for a description of this ACD activity.

3. Electric design basis analysis: An analysis that quantifies the electricity requirements for the repository. The analysis will include the requirements for uninterrupted power, emergency power, and power for the experimental programs. The analysis will project power requirements through repository closure.

4. Surface facility criticality analysis: The waste preparation and storage areas of the surface facility will be analyzed to ensure there is no possibility for a criticality accident.

5. Water requirements evaluation: An evaluation to determine the quantity requirements for the fire, mining support, potable, and nonpotable water needed at the repository.

6. Waste transporter study: A comparative study of electric, diesel electric, and diesel locomotion for the waste transporter with emphasis on the impact of a decision on repository configuration, operations, cost, and safety and the effect of vehicle emissions on meeting performance objectives.

7. Hoist, headframe, and collar design alternatives evaluation: An evaluation that will result in the selection of the mine hoist type to be used at the repository.

Lists of supporting studies and trade-off evaluations will be developed before initiation of each design phase. These lists will be modified as needed during the design phase to reflect new design activities required as the design becomes progressively more detailed.

8.3.2.5.6 Information Need 4.4.6: Development and demonstration of required equipment

The repository system must be designed to accomplish four major tasks: (1) preparation of the waste for emplacement, (2) waste emplacement, (3) waste retrieval, and (4) closure. Each of these tasks relies heavily upon the use of equipment to accomplish the needed work. Most of the required equipment has been used previously for similar purposes; however, each task presents the potential need for equipment that is unique and unproven in similar applications or environments. It is these unproven items that will be the focus of proof-of-principle demonstrations planned before license application.

This information need is the focal point for the equipment development program needed in support of the development of a nuclear waste repository at Yucca Mountain. This information need will have four principal products:

1. List of equipment planned for use in the repository.
2. Designs for equipment that are unique to repository applications.

3. Equipment.
4. Demonstrations to establish capabilities of repository equipment.

Numerous supporting documents (development plans, test procedures, performance goals, design criteria, etc.) will also be created.

The products just identified will be used in a variety of ways, including as the bases for operations planning, as well as safety, cost, and feasibility analyses. Most of the equipment will require little information about the site and will, therefore, not be discussed in detail in this document. The repository design plan will contain substantially more information on the equipment development program needed for the repository. The principal focus of the remaining discussion in this section will be on the activities (and data needs) associated with the evaluation of the feasibility of drilling and lining of long, horizontal, waste emplacement holes.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The operation descriptions for the repository are contained in Section 6.2.3 of this document. The equipment items requiring development and demonstration are included in these operational descriptions. Similar discussions are contained in Sections 3.1, 3.2, and 4.5 of the SCP-CDR (SNL, 1987). The equipment that does not require substantial site data will be described in the repository design plan.

Parameters

The parameters or information needed by the equipment development program are as follows:

1. Site parameters.

   a. Fracture characteristics of host rock.

   b. Abrasiveness of host rock.

   c. Rock-cutting characteristics, including dependence on in situ stresses.

   d. Existence of free water in the rock mass.

   e. Normal and abnormal conditions of drifts and borehole.

2. Other information needed:

   a. Plans for repository operations (Information Need 4.4.3).

   b. Repository design requirements (Information Need 4.4.4).

   c. Design analyses (Information Need 4.4.7).

Logic

Independent of requirements for site data, development and demonstration of a typical piece of equipment generally consists of the following steps to be completed before the license application:

1. Development of reference equipment configurations. The development process will be recorded in topical reports that depict the equipment, present operational procedures, and specify structural and performance criteria.

2. Analysis of the reference designs for verification of functional adequacy, for compliance with the performance goals and for evaluation of necessity for proof-of-principle demonstration. This step will include the generation of separate topical reports for only the more significant analyses (e.g., operator dose).

3. Development of a test procedure for demonstration of the equipment. The emphasis of the procedure will be to identify the sequence of testing to be used to determine if the equipment will perform as required under the anticipated environments for both normal and credible abnormal conditions.

4. Fabrication of equipment, demonstration models, and test facilities as needed for proof-of-principle tests.

5. Demonstration of proof-of-principle.

6. Evaluation of demonstration results and modification of designs and criteria, as appropriate.

This sequence will be implemented for the development and demonstration of the unique, specialized equipment required for the repository. The development and proof-of-principle demonstration of the equipment should be completed before license application.

The Yucca Mountain mined geologic disposal system (MGDS) is introduced in Section 8.2.2. Examination of the subsystems and components of the MGDS will indicate that the preclosure subsystem relies heavily on equipment performing required functions. Subsystems currently being emphasized in the equipment program are highlighted here. The system elements and the equipment within these elements considered potential candidates for demonstration are as follows:

System element		Candidate for demonstration equipment
1.2.1	Mining	Equipment to mine the underground facility by use of mechanical miners
1.2.1.3	Borehole construction	For the horizontal emplacement option, the drill for drilling the long horizontal holes. For vertical emplacement, the drilling of vertical emplacement holes

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System element		Candidate for demonstration equipment
1.2.2.1	Receiving	Remote systems for the removal of shipping cask restraints and cask closures
1.2.2.2	Preparation	Remote welding, inspection, and decontamination
1.2.2.4	Emplacement	Equipment to physically emplace the waste into vertical and horizontal waste disposal boreholes
1.2.2.5	Retrieval	Retrieval equipment for normal conditions and contingent or backup equipment for abnormal conditions, both vertical and horizontal emplacement options

More detail will be provided in the repository design plan regarding the types of equipment planned for use in each of these areas. Because only those items that require significant amounts of site data are considered in this document, the remainder of the discussion will focus on the equipment planned for use in borehole construction (System Element 1.2.1.3). Evaluations will also be made of the potential for using continuous miners and of the experience in using tunnel boring machines in similar types of rock.

A development prototype boring machine (DPBM) is currently being investigated. The DPBM is expected to be capable of drilling and installing a metal lining in long (up to 110 m) horizontal boreholes about 0.9 m in diameter. Demonstration tests for this DPBM are planned as part of the evaluation of the feasibility of horizontal emplacement of the wastes. The site data needed to support the development and demonstration of the DPBM are as follows:

1. Fracture characteristics of the rock. The fracture characteristics are an important part of the determination that the boreholes can be excavated and lined. The parameters needed to assess the fracture characteristics of the rock are presented in Section 8.3.2.5.9, which addresses the feasibility of constructing the underground facility using reasonably available technology.

2. Abrasiveness of the rock. This parameter will affect the costs of the disposal boreholes. Highly abrasive rock will result in frequent cutter replacements and consequently it will affect the emplacement borehole costs. To obtain this parameter, it will be necessary to obtain rock samples for laboratory evaluation.

3. Tests in the exploratory shaft facility (ESF). The tests currently under consideration for the ESF involve the drilling of two 76.2-m-deep horizontal holes into the specific host rock and lining of these holes. 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. These tests will also provide data for cost estimating. Other demonstrations may be planned to simulate the impact of potential abnormal underground conditions that may be encountered by other equipment. Definition

of these tests awaits further definition of equipment and abnormal conditions.

8.3.2.5.7 Information Need 4.4.7: Design analyses, including those addresing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity

Design analyses are important in comparing design options, determining the conditions under which the design meets the designated performance goals, and establishing credibility for the design approach being used. Site parameters, design requirements, and design configurations are required input for this information need. These inputs are used in numerous types of design analysis approaches for assessing the thermal, structural, hydrologic, and ventilation phenomena. This information need is the principal place where rock mechanics analyses (including seismic effects) and ventilation calculations are discussed. Both normal and abnormal conditions are considered in the analysis of surface and underground effects.

The principal products or types of studies completed under this information need (Table 8.3.2.5-15) are design support studies such as tradeoff studies, sensitivity studies, reference calculations, and, where required, calculations to verify and validate the design approaches being used. The areas of analysis considered in this information need are shown in Table 8.3.2.5-15, which serves as the basis for the organization of the discussions presented in the logic section where the specific kinds of analyses to be done are identified.

The results of the design analyses completed under this information need will be used by the other information needs of this issue where the analysis will form the basis for needed modifications to the design or the design requirements and will provide the substantiation for the identified data needs. Compliance with retrievability requirements (Issue 2.4, Section 8.3.5.2), with requirements for nonradiological safety (Issue 4.2, Section 8.3.2.4) and comparisons of the analysis results with the goals established in Issues 2.4 and 4.2, will also rely heavily on (and will audit) the analysis performed here. Similarly, interfaces with goals from postclosure issues must be recognized. Examples of these interfaces are goals concerning waste package environment, the extent of the disturbed zone, and the areal power density.

This information need will be considered satisfied with the publication of the design analyses showing that performance goals and design criteria have been met.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The design analyses described in this information need relate directly to other chapters of this document, particularly Chapter 6. The most substantial coverage of the current status of the analysis work is contained in Section 6.4.10. Numerous technical publications documenting the analyses completed to date are also referenced in this section of Chapter 6. The data

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Table 8.3.2.5-15. Preclosure design analyses

Areas of analysis[a]	Products or types of studies
UNDERGROUND	
Rock mechanics (thermal, structural, seismic)	Design support studies tradeoff studies
Ventilation Hydrologic Other	Sensitivity studies Reference calculations Verification and validation studies
SURFACE	
Rock mechanics	Design support studies tradeoff studies
Hydrologic Soil/mechanics/foundations Other	Sensitivity studies Reference calculations Verification and validation studies

[a]Each area includes, where appropriate, evaluations of normal and abnormal conditions.

used as the reference basis for most of the recent calculations is in Section 6.1 while the design that forms the basis for most of the calculations is given in Section 6.2.

The relationship between this information need and the SCP-Conceptual Design Report (SCP-CDR) (SNL, 1987) is similar to its relationship with Chapter 6. In the SCP-CDR, issue resolution status is provided in Chapter 8, and relationship to the NRC concerns is in Chapters 6 and 7. Chapter 2 of the SCP-CDR provides the basis for the current analysis while Chapters 3, 4, and 5 describe the current design.

Parameters

The parameters needed from site characterization to accomplish the analyses identified in the following logic section are summarized in the following list. The parameters are categorized and as follows:

1. General geometrical, soil, and rock parameters needed for surface facility design.

2. Rock parameters needed for subsurface design.

3. Hydrological parameters needed for surface and subsurface design.

4. Meteorological parameters..

5. Tectonic parameters.

General geometrical, soil, and rock parameters needed for surface facility design follow. The geometrical parameters are

1. Surface topography at facility locations.
2. Surface topography of access routes.

The soil parameters are

1. Alluvial stratigraphy.

2. Allowable foundation bearing load considering shear failure and total and differential settlement.

3. Soil structure interaction (if required).

4. Slope stability.

5. Time dependent settlement of earthfills and retaining structures if saturated clays are encountered (not likely).

6. Hydraulic related soil parameters.

The rock parameters are

1. Rock stratigraphy.

2. Allowable foundation bearing load considering shear failure and total and differential settlement.

3. Rock-structure interaction response (for soft rock with low shear wave velocity).

4. Slope stability.

The rock properties needed for the subsurface design for the linear elastic analysis of accessways and drifts are

1. Poisson's ratio.
2. In situ stresses.
3. Initial temperature.
4. Coefficient of thermal expansion.
5. Thermal conductivity.
6. Young's modulus.
7. Deformation modulus.
8. Joint cohesion and angle of friction.
9. Heat capacity.

10. Confined and unconfined compressive strength.
11. Cohesion of rock and angle of internal friction.

Additional rock parameters needed for incorporation of a rock joint model into analysis codes for the subsurface design are

1. Joint normal and shear stiffnesses properties.
2. Joint wall compressive strength.
3. Joint roughness coefficient.
4. Cohesion and coefficient of friction.

Additional parameters needed to use empirical methods for underground opening and ground support design are

1. Number of joint sets.
2. Frequency and spacing of joint sets.
3. Joint orientation.
4. Length of joint.
5. Rock quality designation.
6. Wall rock alteration.
7. Construction method.
8. Presence of squeezing or swelling ground.
9. Joint condition (roughness/free water/infilling).
10. Water inflow.
11. Expected seismic loading.

Other rock parameters are

1. Radon emission rate.
2. Abrasiveness of rock.
3. Porosity.
4. Saturation.
5. Permeability.
6. Radiation shielding characteristics.

The hydrological parameters needed for surface and subsurface design are

1. Subsurface.

    a. Estimate of water inflow into subsurface.

    b. Existence/location of perched water sources.

    c. Sustained yield of pumped water source for support of operations.

2. Surface (surface hydrology at surface facilities and access portals).

    a. 10-, 25-, 50-, 100-, and 500-yr floods.
    b. Probable maximum flood (PMF).
    c. Area of inundation.
    d. Flow velocities in areas in inundation.
    e. Debris load of flows.

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The meteorological parameters are

1. Diurnal temperature and humidity of ambient air.
2. Seasonal temperature and humidity of ambient air.
3. Atmospheric dispersion.
4. Mixing height.
5. Average temperature.
6. Relative humidity.
7. Precipitation.
8. Wind speed.
9. Design wind load.
10. Design snow load.
11. Design value for precipitation.
12. Heating and cooling design values.

The tectonic parameters are

1. Surface fault displacement parameters.

    a. Identification and classification of late Quaternary faults within 100 m of facilities important to safety (FITS).

    b. Classification.

    c. Location at surface.

    d. Orientation at surface.

    e. Identification of any fault within 100 m of FITS with greater than 1 in 100 chance of producing more than 5 cm of surface offset in 100 yr.

    f. Integrated potential for fault displacement beneath FITS

    g. Probability vs. displacement relationship for area beneath FITS.

2. Underground fault displacement parameters.

    a. Identification and characterization of late Quaternary faults in the repository block:

        i. Classification.
        ii. Location at surface.
        iii. Orientation at surface.

    b. Identification and characterization of any faults within the waste emplacement area with greater than 1 in 10 chance of producing more than 7 cm of subsurface offset during the preclosure period.

    c. Integrated potential for fault displacement on faults that intersect underground facilities.

d. Probability versus displacement relationship for the area of waste emplacement.

3. Surface vibratory ground-motion parameters.

a. Design-basis ground-motion time histories (minimum bandwidth = 0.5 to 33 Hz) and corresponding response spectra (at 1 Hz intervals for surface FITS).

b. Integrated potential for vibratory ground motion at FITS.

c. Probability vs. peak acceleration, peak velocity, and peak velocity response at selected frequencies, at surface FITS.

4. Underground vibratory ground-motion parameters

a. Design-basis ground motion time histories and corresponding response spectra for underground facilities (at various depths) (minimum bandwidth = 0.5 to 33 Hz; 1 Hz intervals for response spectra).

b. Integrated potential for vibratory ground motion at underground facility locations.

c. Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies, at underground facility locations.

5. Surface volcanic activity parameters.

a. Probability of volcanic eruption at location of surface FITS.

b. Design-basis ashfall thickness at sites of all surface facilities.

c. Ashfall particle density and size distribution.

6. Underground volcanic activity.

a. Probability of volcanic eruption through the area of waste emplacement.

b. Design-basis ashfall thickness (at surface vent intakes and exhausts).

c. Ashfall particle density and size distribution.

Logic

The analysis of the preclosure performance of the repository is an ongoing process. The process is progressively improved with each design iteration by the incorporation of new and better data and the use of improved analysis techniques. The current design of the repository is based on analysis techniques that may be improved as the design process evolves. The

currently used methods of analysis are presented in this section for two reasons: (1) to illustrate the computer code types used for judging the applicability of the codes for repository design and (2) for the purpose of identifying the parameters needed to support the application of these computer codes. It is not anticipated that further improved codes or analyses techniques will require additional data beyond that identified in this section.

Only those analyses that require site data are presented. The analyses are categorized as (1) underground and (2) surface; under these categories the analyses are further divided into the basic types of analyses required. The rationale for reference calculations, sensitivity analysis, and computer code validation are also presented in the end of this logic subsection.

Analysis of underground repository facilities--structural-thermal analysis

The repository underground system elements that require structural analysis are 1.2.1.1, access construction (shafts and ramps); 1.2.1.2, drift construction; and 1.2.1.3, borehole construction. For some of these elements, (1.2.1.2 and 1.2.1.3) the structural analysis must be expanded to address the effects of the temperatures generated by heat from the waste. The potential long operational life of the repository dictates that the methods of analysis be adaptable for predicting the design adequacy for a long period of time.

System Element 1.2.1.1, Access construction (shafts and ramps)

Geomechanical analyses consider mechanical, thermal, and thermomechanical response of the rock mass through the emplacement and retrieval periods. The geomechanical goals indicate the need to understand the response of the host rock to excavation and thermally induced stresses. Excavation-induced stresses depend on the in situ stress field with superposed stresses derived from the size and geometry of the opening considered. Thermal stresses developed in the rock as a result of heating depend primarily on the magnitude of individual or combined heat sources, thermal properties of the rock, and the heat transfer mechanism; thus, these stresses vary with time and position. The effects of excavation-induced stresses are first evaluated and then the effects of thermal stresses are superposed on the former such that the thermomechanical response (the sum of the mechanical and thermal load components) also varies with time and position.

Our current understanding of the mechanical response of tuff is that the fractured rock mass can be treated as an elastic, elastic-plastic, or compliant-jointed media (Chapter 2 and Section 6.4.2). Current understandings of the mechanical response of fractured tuff have been based on and supplemented by three integrated sources of data: (1) field studies of the local and regional geology of the site (Chapter 1), (2) laboratory and field data indicative of the mechanical and thermal response of the rock from Yucca Mountain, and (3) data from in situ field experiments at Rainier Mesa and from laboratory experiments and rock samples from Rainier Mesa. The mechanical response predicted by a given analysis or set of analyses will depend on the scale, loading, and boundary conditions of the problem.

The approach to understanding and predicting mechanical response has been to use progressively more complex models through the course of design, performance, and safety analyses. For example, engineering judgment and practices are often applied at the onset to provide initial guidance to developing repository design. This judgment is qualified by data available before site characterization. The preliminary design warrants evaluation and confirmation through use of boundary element and finite element methods, and in situ test results. The predominant basis for planned license application analyses will be finite element methods.

The types of analytical tools being developed to provide a perspective of the rock mass mechanical response to address Issues 1.11 (configuration of underground facilities--postclosure, Section 8.3.2.2), 4.2 (nonradiological health and safety, Section 8.3.2.4), and this issue include the following:

1. Tunnel index methods (Barton et al., 1974a; Bieniawski, 1974), which are experience-based empirical methods that permit conclusions regarding ground support requirements and opening size. As yet, these methods do not account for the effects of heat.

2. Calculations using boundary element techniques will be used in preliminary evaluations of ground support requirements and will be compared with those determined by the tunnel indexing methods. The effects of excavation and heat may be included in the analysis. Rock strength, fracture slip, or both may be used to interpret results. These methods allow for parametric studies to be undertaken in which design tradeoffs can be evaluated through the predictions of deformations and stress at specific locations as a function of time. The usefulness of boundary element methods will be tested through comparison with closed form analytic solutions, finite-element codes, and underground exploration.

3. The predominant basis for planned license application analyses will be finite-element methods. Calculations using finite-element methods, treating the rock mass as an elastic, elastic-plastic, or compliant jointed media, will test the conclusions drawn from tunnel indexing and boundary element methods based on the effects of excavation and heat predicted throughout the area of interest as a function of time. These methods have the potential to consider rock strength, fracture slip, and fracture deformability as part of the computation, or these methods may be used to interpret results. Finite-element methods will be tested through comparison with closed-form analytic solutions, boundary element codes, underground exploration, and laboratory and field testing. The calculations using these methods will provide the final measure of the usability and performance of the designs.

Parameters necessary for the empirical structural design of the shafts and ramps. The design of the shaft and ramp cross-sections and the required ground support by use of a traditional, rock mass classification approach can be accomplished using a number of methods (e.g., Barton et al., 1974a (Norwegian Geotechnical Institute method) or Bieniawski, 1976 (Council for Scientific and Industrial Research method)). The method that will be used for the repository has not been selected. The parameters required for most

empirical or experienced-based methods are specified in this section. Because the ramps and shafts pass through both the lithophysae-abundant and lithophysae-free parts of the Topopah Spring Member and the overlying members, parameters are required for both types of rock.

Parameters necessary for the analytical structural design of shafts and ramps. The accesses (shafts and ramps) must survive, in a usable condition, for a period of time equal to the retrievability period plus the time required for decommissioning. The time currently used to encompass the retrieval period is 84 yr, and the estimated time for postretrieval decommissioning is 6 yr; therefore, the total time required is 90 yr. Postclosure aspects of repository design, including shafts and ramps, are discussed in Section 8.3.2.2.6.

Shafts and ramps will not be subjected to significant temperature changes during the repository operations. This is due to the distance between the shafts and ramps and the waste disposal area. The eventual temperature increase in the shafts and ramps is expected to be small and probably will not occur until they have been backfilled as planned by the seal program. Nonetheless, the analytical verification of the design of the shafts and ramps will consider the effects of thermally induced stress changes resulting from the adjacent waste disposal areas. This will allow an assessment of the effects of increased horizontal stresses and formation uplift due to thermal expansion.

The computer codes to be used for the initial structural design of the shafts and ramps will be selected from the list of codes provided in Section 6.4 (or similar codes will be used). Results of testing in the exploratory shaft facility will assess the suitability of these codes for design analyses supporting license application. The data or parameters required to apply these codes and to evaluate the potential for joint slip or excessive rock mass deformation are similar to the data that will be required for the codes selected for final design analysis. Two sets of parameters are required: (1) the parameters required when the rock mass is characterized as linearly elastic or elastic-plastic and (2) the additional parameters required to incorporate a description of the joints within the rock mass. These parameters are specified earlier in this section.

Two categories of parameters are needed: (1) those that can be measured directly or derived from measured values and (2) those that are subjective and must be determined by applying judgment factors. For the first category of parameters, the confidence with which the parameter needs to be determined depends on the sensitivity of the analysis method to the particular parameter as well as on the expected rock mass response. Preliminary sensitivity analyses indicate that the dominant parameters for assessing stability and in evaluating access opening shapes include (1) the unconfined compressive strength, (2) in situ stress, (3) the joint strength parameters, and (4) rock quality designation (RQD). Note that jointing at the site is predominately vertical based on current information; thus, the RQD determination may be biased. This bias will be examined through considerations of fracture spacings in three dimensions.

Parameters in the first category need to be determined by applying methods and selecting sample quantities that will give the required confi-

dence in the resulting values. For the second category of parameters, only a medium confidence is required. These parameters must be obtained for all differing rock types encountered in the construction of the shafts and ramps. In using the compliant joint model, the significant parameters, in addition to those just listed, are the joint stiffness parameters.

System Element 1.2.1.2, Drift construction

The structural design of drifts differs from the design of accesses (shafts and ramps) in that the drifts may experience moderate temperature increases due to the heat output of the waste during the operational life. The effects of the increase in temperature on the design approach and the parameters needed are discussed in the following text.

Ground support design. The methods used and the parameters required for ground support design are the same as empirical and analytical methods described for the design of accesses. Support categories expected include rock bolts with wire mesh and localized shotcrete. In areas of poor rock quality, enhanced support may be required. These support systems are commonly used but they will require confirmation and careful material selection to ensure adequate performance during the retrievability period and compliance with postclosure requirements for chemical compatibility (Information Need 1.10.4, Section 8.3.4.2.4).

The planned approach to the design of the ground support for the repository may involve developing approximately four ground support designs. These designs could vary from simple rock bolts up to and perhaps including full concrete lining. Each design will be developed for a specific range of rock classifications. As varying rock conditions and types are encountered in the exploratory shaft facility (ESF), the preselected ground support may have to be varied. The support will be monitored for performance, providing an experience base that can be used in the repository. The ground support verification tests proposed for the ESF are described in Section 8.3.2.4.1.

The parameters needed to design the rock support system and to assess drift shape and size are the same as those listed for the access system element, but for the drifts, these parameters will be required only for the disposal horizon.

Long-term design considerations for drifts. The methods used to select drift size, shape, spacing, and support systems to accommodate long-term considerations are the same as for the access (shafts and ramps) except that now the effects of the heat generated from the decay of the waste must be incorporated. It will be determined if the heat effects can be simulated by the empirical methods such as those of the Norwegian Geotechnical Institute by increasing the stresses to account for the thermally induced stresses occurring after waste emplacement. Analytical techniques are available to explicitly model the temperature distribution around the drifts and calculate the thermally induced stresses. The support system designed and selected to accommodate the long-term considerations will be installed during construction.

The thermally induced stresses are expected to enhance stability in some areas and to destabilize other areas. If the degree of destabilization ex-

ceeds the capacity of the support system, then it will be necessary to enhance the support system or to reduce the temperature to decrease the thermal loads. Consideration of the thermally induced loadings requires additional thermal and thermomechanical parameters for the host rock and the support system. The thermally induced stresses depend on the temperature distribution in the rock, which depends on the waste form and age, emplacement geometry, the areal power density of the emplaced waste ventilation conditions, and the rock thermal properties.

Currently the dominant heat transfer mechanism in the unsaturated tuff is understood to be temperature-dependent conduction. This understanding is based on laboratory and field tests and analyses (Section 2.5.3, relationship between intact rock and large-scale properties). The types of analytical tools being developed to provide perspectives of the rock mass thermal response include the following:

1. An analytic solution for heat conduction for finite cylinder heat sources with a decaying exponential source term with a time and linear superposition of sources. This analytical tool will serve the purpose of making preliminary design assessments for the repository.

2. An analytic solution for heat conduction for finite line heat sources that may be constant or exponentially decaying with time. This analytical method is an integral part of the boundary element method to be used to perform design and sensitivity analyses.

3. A numerical model capable of steady and transient linear and nonlinear thermal conduction analyses in at least two dimensions.

Possible boundary conditions include constant temperature at a node, constant or time-dependent temperature along the side, adiabatic surface, forced convection, natural convection, and thermal radiation. Material properties (densities, specific heats, and conductivity tensors) may depend on temperature. The method used will be tested using closed-form analytic solutions, benchmarking activities, and laboratory and field experiments. Heat transfer codes similar to the ones being considered have been successfully applied to analyses of heat transfer in salt (Waste Isolation Pilot Plant and Project Salt Vault), granite (Stripa), and tuff (Sections 2.5.2 and 2.5.3). The results of these analyses are used as input for thermomechanical analyses.

The current understanding of the combined contributions of the excavation and thermal effects upon rock-mass response is presented in Section 2.5. Based on this understanding, two methods are currently being applied to predict thermomechanical response. In the first, using boundary element techniques, thermal stresses and displacements are calculated by treating the thermal stress and the initial stress as a time varying boundary condition. In the second, using finite element techniques, mechanical responses from excavation and thermal responses from the heat source are separately analyzed and then the thermal results are input to the mechanical analysis to determine the thermomechanical response.

The temperatures will be estimated using a temperature-dependent heat conduction code similar to those used to predict temperatures in small-scale heater tests conducted in the G-Tunnel complex at the Nevada Test Site. These codes include SPECTROM-41, VISCOT, ADINAT, and COYOTE. The application of these codes requires the parameters, specified in Table 8.3.2.5-2.

Of the thermal properties needed, preliminary sensitivity analyses show the thermal coefficient of expansion has the most significant effect on the code outputs. The thermal coefficient of expansion is assumed to be isotropic, based on existing data presented in Chapter 2. Unlike mechanical properties, thermal properties are not expected to show any significant anisotropic effects as a result of joint sets (dominant or minor).

System Element 1.2.1.3, Borehole construction

The stability of the waste emplacement boreholes is important for maintaining the capability to retrieve the waste. Stability of the boreholes will be analyzed using the same methods and parameters as used for the analysis of the accesses and drifts.

Analysis of underground repository facilities--ventilation analysis

The repository underground system elements that require ventilation analysis are 1.2.1.6 (mining ventilation) and 1.2.2.7 (waste-handling ventilation). Analyses that have been used to this point in the design process are identified for the purposes of applicability assessment and to substantiate the parameters identified as necessary from site characterization. The design analysis techniques and codes may change for future designs; however, the data required to support the new analyses techniques is expected to remain the same as that identified here.

System Element 1.2.1.6, Mining ventilation

The current ventilation analyses use two computer codes. These codes are typical of codes used for mine ventilation analysis. The codes used are identified as VNET (ventilation network analysis) and CLIMSIM (climate simulation). They are used here only to substantiate the data needs specified and there is no intent to identify these as the codes that will be used for the license application analysis. In application, these codes are interdependent in that the results of CLIMSIM are input into VNET to determine ventilation system performance. CLIMSIM is used to model the psychrometric and environmental conditions in the airways. VNET is used to model the underground airflow distribution, calculate air-flow resistance, calculate friction pressure losses, and to establish ventilation fan requirements.

The information needed to apply these ventilation codes is identified in Section 8.3.2.5.7 and reiterated as follows:

1. Radon gas emission rates--the actual value of the emission rate is required. Also, it is important to know how the emission rate varies with rock type, natural and ventilation pressures, and location within the repository. Emission rates are needed to verify that the air quantities are sufficient to sweep areas of radon and to dilute concentrations to levels specified by regulations.

2. In situ moisture in the rock and the corresponding release rate to the ventilation airstream--required as a function of time, temperature, rock type, and location within the repository.

3. As-mined drift surface roughness--a determination of the roughness for each rock type, mining and support method used.

4. Potential for airborne respirable particulates--the particulate types and quantities are required.

5. Diurnal and seasonal barometric pressure, temperature, and humidity variations at the locations of the ventilation supply and exhaust portals.

6. Elevation of ventilation entrances and exhausts.

7. Surface rock wall temperature--the surface rock wall temperature in the unventilated drifts is required to perform cool down analysis. The surface rock wall temperature is calculated using computer codes such as SPECTROM-41 series, VISCOT, ADINAT, and COYOTE. The parameters needed to use these codes are given under the analysis requirements for System Element 1.2.1.2, Drift construction.

8. Heat transfer film coefficients for the rock walls--these coefficients will be derived from other parameters. The site parameter used in this determination is the surface roughness of the rock walls. This parameter has already been identified as necessary in other parameter lists.

System Element 1.2.2.7, Waste handling ventilation

The design and operation of the system required to provide ventilation to the underground areas where waste is handled is the same as that described under System Element 1.2.1.6 (mining ventilation). The site parameters required are the same as for System Element 1.2.1.5. Temperature increases in the rock are not considered during the emplacement activities but are of concern during waste retrieval and decommissioning.

Analysis of underground repository facilities--hydrologic analysis

The preclosure hydrologic analysis that will be required by the underground design will be the analysis to determine the potential for water in the emplacement boreholes. This analysis will provide a major input to the analysis for corrosion of the borehole components. The results of the hydrologic analysis will also be used for analysis of the environment in the emplacement borehole and for the analysis of the impact of formation water on the ventilation system.

Site parameters necessary to support hydrologic analysis are identified previously in this section.

Analysis of underground repository facilities--site seismic analysis

The seismic analysis of the underground facility can be done by several methods. The methods to be used for the repository have not been specifically identified. The methods used will probably be the same as those used for the design of surface facilities to resist earthquake loading. The parameters necessary to apply the methods used are identified previously in this section.

Analysis of underground repository facilities--other underground analyses

There are other analyses that will be required for elements of the underground facility. Specifically, material compatibility analysis will be required for System Elements 1.2.2.4, emplacement, and 1.2.2.5, retrieval. The compatibility analysis will be done to ensure that the materials selected for the waste emplacement borehole liner will be compatible with the host rock and the waste package. The analysis required will principally involve corrosion analysis for determination of material corrosion and the determination of potential corrosion products. Chemical constituents of materials used in excavation or ground support will also be considered.

Analyses of repository surface elements

The information needed to develop the layout of the surface facility is identified previously in this section.

The structural analysis performed on the surface facilities will be based on currently accepted practices such as those recommended by the Uniform Building Code. Parameters necessary for the structural design of the surface facilities are identified previously in this section.

Types of analyses to be conducted

Table 8.3.2.5-16 lists some of the analyses to be conducted in support of the design. These analyses address the needs for reference calculations, sensitivity studies, tradeoff studies, and validation and verification of analytic techniques.

Rationale for reference calculations

Reference calculations are calculations whose results are incorporated in the reference information base (RIB). These calculations are based on current documented design geometries and configurations and use material properties data from the RIB. The purpose of reference calculations is to provide the DOE current referenceable design and performance analyses. Certain of the reference calculations may be used as input to other design or performance analyses, whereas others may serve as the basis for comparison in sensitivity analyses.

Reference calculations, as envisioned, will be performed for as many disciplines of the repository program as are necessary. Examples of these disciplines may include mechanical, thermal, thermomechanical, ventilation, seismic, and safety analyses.

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Table 8.3.2.5-16. List of planned analyses

Analysis name[a]	Analysis objective	Analysis type[b]
DIM (H)	Selection of borehole spacing/length and waste standoff for horizontal emplacement	T
DIM(V)	Selection of borehole spacing/length/ waste standoff and drift spacing for vertical emplacement	T
DIM(E)	Selection of excavation geometry/ dimensions	T
BORE(V)	Vertical borehole analyses using elastic and inelastic codes	R
BORE(V,S)	Vertical borehole sensitivity analyses to variations in spacing and properties	S
BORE(H)	Horizontal borehole analyses using elastic and inelastic codes	R
BORE (H,S)	Horizontal borehole sensitivity analyses varying input properties	S
LINED	Horizontal borehole liner analyses including the structural interaction of the rock with liner (3-D effects)	R
LINED(S)	Horizontal borehole liner analyses including fault intersection, canister present	R
DRIFT(H)	Elastic and inelastic drift analyses for horizontal emplacement	R
DRIFT(V)	Elastic and inelastic drift analyses for vertical emplacement	R
DRIFT(S)	Drift sensitive studies for variation of input properties for horizontal emplacement	S

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Table 8.3.2.5-16. List of planned analyses (continued)

Analysis name[a]	Analysis objective	Analysis type[b]
ANAL	Analyses on the effects of anomalies on the stability of drift and other excavations	S
VENT(V)	Time dependent heat flux and nonradial heat flow analyses for vertical emplacement	R
VENT(H)	Time dependent heat flux and nonradial heat flow analyses for horizontal emplacement	R
VENT(G)	Evaluation of radon and other gas dilution as well as moisture variations throughout the ventilation system	R
BOIL(H)	Analyses determine the time and extent of rock above boiling	R
BLAST	Structural effects of blast cooling both horizontal and vertical drifts	R
SEISMIC	Stability of underground excavations as effected by natural or induced tectonics	S
IN SITU TEMPERATURE	Determine the in situ temperature state as a function of position. Vary material properties, and boundary conditions to arrive at an applicable method which honors field data	R
ROCK MASS DEFORMABILITY PROPERTIES	Determine rock mass deformability properties for each thermal/mechanical unit using the compliant joint material model and laboratory and field data of intact rock and fractures	R

Table 8.3.2.5-16. List of planned analyses (continued)

Analysis name[a]	Analysis objective	Analysis type[b]
SMALL DIAMETER HEATER	Perform posttest thermal and mechanical analysis of the small diameter heater experiment from the G-Tunnel underground facility to evaluate rock mass response and thermal and mechanical analysis techniques	V
HEATED BLOCK	Perform posttest thermal and mechanical analysis of the heated block experiment from the G-Tunnel underground facility to evaluate rock-mass response and thermal and mechanical analysis techniques	V
ANISOTROPIC RESPONSE OF ROCK MASS	Perform a series of finite-element analyses to determine the relative effects of anisotropic material properties upon rock-mass response to in situ stress state, and supposed thermomechanical headings	S
ROCK MASS PROPERTIES	Performed analyses and update recommended rock-mass properties based on field and laboratory data	R
SLOT STRENGTH TEST	Perform pretest scoping analysis to support design of the slot strength test	S,V
SLOT STRENGTH TEST	Perform mechanical analysis of the slot strength test to evaluate rock-mass response and mechanical analysis techniques	V
SMALL DIAMETER HEATER	Perform thermal and thermomechanical analysis of the small-scale heater experiments to evaluate rock-mass response and thermal and thermo-mechanical analysis techniques	V

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Table 8.3.2.5-16. List of planned analyses (continued)

Analysis name[a]	Analysis objective	Analysis type[b]
IN SITU MECHANICAL MODEL	Analyze the regional tectonics, stress measurements, and finite-element calculations at Yucca Mountain using the compliant joint model to provide an updated in situ mechanical model recommendation of Yucca Mountain for design analyses	R
FRACTURE CHARACTER-ISTICS	Update recommended fracture characteristics-based analysis of field and laboratory data	R
HEFF QUALIFICATION	Complete verification analyses for HEFF boundary element code	V
JAC VERIFICATION	Verify response of constitutive model components for the JAC compliant joint model	V
JEM VERIFICATION (SPECTROM)	Verify response of constitutive model components for the JEM compliant joint model	V
G-TUNNEL MINING EXPERIMENT	Perform post-test mechanical analysis of the G-Tunnel mining experiment from the G-Tunnel underground facility to evaluate rock-mass response and mechanical analysis techniques	V
BENCHMARK I	Perform benchmark calculations (code comparison) between compliant joint models to evaluate isothermal mechanical response at appropriate scales	V
LABORATORY LARGE BLOCK TEST-1	Perform pretest scoping analysis to support design of the large block laboratory test	S,V

Table 8.3.2.5-16. List of planned analyses (continued)

Analysis name[a]	Analysis objective	Analysis type[b]
LABORATORY LARGE BLOCK TEST-2	Perform analysis of large block test to continue validation procedure for compliant joint models	V
YUCCA MOUNTAIN HEATED BLOCK-1	Perform pretest scoping analysis to support design of the Yucca Mountain heated block experiment	S,V
YUCCA MOUNTAIN HEATED BLOCK-2	Perform thermal and thermo-mechanical analysis of the Yucca Mountain heated block experiment	V
SEQUENTIAL DRIFT MINING-1	Perform pretest scoping analysis to support design of the Yucca Mountain sequential drift mining experiment	S,V
SEQUENTIAL DRIFT MINING-2	Perform mechanical analysis of the sequential drift mining experiment to evaluate rock-mass response and mechanical analysis techniques	V
COMPLIANT JOINT BENCHMARK 2	Perform benchmark calculations (code comparison) between compliant joint models to evaluate mechanical and thermomechanical response at appropriate scales	V
G-TUNNEL SLOT TEST	Perform posttest mechanical analysis of the G-Tunnel slot test to evaluate and rock-mass response and mechanical analysis techniques	S,V
PLATE LOADING EXPERIMENT-1	Perform pretest scoping analysis to support design of the plate loading experiments	S,V
PLATE LOADING EXPERIMENT-2	Perform analysis of plate loading experiments to evaluate rock-mass response and mechanical analysis techniques	V

Table 8.3.2.5-16. List of planned analyses (continued)

Analysis name[a]	Analysis objective	Analysis type[b]
CANISTER SCALE HEATER EXPERIMENT-1	Perform pretest scoping analysis to support design of the canister scale heater experiment	S,V
CANISTER SCALE HEATER EXPERIMENT-2	Perform thermal and thermomechanical analysis of the canister scale heater experiments to evaluate rock-mass response and thermal and thermomechanical analysis techniques	V

[a]Analysis names: H = horizontal emplacement, V = vertical emplacement, S = sensitivity, B = borehole intersection, E = excavation, N = near-field, F = far-field, G = gases, R = radiological, NR = nonradiological, and A = accident.
[b]Analysis types: T = tradeoff study, S = sensitivity study, R = reference calculation, and V = verification or validation.

Rationale for tradeoff studies

Tradeoff studies are studies in which elements or components of design are selected through choice comparisons. Tradeoff studies are typically done to select design options that will enhance functional capability and performance, increase safety of operation, will increase operational efficiency, or limit costs.

Rationale for sensitivity analysis

Sensitivity analysis will be done for numerous reasons, including

1. To determine the impact of the normally expected variations in parameters on the analyses and the design configurations.

2. To assign the quality requirements to the data needed (i.e., if the analyses using the data are only minimally or moderately sensitive to a parameter, then it will be sufficient to determine the parameter with a lesser degree of accuracy).

3. To determine the impact of design alternatives on repository function and costs.

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4. To determine the impact of data variations on the ability of the repository design to meet the required performance goals.

The following studies are examples of sensitivity analyses:

1. A study to determine the effect of the length of the horizontal emplacement borehole on repository costs.

2. A study to assess the performance impact of the emplacement borehole orientation.

3. Analysis of alternative emplacement configurations, including short horizontal borehole concepts.

Rationale for validation of codes used for analysis

A generic discussion of verification and validation of models and codes identified for performance, safety, and design analysis is presented in Section 8.3.5.20. A brief discussion of the studies that have been conducted and that will be conducted in the site characterization program to test the models and codes needed for the analysis is given below.

Thermal Codes. Previous work and tests indicate that the ability to predict accurately the heat flow and temperatures developed from the emplacement of a decaying heat source in a geologic media is possible with the currently available codes, provided that the primary heat transfer mechanism is conduction. The previous work and tests include the following:

1. Climax--an experiment at the NTS performed in granite in which spent fuel was placed into boreholes drilled in the floor of a mined drift.

2. Project Salt Vault--an early experiment performed for salt in Lyons, Kansas. This experiment involved the placing of electrical heaters into salt. The temperatures in the salt surrounding the heaters was monitored and compared with predictions.

3. WIPP--extensive heat transfer experiments have been conducted in salt at the Waste Isolation Pilot Plant (WIPP) facility near Carlsbad, New Mexico. These experiments placed electrical heaters into holes bored into the salt. The temperatures developed in the salt are monitored and compared to temperatures predicted using predictive codes.

4. G-Tunnel--heat transfer experiments have been conducted at the G-Tunnel complex at the NTS. These experiments are conducted in volcanic tuffs.

Properties and characteristics of the Yucca Mountain site that will be used to evaluate the thermal codes will be obtained in laboratory tests (Section 8.3.1.15.1.1), from site heater tests (Section 8.3.1.15.1.6), and from the study of in situ temperature conditions.

Mechanical codes. As outlined previously, three levels of approach are to be applied to problems requiring mechanical analyses; these include the following:

1. Tunnel index methods--these methods have been proved for underground excavations without the addition of heat. Qualification of these methods will include an incorporation of the thermally induced stress into support designs derived using these methods.

2. Boundary element methods--these methods have been recently applied to evaluations of underground stability. Within the limits of the intended applications of these methods, they require further qualification only through validation.

3. Finite-element methods--as currently developed, these methods allow for the most complex geometry, boundary conditions, and material behavior to be included in the analysis to evaluate underground stability. The current approaches to modeling rock-mass mechanical response include treating it as a linear elastic solid, as a continuum composed of intact rock and fractures, or, for applications near faults, as a continuum with discrete faults.

The mechanical response of the rock mass should be evaluated for ambient as well as increasing temperature conditions.

The measured mechanical response should be used to evaluate the applicability of the mechanical material models. For example, a linear elastic model may adequately represent the rock-mass response for certain load conditions. The constitutive description of the rock as a composition of linear elastic intact rock and nonlinear fractures should be evaluated as part of the qualification procedure. Each of the approaches will be carefully evaluated as regards applicability of the method and associated constitutive models; such evaluations will rely heavily upon actual observations during exploratory shaft facility construction and testing. Properties and characteristics of the host rock that will also be used to evaluate these codes will be obtained in studies in the laboratory (Section 8.3.1.15.1.3) and in situ (Sections 8.3.1.15.1.6, 8.3.1.15.1.7, and 8.3.1.4.3.2) and in design verification studies (Section 8.3.1.15.1.8). Thermomechanical codes will be evaluated against the results of the heater test (Section 8.3.1.15.1.6). The behavior of fractures will be modeled and the results will be evaluated in the laboratory studies (Section 8.3.1.15.1.3).

Seismic codes. Methodologies have been derived for predicting ground motion and seismic hazards (Vortman, 1986) based on limited field data. These methods require testing through the planned field program (Section 8.3.1.17.3.5).

Underground ventilation codes. The codes used for the design of the underground ventilation system should not require additional work for validation. This is because

1. These codes have been used for the design of numerous conventional mine ventilation systems and have successfully predicted the system performance.

2. The codes are based on older codes that have historically been successfully used for underground ventilation design. The codes used incorporate improvements to these older codes.

These codes will be evaluated in the in situ design verification study (Section 8.3.1.15.1.8).

8.3.2.5.8 Information Need 4.4.8: Identification of technologies for surface facility construction, operation, closure, and decommissioning

This information need evaluates the effectiveness of those elements of the site that affect the design, construction, and operations of the repository facilities primarily during the preclosure period using reasonably available technology. If it is determined that any portion of the repository facilities cannot be built with reasonably available technology, then questions may be raised as to the feasibility of designing and constructing a repository facility that is safe and effective. In order to perform this evaluation, the characteristics of the waste and waste packages, surface conditions of the site, tectonic and igneous activities at the site, etc., must be understood because of their direct relationships to the design process and the operations of the repository. The evaluation of whether or not there is reasonably available technology will be based on potential of each associated system element to meet the performance goals for that element. The evaluation criteria to be used are as follows:

1. Determine that the proposed construction techniques have been used successfully in other applications or that there is no reason to believe that the techniques cannot be applied successfully at the repository.

2. Determine that design loadings and performance goals similar to those expected for the repository have been used for other surface facilities, including seismic loads, thermal loads, surface conditions, foundation conditions, flood and tornado type loads, and radiation containment, or that there is no reason to believe that they cannot be applied successfully at the repository.

3. Determine that operations similar to those needed to operate the repository have been performed successfully at other installations, or that there is no reason to believe that they cannot be applied successfully at the repository.

4. Determine that technology for constructing, predicting design and performance, and operating the repository can be demonstrated (by proof-of-principle demonstration, if appropriate) before license application to ensure its successful application in the repository.

The product of this information need will be evaluations that determine if the surface facilities can be constructed, operated, closed, and decommissioned using reasonably available technology.

Details of each of these evaluations along with their results will be provided in the different chapters of major design reports (e.g., advanced conceptual design report and licensing application design report). In addition, topical reports will be generated on some of the more important aspects (e.g., seismicity-tectonics and the associated design, flood control measures, foundation and structural design of waste handling buildings, and waste handling operations).

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

In this document, the use of reasonably available technology is reflected clearly in the performance goals described in the issue resolution strategy for this issue and is discussed in Section 6.4. Section 6.2 contains the current design and is the basis for statements made concerning technical feasibility.

Chapters 3, 4, and 5 of the SCP-CDR describe the current design, and Chapter 8 briefly discusses the use of reasonably available technology for the surface facilities.

Parameters

The determination that reasonably available technology is being used in the surface facilities relies heavily upon information produced by other information needs, including the following:

1. Reference designs for repository surface facilities.
2. Reference designs for waste containers.
3. Waste quantities and characteristics.
4. Repository operations plan.

In addition, a number of site parameters have been identified for input to the assessment of reasonably available technology. These parameters should be interpreted generally as being needed in the immediate vicinity of the surface facilities; they include the following:

1. Topographic characteristics of the surface facilities site.

2. Local meteorological conditions at the site.

3. Characteristics of the surface water systems at the site.

4. Flood recurrence intervals and levels at the site.

5. Location and characteristics of near-surface structural features of the site.

6. Location of adequate water supplies at the site.

7. Rates and magnitudes of igneous activity at the surface facilities.

8. Fault movements and tectonic activity at the surface facilities.

9. Ground motion at the surface facilities from man-made or natural seismic events.

10. Soil and bedrock properties at the surface facilities, static and dynamic moduli, bearing capacity, shear modulus and damping versus strain and depth from surface, shear wave velocity profile or a function of depth from surface, depth and extent of alluvium, settlement, etc.

11. Attenuation of ground motion with depth at the site.

Logic

The design of the surface facilities depends on site parameters. In particular, foundation design, flood protection system design, and evaluations of seismic effects on surface facilities require data. The data requirements for the design and supporting analyses are defined in Information Needs 4.4.5, and 4.4.7; data required for technical feasibility evaluations are generally limited to a need to confirm that the site data is not substantially outside the range currently being used for design. The logic used to identify the data needed is to determine the potential impact of being outside the current design basis values. This logic is displayed in the following:

1. If the underlying soil or rock conditions do not provide adequate strength to support the facility buildings or if they are susceptible to large settlements not acceptable for the repository buildings or operations, then construction or operation procedures may be more complicated than the currently accepted state-of-the-art techniques. Therefore, data are needed to confirm current design basis data that indicate that construction will be within state-of-the-art techniques.

2. Profiles of shear wave velocity, shear modulus, damping, and the extent of alluvium affect the soil-structure interaction on the loads on the structures due to earthquake loads. If these parameters are determined to be substantially beyond those used in the design, then modification of the existing analysis and design methodology may be required to produce designs that are capable of development with reasonably available technology.

3. Data on ground motion at the site from man-made or natural seismic events, significant surface fault rupture due to fault activities at the site, and effects of significant igneous activity at the site are needed to determine if current design basis expectations are acceptable.

4. Local meteorological conditions, topography and surface conditions, flood recurrence intervals and levels at the site, and characteristics of the upland drainage areas impact the flooding potential and may influence location of the surface facilities and the underground accesses. Technical data are needed to determine if the

planned flood protection systems are feasible at the identified locations for the surface facilities.

Other items important in determining if reasonably available technology is being used will be described in the repository design plan. Only the site-related items have been described here.

The criteria identified in the introduction to this information need will be applied at each phase in the design to assess if reasonably available technology is being used. These evaluations will be documented in the major design reports (advanced conceptual design, licensing application design, and final procurement and construction design) and, where needed, in supporting topical reports.

Technical procedures to be used for characterizing the listed parameters should be consistent in level of Quality Assurance control with similar NRC Regulatory Guides and American Society for Testing and Materials Standards. Quality assurance requirements to be used will be consistent with the DOE Quality Assurance Program, as described in Section 8.6.

8.3.2.5.9 Information Need 4.4.9: Identification of technologies for underground facility construction, operation, closure, and decommissioning

The use of available, proven technology in the underground facilities of the repository will provide assurance that the repository can be successfully constructed, operated, closed, and decommissioned.

The determination that reasonably available technology is being used will be based on the following criteria for the underground facility:

1. The proposed construction techniques have been successfully used in other applications under similar construction conditions or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time.

2. The techniques proposed for the construction of shafts, ramps, and underground openings have been successfully used in similar geologic and hydrologic conditions or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time.

3. The operations necessary to emplace, retrieve, and transport the waste have been based on operations that have been successfully demonstrated in other facilities or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time.

4. The items necessary for construction and waste handling that require development have been demonstrated before license application to ensure their successful performance in the repository.

The products of this information need, in aggregate, will constitute the assessment that determines that all aspects of the underground facility can be constructed, operated, closed, and decommissioned using reasonably available technology. This assessment will be included in a summary chapter of the documents that define the reference preclosure repository designs.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Chapter 6 of this document describes the current repository design in Section 6.2 and summarizes the status of this issue in Section 6.4.10. Chapter 2 contains the data base of geoengineering data used to support that design.

Chapters 3 through 5 of the SCP-CDR (SNL, 1987) describe the current repository design, while Chapter 8 summarizes the status of work toward this issue.

Parameters

The determination that reasonably available technology is being used relies heavily upon information developed in other information needs under this issue, including the following:

1. Repository operations plan.

2. Lists of equipment used in repository and anticipated equipment performance.

3. Design analyses.

The parameters needed for each of the applicable system elements for subsystem evaluations are listed as follows:

System Element 1.1.2, Subsurface

1. Host rock upper and lower contacts.
2. Location and properties of geologic structures.
3. Surface topography.
4. Site hydrology.

    a. Perched water.
    b. Flow-through structures.

5. Subsurface seismic characteristics.

    a. Peak acceleration.
    b. Peak particle velocity.
    c. Frequency spectrum.

System Element 1.2.1.1, Access construction (shafts and ramps)

1. Design analysis results on shaft and ramp stability (Information Need 4.4.7).

2. Rock characteristics (same as in Information Need 4.4.7).

3. Construction, demonstration, and monitoring results from exploratory shaft.

System Element 1.2.1.2, Drift Construction

1. Design analysis results on drift stability (Information Need 4.4.7).

2. Rock characteristics (same as in Information Need 4.4.7).

3. Construction, demonstration, monitoring results, and maintenance requirements from exploratory shaft facilities (ESF) including construction through structural features and lithophysae.

System Element 1.2.1.3, Borehole construction

1. Rock characteristics.

2. Consideration of results from any Development Prototype Boring Machine (DPBM) testing activities in G-Tunnel and ESF.

   a. Fracture characteristics of host rock.

   b. Abrasiveness of host rock.

   c. Rock-cutting characteristics, including dependence on in situ stresses.

   d. Existence of free water in the rock mass.

System Element 1.2.2.4, Emplacement

Equipment designs and demonstrations (see Information Need 4.4.6)

System Element 1.2.1.5, Water removal

Confirmation of design assumptions on limited available water quantities

System Element 1.2.2.5, Retrieval

See Issue 2.4 (waste retrievability, Section 8.3.5.2)

Logic

The parameters identified as required to evaluate the level of technology necessary for design, construct, and operate the repository will be used to develop the repository design and the design supporting analysis. These designs and associated analyses will be compiled in the milestone

reports identified for this information need. The results of the design and analysis process will be judged according to the criteria specified to conclude that existing technology is sufficient.

The logic used to identify the site parameters needed for reasonably available technology assessments is to identify the relevant system elements, evaluate the operations within each identified element, and determine the site data needed to support the design (and demonstration) of the system element. Those underground system elements identified in the issue resolution strategy for this issue that must be evaluated to determine if advanced, untried technology is required to construct, operate, close, and decommission the underground portion of the repository are as follows:

System element	Name
1.1.2	Subsurface
1.2.1.1	Access construction
1.2.1.2	Drift construction
1.2.1.3	Borehole construction
1.2.1.4	Rock handling
1.2.1.5	Water removal
1.2.1.6	Mining ventilation
1.2.2.4	Emplacement
1.2.2.5	Retrieval
1.2.2.7	Waste ventilation
1.2.4.1	Underground closure

For each of the identified system elements, the explanation is provided below regarding the parameters needed to determine if reasonably available technology is being used. For numerous system elements, the same data are needed to establish technical feasibility as for design or analyses; hence, references to other information need discussions are common.

System Element 1.1.2, Subsurface

The ability of the subsurface to meet repository requirements without the need to use advanced, untried construction methods or operational procedures will depend on evaluations based on the following information:

1. Vertical location of the upper and lower contacts of the chosen repository formation at selected points within the potential repository area. This information will determine if the thickness of the acceptable host rock is adequate to support repository construction.

2. Location and geoengineering properties of geologic structures. The location of geologic structures will be used in the design of the subsurface facility; primarily, the information will be used to locate various parts of the underground facility and to determine the possible need for supplemental ground support.

3. Surface topography. The surface topography should be mapped to provide contours for the entire site area. This information will be used to establish overburden thicknesses.

4. Site hydrology. The existence of any overlying perched water reservoirs and aquifers must be determined. The existence of any underlying aquifers must be determined. These potential water sources must be evaluated in regard to their potential flow and hydraulic head potentials at the repository horizon. Flow through fractures or major geologic structures should be identified and quantified where possible.

5. Subsurface seismic characteristics. Values of the peak seismic accelerations, the peak particle velocity, and the frequency spectrum will be needed.

System Element 1.2.1.1, Access construction (shafts and ramps)

Note that the shafts and ramps, which provide the access to the underground, do not include any lateral development from the point of intersection with the repository horizon.

The conclusion that the shafts and ramps can be constructed using conventional techniques will be based on the design analysis and previous construction experience. If the analysis shows that the stresses are within the load carrying capabilities of the rock and that the selected support system and that other rock properties, such as fracture characteristics, are also amenable to conventional support systems, then it can be concluded that the construction can be done using existing technology.

The design process and analysis methods for the shafts and ramps are identified in Information Need 4.4.7. This information need also identifies the rock properties of the rock that are needed to perform the analysis.

System Element 1.2.1.2, Drift construction

The emplacement drifts are the elements of the repository where waste is emplaced. Access drifts are provided to connect the main haulageways with the emplacement drifts. A consequence of the waste emplacement in the drifts is an increase in the temperature of the rock. The maintenance of openings in a geologic media subjected to heating is uncommon; consequently, additional analysis beyond that required for the accesses (shafts and ramps) will be required to ensure that the openings can be maintained without the need for new, untried, or highly costly support systems. If the analyses show that the stresses induced by both excavation and waste-induced heating are within the load carrying capabilities of the rock and the selected support system and that other rock properties, such as fracture characteristics, are also amenable to support systems, then it can be concluded that the construction can be done using existing technology.

The analysis methods that are used to analyze the drifts for both the construction (preheated phase) and the operational phase where temperatures are increased are presented in Information Need 4.4.7. This information need also identifies the parameters needed to use these analysis methods.

The long-term stability of the drifts will be enhanced by a maintenance program that will ensure usability of the drifts to the extent required for inspection, maintenance, and retrieval. New or excessively costly ground support systems might be required if usability over the operational period is without the provision of a maintenance program. With a maintenance program the design of the long-term support systems is not expected to require new technology. In addition, construction demonstrations, monitoring results, and maintenance observations planned in the exploratory shaft facility will provide confirmation (or lack of) that the planned construction techniques can be used, even though structural features and in areas of relatively high lithophysae content.

System Element 1.2.1.3, Borehole construction

The borehole is defined here to include the actual hole bored into the host rock and the liner system that is installed into the bored hole to assist retrieval. The ability to construct the waste disposal boreholes and to design and install the borehole liner using reasonably available technology will depend on the same parameters identified for the development prototype boring machine demonstration testing discussed in Information Need 4.4.6.

System Element 1.2.1.4, Rock handling

Mining demonstrations conducted in the G-Tunnel complex at the Nevada Test Site indicate that rock fragmentation size produced by blasting is compatible with all commonly used rock handling systems. Based on these results, there is no need for additional site parameters or for advanced technology to design the repository rock handling system.

System Element 1.2.1.5, Water removal

The unlikely existence of large quantities of water in the mining horizon or in the strata penetrated by the accessways nevertheless could result in the need for high capacity water removal systems. Currently available information does not indicate the potential for water inflow sufficient to cause the need for advanced or unproven technology; thus, no specific parameter needs are identified except to indicate that confirmation is needed for design assumptions made regarding limited quantities of available water.

System Element 1.2.1.6, Mining ventilation

To determine if the ventilation of the mine (underground facility) will require systems that are beyond currently available technology, it will be necessary to analyze the ventilation based on the requirements for air quantity, quality, and cooling capacity. This determination will identify any area that might require ventilation flow quantities that necessitate excessive drift or shaft sizes, areas where the cooling requirement cannot be met with currently available hardware, and areas where condensate formation could occur and might hamper operations or present potential for spread of contamination. The analytical methods for the ventilation system and the parameters needed to apply these methods are identified in Information Need 4.4.7.

System Element 1.2.2.4, Emplacement

The capacity to emplace the waste into the disposal envelope using currently available technology depends on (1) the development and demonstration of the required equipment (Information Need 4.4.6), (2) the characteristics of the waste package (Information Need 4.4.2), and (3) the shielding characteristics of the host rock. Of these three items, only the shielding characteristics of the host rock require the acquisition of site data, and the data needed has been identified in Issue 2.7 (Section 8.3.2.3).

System Element 1.2.2.5, Retrieval

The ability to retrieve the emplaced waste using equipment and procedures that are within the capabilities of current, reasonably available technology will be evaluated in Issue 2.4. (Section 8.3.5.2); hence, no data needs are related to retrievability.

System Element 1.2.2.7, Waste handling ventilation

The design and operation of the system required to provide ventilation to the underground areas where waste is handled is the same as that described under System Element 1.2.1.6, mining ventilation. The parameters required are the same as for System Element 1.2.1.6. Temperature increases in the rock are not considered during the emplacement activities but are of concern during waste retrieval and decommissioning.

System Element 1.2.4.1, Underground closure

The operations required to close the underground portion of the repository are primarily based on current techniques and equipment. The potential exception is backfilling. If backfilling is done during decommissioning, the following are of concern:

1. The required installed density for the backfill. If the densities are beyond the capabilities of existing equipment, a development program may be required. The need for high densities is not presently anticipated.

2. The amount of dust generated during backfilling and the water control requirements during backfilling. There is a potential for the generation of large quantities of dust during a backfilling operation. Coordination of dust suppression techniques with water control requirements will be required.

Other items important to determining if reasonably available technology is being used will be described in the repository design plan. Only the site related items have been described here.

The criteria identified in the introduction to this information need will be applied at each phase in the design to assess if reasonably available technology is being used. These evaluations will be documented in the major design reports (advanced conceptual design, licensing application design, and final procurement and construction design) and, where needed, in supporting topical reports.

8.3.2.5.10 Information Need 4.4.10: Determination that the seals for shafts, drifts, and boreholes can be placed with reasonably available technology

This information need will determine if reasonably available technology is available for emplacing shaft, drift, and borehole seals. To determine if reasonably available technology is being used, repository and seal designs must be available along with the operations plan, the design criteria, and selected placement methods.

The product of this information need will be evaluations that determine if reasonably available technology is being used to emplace seals. Summaries of each evaluation will be provided in major design reports (e.g., advanced conceptual design, license application design, final procurement and construction design). In addition, topical reports may be generated on some of the more critical components.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The technology used to emplace seals depends, to a large degree, on the design of the repository and the desired performance of seals. The design of the repository and current sealing concepts are presented in Section 6.2 of this document. The status of technology evaluations for seals is included in Section 6.4.

In the SCP conceptual design report (SCP-CDR) (SNL, 1987), the seal design concepts are given in Sections 5.2 and 5.3, and the repository design is described in Chapter 4.

Parameters

The parameters or information needed to determine if reasonably available technology can be used for emplacing seals are as follows:

1. Reference preclosure repository designs (Information Need 4.4.5).
2. Reference seal designs (Information Need 1.12.4, Section 8.3.3.2.4).
3. Placement methods (Information Need 1.12.3, Section 8.3.3.2.3).
4. Plans for repository operations (Information Need 4.4.3).
5. Repository design requirements (Information Need 4.4.4).
6. Equipment development and demonstration (Information Need 4.4.6).

Logic

Use of proven technology to emplace sealing components is an integral part of the strategy that has been adopted in the Yucca Mountain Project seal program. This strategy will provide greater assurance that the seals can be emplaced to specified design requirements. Further, the use of proven technology will lead to limited demonstration requirements, thereby limiting potential schedule constraints in being able to license the repository. Site parameters important to the sealing program are defined in Information Need 1.12.2, (seal materials, Section 8.3.3.2.2), and Information Need 1.12.3, (placement methods, Section 8.3.3.2.3) and are therefore not repeated here.

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Determination that sealing components can be placed with proven technology will be made using the performance goals, design requirements, seal designs, equipment requirements, and the list of planned operations. If the design requirements cannot be readily met using available materials or emplacement technology, then multiple options to achieving performance goals will be investigated through the design process. For example, redundant seal designs, through multiple materials or over-designs, is one way that performance goals can be achieved. The materials testing portion of the Yucca Mountain Project seal program is currently investigating granular as well as the cementatious-based materials to give a greater flexibility in sealing the repository. If it is determined during design that other categories of seal materials are more effective in achieving sealing goals, these categories will be evaluated. Emplacement feasibility will be one major consideration in selecting the appropriate materials and designs.

At each phase in the design, the seal designs will be evaluated to assess if reasonably available technology is being used (planned) for seal emplacement. The evaluations will be documented in the major design reports (advanced conceptual design, license application design, and final procurement and construction design) and, where needed, in supporting topical reports.

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8.3.3 SEAL PROGRAM

This section describes the activities required to develop designs and demonstrate performance of seals to be placed in shafts, ramps, drifts, and boreholes. Section 8.3.3.1 provides an overview of the Yucca Mountain Project (formerly the Nevada Nuclear Waste Storage Investigations (NNWSI) Project) seal program and describes the technical approach of the development program. It is important for the reader to understand the planning basis for the seal program. Various aspects of the seal program are discussed in different places in this document (i.e., site hydrology in Chapter 3, seal concepts in Section 6.2, and seal analyses in Section 6.4). The following topics are discussed in more detail in the sections noted:

1. Seal environment--the anticipated environment used to ascertain the need for and performance of sealing components (Section 8.3.3.1.1).

2. Seal components testing--the laboratory and field testing currently planned in support of the seal program (Section 8.3.3.1.2).

3. Seal design--current designs and design concepts for seals (Section 8.3.3.1.3).

4. Seal modeling--modeling and code development for designing and assessing performance of seals (Section 8.3.3.1.4).

Section 8.3.3.2 (Issue 1.12, seal characteristics) describes the future work planned in support of the sealing program with emphasis upon those activities that use data from site characterization. The discussion includes a preliminary performance allocation for the sealing system as evidenced by the performance measures and goals established for the system and its components. In addition, the site characterization data (parameters) needed in support of the seal program are identified. The discussions of future activities are organized on the basis of four information needs that must be satisfied to resolve the seal characteristics issue.

While the specific wording of Issue 1.12 appears to address only shaft and borehole seals, a broader interpretation is adopted in Section 8.3.3.2. To provide a complete and unified discussion of the sealing system for the proposed Yucca Mountain mined geologic disposal system (MGDS), Issue 1.12 addresses all sealing components within the underground facility in addition to the seals for shafts, ramps, and boreholes.

8.3.3.1 Overview of the seal program

The primary objective of the Yucca Mountain Project (formerly the Nevada Nuclear Waste Storage Investigations (NNWSI) Project) repository sealing program is to develop sealing designs that will act to ensure that water will not compromise the containment and isolation of radionuclides from the accessible environment.

Because of the timing of the activities, the seal program is somewhat different from other design-related activities. The repository surface facilities, the accesses, and portions of the underground facility will be constructed shortly after construction is authorized; the remainder of the underground facilities will be constructed and waste packages emplaced during repository operations. The seals, on the other hand, will not generally be installed until the repository is decommissioned. If conditions anticipated as a result of exploratory drilling are confirmed during excavation of the exploratory ramp and shaft, it will be unnecessary to install either permanent or temporary shaft or ramp seal components at the time of access construction. Additional conditions such as sheet flooding will be further analyzed during the design to confirm that operational seals are not required. If a shaft is contructed, the shaft liner can be removed to emplace seal components later. Several different liner removal techniques are discussed in Fernandez et al. (1988). Because the liner does not provide structural support for the formation, removal of the liner is not expected to cause significant additional stress redistribution or to significantly modify the permeability.

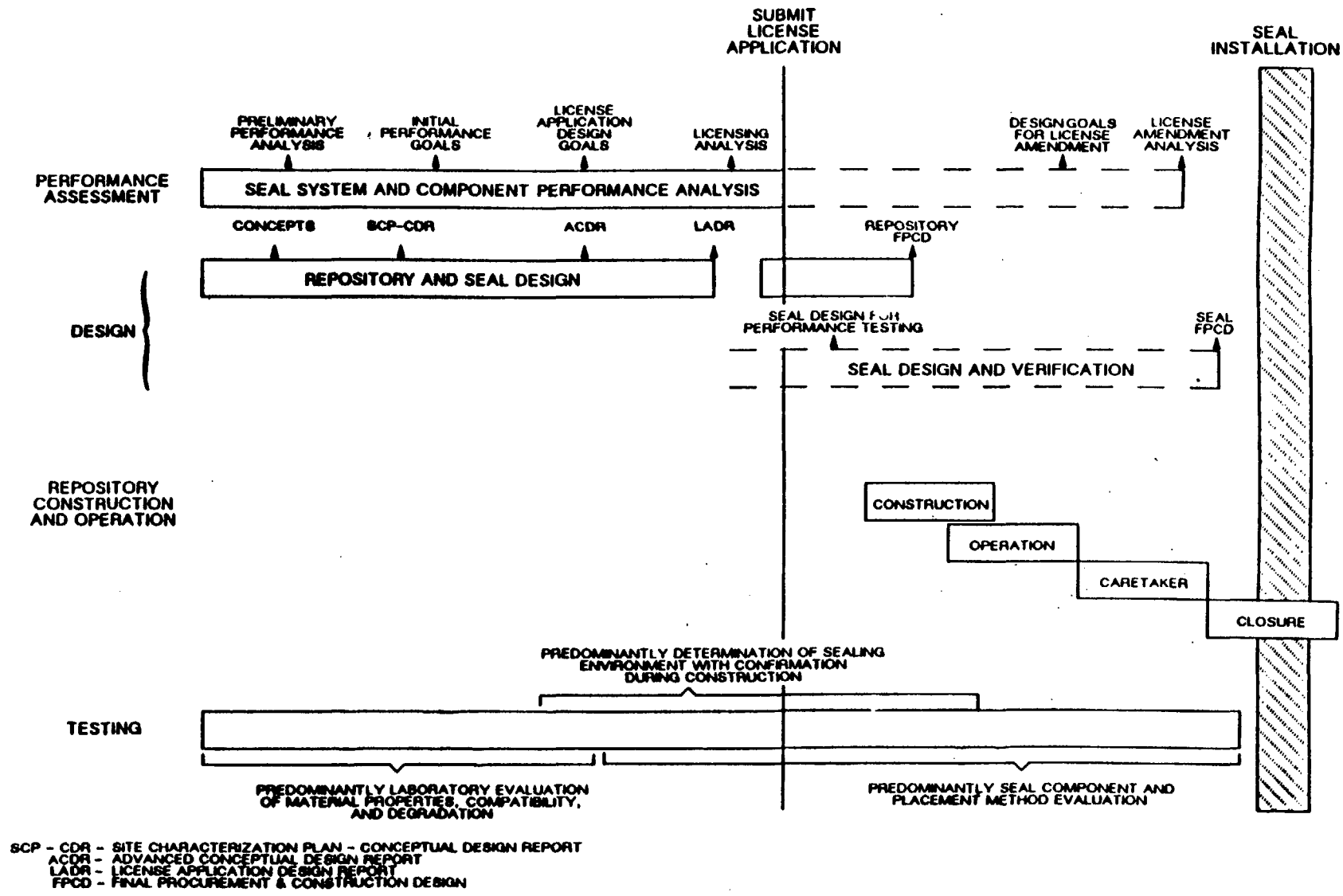
The sequencing of testing in support of the seal program also depends upon the planned timing for the installation of the seals. As noted in Figure 8.3.3.1-1, there is substantial time for testing of seal components after the initiation of repository construction. The timing is consistent with the NRC requirements (10 CFR Part 60, Subpart F) for the performance confirmation program, which note

1. It is anticipated that testing will be conducted "During early or developmental stages of construction..." (10 CFR 60.142(a)).

2. "Test sections shall be established to test the effectiveness of borehole and shaft seals before full-scale operation proceeds to seal boreholes and shafts" (10 CFR 60.142(d)).

Both of these statements indicate that the sealing testing will continue after the license application, however, enough testing will be performed during site characterization to support the postclosure performance of sealing components.

The seal designs included in the license application design (LAD) may not be the designs used for actual construction of the seals since several (possibly as many as 50) years will pass before the seals are installed. During these years, many of the assumptions made in the development of the seal designs will be evaluated as data from access and underground facility construction becomes available. Similarly, data obtained from potential testing of seal components during repository operations will be available as a basis for design modifications. It is reasonable to expect that additional



SCP - CDR - SITE CHARACTERIZATION PLAN - CONCEPTUAL DESIGN REPORT
ACDR - ADVANCED CONCEPTUAL DESIGN REPORT
LADR - LICENSE APPLICATION DESIGN REPORT
FPCD - FINAL PROCUREMENT & CONSTRUCTION DESIGN

Figure 8.3.3.1-1. Anticipated sequencing of sealing activities.

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knowledge will be incorporated into the final design of the seals. The role of the LAD for seal components is, therefore, to serve as the basis for analyses that will be included with the license application to establish the following:

1. The technology for constructing seals is reasonably available.

2. There is reasonable assurance that the seals have been designed so that, following permanent closure, they do not become pathways that compromise the geologic repository's ability to meet the postclosure performance objectives.

However, during the pre-license application period, several laboratory or bench-scale tests may be performed to increase the confidence that performance goals can be met. These pre-license application tests could include the following:

1. Laboratory or bench-scale testing to determine the rate of movement of fines into fractures as a function of flow volume.

2. Laboratory testing to determine index properties for the emplacement of grout and earthen or cementitious materials.

If the results of the laboratory test program indicate a potentially significant effect, then it may be necessary to perform a siltation-filtration test at the repository horizon with the addition of fines. The field test in which floor infiltration rates are made and compared with predicted flow rates through the use of fundamental constitutive relationships and modeling will serve to confirm the current understanding of infiltration rates at the repository horizon. If the results of laboratory testing indicate the need for removal of fines from the floor, then the effect of this treatment may also need to be investigated in the field test.

The post-license application tests may include small-scale in situ testing to examine specific design issues that evolve from the advanced conceptual design trade-off studies. The development for the need for specific sealing-related tests will continue during the advanced conceptual and license application design periods. During these periods, trade-off studies will be performed to give direction to the sealing design efforts and, subsequently, to the tests necessary to confirm performance or assumptions used in the design process. The entire seal design process, which culminates in the final procurement and construction design for the seals, will include the results of performance confirmation testing of seal components. This will include modification of sealing methods and concepts that might be necessary if the currently proposed sealing methods prove to be inadequate during performance confirmation testing. The discussions of the seal program in this document are structured around the efforts leading up to and required for the construction authorization application. The seal program includes the following activities:

1. Defining the sealing concepts.

2. Establishing performance goals and design requirements.

3. Developing the conceptual designs for sealing components.

4. Developing the license application design.

5. Establishing the properties of the sealing materials planned for use.

6. Evaluating the performance of sealing components at each stage in the design process.

8.3.3.1.1 Seal environment

The site hydrology is the dominant aspect of the environment for the seals. The current understanding of the site hydrology is described in Chapter 3. The partially saturated nature of the Topopah Spring Member in which the repository would be located, the anticipated relatively low water flux through the unit, and the potential for flow through discrete fractures or faults are important hydrologic aspects that require further evaluation. Other aspects of the seal environment that require consideration are related to surface rainfall and the potential for flooding, the stress and temperature fields to which the seals would be exposed, the bulk chemistry of the formation and the chemistry of the ground water, the potential for seismically induced forces or motion, and (principally for the borehole seals) the flow-related characteristics of the regions in the saturated zone below the repository.

Specific site information needed for the design and evaluation of the seals is identified in Section 8.3.3.2.1. Information such as the saturated hydraulic conductivity, gradational analyses, compressibility of ramp or shaft fill, borehole construction, and geologic logs associated with specific boreholes, will support the design process in the selection of the appropriate methods to emplace sealing components. Site information needed to validate analytical methods may include hydrologic characterization of the Topopah Spring Member (TSw2). Specific properties required are unsaturated matrix properties and the drainage capacity of the TSw2 unit. Prevalence of water-producing zones, if any, and the hydrologic nature of the Ghost Dance fault, the area underlying Drill Hole Wash, and the rock matrix will all be important site information needed to select the most appropriate sealing designs. The description of data needed in support of establishing or confirming the seal environment is based in part on the analysis work completed to date and the seal design concepts being used; these analyses and designs are summarized in Sections 6.4.3.2 and 6.2.8, respectively.

8.3.3.1.2 Seal components

In the Yucca Mountain mined geologic disposal system (MGDS), discussed in Section 8.2, the seals are identified as parts of two subsystems:

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System Element	Description
2.2.3	Shaft and borehole seals subsystem
2.2.2.3	Repository seals and backfill subsystem (part of the repository engineered barriers)

A sealing component is a specific engineered structure that is part of one of these two system elements. The components (or sealing system elements) discussed below are based mostly on the work of Fernandez and Freshley (1984), which specifically addressed a repository located in the unsaturated portion of Yucca Mountain; the concepts of Fernandez and Freshley were modified during the development of the Site Characterization Plan-Conceptual Design Report (SCP-CDR) (SNL, 1987).

For a shaft, the components of the seals being considered are surface cover, shaft collar cores, anchor-to-bedrock plug and seal, settlement plugs, shaft fill, and the repository station seal (refer to Section 6.2.8 for further discussion of the components). For the Yucca Mountain site, ramps are planned (in addition to shafts) as a means of repository access. The seal components for the ramps are similar to those for the shafts. For the current concepts, the principal component of the seals for the boreholes is the seal in the portion of the borehole that penetrates the tuffaceous beds of Calico Hills; the remainder of the borehole may be filled with a granular material or a cementitious material as needed to control possible water inflow from the surface or gaseous movement of radionuclides from the repository. Decisions on which boreholes may need to be sealed will be made for each specific borehole with adequate consideration given to the effects of water and gas flow, including potential thermal effects resulting from the repository. Further discussion of the logic regarding which boreholes may need to be sealed (including location, depth, and distance from the site boundary) is provided in Fernandez et al. (1987) and in Section 8.3.3.2.

For the repository seals, the principal concern is related to options for sealing a discrete fault or fracture zone that may contain water. Options under consideration are discussed in Section 6.2.8.6 for a wide range of inflow. The determination of whether or not such inflow is credible at the Yucca Mountain site is one of the reasons for tests to be conducted in the exploratory shaft facility relative to structural features (Ghost Dance fault, Drill Hole Wash). Potential components for these options include excavation of a channel in a drift floor to constrain flow; small dams placed in drifts to impede lateral flow of water; and emplacement of physical barriers of bentonite, clay, or cementitious materials on each side of the flow to divert the flow downward and away from the waste packages.

The long-term compatibility of sealing components with their environment must be considered to ensure that long-term performance of the sealing components is acceptable. The testing program to provide data for assessing this compatibility is described in Section 8.3.3.2.2. These tests are intended to quantify the initial and (where possible) the altered physical, hydrologic, mechanical, and thermal properties of the seal materials. Additionally, the chemical stability of the materials and their reactivity with the surrounding formation are being assessed for various components.

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Currently in the Yucca Mountain Project sealing program, a broad range of sealing options and associated design requirements are proposed to provide assurance that performance goals can be met even if unanticipated conditions are encountered. Considering these sealing options and the associated design requirements, several material categories were recommended for future study. These categories are as follows:

1. Concrete.
2. Grout.
3. Crushed tuff.
4. Crushed tuff and clay.
5. Crushed tuff with fines removed.

The specific requirements or conditions considered in selecting these categories included hydraulic conductivity, strength or density, emplacement consideration, the potential adverse influences of seals on ground-water chemistry, and emplacement conditions. The current material preference in the Yucca Mountain Project sealing program is to use earthen materials, specifically crushed tuff, for as many applications as possible to minimize (1) potential degradation of physical properties and (2) potentially adverse effects on ground-water chemistry in the repository environment. In some locations cementitious materials may be more appropriate.

In 1987, the Stripa Task Force on Sealing Materials and Techniques conducted an overview and issued a state-of-the-art report on acceptability of different seal materials. The task force, composed of technical experts from the USA, Sweden, Canada, Switzerland, United Kingdom, Finland, and Japan, considered the following properties of prospective seal materials:

1. Permeability.

2. Thermal stability.

3. Emplaceability and resistance to fracturing.

4. Toxicity.

5. Avoidance of materials that might impair overall system performance, e.g., organic sealants.

6. Longevity.

After screening a multitude of material types, the task force concluded that cementitious materials and clay materials had a high probability of creating acceptable seals in virtually all repository environments (Coons et al., 1987). The bases for this conclusion include the low intrinsic permeabilities that can be achieved by clays and concretes, their thermal stability, their ease of emplacement, and their potential to perform satisfactorily overtime. These properties are discussed briefly in the following paragraphs.

Earthen materials (clays and crushed rock) can achieve hydraulic conductivities of less than 10^{-10} cm/s depending on the content of clays. For example, a value of 10^{-10} cm/s can be obtained from a mixture of crushed tuff with 30 percent Na-bentonite (Fernandez et al., 1987).

The range of typical concrete hydraulic conductivities is 10^{-8} to 10^{-6} cm/s while values of 10^{-10} cm/s have been achievable (Mather, 1967). Values obtained by the Yucca Mountain sealing program for two grouts and one concrete ranged from 1.6×10^{-10} to 9.5×10^{-10} cm/s (Fernandez et al., 1987).

Low hydraulic conductivities have also been achieved by other programs for clay mixtures (Wheelright et al., 1981; Westik et al., 1983; Dixon and Gray, 1985) and cementitious mixtures (Gray, 1986; Hooton, 1986).

Clays and portland cements have the ability to generate low permeability at the seal-rock interface and to heal or resist fracturing. In clay materials these properties are produced by the swelling of Na-montmorillonite (a mineral in bentonite) that occurs due to the uptake of water (Pusch, 1986). In portland cement these properties are generated by chemical reactions across the interface combined with high strength (Roy et al., 1982), or by a very low ratio of water to cement (Onofrei et al., 1988).

Both clays and portland cements possess comparatively high thermal stability. Both materials are apparently stable at temperatures below 100°C and may perform acceptably to temperatures as high as 250°C (Koster van Groos, 1981).

Clay and cement are highly deformable materials upon initial placement and may be emplaced to conform to the contours of any constraining volume. Thus, either material can be used to fabricate an effective hydraulic barrier in boreholes, tunnels, ramps, and shafts (Gulick, 1978; Pusch et al., 1985; Ballivy, 1986; McCombie and Knecht, 1986; Pusch, 1986).

Clays are natural materials, such as crushed tuff, and reflect the stable products of chemical action on igneous and metamorphic rocks. Their stability in nature implies long-lived performance. Moreover, the alteration of Na-montmorillonite to other clays (e.g., illite), which could lead to decreased performance, is kinetically hindered to time periods in excess of hundreds of thousands of years if temperatures do not exceed 100°C (Eberl and Hower, 1976; Meyer and Howard, 1983). Some ancient portland cements have retained much of their structural integrity in both submerged and air-exposed environments for periods in the range of hundreds of years to a thousand years (Roy and Langton, 1982). These factors combined with the low solubility of the materials and the potential to increase life by compositional adjustments (Grutzeck et al., 1980) leads to the inference of long-term stability.

8.3.3.1.3 Seal designs

The current designs for the seals are described in Section 6.2.8. More detail is provided in the SCP-CDR (SNL, 1987) and in the sealing concepts report (Fernandez and Freshley, 1984) published earlier. The technical basis for an initial set of design requirements and performance goals for the sealing components have been published (Fernandez et al., 1987). This technical basis consists of numerous evaluations of hydrologic conditions that exist at the site and that might exist in the future.

The advanced conceptual design and the license application design will be the next two phases in the design of seals. Trade-off studies will be performed to aid in the selection of appropriate configurations for seal components, selection of placement methods, and selection of the materials to be used. These trade-off studies will also allow refinement and reevaluation of the design requirements and performance goals. Several different types of design analyses have been identified in Section 8.3.3.2.4.2. These include analyses to evaluate the potential for drainage through drift floors, shafts, and ramps.

Additional evaluations to estimate the quantities of water that might enter shafts, ramps, and repository drifts from discrete faults and episodic flooding events are planned. The potential for flow through backfilled drifts will also be evaluated. These types of analyses will allow more definition of strategies for sealing discrete water-producing zones (if any are found), for dissipating water that might enter from extreme events, and for selecting materials to be proposed for use. Nearly all these analyses require site characteristics; the testing required to verify the conclusions reached in the preliminary studies will therefore be focused on confirming the site characteristics that are being (and have been) used as the basis for the design. As identified in Figure 8.3.3.1-1, the testing program for verification of the designs can then be developed in detail on the basis of the additional data collected for the site.

8.3.3.1.4 Seal modeling

Modeling seal performance is an integral part of the design activity for the seals. As indicated in the preceding section, modeling is used to establish the need for seals, the performance requirements, and the anticipated performance of the various components.

The logic for how seal performance is evaluated is given in Section 8.3.5.11, and the strategy for resolving the sealing issue is presented in Section 8.3.3.2. Models are needed for both saturated and partially saturated flow. Both numerical and analytical models have been used; the results published to date are described briefly in Section 6.4.3. The types of numerical and analytical approaches used to date are in Section 6.4.3.1.

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No new fluid-flow codes are expected to be required specifically for use in the seal program. Rather, codes that are being developed for use in other hydrologic performance analyses will be used for the seal program. Some potentially applicable computer codes, their capabilities, material models, and the status of their documentation are described in Sections 8.3.5.19 and 8.3.5.20.

8.3.3.2 Issue resolution strategy for Issue 1.12: Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information for the resolution of the performance issues?

This issue is concerned with developing seals needed for shafts, ramps, exploratory boreholes, and the underground facility. The regulatory basis for this issue, the strategy for resolving the issue, and the future work needed in support of developing and evaluating seal designs are described.

While the specific wording of Issue 1.12 appears to address only shaft and borehole seals, a broader interpretation is adopted in Section 8.3.3.2. To provide a complete and unified discussion of the sealing system for the proposed Yucca Mountain mined geologic disposal system (MGDS), Issue 1.12 addresses all sealing components within the underground facility in addition to the seals for shafts, ramps, and boreholes.

Regulatory basis for the issue

There are several sections in 10 CFR Part 60 that relate to sealing, specifically 60.134(a) and (b), 60.112, 60.113(a), and 60.142(a), (b), (c), and (d).

Section 60.134 of 10 CFR Part 60, "Design of seals for shafts and boreholes," states

> (a) General design criterion. Seals for shafts and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives for the period following permanent closure.
>
> (b) Selection of materials and placement methods. Materials and placement methods for seals shall be selected to reduce, to the extent practicable: (1) the potential for creating a preferential pathway for ground water to contact the waste packages; or (2) radionuclide migration through existing pathways.

These requirements specify the design criteria to be addressed by this issue. Provision (a) above also specifies the performance objectives in paragraphs 111-113 of 10 CFR Part 60. 10 CFR 60.111 refers to the performance of the geologic repository operations area through permanent closure, in particular, it refers protection against radiation exposures and releases of radioactive material before permanent closure and the retrievability of the waste (10 CFR 60.111). The seals systems may play a role in meeting this performance objective. This role is addressed by the preclosure performance and design issues, in particular, Issues 2.1, 2.2, 2.3, and 2.7. The reader

is therefore referred to those sections of the SCP (8.3.5.3, 8.3.5.4, 8.3.5.5 and 8.3.2.3, respectively) for these issues.

Section 60.112 of 10 CFR Part 60 spells out the performance objective for the overall system performance for the geologic repository after permanent closure. The section states

> The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the U.S. Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events.

The NRC defines the engineered barrier system as the waste packages and the underground facility, and the underground facility as the underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals.

Section 60.113 of 10 CFR Part 60, "Performance of particular barriers after permanent closure," which specifies the following requirements for the engineered barrier system:

> (a) General provisions. (1) Engineered barrier system. (i) The engineered barrier system shall be designed so that assuming anticipated processes and events: (A) Containment of HLW will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay; and (B) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times . . . (ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that: (A) Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 60.113(b) provided that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; and (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% 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.

Section 60.142 of 10 CFR Part 60 addresses the design testing associated with confirming performance of backfill and shaft and borehole seals. This section is as follows.

> (a) During the early or developmental stages of construction, a program for in situ testing of such features as borehole and shaft seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater shall be conducted.
>
> (b) The testing shall be initiated as early as is practicable.
>
> (c) A backfill test section shall be constructed to test the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun.
>
> (d) Test sections shall be established to test the effectiveness of borehole and shaft seals before full-scale operation proceeds to seal boreholes and shafts.

To provide a complete and unified discussion of the sealing system, this issue (1.12) addresses seals related to shafts and boreholes as well as all sealing components within the underground facility and ramps.

Approach to resolving the issue

The approach to be used to resolve Issue 1.12 consists of a methodology for developing a seal system design that ensures compliance with the regulatory requirements. The methodology, when fully executed, provides the needed information at appropriate times to complete the design process for license application by demonstrating that Issue 1.12 is resolved.

The methodology for the resolution of Issue 1.12 is illustrated in Figure 8.3.3.2-1a and 8.3.3.2-1b and includes the following (steps are identified and discussed in the following paragraphs):

1. Issue identification (Step A). Includes (a) specifying the applicable regulatory requirements and (b) developing a system description.

2. Performance allocation (Steps B to F).

3. Testing.

4. Design and performance analyses.

This process is iterative, that is, as information is obtained, the design can be refined and the strategy can be suitably modified. Additional testing can then be conducted until the desired degree of confidence is obtained that the regulatory requirements are met.

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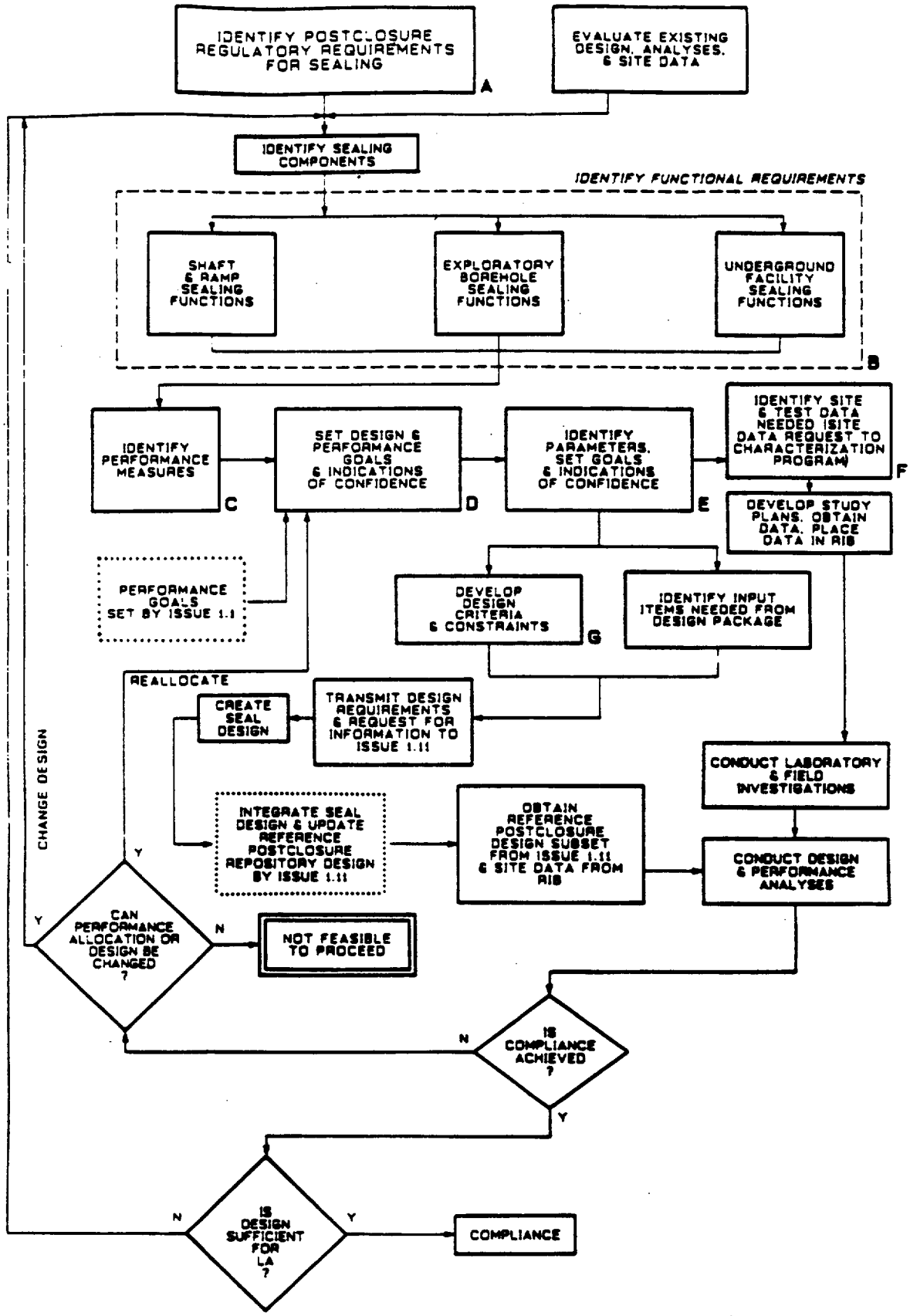

Figure 8.3.3.2-1a. Logic diagram for issue 1.12 (seal characteristics). See Figure 8.3.3.2-1b for legend. Section 8.3.2.1 describes the relationships and interfaces between design and performance issues.

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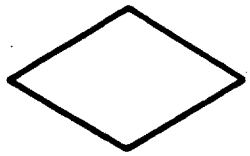
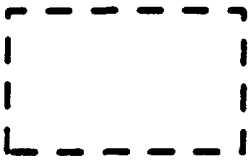
LEGEND

ACTIVITY PERFORMED TO RESOLVE ISSUE



TEST TO DETERMINE SUBSEQUENT ACTIVITY

ACTIVITY PERFORMED BY INDICATED ISSUE



ACTIVITY WITH MULTIPLE SIMILAR ACTIVITIES OR TESTS

DECISION ABOUT ISSUE RESOLUTION

Y - YES
N - NO
LA - LICENSE APPLICATION
RIB - REFERENCE INFORMATION BASE

Figure 8.3.3.2-1b. Legend for Figure 8.3.3.2-1a.

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In applying the iterative methodology illustrated in Figure 8.3.3.2-1 to obtain a final design, it is important to consider the interface occurring between Issue 1.11 and Issue 1.12. This interface involves the transfer of sealing-related requirements, constraints, and information to Issue 1.11. It is then in Issue 1.11 that the sealing designs are integrated with other postclosure designs. The integrated reference postclosure design together with selected site and test data from the reference information base (RIB) is used to determine if Issue 1.12 is resolved.

The approach to be applied is indicated in Figure 8.3.3.2-1a. The process related to this issue (issue identification in step A and performance allocation in steps B through F) is briefly summarized in the following table:

Step	Summary
A	Use the regulatory requirements and the existing design, analyses, and site data, to identify the sealing components that make up the sealing subsystem.
B	Define the functional requirements for the seals (i.e., the function that each selected sealing component is to perform and the process that must be considered in assessing its ability to perform its function).
C	Identify the performance measures that can be used to show how well the sealing components perform their intended function.
D	Establish the tentative goals for the performance measures and the confidences needed in reaching the performance measure goals.
E	Define the parameters, establish tentative parameter goals, and estimate the level of needed and current confidence in meeting the parameter goals.
F	Identify information needed to resolve this issue. The identified information will be obtained as part of the activities that will satisfy various information needs including those under this issue, as well as under some other issues, particularly Issue 1.11 (Section 8.3.2.2, configuration of underground facilities--postclosure).
G	Develop the design requirements that apply to sealing options and identify the design constraints that are imposed on nonsealing system elements from the sealing system.

After these steps are completed, the Project will conduct laboratory and field investigations to obtain needed information. These investigations will feed design and performance assessment analyses.

Understanding each of these steps is essential for understanding how the information needs, which when satisfied by obtaining the data, will be used to resolve this issue. A more detailed description of steps A through G follows. Other descriptions relevant to these steps are described in other sections of the SCP.

Step A: Identify sealing system components

The tentative sealing component identified in Sections 6.2.7 and 6.2.8 were originally described in Fernandez and Freshley (1984) and consist of components associated with shafts, ramps, the underground facility, and boreholes. Figure 8.3.3.2-2 indicates the system elements that make up the sealing subsystem as discussed here, the potential locations of seals, and the sealing components being considered for each potential location. These sealing components are also identified in Table 8.3.3.2-1, together with their associated functions, processes, material properties, performance measures, and tentative goals. Sealing-related repository design constraints and goals are identified in Table 8.3.3.2-2. The site data needed to support resolution of the sealing issue are identified in Tables 8.3.3.2-3 and 8.3.3.2-4. Details of the entries are described in the discussion of the steps that follow.

There are three primary sealing components proposed for sealing the shafts and ramps: the anchor-to-bedrock plug/seal, the general fill, and the station plug. A fourth sealing component, the Topopah Spring Member, although a physical feature of the site, is included here because water drainage through this sealing component at the base of the shafts and ramps is part of the sealing strategy. Although not specifically indicated on Figure 8.3.3.2-2, the alternative of providing additional plugs/seals at various locations within the shaft exists. Similarly, if anomalous conditions occur (such as localized flow that may be significant for the underground facility), alternative components specific to the situation will be considered. In the ramps, numerous dams could be placed along the length of the ramp to periodically interrupt flow along the floor of the ramp. Alternatively, a single repository station seal placed at the end of the ramp could possibly accomplish the same function as these numerous dams and will be considered as appropriate.

Several sealing design options are proposed for sealing components within the underground facility as discussed in Fernandez et al. (1987). These options include single dams or bulkheads, double bulkheads, backfilled sumps, backfilled channels, plugs in horizontal emplacement boreholes, and drift backfill. An integral part of these sealing components is the drainage capacity of the Topopah Spring welded unit (TSw2) upgradient from the sealing component. The identification of these sealing components on Figure 8.3.3.2-3 does not suggest that all these components will be required in the underground facility. Rather, they represent options that can be emplaced in the underground facility to accommodate a broad range of water inflows, if necessary.

Exploratory boreholes drilled from the surface provide potential pathways for radionuclide migration from the repository. As a minimum, all such boreholes will be sealed or plugged according to applicable regulations. A decision on the degree of sealing required for each borehole will be made.

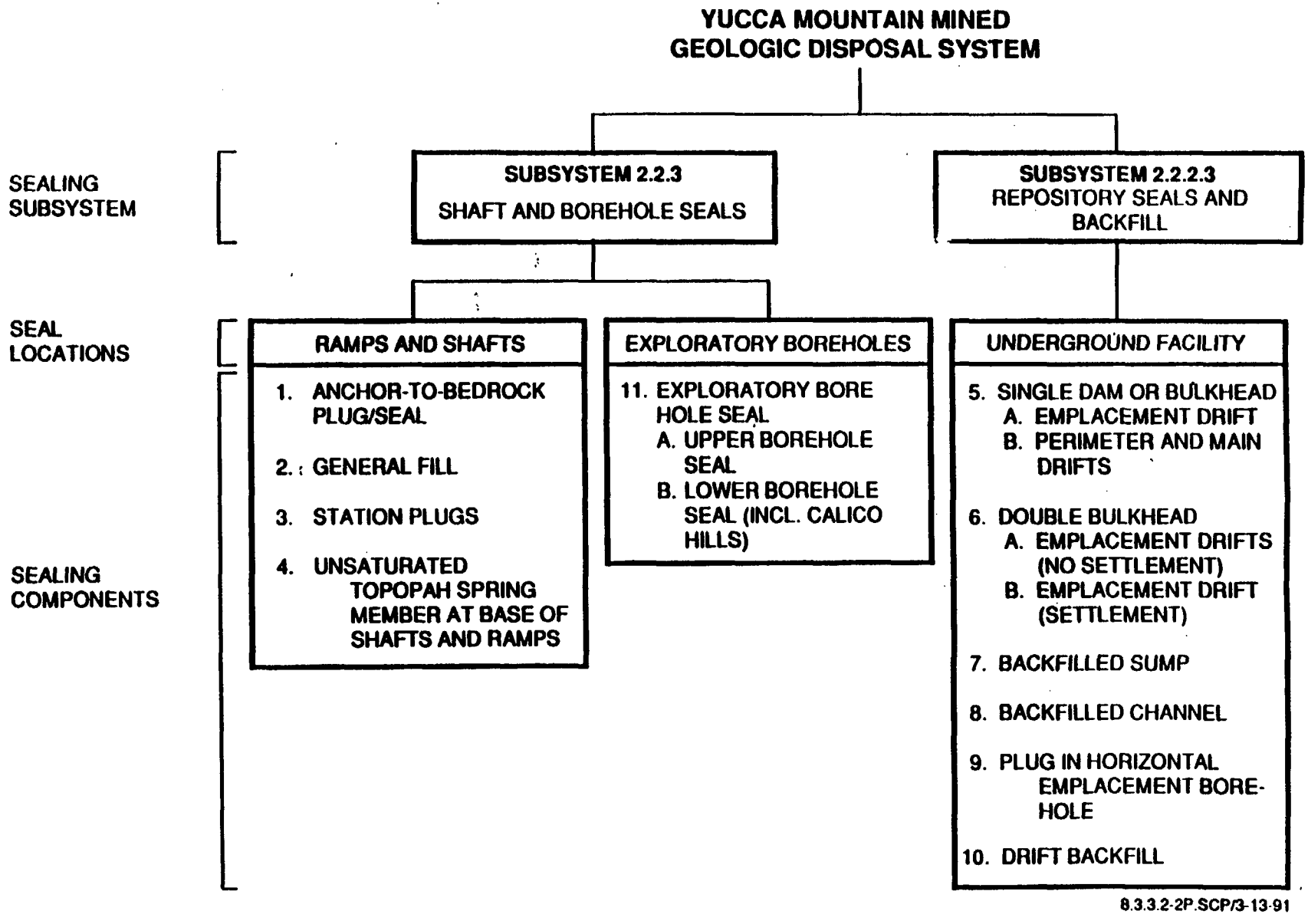

Figure 8.3.3.2-2. Sealing subsystem, seal locations, and seal components (Identifying numbers of sealing components correspond to those used in Table 8.3.3.2-1).

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

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

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

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

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

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

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

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

[a]As used here a design goal applies to a specific sealing component and a performance goal applies to sealing subsystems such as the underground facility subsystem. Tentative performance goals for the sealing subsystems are given in Table 8.3.3.2-5.
[b]Specific sealing components will be selected as part of the design process.
[c]Probably will not be used because it is most likely that no waste would be emplaced in boreholes with water inflow.
[d]Borehole system includes the borehole seals, the interface zone, and the modified permeability zone surrounding the borehole sealing. Boreholes are categorized for sealing purposes in Table 8.3.3.2-1a.

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

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

[a]Category A boreholes represent potential pathways to the accessible environment. Category B boreholes are not believed to be potential pathways to the accessible environment but because of their proximity to the repository boundary are currently planned to be sealed.
[b]Shallow boreholes that do not require sealing for repository purposes will be backfilled or sealed as required by other regulations.
[c]The zone of influence, and hence those additional holes that may need to be sealed, will be further analysed based on data gathered during site characterization.
[d]This borehole does not penetrate the repository horizon.

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Table 8.3.3.2-2. General design constraints passed [illegible]e 1.11, configuration of underground facilities (postclosure), for major repository f[illegible] from sealing program (page 1 of 2)

Step A	Step B		Step C	Step D	
Major repository feature	Function	Process	Performance measure	Tentative design goal	Needed confidence
12. Shafts and ramps	Provide entry into repository	Water flow in shafts and ramps	Location of surface entry	12A. Place portals of shaft and ramps outside of flood-prone areas	High
		Water flow in shafts and ramps	Number of entry points into the repository	12B. Restrict the number of shafts and ramps	High
13. Shafts	Provide entry into repository	Retain capability for permanent seal installation	Ease of liner removal	13A. Ensure shaft liner can be removed, especially at the base of the shaft	High
		Limit potential for preferential pathway	Depth of shaft	13B. No shafts should penetrate into the Calico Hills unit.	High
		Encourage shaft inflow drainage at base of shaft	Water storage capacity at base of shaft	13C. 150 m^3 (backfilled assuming porosity of 0.3)	High
		Limit potential for preferential pathway	Effective thickness of the zeolitic portion of the Calico Hills unit between the lowest portion of the exploratory shaft facility (ESF) and the ground-water table	13D. The thickness between the bottom of any shaft or any ESF drifting and the ground-water table should be greater than the minimun thickness of the Calico Hills unit above the water table anywhere within the repository boundary	High
14. Underground drifting	Provide access to waste disposal areas	Potential water flow in underground facility	Drift grade	14A. Establish drainage pattern from emplacement drifts to non-emplacement drifts	High

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

Step A	Step B		Step C	Step D		
Major repository feature	Function	Process	Performance measure		Tentative design goal	Needed confidence
14. Underground drifting (continued)			Water storage capacity in low point of repository	14B.	Provide 10,000 m^3 of water storage capability before any water enters the waste emplacement drifts (assume drifts are backfilled with backfill having porosity of 0.3)	High
			Ease of restoring drift floors to enhance drainage	14C.	Ensure the compacted tuff on drift floors in selected areas can be removed and the floor reconditioned to enhance drainage	High
15. Underground facility	Prevent complication of seals installation	Standoff from exploratory boreholes	Ease in sealing exploratory boreholes within the repository boundary	15A.	Drifting should be at least 15 m from exploratory boreholes	High
16. Shafts and underground facility	Prevent complication of seal evaluation and emplacement	Limit chemical alteration in seal environment	Ease of emplacing a grout curtain in selected locations where seals are currently proposed	16A.	No grouting should take place at these locations during the construction period	High
		Limit blast-induced permeability changes	Ease of restoring the modified permeability zone in selected locations where drift seals are proposed	16B.	Reduce the potential for fracturing rock in selected seal locations by exercising as much control as possible and practical, while excavating the shaft, ramps or drifts in these locations	High

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

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

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

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

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

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

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

[a]Design goals identified here are from Table 8.3.3.2-1.
[b]Thermal/mechanical units used in the modifier column are as follows: TSw2 = Topopah Spring, welded (repository horizon); TCw = Tiva Canyon, welded; CHnl = Calico Hills, nonwelded. Other abbreviations are as follows: ES-1 and -2 = exploratory shafts 1 and 2; MM = man and material shaft, EE = emplacement area exhaust shaft.
[c]GP = poorly graded gravel; GM = silty gravel.
[d]K_{SAT} = saturated hydraulic conductivity.

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

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

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

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

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

Related design goal[a]	Performance or design parameters	Modifiers[b]	Tentative parameter goal	Needed confidence	Current confidence	Expected parameter values	SCP section providing data
1A, 3A, 5A, 5B, 6A, 6B, 7A, 10A, 11A	Maximum temperature at seal locations	Upper portion of shaft	<90°C	High	Low	<90°C	8.3.2.2.6
		At repository horizon around shaft	To be determined through design tradeoff studies	TBD[c]	TBD	<115°C	8.3.2.2.6
		At selected drift locations in repository horizon	To be determined through design tradeoff studies	TBD	Low	<150°C	8.3.2.2.6
		Calico Hills unit in boreholes below the repository	<90°C	High	Low	<90°C	8.3.2.2.6
3A, 5A, 5B, 6A, 6B, 7A, 9A, 11A	Thermal expansion, heat capacity, and thermal conductivity of seal emplacement environment	TSw2 CHn1	To be determined through design trade-off studies	Medium	Low	See Table 6-16	8.3.1.4.2 8.3.1.14.2
2A, 2B	Shaft and ramp fill properties						
	Saturated hydraulic conductivity		1×10^{-2} cm/s	High	Low	1×10^{-2} to 1×10^{-6} cm/s	8.3.3.2.2 8.3.3.2.4
	Gradational analyses, angle of internal friction, compressibility		To be determined through design trade-off studies	High	Low	Not applicable	8.3.3.2.2 8.3.3.2.4

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

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

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

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

[c]TBD = to be determined.

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

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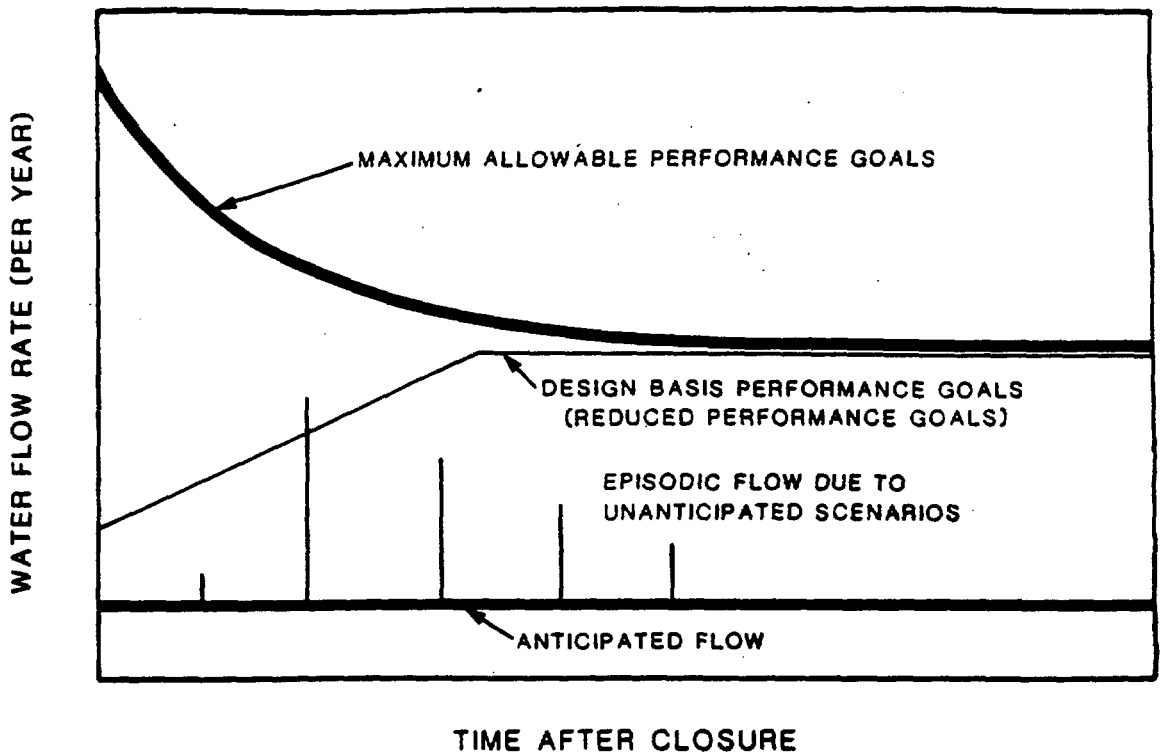

Figure 8.3.3.2-3. Schematic diagram of performance goals and relationship to anticipated and unanticipated episodic flows for sealing. (Yearly flow rate is used since the release criteria are specified on a per year basis.)

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The most extensive requirements for borehole sealing are expected for those boreholes that could have some potential for waste isolation impacts. The decisions will consider factors such as distance from the repository, depth, and liquid or gaseous transport mechanisms. Preliminary evaluations of borehole sealing requirements related to water flow have been completed and are described below.

Exploratory boreholes drilled from the surface provide potential pathways for radionuclide migration from the repository to the water table. Currently, there are four existing boreholes within the proposed repository perimeter that penetrate to the water table. About 25 additional boreholes penetrate to the water table within 5 km of the repository perimeter. Among these holes, a potential pathway from the repository to the water table exists for only those holes that are downdip (generally east or northeast) from the repository, if water were to drain through the repository floor and then were to become perched at a stratigraphic contact.

Most of the existing and proposed deep boreholes penetrate through the underground facility and into the ground-water table. Shallow boreholes that penetrate into the Topopah Spring Member or overlying members are not likely candidates for borehole seals because they are not considered to represent significant liquid pathways to the accessible environment. For the purpose of identifying sealing components, boreholes that are currently planned to be sealed have been divided into categories A and B as follows.

Category A boreholes are those that represent potential pathways for water movement to the accessible environment. The further the borehole is located from the repository boundary, the lower its potential to act as a pathway to the accessible environment. Those boreholes located generally to the northeast, southeast, and east of the underground facility fall into category A.

Category B boreholes are those boreholes that are not believed to represent potential pathways for water movement to the accessible environment but, because of their proximity to the repository boundary, will probably be sealed. Those boreholes immediately to the south and north of the underground facility are included in category B. Those boreholes not included in either category are located to the west, to the far north and far south, or 5 km or more from the edge of the repository boundary. They are not included because they are neither believed to represent potential pathways to the accessible environment, nor are they close to the planned boundaries of the repository. Additional evaluations of the potential for both liquid and gaseous flow through boreholes are planned.

Step B: Define component functions and related processes

In this step of the methodology, the functions of each selected seal component are identified and the processes and mechanisms that must be considered in assessing its ability to perform its function are considered. The primary functional requirements identified for the seal program are to (1) reduce the potential for radionuclide release by controlling water and gas flow and (2) reduce the potential for radionuclide release by discouraging human intrusions. For these general requirements, specific requirements for individual components have been developed. Some of the func-

tions of individual components may require redefinition as more information on design and data become available, and the related design concepts are reevaluated.

Two ways that have been identified in which the shaft and ramp sealing components can reduce the radionuclide releases from the repository are to (1) reduce the amount of water that could potentially reach the waste emplacement drifts and (2) reduce the amount of airborne radionuclides that could preferentially exit from the repository. The physical processes of concern for these functions include water entry into the shafts and past sealing components and release of airborne radionuclides caused by convective air movement resulting from thermal effects in the repository.

Another functional requirement of sealing components associated with shafts and ramps is to reduce the potential for human intrusion into the repository. For this requirement, the process of concern is penetrability through the sealing component, either the anchor-to-bedrock plug/seal or the general fill.

Not all the sealing components will be relied on to achieve all the functions identified previously. For example, the anchor-to-bedrock plug/seal is not relied upon to limit gaseous releases, while the shaft fill performs this function. Conversely, more than one may be relied on to achieve the same function. For example, the anchor-to-bedrock plug/seal, the repository station seal, and shaft fill can be emplaced to reduce the amount of water entering the waste emplacement drifts. The unsaturated Topopah Spring Member (unit TSw2) at the base of the shafts could also be used to promote drainage from the base of the shafts (if any water reached the base) by allowing flow through the rock mass at the base of the shaft.

The use of multiple barriers of similar function presents the possibility of redundancy in achieving performance goals. The anchor-to-bedrock plug/seal and the shaft fill can be emplaced to reduce the potential for human intrusion. Again, emplacement of different sealing components is believed to represent a conservative approach in achieving the performance goals.

The primary function for seals located in the underground facility would be to retain and drain water entering emplacement drifts. This would be done by restricting the lateral migration of water into emplacement drifts by restricting the lateral migration of water on the drift floors. Drainage of water through floors of nonwaste emplacement areas could also add a level of redundancy to the design. Such areas could include those used for development shops, warehouse, emplacement shops, and nonemplacement drifts. Diverting waters that enter the shaft to nonwaste disposal areas would potentially reduce the amount of water entering the waste emplacement drifts.

The primary function of borehole seals is to reduce the potential for water-transported radionuclides through preferential transport in boreholes. The physical process of concern would be preferential ground-water flow through the repository, the Calico Hills unit, and into the saturated zone. It must also be ensured that the boreholes not become preferential pathways for water flow into the repository or gaseous release out of the repository.

Processes and mechanisms influencing a component's performance will be examined as more detailed analyses are performed that characterize the response of each component. The scenario classes and processes identified for total system performance evaluations (Section 8.3.5.13) will be used as input to these analyses. Depending on the effect of the process or mechanism on the performance, the importance of the component's functions may need to be reevaluated and the design concepts modified as necessary.

Step C: Identify performance measures and goals

The purpose of this step in the methodology is to identify the performance measures that can be used to indicate the effectiveness of each sealing component in performing its intended functions.

Performance measures, as presented for this issue, are the primary qualitative measures that will be used to determine the performance of each sealing component. There are several performance measures selected within the seal program. Generally, the most important is the quantity of water passing sealing components. Others include the percentage of a certain type of flow as in the case of borehole, ramps, and shaft seals for airborne release. Reduction of the potential for human intrusion would require the physical presence of material in the ramp and shaft. When the function is to enhance the vertical drainage of water through the Topopah Spring Member, the performance measure is drainage capacity. The preliminary list of performance measures is discussed later in this section. (Secondary properties, such as the porosity of the shaft fill, are not listed in Table 8.3.3.2-1.)

Step D: Establish performance goals

Tentative goals and required confidence in reaching each goal can be established for each measure. Analyses, using available site information and repository design information, can be used to set quantifiable values. If regulations cannot be met after a proposed design is developed, then component designs, component functions, and performance measures may have to be modified so that a revised design can be developed that will meet regulatory requirements.

As part of the preliminary performance allocation process, tentative hydrologic performance goals were established for the sealing subsystem. Details of these evaluations are documented in a report by Fernandez et al. (1987). The logic used in establishing the goals will be described in succeeding paragraphs.

In selecting performance goals for allowable water flow rates for the sealing subsystem, the results from two radionuclide release models are considered, both of which conservatively assume that all water entering the waste disposal area contacts the waste (Fernandez et al., 1987). This assumption is thought to be conservative because most water is expected to be contained within the rock matrix and, therefore, will not contact any waste packages. The differences between the two models are primarily related to differences in how the failure rate of the waste package is estimated; hence the two models would be expected to be very similar after most of the packages are assumed to have failed. The results of both models are shown in Figure 8.3.3.2-3. The results of one model are displayed as the

maximum-allowable-performance goals curve, while the more conservative model is identified as the design-basis-performance-goal curve. Hence, the approach taken in developing the preliminary performance goals for the sealing program is to use the more conservative of two models as the basis.

The first model assumes a constant rate of failure of waste packages and a release of radionuclides from areas within and outside the uranium dioxide matrix of the spent fuel. The result from this model is displayed as the maximum-allowable-performance-goals curve in Figure 8.3.3.2-3. The maximum-allowable-performance goals are based on the evaluations of the performance objectives for the engineered barrier system defined in 10 CFR 60.113. On the basis of this analysis, if the inflow to the waste packages was less than the value specified by the curve shown in Figure 8.3.3.2-3, the performance objective for gradual release from the engineered barrier system would be met. The constant waste package failure rate probably over estimates the actual failure rate, and this curve is believed to represent a conservative, but realistic, performance goal.

The second model assumes that all radionuclides are located in the matrix of the spent fuel and all waste packages fail 300 yr after repository closure. The results of this model are displayed as the design-basis-performance-goal curve shown in Figure 8.3.3.2-3. This curve incorporates the much more conservative assumption of total waste package failure at 300 yr after closure. The design-basis performance-goal curve was selected for use in the initial identification of performance goals because it is the more conservative of the two models. The differences between the two curves are primarily related to the differences in how the waste package failure rate was modeled over the first 1,000 yr; therefore, both models predict very similar allowable water flow rates after the first 1,000 yr. In summary, the preliminary hydrologic performance goals for sealing, derived from these radionuclide release models, are believed to be very conservative.

Figure 8.3.3.2-3 also shows the anticipated flow and episodic inflow from unanticipated processes and events and suggests that a seals system may not be needed at the Yucca Mountain site to meet this performance objective. However, there are uncertainties in the evaluations both for the performance goals and for the estimates of anticipated and unanticipated inflows, and the site characterization program will need to address these uncertainties. Taking into account only the need to address the performance objective of 10 CFR 60.113, the lower curve in Figure 8.3.3.2-3 (i.e., the design basis performance goals curve) provides the set of performance goals for the inflow rate. Furthermore, the preliminary performance allocation developed to date will be modified in the future to directly consider the scenario classes developed in Section 8.3.5.13 (total systems performance) for both nominal and disturbed conditions.

Numerical values for the design-basis performance goals for the sealing subsystem are identified in Table 8.3.3.2-5. The goals for the total quantity of flow are then divided (allocated) between the shafts and ramps and the underground facility. The subsystem goals were then further subdivided into the tentative design goals for the various sealing components; these component goals for the components are provided in Table 8.3.3.2-1.

Table 8.3.3.2-5. Design-basis performance goals for the sealing subsystem[a]

Time after closure (year)	Design basis performance goals (m^3/year)		
	Underground facility	Shafts and ramps	Total design-basis performance[b]
0-300	1,180	0	1,180
400	2,600	0	2,600
500	5,600[c]	90	5,690
600	5,600	6,700	12.300
700	5,600	20,900	26,500
800	5,600	50,300	55,900
900	5,600	110,400	116,000
1,000	5,600	130,400[c]	136,000
1,000-10,000	5,600	130,400	136,000

[a]Source: Fernandez et al. (1987).

[b]The total design-basis performance goal is the sum of the performance allocation for the underground facility and that for shafts and ramps.

[c]Beyond this point in time the design-basis performance goal (i.e., allowable flow rate) exceeds potential flow due to anticipated and unanticipated events. No performance of the sealing components at these locations is required after this time.

Reevaluation of performance goals and design requirements will occur as more design information, site data, and performance evaluations are completed during ACD and LAD. These evaluations will allow better comparison between needed and expected performance of seals.

Step E: Define performance parameters

The methodology developed to resolve Issue 1.12 includes a step to identify the specific parameters required to support an evaluation of the performance goals identified for each performance measure. This step involves identifying support parameters, establishing goals for each parameter, and estimating current and eventually needed level of confidence. The parameters are used in analyses to predict the magnitude of the performance measures defining the relationships for processes and/or mechanisms.

The parameters required to address each information need in this issue are described under the appropriate information need. The hydrologic and miscellaneous parameter needs are shown in Tables 8.3.3.2-3 and 8.3.3.2-4 and discussed in more detail in Section 8.3.3.2.1. In general, the preliminary needed confidence for most parameters is identified as either high or medium. For some parameters a low needed confidence is assigned for meeting the tentative performance goals when the parameter is not expected to be a signifi-

cant variable in licensing-related analyses. This may occur as a result of (1) a related component performance having a low needed confidence or (2) the anticipation (based on engineering judgment or preliminary analysis results) that the component performance is relatively insensitive to plausible variability in the value of the parameter.

Step F: Identify information needed to resolve the issue

As indicated in Figure 8.3.3.2-1, the information needed to respond to this issue must also be identified and transmitted to Issue 1.11 so that the postclosure underground facility design can be developed. This needed information is defined in Tables 8.3.3.2-3 and 8.3.3.2-4 and is described in the parameter sections under the appropriate information need.

Step G: Design requirements and constraints

After the functional requirements and performance allocation processes have been developed, it is necessary to define the design requirements for the seal system. This step in the issue resolution methodology identifies design requirements, design constraints imposed on nonsealing system elements, sealing strategies, and seal material specifications. The purpose of this step is to provide the design requirements necessary to develop a design that will meet the design goals and hence the performance goals.

As indicated in the first part of this section, sealing design requirements and constraints will be transmitted to Issue 1.11 (Section 8.3.2.2) to develop an appropriate postclosure design. Design requirements primarily include the quantitative and qualitative requirements imposed on the seal components to achieve a desired performance. The technical basis for the design requirements is presented in Fernandez et al. (1987).

Some general constraints placed on major repository elements by the seal program are given in Table 8.3.3.2-2. The majority of the performance measures relate to grading drifts within the underground facility to achieve the specified performance goals and to restoring the drift floors to encourage vertical drainage of water through drift floors. Other constraints include no grouting within rock in selected locations where components are proposed and ensuring that penetration into the Calico Hills unit is controlled. Finally, because drifting across exploratory boreholes could compromise the sealing efforts for these boreholes, a constraint is imposed on drifting. This constraint is not to intersect the boreholes and also to maintain a minimum distance from the boreholes. Directional logs for boreholes within the repository boundaries will be needed to aid in ensuring that this constraint can be met.

Relative to the exploratory ramps and shafts planned for Yucca Mountain, the ESF excavation techniques and ramps and shaft design conservatively attempts to limit uncertainties in the sealing program in the following principal ways:

1. Ramps and shafts are located to limit potential water inflow and thereby reduce uncertainty in seal performance.

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2. Mechanical mining techniques are used throughout ramp and shaft construction, thereby allowing installation of seals in multiple and optimal locations at closure when maximum information is known about the site behavior, sealing materials, sealing designs, and performance requirements. This reduces uncertainty in the ability to emplace the seals and to predict their performance.

3. Concrete shaft liner and temporary ground support are installed to limit rock movement and thereby reduce uncertainty in both the ability to emplace seal components and the extent of the zone of modified permeability near the shaft.

Design requirements and seal material specifications developed to date in the conceptual design process are guidelines for design analyses and future materials testing, and the requirements are very preliminary. Current design requirements are presented by Fernandez et al. (1987). Revisions and additional design requirements are expected to emerge from the advanced conceptual design and during the license application design.

Seal system performance and seal component designs are addressed directly by this issue (seal characteristics) as presented in the preceding discussion.

The planned investigations that will be used to assess the performance of proposed sealing designs and to develop design information necessary for the license application design are defined as follows:

Information need	Description
1.12.1	Site, waste package, and underground facility information needed for design of seals and their placement methods (Section 8.3.3.2.1).
1.12.2	Materials and characteristics of seals for shafts, drifts, and boreholes (Section 8.3.3.2.2).
1.12.3	Placement methods for seals for shafts, drifts, and boreholes (Section 8.3.3.2.3).
1.12.4	Reference design of seals for shafts, drifts, and boreholes (Section 8.3.3.2.4).

Information Need 1.12.1 identifies information that will be obtained from sources outside the Yucca Mountain Project repository seal program and that will influence the design and performance of the repository seals.

Information Need 1.12.2 identifies activities, primarily related to laboratory testing, needed to determine the properties of seal materials that may be used in an unsaturated tuff environment.

The placement methods of sealing components (Information Need 1.12.3) depend on the need for sealing components as determined by the appropriate activities defined by Information Need 1.12.4 and the selection of sealing materials as determined through the laboratory testing defined by Information Need 1.12.2. The bulk of the design work, including design selection, trade-off analyses, development of design requirements and design descriptions, and modeling associated with the performance of sealing components, is incorporated into the activities defined as part of Information Need 1.12.4. No computer code development is currently anticipated as part of the Yucca Mountain Project seal program. Existing computer codes developed in support of other performance analyses will be used in seal design analyses. Computer codes that have been or may be used in the seal program are named in Section 6.1.3.2.3. Depending on the verification requirements, some efforts may be required to verify results using the identified codes.

Interrelationships of information needs

The question raised by this issue is aimed at determining if the emplacement of ramp, shaft, and borehole seals and seals for backfill in the underground facility shows compliance with the postclosure performance objectives.

The available site and underground facility data from Information Need 1.12.1 (Section 8.3.3.2.1) can be used to develop seal performance goals and design requirements for specific sealing components. The development of these design requirements can then be used to select designs of seals for shafts, ramps, drifts, and boreholes (Information Need 1.12.4, Section 8.3.3.2.4). Evaluation of the performance of sealing components is an integral part in the selection of the appropriate designs and, therefore, is part of Information Need 1.12.4 (Section 8.3.3.2.4). The selection of materials and characteristics for seals (Information Need 1.12.2, Section 8.3.3.2.2) and their emplacement methods (Information Need 1.12.3, Section 8.3.3.2.3) can then be made to achieve the performance established for the sealing components. Further, because the underground facility must contribute to repository performance, its design could reduce the reliance placed on drift seals. (Drift seals are part of the underground facility, but ramp, shaft, and borehole seals are not.) The characteristics and configuration of the underground facility as they relate to the postclosure design criteria of 10 CFR 60.133 are discussed in Section 8.3.2.2 (configuration of underground facilities). The general criteria for the underground facility state that "the underground facility...shall contribute to the containment and isolation of radionuclides."

8.3.3.2.1 Information Need 1.12.1: Site, waste package, and underground facility information needed for design of seals and their placement methods

Technical basis for addressing the information need

The technical basis for addressing the information need is discussed in the following paragraphs by first identifying the contents of related sections of the SCP and other documents. Needed parameters are then described.

The logic for the technical activities is described and planned design activities are identified.

Link to the technical data chapters and applicable support documents

As mentioned in the discussion under Step E, the information identified in this information need will be obtained outside the Yucca Mountain Project seal program. This information falls into two categories: site and underground facility design. Under site, the primary information needed is an understanding of the water inflow into the repository and the hydrologic characteristics of selected geologic units. This type of information is discussed in Section 3.6 (regional hydrologic reconnaissance of candidate area and site). In particular, the description of the hydrologic units and hydraulic characterization of principal hydrogeologic units will be important from a sealing perspective. Information obtained in Section 3.9 (site hydrogeologic system) as well as surface flooding in Section 3.2 (floods) will also be used in resolving this issue.

The underground design is described in Section 6.2.2, which describes the overall design of the repository, and Sections 6.2.5 and 6.2.6, which describe the shaft and ramp designs and the subsurface design. These ramp and shaft designs are being revised; new designs will be determined for the Title II design effort. Additional details of the repository design are provided in the conceptual design report developed in support of the site characterization plan (SCP-CDR) (SNL, 1987).

Parameters

A variety of site and repository design parameters are required as part of this information need. Table 8.3.3.2-3 lists the hydrologic parameter needs, the ranges of parameters, and the confidence needed in meeting the performance goals. Table 8.3.3.2-4 presents the same information for miscellaneous (site or design) parameters. Additionally, these tables indicate what SCP sections describe the information needs that will provide values for the parameters. In all instances, a correlation is made between the design goal and the required parameter.

The majority of the parameters and parameter ranges for shaft and ramp sealing components deal with defining the potential for surface water infiltration to enter ramps and shafts. Realistic estimates can be obtained by characterizing near-surface geologic units such as alluvium and the Tiva Canyon Member. For alluvium, required parameters include saturated hydraulic conductivity, gradation, sieve analysis, saturation profiles, unsaturated properties, and thickness. The saturated hydraulic conductivity of the Tiva Canyon is also identified as a parameter need. In addition to these near-surface site parameters, the quantity of water due to surface flooding events is also identified as a parameter need. The modified permeability zone (MPZ) is 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. Because water flow down the ramps and shaft (under saturated conditions) can be controlled by the MPZ, knowledge of the MPZ characteristics is needed. The parameter goal range is taken from a report that developed a model for the zone surrounding a vertical penetration in welded tuff (Case and Kelsall, 1987).

If water reaches the base of the ramp or shaft, it is important to know the drainage capacity of the sump locations so that the anticipated amount of water entering the ramp or shaft can be dissipated effectively. Similarly, the drainage capacity of water through drift floors is an additional parameter for consideration in the seal program. The acceptable parameter range for the saturated, rock-mass hydraulic conductivity depend on the design option proposed and the amount of water to be drained. Nevertheless, a lower limit of 1×10^{-5} cm/s is proposed based on current design efforts. Finally, erosion potential is listed as a parameter need so that excessive erosion does not occur at the ramp or shaft entry points and subsequently increase the potential for water to enter the ramps or shafts.

In Table 8.3.3.2-4 nonhydrogeologic parameters are identified. They include the following:

1. Design information such as the dimensions of all openings where seals may be emplaced. This includes dimensions for shaft, ramps, and drifts. Information on drift grades is also required to properly design dams or bulkheads in the underground facility. Variations in drift grade do occur in the current design. Such variations can influence the area of drift floor that becomes inundated and subsequently the drainage capacity of the area upgradient from the dam or bulkhead.

2. Borehole construction and geologic logs are routinely obtained as part of the site investigation work within the Project and are necessary to establish a strategy in effectively sealing boreholes.

3. The thermal and mechanical properties (strength, modulus, conductivity, etc.) of the rock mass for selected geologic units and in situ stresses at potential seal locations are required to assess the structural response of these seals. Because structure failure could incur a decrease in hydrologic performance, it is possible that some sealing elements may not achieve their design goals. Therefore, tradeoff studies would be required to evaluate the impact of structural deformations of the rock mass (if any) on the performance of specific sealing elements. Seismic forces could also modify the properties of the sealing elements. Therefore, the seismic response spectra would be required at seal locations to evaluate the potential for modifying the properties of sealing elements.

4. Performance of near-surface sealing elements can be affected by meteorological and chemical conditions that exist at the surface. For this reason, temperature variations at the ground surface together with two chemical parameters, pH and soluble sulphate, are identified.

5. These chemical parameters and parameter ranges are based on the current concept that the sealing material at the surface is concrete. The parameter ranges, therefore, are specifically associated with a concrete located at the surface. If it is determined through design studies, as part of the advanced conceptual design phase,

that concrete is not needed and another material may be better suited, then this parameter need will be dropped.

6. Chemistry of the seal environment is included so that durability of the seal material can be assessed. The chemistry of alluvium; Tiva Canyon, welded (TCw); Topopah Spring, welded (TSw2); Calico Hills, vitric (CHv); and Calico Hills, zeolitic (CHz) are identified as being required to assess geochemical durability of the sealing element.

7. A limit on the temperatures at two potential seal locations (i.e., at the upper portion of shaft and ramps and at the Calico Hills borehole seal locations) is given in Table 8.3.3.2-4. Such limits will reduce the potential for alteration of the seal materials.

8. Calculations presented elsewhere (Fernandez et al., 1987; Fernandez et al., 1988) have shown that infiltration of surface waters into a shaft fill can be acceptably reduced and retarded if the saturated hydraulic conductivity of the shaft fill is less than 1×10^{-2}cm/s. Air flow through shaft fill can also be acceptably reduced assuming the same saturated, hydraulic conductivity. These sensitivity analyses evaluated possible ranges in air and water flow through the shaft and surrounding rock. Values for hydraulic or air conductivities were varied for the rock mass, the shaft fill, the modified permeability zone near the shaft, and, in some cases, the overlying alluvium. For example, the rock mass hydraulic conductivity for one analysis (Fernandez et al., 1987) was varied from 10^{-2} to 10^{-5} cm/s. Gradational analyses, angle of internal friction, and compressibility of the shaft fill will also be necessary to determine if excessive settlement of the shaft fill could occur. Excessive settlement (assuming the emplacement of no anchor-to-bedrock seal) could increase the potential for more surface waters to enter the shaft. If found to be necessary, additional calculations will be done to evaluate fill in ramps.

9. Sealing fractures around selected sealing elements may be required to achieve a desired level of performance. Therefore, the thermal/mechanical units that may require some fracture characterization would be Tiva Canyon, welded (TCw); Topopah Spring, welded (TSw2); Calico Hills, nonwelded (CHn1); and the Paintbrush Tuff, nonwelded (PTn). Using this data, effective plans to seal these fracture zones could be developed.

10. The remainder of the required parameters may not be available at the time that testing is completed in the exploratory shaft facility. Specifically, if water-producing zones are encountered it would be appropriate to characterize the chemistry of the fault zone waters including the sediment content, if any. This data could then be used to evaluate the potential for reducing the drainage capacity of the drift floor or perhaps reducing the effectiveness of the seal component that it contacts. The measurement of the volume of waters draining into drifts could also suggest the amount that could enter horizontal emplacement holes.

Logic

The geomorphology, meteorology, and surface hydrology of the shaft and ramp locations, the risks of flash flooding, the configurations of the shafts and ramps, and the geotechnical properties of the near-surface alluvium and bedrock are required for the design of the ramp and shaft sealing components. The properties and depth of the alluvium must also be known to predict the potential for ground-water inflow to the ramps or shafts through the alluvium.

Information about the hydrologic properties of the stratigraphic units penetrated by the ramps and shafts is needed to determine the potential for ground-water inflow into the ramps and shafts and the underground facility. Initially, the inflow will be predicted based on data obtained from boreholes, available analytical solutions, and the hydrologic properties of the stratigraphic units at Yucca Mountain. Later, an indication of the potential inflow will be determined from direct observation of water inflow during and after construction of the ramps and the underground test facility. The stratigraphy and the configuration of the ramp and shaft, including the ramp or shaft station, will be used to determine suitable locations for ramp and shaft seals should they be necessary. For example, seals may be necessary below certain stratigraphic contacts at which ground-water perching could occur. The drainage capacity of the base of the ramp or shaft will be assessed to determine whether ground-water inflow would drain from the sump rather than flow into the repository.

The waste emplacement mode (i.e., vertical or horizontal) selected for the repository may influence the types of seals that are selected. For example, if the horizontal mode is selected, ground-water inflows to drifts may have no impact on the waste. The location of the repository including the ramps with respect to faults may influence the occurrence of ground-water inflow from discrete fault zones. The amount of inflow may be influenced by the hydrologic properties (permeability and porosity) of the fault zones and by the size of the underground opening and its orientation with respect to the fault. Initially, the amount of ground-water inflow will be predicted from surface observations and borehole data. Later, the predictions will be revised according to observations of inflows and fracture characteristics in the exploratory shaft test facility. The predicted rates of inflow will then be compared against the measured drainage capacity of the drift floors. During the testing associated with the exploratory shaft facility, drainage capacity of the densely welded tuff will be determined. The bulk permeability and infiltration tests will provide data on the ability of the repository to drain waters that may enter the repository.

Construction details associated with exploratory boreholes drilled from the surface are required to select appropriate seal designs. Characteristics of interest include location, depth, drilling history (including any lost circulation zones), and casing configuration.

Information about the physical, mechanical, chemical, and thermal properties of stratigraphic units, including those encountered in the shafts and ramps as well as in the repository, are required to ensure that seals, as designed, can withstand in situ hydraulic, structural, chemical and thermal loads. The extent and properties of the modified permeability zone around

openings are needed for analysis of total ground-water flow through seal zones and, possibly, for the design of seal emplacement methods. In situ stresses, seismicity, and the temperature at possible seal locations are also required for structural and thermal analyses.

All the data required to satisfy this information need will be obtained from site characterization activities described elsewhere in the SCP. Sealing-related activities are included in the discussions in Sections 8.3.3.2.2, seal material; 8.3.3.2.3, placement methods; and 8.3.3.2.4, reference seal designs.

8.3.3.2.2 Information Need 1.12.2: Materials and characteristics of seals for shafts, drifts, and boreholes

Technical basis for addressing the information need

The technical basis for addressing the information need is discussed below by first identifying the contents of related sections of the SCP and other documents. Needed parameters are then described. The logic for the technical activities is described and planned design activities are identified.

Link to the technical data chapters and applicable support documents

Two basic areas that will support the seal material development effort include geochemistry of the emplacement horizon and the in situ and anticipated alterations on the rock mass due to the existence of the repository. Information on geochemistry (Chapter 4) is included in Section 4.1, geochemistry of the host rock and surrounding units. Information on the alteration of the host rock is included in Section 4.2 (geochemical effects of waste emplacement); Chapter 2 (dealing with the geoengineering properties of the rock mass due to excavations); and Section 7.1 (emplacement environment) of Chapter 7.

The main purpose in obtaining the geochemical information will be to confirm the geochemistry of the ground waters and rock units at the repository horizon. Additional geochemical information will be needed if seal materials are chemically different from the medium into which they are placed. Geochemical information collected will also be used to confirm the predicted effects due to the presence of the repository, specifically the temperature elevation in the emplacement medium.

Parameters

Materials and material properties of concern will be defined following the development of the design requirements. Repository seals, if needed, will be designed to limit the ground-water flow into or out of the repository and potential gaseous transport from the repository. Since the most important parameters or material characteristics are yet to be determined through the continuing design requirements effort (Information Need 1.12.4, Section 8.3.3.2.4), potentially important material properties only can be

defined. These potential material properties are presented in Table 8.3.3.2-6. Material properties include those related to placement as well as performance.

Parameter ranges and confidence in parameter ranges for seal properties are not presented in Table 8.3.3.2-6. These values will be determined by the design activities described in Section 8.3.3.2.4. Selection of the parameter ranges will depend on the ability and need to achieve the performance goals discussed in Section 8.3.3.2.1 (information needed for seal design). Parameter ranges and confidence levels for pertinent site information are given in Section 8.3.3.2.1.

To accommodate the potential need for man-made materials and crushed tuff, laboratory testing is proposed. The testing scope will be modified, if necessary, as the seal design requirements are defined in more detail. Because emplacement conditions may vary within the underground facility, a broad range of environmental conditions will be considered in the laboratory testing of cementitious-based materials. The data obtained as part of the site characterization effort, that is, the geochemistry of the emplacement horizon and the repository design activities (temperature histories and mechanical properties of the repository unit), will confirm environmental conditions to be encountered. Any information on seal materials and their characteristics that is needed will be obtained as part of this information need.

Logic

Physical and mechanical properties of candidate seal materials must be known to select materials that will resist imposed structural loads. Early age properties of some materials (e.g., slump and viscosity in grouts or concretes) are required for selection of appropriate placement methods.

Hydrologic properties of candidate seal materials must be known to select suitable materials that meet design requirements for reduction of ground water. Additionally, hydrologic properties are also required for performance assessment of the seal system.

Thermal properties of candidate seal material must be known for analysis of the response of seals to thermal loads. The mineralogy and chemistry of candidate seal material must be known to evaluate possible adverse interactions between the materials and the host rock and ground water.

Emplacement conditions (e.g., temperature, presence of free water) and emplacement method (e.g., degree of consolidation of concretes or degree of compaction of granular materials) can influence the material properties. These conditions will be considered in the selection and design of seals.

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Table 8.3.3.2-6. Potentially important material properties of concern for sealing components

Categories of properties	Specific material properties	Reason required
Initial and altered physical properties of materials	Density, porosity, compressive strength, Young's modulus, Poisson's ratio, modulus of rupture, shear strength, expansivity, bond strength, viscosity, slump (concrete, grouts), tensile strength, creep of seal material, drying shrinkage strain	Structural analysis, settlement analysis, interface stress development, selection of emplacement method
Initial and altered hydrologic properties of materials	Compressibility gradation, porosity (total and effective), saturated hydraulic conductivity, interface hydraulic conductivity	Hydrologic analysis
Initial thermal properties of materials	Thermal conductivity, specific heat, heat of hydration (concrete, grouts), thermal expansion	Thermomechanical analysis, interface stress development
Material reactivity and stability (longevity) in seal zone	Overall composition, composition and proportion of phases, particle size, solubility of phases and precipitation, phase transformations (including dehydration), microbial activity, thermodynamic properties, chemical properties of leachate	Evaluation of durability of seal materials

8.3.3.2.2.1 Study 1.12.2.1: Seal material properties development

8.3.3.2.2.1.1 Activity 1.12.2.1.1: Detailed property determination of cementitious-based and earthen materials

Objectives

The objective of this activity is to initiate laboratory testing to determine material properties for sealing elements needed to resolve this issue.

Description

Before initiating laboratory testing, a detailed plan will be prepared indicating the parameters to be measured and how these parameters will be used to resolve the issue of materials longevity. Currently, it is believed that this plan will include details of laboratory testing involving potential alteration of sealing materials and response of sealing materials in restrained environments.

Because the durability of sealing materials in anticipated environments cannot be evaluated in real time, thermodynamic models, supported by laboratory experiments, will be used to understand the potential for alteration of sealing material and their properties. Input from theoretical studies (i.e., thermodynamic models such as the degradation model) will be used to define suitable materials for testing. The program will then include periodic characterization and testing to determine progressive alteration in properties after the materials are subjected to various experimental conditions (such as temperature and moisture conditions) for successively greater lengths of time. Experimental conditions will also consider the conditions of the seal environments. Other tests may determine the volume stability of the seal material within a block of tuff to determine the long-term performance of the interface. In general, material properties such as those identified in Table 8.3.3.2-6 will be determined to assess if the design goal for a sealing components can be achieved.

8.3.3.2.2.1.2 Activity 1.12.2.1.2: Hydraulic conductivity and consolidation testing of crushed tuff

Objectives

The objective of this activity is to establish the hydraulic conductivity and consolidation behavior of crushed tuff to support the development of criteria for ramp and shaft fill and drift backfill.

Description

To establish an acceptable hydraulic conductivity, gradation, and density of compacted ramp and shaft fill, laboratory studies will be required. Because mining and processing of tuff create very fine-grained

material, tests will be performed on at least two gradations of welded tuff: one optimally graded to enhance drainage and reduce settlement and one that contains fine-grained particles. The source material for this laboratory analysis will be tuff extracted through the mining of the exploratory shaft facility. Specific tests will characterize the gradation, compaction characteristics, and the saturated hydraulic conductivity for the various samples.

8.3.3.2.2.2 Design Activity 1.12.2.2: A degradation model for cementitious materials emplaced in a tuffaceous environment

Objectives

The objective of this activity is to develop a degradation model that will provide insight into how material properties of sealing components, especially permeability and strength, could alter after being in contact with tuff.

Description

Because the phase assemblages of grout and concrete probably will not be in thermodynamic equilibrium with tuff, phase transformations may occur. The rate of alteration will be enhanced because of the elevated temperatures surrounding the waste package. Therefore, one approach in developing a degradation model is to assess the impact that alteration of the phases present can have on the material properties of concern. Testing will be required to obtain the data on phase transformations, dissolution, or precipitation in the seal-host system.

Changes in mineralogy may affect solubility of phases in the cementitious material, induce volumetric changes that could increase or decrease the permeability and strength of the grout, and change the matrix and bond strengths. Therefore, the final output from this task will be a qualitative assessment of how the structural, hydrologic, and chemical properties of cementitious-based sealing material can change in their emplacement environment.

8.3.3.2.2.3 Study 1.12.2.3: In situ testing of seal components

Objectives

The objective of this study is to initiate in situ testing to evaluate the behavior of selected sealing components under realistic in situ conditions as well as under unlikely conditions.

Description

This section presents the process to determine the need for in situ testing of sealing components. The process includes the following steps:

1. The first step is an evaluation of current information needed to resolve performance/design/emplacement issues of the seal system as identified in the SCP and the technical basis report for sealing (Fernandez et al., 1987). The needed information is categorized into three groups: (a) specific properties of the site, primarily hydrologic properties, (b) properties of seal materials and the seal environment after waste package emplacement, and (c) specific properties of sealing materials necessary to ensure adequate emplacement.

2. The second step is an evaluation of the adequacy of the data by comparing the current confidence with the needed confidence in the data and the current state of the art in emplacing sealing components to achieve specific performance goals.

3. The third step is definition, evaluation, and selection of in situ tests of seal components. This step includes an understanding of the environment anticipated for seal components obtained from the site characterization program. Evaluations of the ability to reduce uncertainties in seal performance also includes evaluating the significance of the sealing subsystem in achieving the overall performance objective of the repository performance objective. Finally, it includes a refinement of the seal design considering site properties and the role of the sealing subsystem in overall repository performance.

4. The final step is detailed definition and design of specific field test(s) to evaluate performance of seal components. This includes laboratory test results to refine the scope of the field test. It can also include the impact of performing the test at specific locations.

Currently, the first two steps of the process just defined are completed and are discussed below. Steps 3 and 4 cannot be completed until some of the information from the site characterization program is obtained.

Information needed

The first step of the process evaluates the information needed. In the following discussion, SCP activities that contribute to the resolution of Issue 1.12 (this issue) are considered since the sealing program depends on diverse activities of the repository program to provide the information required to assess the need for sealing and to develop design requirements. The information needed falls into three categories:

1. Specific site properties (Table 8.3.3.2-7).

2. Seal material properties and altered properties of the seal emplacement environment (Table 8.3.3.2-8).

3. Seal material properties related to seal emplacement concerns (Tables 8.3.3.2-9a and -9b).

Tables 8.3.3.2-3 and 8.3.3.2-4 identify the properties needed with the appropriate modifiers, the tentative goals for the specific properties, the needed and current confidence in achieving the property values. SCP activities that will determine the value of the specific property are identified in Tables 8.3.3.2-7 and 8.3.3.2-8.

The following sections discuss the second-step evaluations: the adequacy of the existing data and state-of-the-art considerations.

Adequacy of data--site properties. The site properties identified in Table 8.3.3.2-7 will be evaluated by existing SCP studies and activities. In certain instances existing plans may not precisely designate specific locations for property or inflow determinations. However, appropriate locations are expected to be identified through future planning.

The ability to disperse water that flows to the repository via ramps/shafts, and intersected fault zones is primarily a function of the percolation rate of water into the floor of the repository in the Topopah Springs welded tuff. The percolation test planned for the exploratory shaft facility (Section 8.3.1.2.2.4.2) will ascertain the percolation rate in the Topopah Spring unit, but will provide little information regarding the spatial variability of infiltration rates at the repository horizon. Other similar tests may need to be considered for drifts that explore the repository horizon, such as the drifts planned to investigate the fault zones present within the repository limits. The results of these tests may allow correlation with observations of the macroscopic features of the rock to allow estimates of infiltration rates for other areas of the repository horizon.

An additional issue is a question of the effects of fines on the infiltration rate as a function of time. The ramps/shafts and drifts will ultimately be filled with an engineered backfill having specific hydraulic properties. Through time, it might be expected that the finer particles will migrate downwards and could potentially alter the infiltration properties at the base of the ramps/shafts or at the repository horizon where hydraulic conductivity is derived largely from fracture porosity. The extent to which fines may affect the fracture permeability can be investigated through design studies and laboratory and field testing, possibly as an addition to the existing percolation test in the exploratory shaft facility.

Needed rock properties within the repository are also given in Table 8.3.3.2-7. Again, the bulk of these properties will be generated by existing planned activities with the exception of items such as seismic monitoring at specific sealing locations, which will not become available until the excavation is well developed. Similarly, the site-specific characterization of hydraulic conductivity and saturation of the alluvium adjacent to ramp/shaft locations constitutes a set of determinations important to the calculation of water inflow into the ramps/shafts during and following precipitation events. The surficial geology surrounding the ramp/shaft locations will be characterized. The integration of the hydraulic measurements with these activities will be important to addressing the potential for water to be directed towards the ramps/shafts.

Table 8.3.3.2-7. Site properties needed for Issue 1.12 (seal characteristics)

Properties	SCP sections
Saturated hydraulic conductivity of alluvium near ramps/shafts	8.3.1.2.2.1.1, 8.3.1.2.2.3.1, 8.3.1.2.2.3.2
Saturated bulk rock hydraulic conductivity of Tiva Canyon Member	8.3.1.2.2.3.2, 8.3.1.2.2.4.4
Morphology of bedrock surface near ramps/shafts	8.3.1.4.2.1
Thickness of alluvium near ramps/shafts	8.3.1.2.2.1.1, 8.3.1.4.2.1, 8.3.1.14.2.1.2, 8.3.1.14.2.1.3
Quantity of water due to surface flooding events 100 and 500 yr flood and probable maximum flood including area of inundation and debris load of flows at ramp/shaft locations	8.3.1.2.1.2, 8.3.1.2.1.2.2, 8.3.1.14.1, 8.3.1.16.1.1.1
Continuous saturation profile of alluvium to bedrock-alluvium interface at ramp/shaft locations	8.3.1.2.2.1, 8.3.1.2.3.1, 8.3.1.14.2.1.2, 8.3.1.16.1.1.1
Gradation of alluvium at ramp/shaft locations	8.3.1.2.2.1.1, 8.3.1.14.2.1.2, 8.3.1.14.2.1.3
Extent and hydraulic conductivity of the modified permeability zone (MPZ) in welded Tiva Canyon unit (TCw) and Topopah Spring welded (few lithophysae) unit (TSw2)	8.3.1.2.2.4.4
Unsaturated hydraulic, matrix properties of TSw2	8.3.1.2.2.3.1, 8.3.1.2.2.3.2
Drainage capacity of TSw2 at selected drift floor locations at repository horizon and bottom of ramps/shafts	8.3.1.2.2.3.1
Saturated, bulk rock hydraulic conductivity of Calico Hills nonwelded unit (CHnl) at bottom of ramps/shafts, if constructed into CHnl, and in boreholes	8.3.1.2.2.4.4, 8.3.1.2.2.4.6
Magnitude of water entering ramps/shafts	8.3.1.2.2, 8.3.1.16.1.1.1

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Table 8.3.3.2-7. Site properties needed for Issue 1.12 (seal characteristics) (continued)

Properties	SCP sections
Erosion potential in ramp/shaft vicinity	8.3.1.6.1.1, 8.3.1.6.2.1, 8.3.1.16.1
Compressive strength of rock mass (TCn, TSw2, and CHnl) at ramp/shaft locations	8.3.1.15.1.3.1
In situ stresses in TCn, TSw2, and CHnl	8.3.1.15.2.1.1, 8.3.1.15.2.1.2
Seismic response spectra at selected areas in ramps and underground facility	8.3.1.8.2.1.5, 8.3.1.17.3.5, 8.3.1.17.3.6
Meteorological environment	
Temperature variations at ground surface at ramp/shaft entry points	8.3.1.2.1.1
pH of rainfall	8.3.1.12.1.1
Chemistry of alluvium at ramp/shaft locations	
Dissolved sulphates SO_4^{2-}	8.3.1.3.1.1
pH of alluvium	8.3.1.3.1.1
Geochemistry of TCn, TSw2, and vitric and zeolitized CHnl, (CHnlv and CHnlz)	8.3.1.3.2.1
Thermal expansion, heat capacity, and thermal conductivity of seal emplacement environment especially at TSw2 and CHnl	8.3.1.4.2.2, 8.3.1.15.1.1, 8.3.1.15.1.2, 8.3.1.15.1.3
Fracture characteristics of TCn, TSw2, CHnl at base of ES-1, if drilled into CHnl and Paintbrush nonwelded unit (PTn)	8.3.1.4.2.2
Chemistry of waters (if any) in fault including sediment content	8.3.1.3.1.1
Moisture flux beneath the repository horizon	8.3.1.2.2.1.2, 8.3.1.2.2.4.1

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Table 8.3.3.2-7. Site properties needed for Issue 1.12 (seal characteristics) (continued)

Properties	SCP sections
Infiltration rate for unanticipated conditions	8.3.1.2.1.1, 8.3.1.2.2.1
Future climatic conditions	8.3.1.5.1.1, 8.3.1.5.1.6, 8.3.1.5.2.2
Unit contacts in exploratory boreholes	8.3.1.4.2.1
Fault recharge rate	8.3.1.2.2.4.9b
Fault zone hydraulic characteristics	
Characteristics of hydrologic flow in fault zones	8.4.2.4.1, 8.4.2.4.2, 8.4.2.4.3
Saturation of alluvium	8.3.1.2.2.1.3
Surface water supply	8.2.1.2.1.2.1

Table 8.3.3.2-8. Seal material and emplacement environment properties needed

Property	Modifiers	Tentative property goal	Needed confidence	Current confidence	Expected property value	SCP section
Shaft and ramp fill properties						
- Saturated hydraulic conductivity		1×10^{-2} cm/s	High	Low	1×10^{-2} to 1×10^{-6} cm/s	8.3.3.2.2.1.2
- Gradational analyses, angle of internal friction, compressibility		To be determined through design trade-off studies	High	Low	NA[a]	8.3.3.2.2.1.1
Grade of emplacement drifts and dimensions	In repository	1 to 10%	NA[a]	High	1 to 10%	8.3.2.5.8, 8.3.2.2.7
Casing location and condition for exploratory boreholes	All boreholes in categories A and B[b]	Location of casing to ±5 m. Conditions determined by logging and drilling records	High	Medium	See Fernandez and Freshley (1984)	8.3.3.2.4
Thermal effects of water saturation and desaturation		Will balance out over the life of the repository	Medium	Low	Expect will balance out over life of repository	8.3.4.2.4
Intersection of emplacement boreholes and faults		No intersections	High	Low	Expect no intersections	8.3.1.4.2.3, 8.3.1.17.4.7
Maximum temperature at seal locations	Upper portion of shaft	<90°C	High	Low	<90°C	8.3.2.2.6
	At repository horizon around shaft	To be determined through design trade-off studies	TBD[c]	TBD	<115°C	8.3.2.2.6
	At selected drift locations in repository horizon	To be determined through design trade-off studies	TBD	Low	<150°C	8.3.2.2.6
	Calico Hills unit in boreholes below the repository	<90°C	High	Low	<90°C	8.3.2.2.6

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

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Table 8.3.3.2-9a. Emplacement concerns for the preferred sealing options (page 1 of 4)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
Anchor-to-bedrock plug	Limit surface waters entering shaft to 1,700 m^3/yr from 0 to 500 yr and 23,000 m^3/yr at the end of the sealing period (1,000 yr)	Can the liner be removed before plug placement without propagating the modified permeability zone (MPZ) outward at the plug location?	Medium	High	Unconfined compressive strength of the liner
		- Can the liner be drilled and split by one of the drill and blast or hydraulic splitter methods?	High	High	Unconfined compressive strength of the liner
		- Can the broken liner be mucked to the surface?	Low	High	NA[a]
		Can a keyway be excavated before plug construction?	High	High	Unconfined compressive strength of the welded tuff
		- Can the keyway in the welded tuff be excavated?	High	High	Unconfined compressive strength of the welded tuff
		- Can the keyway excavation be performed without propagating fractures outward?	High	High	Tensile strength, unconfined compressive strength, far-field in situ stress
		- Can rock be removed to the surface?	High	High	NA

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Table 8.3.3.2-9a. Emplacement concerns for the preferred sealing options (page 2 of 4)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
Anchor-to bedrock plug (continued)	Limit surface waters entering shaft to 1,700 m^3/yr from 0 to 500 yr and 23,000 m^3/yr at the end of the sealing period (1,000 yr) (continued)	Can grout be placed effectively by the selection of a suitable grout pattern, the use of grout pipes, and the selection of grout injection pressures?	Low to high	Medium	Cement particle size, hydraulic conductivity of tuff, hydraulic conductivity of cement
		Can grout workability be ensured during placement in the in situ moisture and temperature environment?	High	High	Setting time, slump, viscosity
		<u>Cementitious plug materials</u>			
		Can the material be placed with specified properties to form an effective hydrologic barrier?	High	High	Sieve analysis, density, heat of hydration, slump, setting time
		Can shrinkage and temperature effects due to hydration significantly alter the interface zone?	Low to high[b]	Medium to high[b]	Heat of hydration, thermal conductivity, specific heat, thermal expansion
		Can workability be ensured during placement to eliminate either premature setting or particle segregation?	High	High	Setting time, slump, viscosity

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Table 8.3.3.2-9a. Emplacement concerns for the preferred sealing options (page 3 of 4)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
Exploratory boreholes	Reduce potential for flow below the repository horizon to 1 percent of the total flow through the area within the repository perimeter	Can the casing be removed and a plug emplaced in an exploratory borehole?	High	Medium to high[c]	NA
Single dam or single bulkhead with settlement					
Emplacement drifts	Retain a portion of the ground-water inflow near source by providing adequate storage volume and drainage capacity	Can grout be placed effectively by the selection of a suitable grout pattern, the use of grout pipes, and the selection of grout injection pressures?	Low to high[b]	Medium	Cement particle size, hydraulic conductivity of fractures in welded tuff, hydraulic conductivity of cement
	Limit flow through dam to 47 m^3/yr from 0 to 300 yr and 220 m^3/yr to the end of the sealing period (500 yr)	Can grout workability be ensured during placement in the in situ moisture and temperature environment?	High	High	Setting time, workability, slump, viscosity
	Retain a portion of the ground-water inflow near the source by providing adequate storage volume and drainage capacity	Can fines be removed from the floor or controlled from entering the fracture system to reduce silting potential?	High	Low[d] to high	Particle gradation of fines, hydraulic conductivity of fractures in welded tuff

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Table 8.3.3.2-9a. Emplacement concerns for the preferred sealing options (page 4 of 4)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
		Earthen plug materials			
Emplacement drifts (continued)		Can pneumatic, hydraulic, or hand placement methods be used to emplace an earthen material with specified material properties (e.g., gradation, density, high swelling capacity) to form an effective hydrologic barrier?	High	High	Density, moisture content, particle gradation, swelling potential
General ramp/shaft backfill	Reduce potential for water and air flow	Can the shaft fill be emplaced by hydraulic, pneumatic, or hand placement methods to achieve specified properties (e.g., density, swelling capacity, and permeability)?	Medium to high[c]	High	Density, moisture content, particle gradation
Permimeter drifts or mains	Promote drainage through drift floor upgradient from dam by limiting leakage through the dam or bulkhead to 10% of the drainage capacity of the drift floor upgradient from the dam, i.e., <200 m^3/yr	Can a continuous grout structure be achieved by redrilling holes many times and grouting without affecting the sump drainage capacity?	High	Medium	Workability, viscosity, cement particle size
		Can a compacted, low permeability backfill be emplaced by hydraulic, pneumatic, or hand placement methods with specific properties (e.g., optimum moisture content, density, swelling capacity and low density)?	High	Medium	Density, moisture content, particle gradation
		Can cracks due to shrinkage or thermal effects create significant water paths?	Low to high[b]	Low to high[b]	Hydraulic conductivity of fractures in welded tuff

[a]NA = not applicable.
[b]Needed confidence depends on site conditions.
[c]Depends on whether shaft fill is a redundant seal component.
[d]In excavating the sump, it may be beneficial to use a nonexplosive demolition agent (NEDA) in restoring the floor to the original excavation quality.

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Table 8.3.3.2-9b. Emplacement concerns for the secondary sealing options (page 1 of 5)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
Station and ramp/shaft plugs	Limit surface and subsurface waters entering the underground facility to 1,000 m^3/yr (station plug) from 0 to 500 yr and 14,000 m^3/yr at the end of the sealing period (1,000 yr)	Can the liner be removed before plug placement without propagating the modified permeability zone (MPZ) outward at the plug location?	High	High	Unconfined compressive strength of the liner
		- Can the liner be drilled and split by one of the drill and blast or hydraulic splitter methods?	Low	High	Unconfined compressive strength of the liner
		- Can the broken liner be mucked to the surface?	Low	High	NA[a]
		Can a keyway be excavated before plug construction?	High	High	Unconfined compressive strength of welded tuff
		- Can the keyway in the welded tuff be excavated?	High	High	Unconfined compressive strength of welded tuff
		- Can the keyway excavation be performed without propagating fractures outward?	High	High	Tensile strength, unconfined compressive strength, far-field in situ stress
		- Can rock be removed to the surface?	High	High	NA[a]
		Can grout be placed effectively by the selection of a suitable grout pattern, the use of grout pipes, and the selection of grout injection pressures?	High	Medium	Cement particle size, hydraulic conductivity of tuff.

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Table 8.3.3.2-9b. Emplacement concerns for the secondary sealing options (page 2 of 5)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
Station and ramp/shaft plugs (continued)		Can grout workability be ensured during placement in the in situ moisture and temperature environment?	High	High	Setting time, slump, viscosity
		Cementitious materials			
	Provide structural support of ramp/shaft backfill (station and ramp/shaft plugs in ramp/shaft) if necessary	Can the materials be placed with specified properties to form an effective hydrologic barrier?	High	Medium	Density, compressive strength, permeability
		Can shrinkage and temperature effects due to hydration significantly alter the interface zone?	Low to high	Medium to high	Heat of hydration, thermal conductivity, specific heat, thermal expansion
		Can workability be ensured during placement to eliminate either premature setting or particle segregation?	High	High	Setting time, workability, slump, viscosity
		Earthen materials			
		Can pneumatic, hydraulic, or hand methods be used to emplace an earthen material with specified material properties (e.g., gradation, density, high swelling capacity) to form an effective hydrologic barrier?	High	Medium	Density, moisture content, particle gradation
Double bulkhead (no settlement)					
Emplacement drifts	Retain inflow between two bulkheads by providing adequate storage volume and drainage capacity	Can a keyway be excavated before seal construction?	High	High	Unconfined compressive strength of welded tuff

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Table 8.3.3.2-9b. Emplacement concerns for the secondary sealing options (page 3 of 5)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
Emplacement drifts (continued)		- Can the keyway in welded tuff be excavated?	High	High	Unconfined compressive strength of welded tuff
	Limit flow through bulkhead to 24 m^3/yr/bulkhead from 0 to 300 yr and 110 m^3/yr/bulkhead to the end of the sealing period (500 yr)	- Can the keyway excavated be performed without propagating fractures outward?	High	High	Tensile strength unconfined compressive strength, far-field in situ stress
		- Can the rock be removed to the surface?	High	High	NA
		Can grout cements be placed effectively by the selection of a suitable grout pattern, the use of grout pipes, and the selection of grout injection pressures?	High	Medium	Cement particle size, hydraulic conductivity of cement
		Can grout workability be ensured during placement in the in situ moisture and temperature environment?	High	High	Setting time, workability, slump, viscosity
		<u>Cementitious materials</u>			
		Can the material be placed with specified properties to form an effective hydrologic barrier?	High	Medium	Density, compressive strength, and permeability
		Can shrinkage and temperature effects due to hydration significantly alter the interface zone?	High	Low	Heat of hydration, thermal conductivity, specific heat, thermal expansion

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Table 8.3.3.2-9b. Emplacement concerns for the secondary sealing options (page 4 of 5)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
Emplacement drifts (continued)	Limit flow through bulkhead to 24 m^3/yr/bulkhead from 0 to 300 yr and 110 m^3/yr/bulkhead to the end of the sealing period (500 yr) (continued)	Can workability be ensured during placement to eliminate either premature setting or particle segregation during placement?	High	Medium	Setting time, workability, slump, viscosity
		<u>Earthen materials</u>			
		Can pneumatic, hydraulic, or hand placement methods be effectively used to emplace an earthen material with specified material properties (e.g., gradation, density, high swelling capacity) to form an effective hydrologic barrier?	High	High	Density, moisture content, particle gradation
		Can cracks due to shrinkage or thermal effects create significant water paths?	Low to high[b]	Low	Strain parameters - Young's modulus - tangent modulus Poisson's ratio, cohesion foliation angle
Backfilled sump	Retain ground-water inflow near source	Can fines be removed from the floor to reduce silting potential?	High	Low to high	Particle gradation of fines, hydraulic conductivity of welded tuff
Plug in a horizontal emplacement hole	Limit ground-water inflow past plugs to 12 m^3/yr from 0 to 300 yr and 56 m^3/yr at the end of the sealing period (500 yr)	Can the material be placed with specified properties?	High	High	Density, compressive strength, permeability

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Table 8.3.3.2-9b. Emplacement concerns for the secondary sealing options (page 5 of 5)

Design options	Tentative design goals	Emplacement issues and uncertainties	Needed confidence that the operation can be achieved	Current confidence that the operation can be achieved	Material properties of concern
Plug in a horizontal emplacement hole (continued)	Limit ground-water inflow past plugs to 12 m^3/yr from 0 to 300 yr and 56 m^3/yr at the end of the sealing period (500 yr) (continued)	- Can shrinkage and temperature effects due to hydration be controlled by testing to reduce separation at the interface zone?	High	Low	Heat of hydration, thermal conductivity, specific heat, thermal expansion
		- Can workability be ensured during placement to eliminate either premature setting or particle segregation during placement?	High	High	Workability setting time, slump, viscosity
Channel in backfilled room	Channel ground-water inflow away from waste package, dependent on hydraulic conductivity of channel fill material, at the following flow rates: <2,000 m^3/yr (<1 gal/min) 2,000 to 20,000 m^3/yr (1-10 gal/min) 20,000 to 2 x 10^6 m^3/yr (10-100 gal/min)	Can backfill be emplaced in channel subject to quality control testing of specified gradations to eliminate the potential for silting?	High	High	Particle gradation of backfill
	Limit ground-water inflow past plugs to 12 m^3/yr from 0 to 300 yr and 56 m^3/yr at the end of the sealing period (500 yr)	Can grout be injected at the interface zone to reduce conductivity?	High	Medium	Cement particle size, hydraulic conductivity of cement

[a]NA = not applicable.
[b]Needed confidence depends on site condition.

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Several major exploratory drifts will focus on the fault zones and the hydrologic investigations are pertinent to quantify the amount of water (if any) that may enter the underground facility. The effects of anisotropic flow within the fault, characterization of the geochemistry of waters contained in the fault zone, and the effects of overlying alluvial sediments on the recharge of the fault zones will also be considered. Additional concerns regarding sealing, containment, and dispersal of waters from fault zones, and possibly perched water, intersected at depth will be considered in evaluating the field observations. The true importance of these concerns will ultimately rest upon the locations of the zones encountered, the number of zones intersected, the rate and frequency of flow within the fault zones, and the ability to disperse the water by infiltration to below the repository horizon.

Adequacy of data--on seal materials properties. The properties of the ramp/shaft fill are identified in Table 8.3.3.2-8. Additional needed information on seal materials is outlined in Table 8.3.3.2-6, which indicates potentially important material properties of concern for sealing components. These information needs and the required testing will be modified, if necessary, as the seal design requirements are refined.

Adequacy of data--emplacement concerns. Information needs on various operations including the removal of the liner and the emplacement of seal components are evaluated for the preferred and secondary options of seal components in Tables 8.3.3.2-9a and 8.3.3.2-9b respectively. The following evaluations assume that specific seal components would be placed to provide additional assurance that performance goals can be achieved. Specific emplacement concerns are raised, and the needed confidence and current confidence that the emplacement operations can be achieved are identified. The material properties of concern are then identified. A summary of the adequacy of the data is presented below.

In general, there is a high level of confidence that liners can be removed, that keyways can be constructed, that seals composed of either earthen or cementitious materials can be emplaced, and that existing laboratory or field methods for monitoring quality control or defining performance or index properties are available and adequate. The material properties of concern for grouts include cement particle size, the hydraulic conductivity of cement, and the hydraulic conductivity of welded tuff. The properties for cementitious materials include hydraulic conductivity, particle size, density, heat of hydration, slump, and setting time. The properties for earthen materials include density, moisture content, particle gradation, and swelling potential. These properties will be characterized by laboratory testing.

During repository construction and operation, fines may enter the floor and could reduce the floor hydraulic conductivity. This would reduce floor infiltration capacity at the repository horizon. Laboratory testing is required to identify the effects of solids in water (particle size and gradation) on reducing hydraulic conductance. The concerns to be addressed include the potential for fines to migrate as a function of particle size, particle gradation, hydraulic potential, and infiltration rate. This testing may be performed in conjunction with the sand-bed test as described subsequently.

Special concerns regarding grouting or the use of cut-offs are currently expected to be addressed through subsequent advanced conceptual design trade-off studies. Nevertheless, either grout curtains or earthen dams may need to be designed and constructed to cut off flow through the modified permeability zone around ramp/shaft seal components. These possibilities will be considered if low permeability zones with favorable fracture frequencies, orientations, and apertures cannot be located, or if sufficient sump/floor drainage capacity in specific areas at the repository horizon does not exist. In these instances, a postconstruction emplacement test might be required that would test the effectiveness of the grout curtain and confirm that hydrologic performance can be achieved through a suitable grout pattern, the use of grout pipes, and the selection of grout injection pressures.

A sealing component with a tight, low-permeability interface may need to be designed and constructed so that either temperature and hydration effects will be controlled for cementitious materials during emplacement or shrinkage will be controlled for earthen materials during placement. In this instance, consideration may be given to field testing to confirm the performance of the interface zone.

State of-the-art considerations. The following considerations are important in evaluating the need for in situ tests on sealing components prior to license application:

1. Current design requirements for hydraulic conductivity particularly in the case of general shaftfill (10^{-2} cm/s) or for seals (10^{-5} to 10^{-4} cm/s) are expected to be easily achievable with current emplacement methods for cementitious or earthen materials.

2. Current information indicates that the hydrologic properties of the interface zone are not significant in achieving the hydrologic performance goals for the seal system considering unsaturated flow.

3. While the range of potential host-rock properties is significant, it is likely that seals could be located in low permeability zones with minimal modified permeability zone (MPZ) effects. Current designs that would utilize grouting, and keyways may not be required.

4. Depending in part upon the inflow observed at the repository horizon, floor and sump infiltration rates may be quite sufficient in eliminating the potential for lateral flow at the repository horizon and would eliminate the need for earthen dams or bulkheads at this horizon.

5. Laboratory methods are available to evaluate important index properties used for quality control during emplacement and are planned as discussed subsequently.

6. Several seals emplacement methods are currently available and alternative methods are proposed to accommodate varying site conditions. Existing conceptual designs are not dependent on specific emplacement methods.

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7. Additional design information on the underground facility is necessary for the selection of the specific seal locations and emplacement methods that would be available after construction startup.

Several of these considerations are elaborated in the following paragraphs.

In achieving the performance goals, it is currently possible to specify either cementitious or earthen materials with conductivities that are several orders of magnitude lower than the current hydrologic design requirements (10^{-5} to 10^{-4} cm/s) for the preferred sealing options. Typical concrete hydraulic conductivities of less than 10^{-8} to 10^{-6} cm/s are currently achievable, and special concretes with hydraulic conductivities less than 10^{-10} cm/s have been reported (Mather, 1967). For earthen materials, low hydraulic conductivities may be achieved by increasing the content of clay or silt. For example, mixtures using kaolinite clay have conductivities as low as 10^{-8} cm/s, while mixtures with bentonite can be as low as 10^{-12} cm/s (Fernandez et al., 1987).

Previous investigations have evaluated the properties of the interface zone in anhydrite and basalt (Lingle and Bush, 1982; Kelsall et al., 1984). The properties of an anhydrite-interface zone were investigated in laboratory tests. A 48-cm long by 20-cm diameter cement plug was placed in a borehole drilled in the laboratory in a block of anhydrite (Kelsall et al., 1984). The borehole was drilled, and the plug placed in a custom-built pressure vessel that allowed simulation of the in situ conditions, such as overburden stress, bit pressure, and mud pressure. After the plug was cured, a flow test was performed using a differential-fluid pressure of 13.8 MPa (2,000 psi). Dye penetrant was introduced in the permeant to determine the flow path. Finally, after the flow test was completed, the sample was removed from the pressure vessel and sectioned for examination of the interface. Assuming the flow occurred across the cross-sectional area of the cement plug, the equivalent permeability was found to be of the order of 10^{-7} cm/s. Examination of the sectioned plug and the dye penetration revealed clearly that the flow had been concentrated at the interface in a much smaller area than that arbitrarily assigned for calculation of equivalent permeability.

A subsequent test was performed in basalt (Lingle and Bush, 1982). In analyzing the data from basalt, an assumption can be made that flow occurs through the interface zone which behaves like a smooth-wall fracture. Assuming the cubic law applies, an equivalent-smooth-wall fracture aperture may be calculated and plotted as a function of effective stress (the difference between confining pressure and pore pressure) as indicated in Figure 8.3.3.2-4.

The results support the theory that the interface zone behaves like a fracture in that at low effective stress levels, the interface is "open" and exhibits high conductivity. At higher stress levels, the interface becomes "closed" and exhibits a much lower conductivity that is independent of effective stress level. Further evidence is provided by comparing the results with flow tests on a single fracture in basalt (Iwai, 1976) as illustrated in the figure. An equivalent smooth-wall aperture of four micrometers is indicated and would correspond to a "tight" flow zone at high effective stress.

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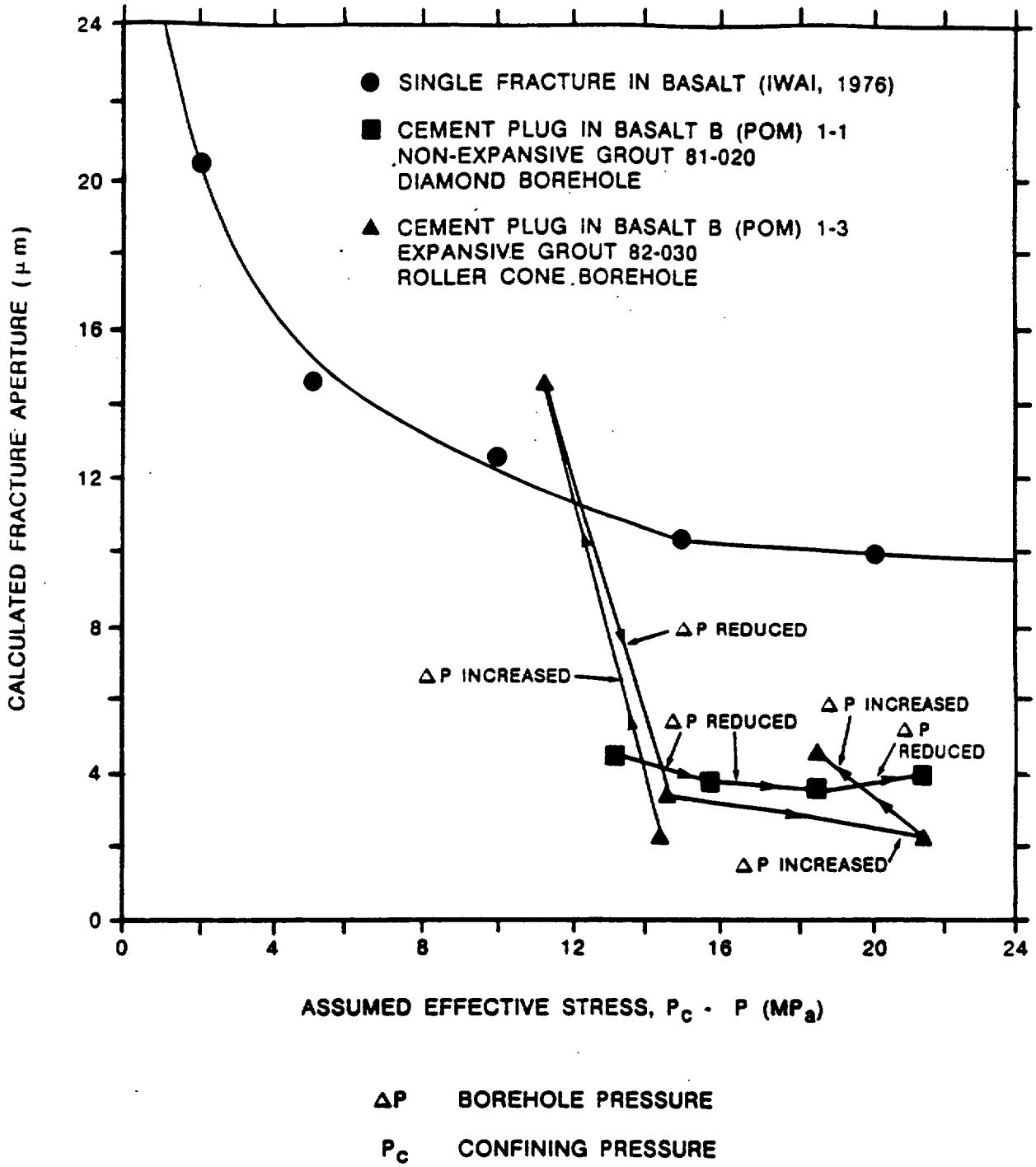

ΔP BOREHOLE PRESSURE

P_c CONFINING PRESSURE

Figure 8.3.3.2-4. Comparison of borehole plug test with experimental data for fractured basalt. Data for plug tests from Lingle and Bush (1982).

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An experiment on a borehole seal in welded tuff has been reported by Daemen et al. (1983). A rock specimen 31 cm long by 15 cm in diameter was installed in a permeameter and loaded axially and laterally with confining stresses ranging from 7 to 20 MPa and axial stresses ranging from 8 to 23 MPa. A coaxial hole (2.5 cm in diameter) was then drilled from each end of the specimen leaving a rock bridge in the center. A differential pressure was applied and flow measurements were performed. After these initial flow measurements were performed, the rock bridge was drilled out and replaced by a cement plug. The plug was then tested under a similar set of total stress and pore pressure conditions. Daemen et al. (1983) expressed the conductivity of the plug as an equivalent conductivity for flow through plug and interface zone. The reported values ranged from 10^{-13} to 10^{-10} cm/s. If the flow is assumed to occur through a smooth-wall "crack" at the plug perimeter, an equivalent smooth-wall fracture aperture of 0.5 to 5 micrometers is calculated, which is similar to the calculated value from the test in basalt.

While application of these results to the emplacement of large-scale seals in welded tuff and the need for future laboratory testing to confirm the interface-zone flow performance is a concern, it is likely that a tight interface zone will be achieved for seals emplaced in welded tuff. In this case, the conductance of the interface zone may not be the controlling factor when compared with the conductance of the plug or the surrounding modified permeability zone.

Modified permeability zone studies (Case and Kelsall, 1987) have examined the potential range of hydrologic properties for shafts excavated in welded tuff (the increase in permeability and radial extent of the damaged zone). Additional studies may be done for ramps if it is determined that they are needed. Tentative design goals (Fernandez et al., 1987) assumed worst case conditions: their assumptions were that the hydraulic conductivity of the host rock is 10^{-2} cm/s, and that the increase in conductivity of the MPZ is 60 times the host rock conductivity. These conditions assume that deformations due to stress relief across fractures are inelastic, that a 1.0-m-wide blast-damage zone has formed, and that changes in fracture conductivity are sensitive to stress. Further, the calculations neglected the role of artificial support in restricting rock deformations. These rock conditions could necessitate the design of a keyway, and treatment of the MPZ if the surrounding host rock conductivity (10^{-2} cm/s) is at the high end of the range of conductivities for welded tuff. However, a location will likely be found for key seals that would have more favorable rock properties (e.g., host rock conductivity is low, rock deformations are elastic, blast damage zone is thin, and fracture conductivity is insensitive to changes in stress). For these conditions, the host rock conductivity might be several orders of magnitude lower and the conductivity in this zone might increase by a lower factor. Treatment of the MPZ by the construction of a keyway or grouting may not be required for these rock conditions.

The drainage through sump areas at the bottom of the shafts or through the drift floor at the repository horizon have been calculated by Fernandez et al. (1987) and compared to anticipated flow rates. It was found that if a sump in a shaft is constructed below the repository horizon, adequate drainage capacity would exist to dissipate flows without water entering the repository. If water were to enter the repository from shafts, it would flow to the lowest part of the repository, which has an estimated drainage capacity of 32,000

m^3/yr (assuming vertical emplacement and a bulk rock hydraulic conductivity of 10^{-5} cm/s). This would be quite sufficient to drain anticipated flow rates. In individual drifts, it is expected that the drainage capacity of the flow will far exceed the anticipated flow rates to the underground facility.

The flow rates for anticipated conditions ranged from 40 to 60 m^3/yr for the entire underground facility. The floor drainage capacity of a single room is approximately 6,000 m^3/yr assuming the saturated conductivity of the tuff is 10^{-5} cm/s. This indicates that the expected inflow is much smaller than the potential drainage capacity.

Backfill can be emplaced using mechanical or pneumatic methods. In the former case, the crushed tuff would be transported by conveyers and emplaced by load-haul-dump vehicles and small bulldozers. As necessary, the material can be compacted with smooth-drum rollers, hand-held tampers or vibratory compactors, or by repeated passes by the emplacement equipment (Hilf, 1975). Effective compaction of sand and gravel has been obtained using vibratory rollers (Terzaghi and Peck, 1967). The material is spread in layers 12 to 14 in. thick and two to four passes of the roller are used. Moisture control is not necessary. In limited areas, self-propelled, hand-operated vibratory compactors have also been found useful.

Pneumatic emplacement can handle earthen materials up to three inches in size, which can be transported directly from the surface. Methods used for pneumatic backfilling of abandoned mines are discussed by Eby (1981). For earthen materials, greater compaction can be achieved in materials containing a wide range of grain sizes (well graded) than in more uniform materials.

Emplacement methods are also available for cementitious materials. Auld (1983) presents information on important construction aspects for batching and transporting concrete, placement methods for eliminating thermal and shrinkage effects, and grouting procedures. Auld (1983) also presents several case histories in which the effectiveness of seal emplacement (reduced flow rate as a function of time) was demonstrated. In one instance, at a mine in England, Auld (1983) reports that a low heat of hydration mix, incorporating a cement replacement material was used to construct an emergency plug that resulted in a one hundred-fold reduction in flow rate.

Possible in situ sealing tests

The process to develop in situ seals tests was described above. Four steps were defined: (1) evaluation of site and seal materials properties, (2) evaluation of the adequacy of these properties including a discussion of the current state of the art, (3) definition, evaluation, and selection of in situ tests of seal components, and (4) detailed definition and design of specifics of field tests. Preliminary evaluations supporting the first two steps have been completed, and some of the evaluations of step 3 are completed. However, before step 4 can be completed, additional information will be required from site characterization activities and from an evaluation of the role that the sealing subsystem plays on the overall repository performance (step 3). Nevertheless, the initial evaluations in step 3, as supported by the assessments performed in steps 2 and 3, do indicate several areas in which field tests may be performed to reduce uncertainties in seal performance. These are verification of emplacement techniques and seal

behavior under anticipated and unanticipated hydrogeologic conditions. Examples of potentially appropriate tests are siltation-infiltration tests, borehole seal tests, and a ramp/shaft seal test.

The definition of the seals tests will be based in part on some of the hydrologic information obtained early in site characterization and data may include the rate of flow of water, degree of fracturing of the rock mass, fracture orientation, fracture interconnectivity, etc. The test definition is planned to be completed in time to conduct needed experiments before license application.

Once in situ tests have been defined, test locations will be selected so other planned or ongoing tests will not be disturbed and also so other tests will not disturb the sealing test. Evaluations will also be made to ensure that the quantity of water proposed for use in the tests will not significantly increase uncertainties relative to postclosure performance.

If it is determined that sealing-related testing influences other tests or leads to postclosure performance uncertainties, consideration will be given to conducting the tests in an alternative location, such as G-tunnel on the Nevada Test Site. A study plan will be prepared to support the in situ test program for seals after detailed concepts for testing are developed.

It is important to emphasize that many tests supporting the sealing program will be performed within the ESF (e.g., the hydrologic tests defined in Table 8.3.3.2-7). Should other tests be indicated as a result of these tests and other activities, sufficient flexibility exists for expanding the ESF to accommodate additional appropriate tests.

8.3.3.2.3 Information Need 1.12.3: Placement method for seals for shafts, drifts, and boreholes

Technical basis for addressing the information need

The technical basis for addressing the information need is discussed below by first identifying the contents of related sections of the SCP and other documents. Needed parameters are then described. The logic for the technical activities is described and planned design activities are identified.

Link to the technical data chapters and applicable support documents

Seals may be required to limit ground-water flow through shafts, drifts, or boreholes that could contribute to release of radionuclides from the repository. These seals, if required, must be designed to be emplaced using adequately established technology and must be emplaced so that seal performance is acceptable. Once the reference designs are selected as part of Information Need 1.12.4, data required to select appropriate placement methods will be obtained.

Information that will be required in selecting a suitable placement procedure for sealing components includes the design of the repository,

conditions of man-made and natural penetrations that must be sealed and the required properties of the sealing materials/systems. Design of the repository is presented in Section 6.2 of the SCP and in the SCP-CDR (SNL, 1987). Knowledge of the conditions to be encountered in the underground facility, the shafts, and ramps will be obtained through observations at the time of the excavation of the exploratory shaft facility. The design portion of the Yucca Mountain Project repository seal program uses the approach that a range of hydrogeologic conditions may be encountered as the repository is developed. These variable conditions could, therefore, require variable placement options. The general descriptions of water entering the exploratory ramps/shafts and the exploratory shaft facility will provide an increased data base on water-producing zones that may require sealing and hence, consideration of the appropriate placement technique.

Data on borehole conditions are currently being recorded. Borehole conditions are briefly described in Chapter 6 of the SCP.

Parameters

Several properties of candidate seal materials are directly affected by placement methods and conditions. Conversely, the selection of a feasible emplacement method may be influenced by properties of the material. Data needed to address this information need include the available placement or construction methods for proposed seal components and those properties of seal materials that affect or are affected by emplacement.

For earthen materials (clays, rockfill), these properties are

1. Density-water content relation.
2. Particle gradation.
3. Hydraulic conductivity related to density.
4. Swelling capacity related to density.

For cementitious materials, these properties are

1. Density.
2. Heat of hydration.
3. Slump, viscosity.
4. Workability.
5. Set time and working time.
6. Maximum particle size of aggregate phases.

The data represented in the preceding list are those variables that can be modified to accommodate the placement strategy to be used for the sealing component. Because multiple placement strategies will be proposed to accommodate varying site conditions, no site parameters will be required to establish the appropriate placement methods. Site conditions as encountered will focus on the appropriate placement method. Design information on the underground facility and existing boreholes is also necessary to select the appropriate placement method. Laboratory analyses will be performed as part of Study 1.12.2.1 (Section 8.3.3.2.2.1) under Information Need 1.12.2 to define the properties of earthen and cementitious-based materials identified previously.

Logic

For granular materials (e.g., clays, crushed rock), the method and degree of compaction may have a strong effect on density and porosity, hydraulic conductivity, and swelling pressure. The required in situ properties may influence the selection of emplacement method, principally according to the degree of compaction necessary. Selection may also be influenced by the gradation and moisture content of the material. For example, pneumatic methods may be limited to certain gradation and moisture ranges. Performance of cementitious materials may be affected by the method of consolidation, the presence of free water, and temperature during emplacement and curing. Selection of placement methods will be influenced by properties such as the heat of hydration, working time, harshness, and viscosity. For example, the heat of hydration of a concrete mix may limit the thickness of any lift that can be emplaced to prevent undue thermal stresses in the seal zone.

There are no planned design activities identified for this information need. Any trade-off design activities evaluating the appropriate placement method will be performed as part of the advanced conceptual design or the license application design (Information Need 1.12.4, Section 8.3.3.2.4). Development of properties of earthen and cementitious-based materials will be obtained as part of Information Need 1.12.2 (Section 8.3.3.2.2).

8.3.3.2.4 Information Need 1.12.4: Reference design of seals for shafts, drifts, and boreholes

Technical basis for addressing the information need

The technical basis for addressing the information need is discussed below by first identifying the contents of related sections of the SCP and other documents. Needed parameters are then described. The logic for the technical activities is described and planned design activities are identified.

Link to the technical data chapters and applicable support documents

This information need will provide the seal design that will become part of the overall repository design. The seal design, therefore, is described in Section 6.2, current repository design description. A further description of the seal component design will be given in the SCP-CDR (SNL, 1987). As part of this information need the seal design, which is based on design requirements, will be developed.

Parameters

To develop the seal design, site and repository design information is required. The parameters needed for design are defined in the parameters subsection of Information Need 1.12.1, Section 8.3.3.2.1. Using the designs provided in this information need description, the appropriate materials (Information Need 1.12.2, Section 8.3.3.2.2) and placement methods (Information Need 1.12.3, Section 8.3.3.2.3) will be selected.

Logic

The seal design effort integrates the parameters from Information Need 1.12.1. If seals are found to be necessary, the design requirements for the seal system can be developed. The design requirements are those properties that the seal system must attain, such as low overall hydraulic conductivity, to meet regulatory guidelines for radionuclide releases.

Design requirements will also specify the requirements for materials to be used in the seals or seal components. These will include the properties needed to attain seal performance requirements. These design requirements form a basis for materials testing (Information Need 1.12.2) and for selecting materials to be included in the seal designs. The placement technology study to be performed as part of the trade-off studies associated with the advanced conceptual design activities will provide additional input to the design regarding suitable construction methods and their effects on seal performance. Thus, the design study and the materials and emplacement studies interface closely and require a degree of iteration between design requirements and materials properties testing.

Both of the design activities defined below are divided into three areas: define design requirements, perform trade-off studies, and develop seal designs.

8.3.3.2.4.1 Design Activity 1.12.4.1: Development of the advanced conceptual design (ACD) for sealing

8.3.3.2.4.1.1 Design Subactivity 1.12.4.1.1: Define subsystem design requirements

Objectives

The objective of this subactivity is to develop design requirements that will assist the designer in the development of sealing components.

Description

Currently, the following tasks will be performed to support the advanced conceptual design:

1. Define sealing components.

2. List state and local regulations to establish the basis for design.

3. Develop functional requirements for the sealing subsystem, including the subsystems role in ensuring long-term waste containment and isolation.

4. Define the performance criteria for the sealing system to establish the level of performance required of the sealing system.

5. Identify the interfaces between the sealing system and other systems.

6. Define constraints in limitations placed on the sealing system or on other systems by the sealing system.

7. Describe the design-basis assumptions (if any) to be used in designing the sealing system.

8.3.3.2.4.1.2 Design Subactivity 1.12.4.1.2: Perform trade-off studies to support advanced conceptual design development

Objectives

The objective of this subactivity is to provide technical justification for the selection of specific design options.

Description

The primary focus of the advanced conceptual design (ACD) work will be the resolution of design and engineering issues through the use of engineering tradeoff studies. These tradeoff studies would

1. Evaluate the potential suitability of gradations for the ramp/shaft and drift fill. If materials from the exploratory shaft facility are unavailable before the development of the design, only an analytical assessment of ramp/shaft settlement will be performed using a simple consolidation theory and available material properties.

2. Evaluate strategies for dissipating water at the floor of ramps and drifts.

3. Evaluate strategies for sealing discrete, water-producing fault or fracture zones encountered in horizontal emplacement holes and drifts.

4. Evaluate the need for settlement plugs by determining the consolidation behavior of various ramp/shaft fills and the subsequent consequence if no plugs are emplaced.

5. Assess the effectiveness of sealing components to deter human entry and propose preferred methods.

6. Assess the techniques available for emplacing various sealing components and the resulting seal performance that can be expected from each emplacement technique.

7. Assess how different materials can accommodate potential variations in stress, temperature, moisture, and geochemical conditions.

8.3.3.2.4.1.3 Design Subactivity 1.12.4.1.3: Develop advanced conceptual design for seals

Objectives

The objective of this subactivity is to provide design details that can be used to develop the license application design and to support the performance assessment activities.

Description

The advanced conceptual design (ACD) will summarize the results of the trade-off studies performed as part of Subactivity 1.12.4.1.2. The following would be included:

1. The basis for sealing designs.

2. A description of the designs.

3. The design alternatives and a description of how the preferred design is selected.

4. Definition of the uncertainties/design issues associated with the preferred designs.

Some secondary information included as part of the ACD would include preliminary cost estimates for emplacing sealing components (this cost estimate will also include the cost associated with additional research and development that may be required to answer the performance-related questions and finalize designs), a schedule for emplacing sealing components as part of the decommissioning process, and a discussion of activities required to support the performance confirmation program.

8.3.3.2.4.2 Design Activity 1.12.4.2: Development of the license application design for sealing

There are three design subactivities in this design activity.

8.3.3.2.4.2.1 Design Subactivity 1.12.4.2.1: Define subsystem design requirements

Objectives

The objective of this subactivity is to refine design requirements that will assist in the development of sealing components for the license application design (LAD).

Description

The development of design requirements for the LAD is expected to be similar to the categories for Subactivity 1.12.4.1.1. The basis for changes would be the results from Subactivities 1.12.4.1.2 and 1.12.4.1.3, as well as results from ongoing performance assessment activities. Changes are anticipated in the development of performance criteria, design interfaces, and constraints identification.

8.3.3.2.4.2.2 Design Subactivity 1.12.4.2.2: Perform trade-off studies to support license application design development

Objectives

The objective of this subactivity is to provide technical justification for the selection of the final seal designs.

Description

The intent of this task is to perform the remaining trade-off studies that will be necessary to select final seal designs. The remaining design and licensing issue is also expected to be resolved by these studies. Some trade-off analyses would

1. Select the preferred strategies for retaining and dissipating water encountered in the underground facility considering material durability and design adequacy in achieving the desired performance.

2. Define the potential licensing issues and propose a resolution of the issues with consideration of the preferred sealing options.

3. Select the preferred method of backfilling the underground facility and evaluate the most effective way in which to expedite sealing of the drifts.

Although not specifically part of the trade-off studies, a performance assessment of sealing components will be initiated during the advanced conceptual design phase and continue into license application design phase. Results from this assessment will be used to develop and refine the design requirements and performance criteria. The plans for evaluating seal performance are discussed in Section 8.3.5.11.

8.3.3.2.4.2.3 Design Subactivity 1.12.4.2.3: Develop license application design for seals

Objectives

The objective of this subactivity is to provide the license application design for seal components.

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Description

The license application design will include the design details primarily for the preferred sealing designs that result from details associated with the tradeoff studies performed as part of Subactivity 1.12.4.2.2 and specific activities performed as part of this task. The following activities would be performed as part of this task.

1. Develop final designs and emplacement procedures for the preferred sealing options.

2. Quantify the physical construction requirements for the emplacement procedures established previously.

3. Develop a reliable cost estimate and a schedule of construction activities needed to emplace the sealing components in the repository. The cost estimates will include a detailed statement of the costs incurred to emplace seal components. Manpower, materials, and equipment requirements will be included.

4. Develop contingency plans for sealing in the event that unforeseen geologic conditions are encountered.

8.3.4 WASTE PACKAGE PROGRAM

The waste package program is organized to address two performance issues (Issues 1.4 and 1.5) and three design issues (Issues 1.10, 2.6 and 4.3) included in the issues hierarchy. This section describes the overall waste package postclosure compliance strategy and the design issues of the waste package program for the Yucca Mountain Project (formerly called the Nevada Nuclear Waste Storage Investigations Project). The performance issues of the waste package program are discussed in Sections 8.3.5.9 and 8.3.5.10.

Section 8.3.4.1 provides an overview of the program. The design activities and site data needs for addressing the postclosure waste package requirements are described in Section 8.3.4.2 (Issue 1.10). This discussion includes a description of the studies and activities required to characterize the waste package emplacement environment. Section 8.3.4.3 describes the preclosure containment requirements for the waste package and discusses the information to be obtained on waste forms (Issue 2.6). Information needed to develop the technologies for production of the waste package is described in Section 8.3.4.4 (Issue 4.3).

Sections 8.3.5.9 and 8.3.5.10 discuss the waste form, package materials, and site data needs and describe the activities planned to demonstrate compliance with the performance objectives for waste package containment and engineered barrier system release.

Waste package postclosure compliance strategy

The waste package postclosure compliance strategy is designed to resolve waste package issues in an integrated manner as shown in Figure 8.3.4-1. The waste package issues and information needs are based on the requirements in the U.S. Nuclear Regulatory Commission's (NRC) 10 CFR Part 60 with considerations of the Nuclear Waste Policy Act of 1982, the U.S. Environmental Protection Agency's 40 CFR Part 191, the U.S. Department of Energy's (DOE) 10 CFR Part 960, and the Generic Requirements for the Mined Geologic Disposal System (MGDS). Figure 8.3.4-1 provides an overview of the process that the Yucca Mountain Project is following to develop a licensable, cost-effective waste package design on the required schedule. This simplified format depicts only the key elements of the waste package program strategy and the major interactions among them. For the purposes of the site characterization plan, the Yucca Mountain Project has adopted the DOE interpretations for the regulatory terms "substantially complete containment," "engineered barrier system," and "anticipated processes and events."

Approaches taken by the Project for the waste package postclosure compliance strategy are to employ multiple barriers consistent with the NRC's philosophy and to use logical and defensible arguments based on scientific investigations and engineering analyses. From the existing data bases for waste forms, characteristics of the Yucca Mountain site, and the preliminary process and event scenarios, the Project has developed a waste package concept and a coupled waste package near-field environment scenario, from which a conceptual waste package design has evolved. The conceptual design

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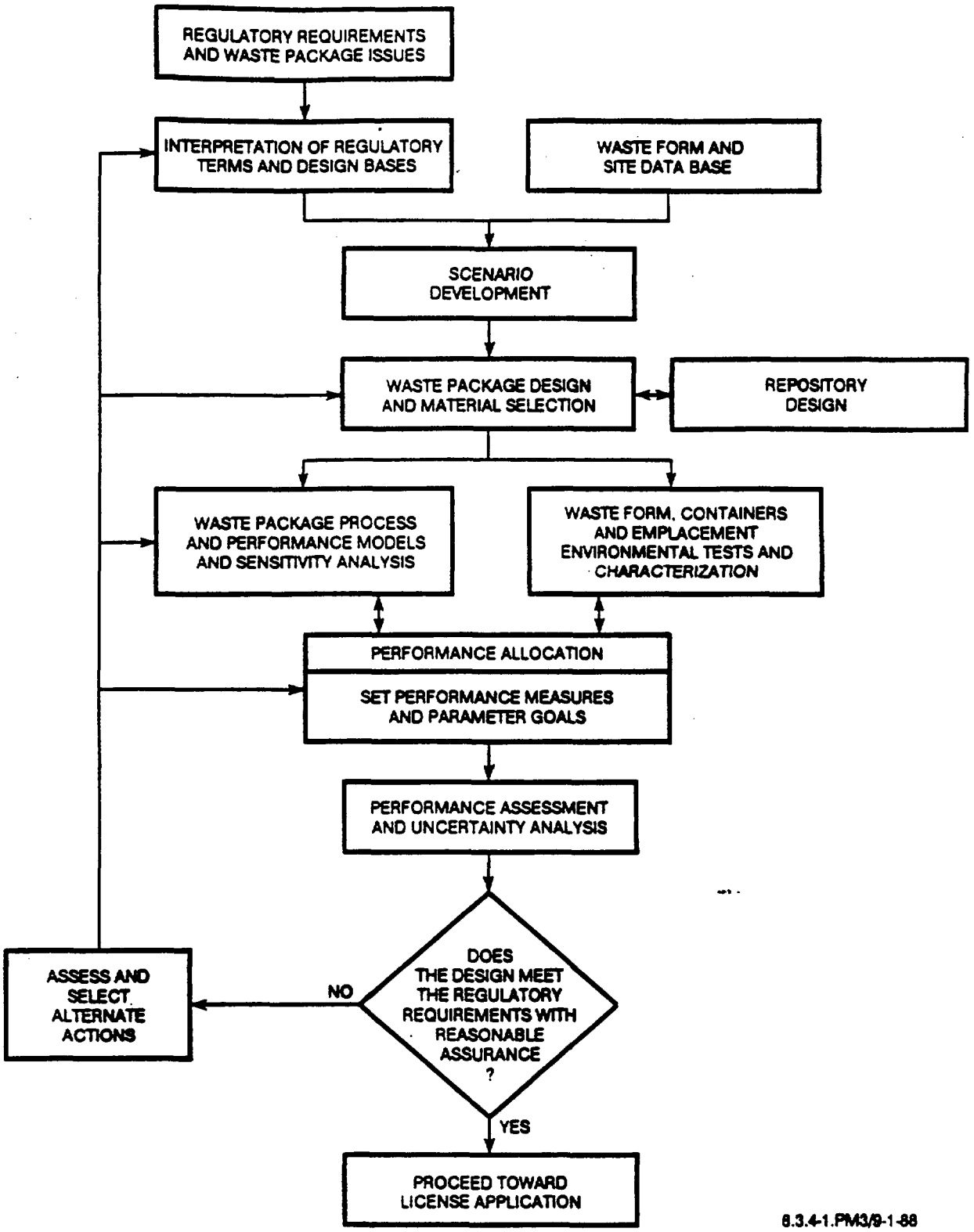

Figure 8.3.4-1. Waste package postclosure compliance strategy

in turn provides the basis for the development of the waste package testing and performance assessment activities utilizing computational models. These models are used to guide the design and testing programs and to aid in performance allocation to waste package components. Sensitivity analyses are performed to quantitatively relate performance measures (e.g., containers breached versus time) to design or environment parameters.

The essence of the waste package compliance strategy lies in the iterative process of performance allocation, performance assessment, testing to determine if goals are met, and, if not, evaluation and selection of alternative actions such as changes in waste package design or materials, modification of computational models, performance of additional tests to improve data bases for the waste package and the environment, or the reallocation of component performance. It is also possible that an alternative definition or interpretation of the regulatory terms "substantially complete containment" and the "engineered barrier system" by the NRC or the DOE may change the performance allocation. The iterative process continues until the performance objectives are met with reasonable assurance. The selection of the alternative actions will be determined based on the results of performance assessment.

The waste package postclosure compliance strategy for the Yucca Mountain Project is structured within an issues hierarchy, and the performance allocation process is used to resolve the issues. There are three interrelated issues on postclosure performance of the waste packages. Sections 8.3.4.2, 8.3.5.9, and 8.3.5.10 discuss the specific performance allocation strategies to resolve the Issues 1.10, 1.4, and 1.5, respectively. The Yucca Mountain Project has chosen to allocate performance to the components of the waste package, namely the container and the waste form, together with the near-field environment as altered through engineering design.

The waste package design strategy takes advantage of the unsaturated nature of the Yucca Mountain site. The near-field environment will also be engineered by designing the waste package emplacement configuration and thermal loading to enhance the unsaturated condition and inhibit liquid water contacting the waste packages during the containment period. For the bounding condition, the Project assumes that water will contact some of the packages, and hence containment performance has been allocated to the package components. However, the expected quality of the water is such that it will have little impact on the long-term integrity of the waste packages.

Substantially complete containment, as interpreted by the DOE in this section, relies on the container and waste form. The Yucca Mountain Project has selected six metallic corrosion-resistant container materials as candidates for further evaluation. These materials fall generally into two alloy families selected to avoid common mode failure due to localized corrosion modes. The material selection criteria, which will be peer-reviewed, include the material properties, fabricability and closure requirements, and the ability to model the performance of the container over time under anticipated repository conditions to predict with confidence that

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the containment and release rate goals can be met. As a backup to metallic containers, alternative container materials and designs are also being evaluated. Performance is also allocated to the glass and spent fuel waste forms. For spent fuel, reliance is placed on the cladding during the early years to limit the release of the radionuclides with short half lives. Reliance is also placed on the fuel matrix to limit the release of actinides and other radionuclides.

During the post-containment period, primary reliance is placed on the properties of the waste form to achieve the goal of limiting the release of radionuclides from the engineered barrier system. Performance is also allocated to other components.

Performance is allocated to the engineered environment for both periods. The expected condition is that the site will remain unsaturated for both the containment and post-containment periods. Use of the engineered near-field environment and the nature of the unsaturated site (i.e., high matric potential) will play an important role in limiting accessibility of liquid water to the waste packages.

8.3.4.1 Overview

Section 8.3.4 describes the plans for completing the waste package design tasks through the sequence of design phases leading to the preparation of a license application. The tasks are organized to address three design issues included in the issues hierarchy. (See Section 8.2 for a listing of the issues and a description of the general approach to resolving these issues.) These three issues are

1.10 Characteristics and configurations of the waste packages, including the package environment (postclosure)

2.6 Characteristics and configurations of the waste packages (preclosure)

4.3 Waste package production technologies

These issues are discussed in Sections 8.3.4.2 (Issue 1.10), 8.3.4.3 (Issue 2.6), and 8.3.4.4 (Issue 4.3).

The tasks to be undertaken for these three issues are closely related to issues discussed in several other sections of this document. Requirements and constraints are imposed on the waste package designs by the postclosure regulatory performance objectives for the engineered barrier system. The performance issues that address these objectives are discussed in Section 8.3.5. These performance issues also provide the properties of the waste forms and container materials that are needed to design the packages. The waste package designs are closely coupled to the repository designs because one of the important missions of the repository is the assembly and emplacement of the waste packages. The detailed discussions of the repository design issues are in Section 8.3.2.

In one important respect, the division of the waste package design issues into preclosure and postclosure categories is somewhat artificial. Although the requirements and constraints on the package designs differ for the two time frames, there will be only one set of package designs. After emplacement, the environment that the packages will experience does not strongly depend on whether the repository is operational or closed. To avoid unnecessary duplication and to improve continuity of the discussions, the material discussed under the preclosure issues is primarily related to the production, handling, and emplacement of the packages. The postemplacement aspects of the package designs are discussed under the postclosure issue. The relationship between the package design issues, and their relationships to the repository design, and the directly relevant performance issues is shown in Figure 8.3.4.1-1.

As indicated in the figure, the waste package postclosure design issue (1.10) is linked directly to the two performance issues (Issues 1.4 and 1.5, discussed in Sections 8.3.5.9 and 8.3.5.10, respectively) related to the ability of the waste package and engineered barrier system to meet the performance objectives of 10 CFR 60.113. The reason for this relationship is twofold: (1) some of the information needed to perform the package design is developed in the activities described under the performance issues (1.4 and 1.5) and (2) the performance issues require information developed under the

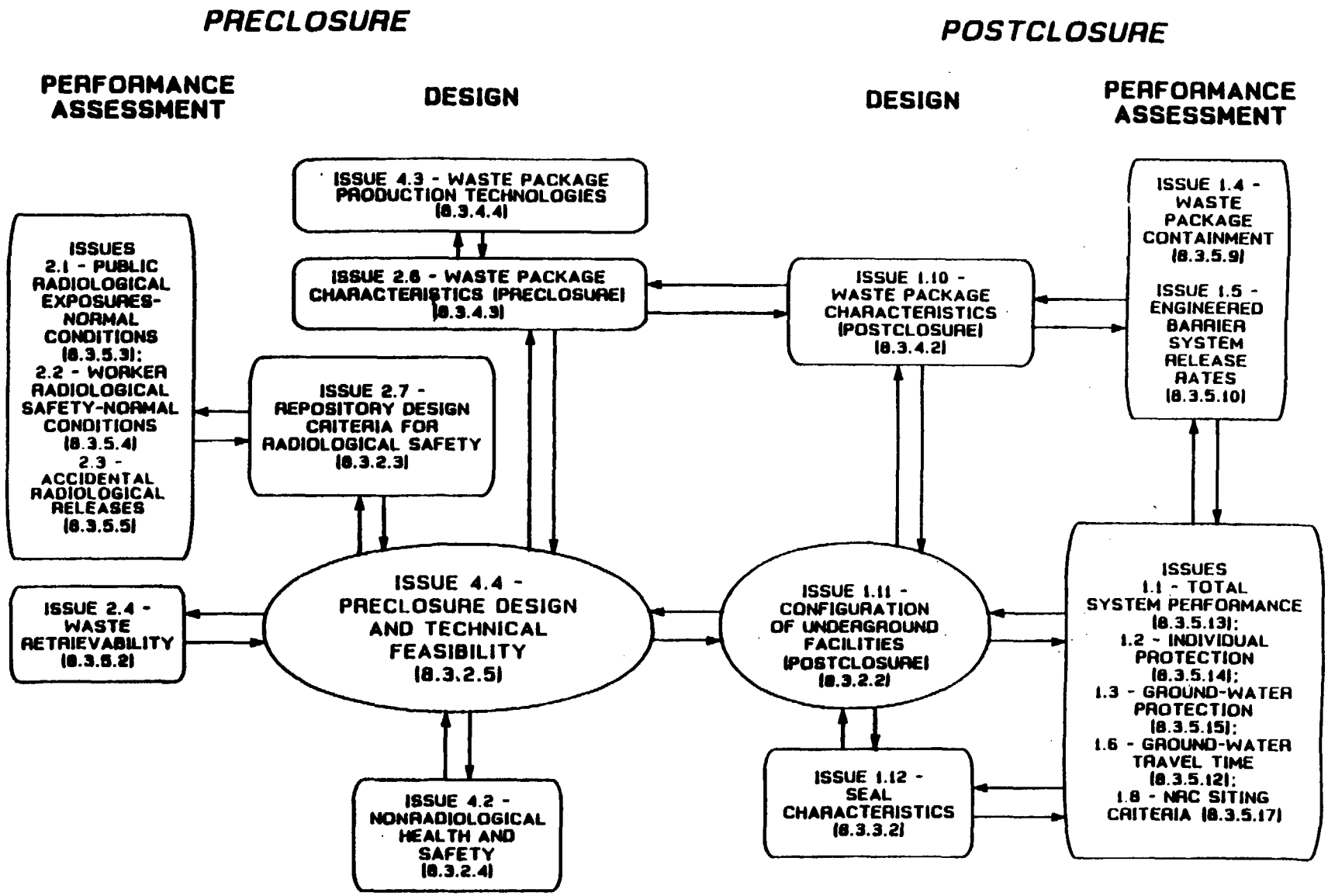

Figure 8.3.4.1-1. Relationships between design- and performance-related issues used directly in performance allocation

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design issue for their resolution. Specific examples of the information that must be exchanged between these issues include container material properties (from Issue 1.4, Section 8.3.5.9), waste form characteristics and configurations (from Issue 1.5, Section 8.3.5.10), and the postclosure environment of the waste packages and the package design configurations (from Issue 1.10, Section 8.3.4.2).

The required postclosure performance of the waste packages, together with the waste form and container material properties, presents a set of design criteria and constraints on the preclosure aspects of the package design. These criteria, and the feedback to the postclosure issues, are also depicted in Figure 8.3.4.1-1. The postclosure performance-derived criteria, together with the preclosure criteria, establish the design requirements to be translated into the package design in Issue 2.6 (Section 8.3.4.3) and reflected in the development of package production technologies in Issue 4.3 (Section 8.3.4.4).

The interaction of the waste package design issues with the repository design issues (both preclosure and postclosure) is handled by the transfer of design criteria and design evaluations between respective issues. Thus, Issues 2.6 and 4.3 will generate criteria for the design of those portions of the repository facilities, equipment, and operations that concern waste packaging, handling, and emplacement to be implemented in Issue 4.4 (Section 8.3.2.5). Similarly, design criteria for the postclosure repository configuration that will influence the waste packages will be generated in Issue 1.10 (Section 8.3.4.2) and implemented in Issue 1.11 (Section 8.3.2.2).

By establishing the relationships just described, a logical mechanism for integrating the waste package and repository subsystems is defined in a way that permits the necessary transfer of design information with minimum duplication; it also provides for adequate feedback between the subsystem designs to verify consistency. The designs are linked to the appropriate performance issues so that the assessments required to demonstrate compliance with the regulations can be made with confidence.

Of the three waste package design issues discussed in this section, only one directly involves the acquisition of site characterization data. Issue 1.10 requires the development of sufficient data, both from the site and in the laboratory, to define the ranges of the anticipated near-field environment conditions, resulting from all anticipated processes and events, for which the emplaced waste packages will be designed. These data will be developed in the activities described in Section 8.3.4.2 and by reference to the relevant site investigations described in Section 8.3.1 (site program). The lack of in situ data on this environment represents a major uncertainty in the adequacy of the design concepts that have been developed in the past (Chapter 7). These data are vital to the successful completion of the waste package designs and the assessments of their performance. To provide resolution of this issue, the results of the waste package and repository design activities also are needed. This reference design information is transferred to the performance issues (1.4 and 1.5) to be used, in conjunction with the other information developed within those issues, in assessments of the engineered barrier system performance.

The other two issues addressed in this section, Issues 2.6 (Section 8.3.4.3) and 4.3 (Section 8.3.4.4), do not directly involve the acquisition of site characterization data. The package designs that evolve under Issue 2.6 must comply with the regulatory design criteria and restrictions on their contents and must be compatible with the repository operations, including maintaining the capability for waste retrieval. The performance-derived criteria and environmental design envelope as received from Issue 1.10 (Section 8.3.4.2) must be accommodated in the designs. Issue 4.3 (Section 8.3.4.4) is restricted to the establishment of technologies capable of producing the packages as designed with a high degree of reliability. These technologies do not require site data since the designs will reflect the requirements imposed by the site characteristics.

8.3.4.1.1 Waste package environment

The environment into which the waste package will be placed and the effect of the waste package on that environment are central elements of waste package design and performance analysis. Our present understanding of the environment at the repository level at Yucca Mountain is summarized in Section 7.1 and in the following paragraphs of this overview. The anticipated range of near-field environmental conditions considers the effects of the range of anticipated processes and events. The work that has been done to characterize alteration to the environment caused by emplacement of waste packages is described in Section 7.4.1.

The repository would be sited above the water table at Yucca Mountain. The emplacement holes are expected to remain free of standing water for the anticipated range of vadose water percolation rates through the repository level and expected permeability of the host rock. The rock characteristics indicate that the boreholes would remain open except for some sloughing of rock from the borehole wall. This implies that the waste packages will not be subjected to large pressures or stresses from rockfall. The pores in the rock at the repository level are filled with a mixture of air and water. This situation will result in oxidizing conditions in the vicinity of the waste package. The repository rock is expected to contain fractures spaced at intervals that are sufficiently close to produce at least one fracture intersection with each emplacement borehole. Site characterization will allow determination of the range of anticipated conditions.

The vadose water is expected to have a chemical composition of dissolved solids similar to that found in well J-13. The J-13 water is predominantly a dilute solution of sodium bicarbonate with moderate amounts of silica, calcium, and sulfate and small amounts of potassium, nitrate, chloride, and fluoride. This water has been used as the reference water for waste package testing. When water is available from the repository horizon, its composition will be compared with that from well J-13. A program of confirmatory testing will then be developed, based on the level of similarity of the vadose water to that of well J-13, to relate the testing using well J-13 water and the testing based on the vadose water composition.

The repository construction will cause changes in the characteristics of the emplacement environment. These changes could have a substantial impact on the subsequent performance of the waste package. As part of the performance allocation process, goals were established for the level of change that could be tolerated without resulting in an altered situation that would invalidate the waste package components testing program. These goals are discussed in Section 8.3.4.2.

Unanticipated but credible processes and events are included in the evaluation of Issue 1.1, total system performance (Section 8.3.5.13). The waste package environments due to interaction of the waste packages with such unanticipated processes and events will be determined to the extent needed to evaluate the radionuclide source term for use in the resolution of Issue 1.1.

8.3.4.1.2 Waste package components

The reference designs for Yucca Mountain Project waste packages consist of various components that depend on the waste form. For spent-fuel waste packages, the components are the spent fuel (in the form of intact assemblies, boxed consolidated rods, or rods consolidated at the repository) and the container into which the spent fuel would be placed. Spent fuel is considered to consist of the uranium dioxide fuel encased in the cladding in which the fuel saw service in the reactor, together with any associated assembly structural materials. Reprocessed waste from the Defense Waste Processing Facility or the West Valley Demonstration Project will come to the repository as a borosilicate glass waste form inside a stainless steel pour canister. The canister will be placed into a metal container similar to that to be used for spent fuel.

To address the possibility that the range of anticipated processes and events will include waste package environment conditions that are more aggressive than can be tolerated by the reference metal container designs, alternative container concepts will be evaluated. These alternatives may include additional components, such as ceramic liners, metallic or other fillers, or coatings, that will significantly alter the modes of container degradation and radionuclide release. Additional descriptions of the activities associated with evaluation of these alternative concepts are included in the activities supporting the resolution of Issue 1.4 (Section 8.3.5.9). These alternatives may also provide additional control of the release of gaseous nuclides, such as carbon-14, from spent fuel that may be released upon container breach.

8.3.4.1.3 Waste package designs

Waste package designs must provide for preclosure and postclosure performance objectives. The criteria for design are based on requirements discussed in Section 7.2.1. The waste package will be designed to provide containment under normal loads imposed by the handling and emplacement systems and will assist in containment under accident conditions. One design approach for the waste package is to obtain information relative to the loads

imposed by the handling and emplacement systems and to design the waste package for those load configurations. A second approach is to design the waste package to meet the overall performance objectives and then to design the handling systems around the waste package strength criteria that resulted. The latter approach has been taken for the conceptual design discussed in Section 7.3. However, the waste package must be designed to consider the overall repository system, including considerations of identification, handling or lifting fixtures, and imposed loads. Thus, the waste package design may be modified in the advanced conceptual design report to reflect the overall repository system. Such modifications are not expected to affect the issue resolution strategy or the information needs.

The preclosure control of criticality and limitation of reactive materials and free liquids are independent of site characterization and will be provided for in the design of the operating system and the waste package. Under normal conditions, preclosure release control will be provided by the waste package container and is thus independent of site characteristics. During accident conditions, the waste package will contribute to the overall system, but again the performance is independent of site characteristics. Preclosure (but postemplacement) temperature limitation is not a function of the waste package alone but includes the emplacement configuration and rock thermal properties. The control of preclosure emplacement temperature will require information regarding thermal properties of the rock and is discussed in Section 8.3.2.2. The final requirement, that the design provide for the use of reasonably available technologies to fabricate, assemble, close, and inspect the waste package, is discussed in Section 8.3.4.4. The information needed to design the waste package for preclosure performance objectives is discussed in Section 8.3.4.3.

The postclosure performance objectives require that the waste package design consider site characteristics. Radionuclide containment will be provided during the 300 to 1,000 yr after closure by the waste package container and the properties of the waste forms. Therefore, the container must be designed to provide substantially complete containment in the emplacement environment. The materials, fabrication techniques, and material thicknesses will be specified after consideration of the site characteristics discussed in Sections 7.1 and 7.4.1, with additional information needed discussed in Section 8.3.4.2. After the containment period, the performance objective is based on the controlled release rate from the engineered barrier system as specified in 10 CFR 60.113(a)(1)(ii)(B). Demonstration that this objective is met is also based on container and waste form performance. There is no discussion of the waste form design in this section. The focus of Yucca Mountain Project effort is to characterize the release rates of radionuclides from the waste forms under the postemplacement site environmental conditions. The performance allocation and issue resolution strategy related to the postclosure performance assessment are discussed in Sections 8.3.5.9 and 8.3.5.10.

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8.3.4.1.4 Waste package modeling

Waste package modeling will be required to support both design and performance information needs. Modeling will be performed to address both preclosure and postclosure information needs. Modeling efforts supporting design include stress analysis for preclosure handling, emplacement and retrieval scenarios, and analysis of stress caused by emplacement borehole failure. Further, design calculations are required for thermal analysis to determine temperatures of waste package components as a function of waste form characteristics.

Postclosure modeling is required to support performance assessment calculations. Much of this activity is included in the waste package performance assessment effort discussed in greater detail in Sections 7.4.5 and 8.3.5.10. Models of the processes that affect loss of containment and radionuclide release will be integrated into the performance assessment calculation models. These models will include the processes of waste form degradation and radionuclide release, barrier degradation, geochemical changes and transport of materials in the waste package environment, and transport analysis within the breached containers.

Many of these modeling activities will synthesize empirical data into mathematical constructs to represent processes that occur following waste package emplacement. The corrosion and waste form degradation and release models are likely to be of this form. Models of other processes mentioned previously will be formulated from the governing differential equations and constitutive relationships. Thermal and mechanical analyses, geochemical equilibrium and kinetics calculations, and hydrothermal flow and transport simulations are expected to be of this form.

The modeling activities will be conducted at two levels. The first level will be a rigorous attempt to simulate processes in two or three dimensions to identify the most sensitive model parameters and obtain a fundamental understanding of the processes. After these modeling activities are complete, a second level of modeling will be used to derive simpler models that are appropriate for use in performance assessment calculations.

Both levels of modeling must demonstrate that the processes are adequately represented for the required waste package performance predictions. Therefore, substantial effort will be required to evaluate these models. The plans to acquire information from the site characterization program to test these models are discussed in Section 8.3.5.20.

8.3.4.2 Issue resolution strategy for Issue 1.10: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.135 and (b) provide information to support resolution of the performance issues?

Regulatory basis for the issue

This issue deals with two aspects of the waste package postclosure behavior. The first aspect relates to the specific requirements contained in Section 135(a) of the NRC rule that states, in part:

(1) Packages for HLW shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages or the performance of the underground facility or the geologic setting.

(2) The design shall include but not be limited to consideration of the following factors: solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions.

These requirements will be addressed by gathering the information detailed under Information Needs 1.10.1 (Section 8.3.4.2.1) and 1.10.4 (Section 8.3.4.2.4).

The second part of this issue is more global in its application. Many of the performance issues require information on the behavior of the waste package. To provide this information, appropriate testing and analyses of the waste package components and system must be done. To identify appropriate tests and analyses, the service environment for the waste package must be determined.

The waste package environment, upon initial emplacement of the package, will depend on the ambient conditions at the repository level and how those conditions are altered by repository construction and operation. The environment following emplacement will depend on the initial emplacement conditions and how those conditions are altered by the waste package characteristics. Therefore, there is an interactive process between design and environment characterization. The design is initially based on the ambient conditions and a prediction of how those conditions would alter under the stresses applied by repository construction and waste emplacement. Once a design is available, analysis of that design provides a set of environmental stress factors. Testing is then done to determine the effects of those stresses, such as thermal and radiation fields and mechanical stresses, on the package environment. Based on those tests and subsequent analyses, designs may be modified and the test and analysis cycle repeated. The relationships among design, environmental, and performance considerations are presented in Figure 8.3.4.2-1.

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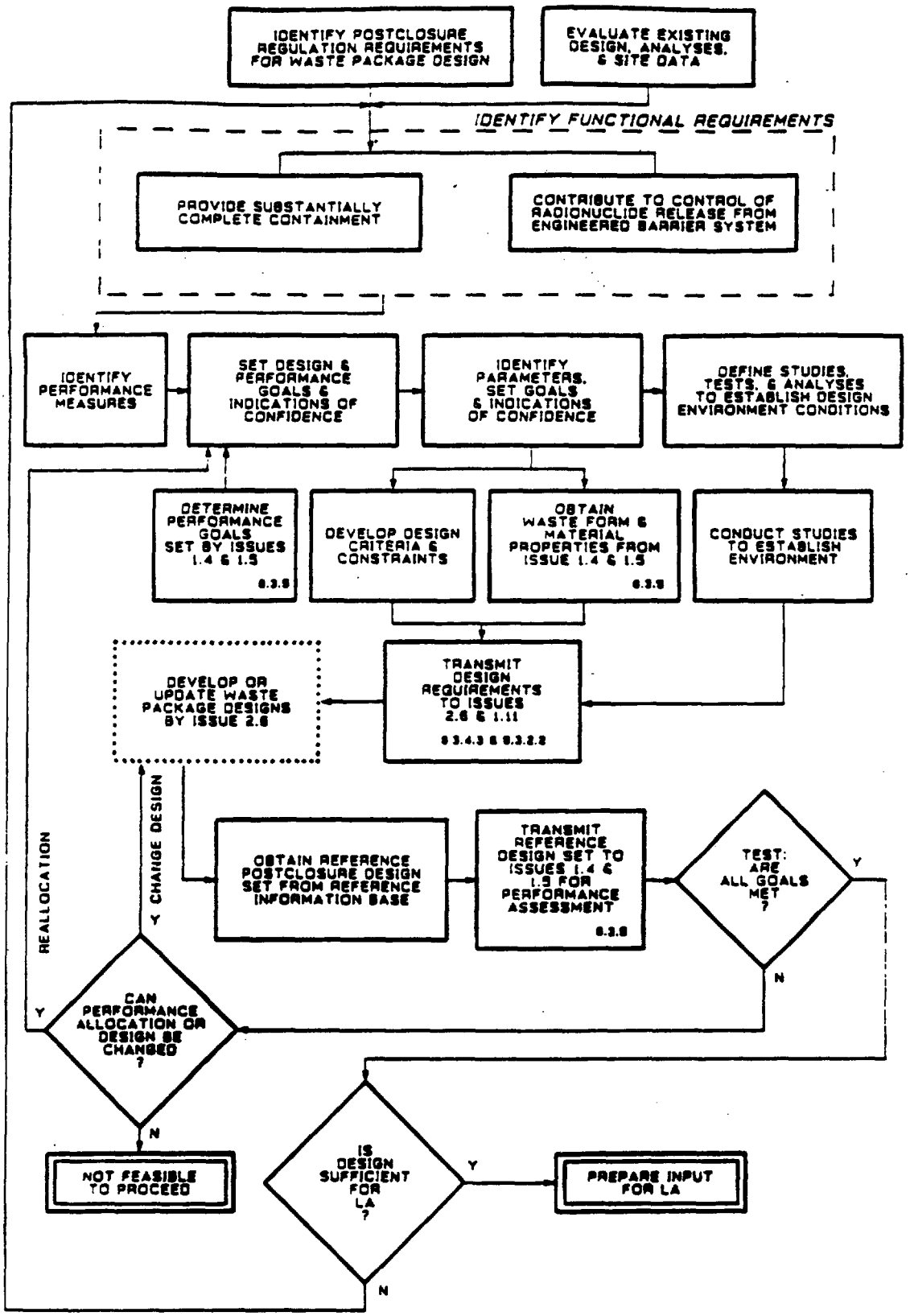

Figure 8.3.4.2-1a. Logic diagram for the resolution of Issue 1.10 (postclosure waste package characteristics). See Figure 8.3.4.2-1b for legend.

The information gathered to resolve this issue will provide the waste package design information and environment description to be used in the performance issues that will describe engineered barrier system compliance with the regulations contained in 10 CFR 60.113. The design and environment description, together with the performance predictions developed under Issues 1.4 and 1.5 (Sections 8.3.5.9 and 8.3.5.10), will provide input data on the source term for radionuclide release, which are necessary to resolve other issues. Source term data will be used in Issues 1.1 (Section 8.3.5.13), 1.8 (Section 8.3.5.17), and 1.9 (Section 8.3.5.18). Issue 1.1 includes evaluation of unanticipated but credible processes and events. Although not included in the basis for design of the waste packages and evaluation of performance Issues 1.4 and 1.5, the near-field environments due to the interaction of waste packages with unanticipated processes and events will be evaluated to the extent necessary to provide input to Issue 1.1.

Approach to resolving the issue

There are many factors to be considered in the development of waste package designs and the analysis of the effect of those designs on the environment. To resolve this issue, a high degree of interaction between design, site characterization, and waste package component performance analyses is necessary.

Identified by highlighting in Figure 8.3.4.2-2 are the products, models, and submodels that provide input to resolution of Issue 1.10. Issue resolution is accomplished by producing a description of waste package/near-field interactions (Information Need 1.10.1) that addresses the factors identified in 10 CFR 60.135 and incorporating these interactions into waste package design considerations. In Table 8.3.4.2-1 the specific activities that provide data for model development are in the SCP sections indicated, along with the model hierarchy. The models and submodels also provide information necessary for resolution of Issues 1.4 and 1.5 through the input pathways indicated in Figure 8.3.4.2-2. In addition, development of the source term (Information Need 1.5.5) requires as input the near-field flow and transport model developed from the description of the postemplacement, near-field environment (Information Need 1.10.4). The testing and design activities described in this section are tentative and are subject to change. Any such change will be reported in semiannual progress reports.

To develop a description of the postemplacement, near-field environment and satisfy Information Need 1.10.4, it is necessary to identify anticipated physical interactions between the as-assembled waste package and the environment that may affect waste container integrity. These physical interactions will be expressed as performance measures that represent design goals for rock-induced load on the waste package, waste package thermal environment, tectonic processes, materials selection, and container handling. These performance measures and their tentative goals are given in Table 8.3.4.2-2.

The performance parameters, their respective performance measures, their respective tentative goals, and the expected parameter values are given in Table 8.3.4.2-3. The activities that address these goals are described in Section 8.3.4.2.4.

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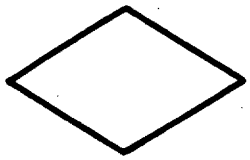
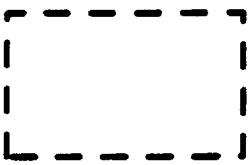
LEGEND

ACTIVITY PERFORMED TO RESOLVE ISSUE



TEST TO DETERMINE SUBSEQUENT ACTIVITY

ACTIVITY PERFORMED BY INDICATED ISSUE



ACTIVITY WITH MULTIPLE SIMILAR ACTIVITIES OR TESTS

DECISION ABOUT ISSUE RESOLUTION

Y - YES N - NO LA - LICENSE APPLICATION

Figure 8.3.4.2-1b. Legend for Figure 8.3.4.2-1a.

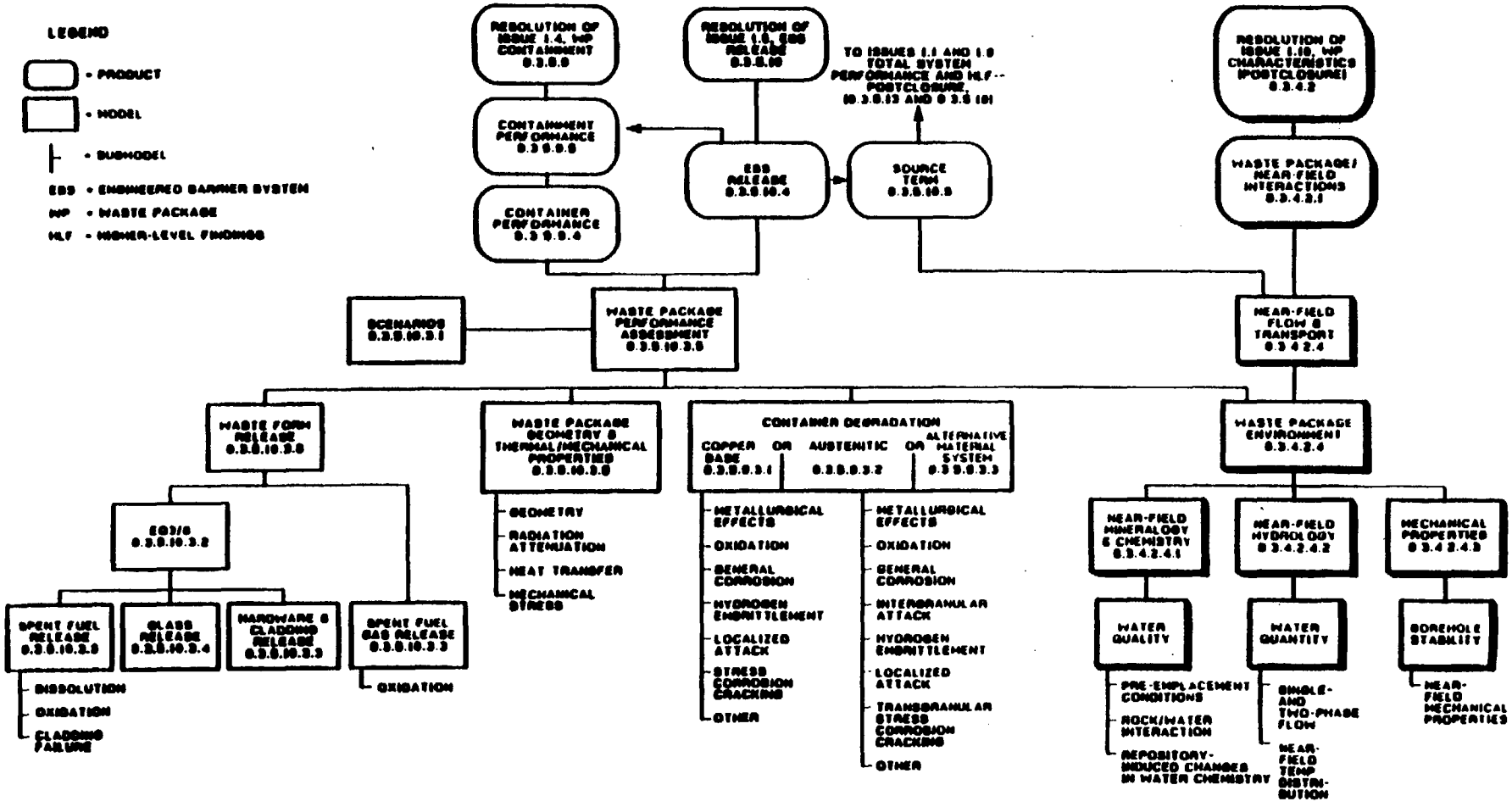


Figure 8.3.4.2-2. Model hierarchy for Issue 1.10 (waste package characteristics—postclosure).

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

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

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

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

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

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

[a]The SCP section references for the near-field flow and transport model refer to discussions on the information need level; specific activities for these input parameters are described in the information need discussions.
[b]TSw2 = welded Topopah Spring Member.

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

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

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

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

[a]TBD = to be determined.

To satisfy Information Need 1.10.4, it is also necessary to obtain input from studies that characterize the postemplacement mineralogy and water quality of the waste package environment (Section 8.3.4.2.4.1), the post emplacement hydrologic features of the waste package environment (Section 8.3.4.2.4.2) and the postemplacement thermal and mechanical properties of the waste package environment (Section 8.3.4.2.4.3). These characterization activities are required to address performance parameters identified in Issues 1.4 and 1.5. The specific performance parameters, their respective characterization parameters and test bases, and the SCP section describing the activity that addresses each characterization parameter are presented in Table 8.3.4.2-4.

The characterization parameters pertaining to water quality reflect the goal that the chemical characteristics of the water will be similar to those existing in the undisturbed environment in the unsaturated Topopah Spring tuff at Yucca Mountain. The characterization constraints are established because water chemistry is a very sensitive parameter in determining corrosion rates and mechanisms for metals and because changes in water chemistry strongly influence the rock-water interaction and hydrologic properties of the tuff. Typical values for water found below Yucca Mountain are discussed in Section 7.4.1.

The quantity of water that contacts containers is constrained as part of the design strategy to meet the containment and release rate performance objectives established in Issues 1.4 and 1.5. The parameters to be evaluated

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

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

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

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

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

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

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

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

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

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

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

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

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

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Radiation effects (continued)		
		Cations present at >40 mg/L	±20 mg/L (1)	
		Formate ions	±30% (1)	
		Oxalate ions	±30% (1)	
		HNO_3	±20% (1)	
		Nitrite: nitrate ratio	±30% (1)	
		CO_2	±20% (g)	
		O_2	±20% (g)	
		NO_x	±20% (g)	
		N_2	±20% (g)	
		NH_3	±30% (g)	
		Corrosion products		8.3.4.2.4.1.6
		Temperature	±5°C	

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

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

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

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

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

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

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

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

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

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

[a]Unless otherwise stated, the specified percentages and plus-and-minus values are characterization goals that indicate the maximum experimental uncertainty for measurements of the indicated parameter. (l) indicates species in the liquid phase, (g) indicates species in the gas phase.
[b]BET = Brunauer-Emmett-Teller.
[c]TBD = to be determined.

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in meeting this goal concern the hydrologic characteristics of the repository site, which control the rate at which water can be expected to move through the rock.

The borehole stability and thermal loading constraints concern engineering practices that influence the integrity of the waste package. In addition, the thermal loading goals provide for an environment for a large fraction of the waste packages that will be above the boiling point of water for the period of time indicated in Issue 1.4 (Section 8.3.5.9). This goal contributes to the strategy to meet the release rate performance objective.

As part of the issue resolution strategy, a design envelope for the waste package has been developed. This envelope is based on present knowledge of the site characteristics (with due consideration for the associated uncertainties and for the range to be determined for anticipated processes and events) and on the known properties of the waste forms (Chapter 7). Activity 1.5.3.1, scenarios, will determine whether the design envelope encompasses the near-field conditions developed due to interactions with all anticipated processes and events. In the following eight sections (A through H), the design envelope is described and the goals for characterization, design, or performance of each part of the design envelope are discussed. Some of these goals provide characterization goals for, or constraints on, other issues.

A. <u>The emplacement hole geochemical system</u>

The characteristics of the host rock mineralogy and chemistry have been established by study of surface outcrop and drill core samples of Topopah Spring tuff located around the exploratory block. The welded, devitrified Topopah Spring tuff from the level of the potential repository shows little variation in chemistry. Because of the limited degree of variability expected in rock chemistry and mineralogy and the need for detailed characterization of the rock (Section 8.3.1.3), additional characterization goals related to rock chemistry are not needed.

Currently, the reference water chemistry is based on water from well J-13, which is located east of the repository block. This well was chosen because of the similarity of its water chemistry to that found in water below the exploratory block. Samples of vadose water from the repository horizon have not yet been obtained. Since the water chemistry plays a critical role in determining the performance of the waste package components, it is necessary to set a goal for the degree of characterization of water chemistry to be accomplished during site characterization. The test bases (or degree of characterization needed for this issue) for the water chemistry characterization parameters will be accomplished in the geochemistry program (8.3.1.3). These test bases are specified to establish the mean value of water chemistry parameters so that the standard deviation of the mean is no greater than the values given in the following list (note that this establishes only how well the mean value must be known; it does not constrain what the value must be). The bases for the limits were the effects of each of the parameters on waste package component performance.

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Characterization goal for water chemistry. The characterization parameters for water chemistry are identified in Table 8.3.4.2-4 along with their test bases (or degree of characterization needed) for this issue. The characterization parameters and test bases for the geochemistry program follow:

Characterization parameters	Test basis
pH:	±1 pH unit
Anions:	±1 mg/L for F^-, Cl^-, PO_4^{3-}
	±5 mg/L for NO_3^- and SO_4^{2-}
	±30 mg/L for CO_3^{2-} plus HCO_3^-
	±1 mg/L for all other anionic species
Cations:	±1 mg/L for species present at less than 6 mg/L
	±5 mg/L for species present at 6 to 40 mg/L
	±20 mg/L for species present at over 40 mg/L
Colloids:	±1 mg/L
Organics:	±1 mg/L
Neutral species:	±1 mg/L

The numerical values for these test bases are established so that they are analytically achievable and are sufficiently constrained so that they do not introduce large uncertainties into the metals and waste form testing results.

The pH is important because of the sensitivity of glass dissolution rates, actinide solubility and speciation, and metal corrosion mechanisms to pH. Fluoride and chloride are deleterious to metal performance, and phosphate can be corrosive to glass; therefore, their abundance in water must be well characterized. Carbonate and bicarbonate are beneficial in that they buffer the pH of the water but are detrimental in that they can form complexes with actinides. A moderate level of precision is needed for these species. Colloids and organic materials may significantly affect transport properties of radionuclides; therefore, a high level of precision is required. Other elements are needed to provide a complete analysis so that charge balance calculations can be used to evaluate the quality of the analysis.

If the site is found to be laterally inhomogeneous to the extent that the characterization goals cannot be met for the site considered as a single unit, the site will be separated into regions for which the characterization goals will apply.

B. The emplacement hole and near-field hydrologic system

The characteristics of the hydrologic system at Yucca Mountain will be determined in the geohydrology program (Section 8.3.1.2). A discussion of the expected hydrologic system in the unsaturated zone is provided in Chapters 3 and 7. Further studies will be conducted under activities described in Information Need 1.5.5 (Section 8.3.5.10.5). The hydrologic parameters that are most important to waste package design and performance are the percolation rate of water through the repository horizon and the flow paths for the water. Of particular interest are the proportion of the flow that occurs in fractures and the variation of the proportion of fracture flow as a function of percolation rate.

Studies will be conducted under activities described in Information Need 1.10.4 (Section 8.3.4.2.4.4) that will characterize the hydrology of the waste package environment. This characterization will establish the extent to which the near-field hydrologic system will contribute to meeting the performance goal set in Issues 1.4 and 1.5 for amount of water that can contact a waste container.

The heat associated with the waste package will perturb the near-field flow paths. Studies to investigate the amount of perturbation and its effects are described in Information Need 1.10.4 (Section 8.3.4.2.4).

The construction of the repository may alter the local hydrologic system. This alteration might be caused by disturbance of the rock mass, the introduction of water during construction, dehydration of the rock mass through use of ventilation systems, or other causes. Some of these alterations could be beneficial to waste package performance; others could be detrimental.

Because of the importance of water volumes, flow paths, and flow rates in the assessment of waste package performance, performance goals for the near-field hydrologic system have been set in Issues 1.4 and 1.5. The goals that are set for an individual waste package are based on a conservative estimate of the amount of water that could contact the ensemble of waste packages in a given year. The goals apply to anticipated processes and events.

The goals for the amount of water contacting waste packages are based on a conservative upper bound of current percolation rate through the repository horizon (i.e., 0.5 mm/yr (Montazer and Wilson, 1984) and a factor of additional conservatism. (The same upper bound value is selected in Table 8.3.5.13-9 for Scenario Class E, normal case, which includes natural events reasonably likely to occur in the 10,000-yr period.) At the 0.5-mm/yr flux, 0.23 L/yr is approximately the annual quantity of water that would pass vertically through the projected area above a 76-cm-diameter, vertical emplacement borehole. Similarly, 1.5 L/yr is the annual quantity of water that would pass vertically through the projected area of a 4-m-long (typical

size) horizontally emplaced waste package. Actually, for either emplacement mode the water is likely to be diverted around the opening and conducted through the rock. Applying a factor for added conservatism, one obtains an annual volume of 5 L passing through that projected area. Other values, either more or less conservative, may be obtained by similarly scaling the volumetric flow of 0.25 L/yr.

Note that these goals on the quantity of water contacting the waste packages are applied without considering whether the water could actually enter the borehole. In an unsaturated host rock, water would not normally enter a borehole unless a saturated region had formed above the borehole, large enough in the vertical direction to provide pore pressures sufficiently high to overcome the capillary pressures at the borehole surface. This condition is not currently anticipated in the unsaturated zone of the repository horizon.

Further, the quantitative values of these factors and the corresponding annual amounts of water are not intended to correspond to either saturated or unsaturated flow conditions. They are intended to provide guidance for the required performance of repository seals for anticipated processes and events. In addition, based on present knowledge of the hydrology of Yucca Mountain, these values are sufficiently large to compensate for uncertainties in our current level of understanding of the unsaturated zone at the repository level.

Analyses conducted under Issue 1.11 (Section 8.3.2.2) will determine if the goals have been achieved. Note that the water volumes allowed for long-term water control greatly exceed those expected based on the current estimates of upper bounds on percolation rates through the repository horizon.

Design goal for water flux control. The repository will be designed and constructed so that, for anticipated processes and events, the following conditions will be met with a high level of confidence:

1. There will be no liquid water in the emplacement borehole immediately before emplacement of the waste package, and conditions will be such that no liquid water can contact the waste package during the period from package insertion until repository closure.

2. For the first 300 yr after repository closure, no liquid water will contact 95 percent of the waste packages, and less than 5 L per package per year will contact the remaining 5 percent.

3. During the period from 300 to 1,000 yr after repository closure, no liquid water will contact 90 percent of the waste packages, and less than 5 L per package per year will contact the remaining 10 percent.

4. During the period from 1,000 to 10,000 yr after repository closure, no liquid water will contact 90 percent of the waste packages, and less than 20 L per package per year will contact the remaining 10 percent.

C. Emplacement hole drainage

The previous section discusses the design goals for water contacting waste packages in a given year. These goals were based on water influx. It is also necessary to determine if water entering the borehole can drain at a sufficient rate to ensure that standing water does not accumulate. The use of a borehole liner might influence drainage in two ways. First, corrosion products from the liner might be flocculent and lead to plugging of the rock pores, thereby decreasing permeability of the rock matrix. Second, for a vertical borehole, a liner with an unperforated bottom plate would totally block drainage. For a horizontal emplacement hole, a liner placed in a hole that was not sufficiently inclined to promote drainage might lead to local accumulations of standing water. Another factor that might alter the drainage capability of emplacement boreholes is the choice of drilling method.

The accumulation of standing water in boreholes would lead to deleterious effects on the waste package performance. For that reason, as part of the performance allocation process, a design goal for drainage from the boreholes has been set. The analyses to show that this goal has been met are described under Issue 1.11 (Section 8.3.2.2).

Design goal for drainage of emplacement boreholes. The borehole and its engineered components, such as liners, shall be designed and constructed so that for anticipated processes and events, the following conditions will be met with a high level of confidence:

1. The borehole will not fill with standing water under anticipatedconditions at any time up to 10,000 yr following repository closure.

2. For the first 1,000 yr following repository closure, no more than 5 L of standing water per waste package will accumulate in emplacement boreholes.

D. Emplacement hole configuration and stability

The configuration of the emplacement boreholes is important in developing scenarios for waste package container degradation and subsequent radionuclide release rate analysis. For a horizontal emplacement configuration, one can envisage some conditions in which water could drip from a fracture onto a waste package. For a vertical borehole, this scenario seems very unlikely since the borehole plug will shield the package from dripping water.

The emplacement hole configuration may also affect the stability of the borehole and be a deciding factor in whether it will be necessary to use a borehole liner. As discussed previously, the liner can affect drainage from the borehole. The liner could also produce interactions with the waste package; this concern is discussed later under item H.

The need for information on the emplacement hole configuration will be met by close interaction between the repository and waste package designers (Information Need 1.10.3, Section 8.3.4.2.3). It is necessary to set a goal to establish what rock-induced loads must be borne by the waste package.

Analyses to determine that the borehole stability meets the goal are conducted under Information Need 1.10.4 (Section 8.3.4.2.4) as shown in Tables 8.3.4.2-2 and 8.3.4.2-3. Inspection of the repository for fault and shear zones will be established by Issue 1.11 (Section 8.3.2.2). The question of what size shear zones must be found to ensure less than 5 cm displacement (accommodated by air gaps in the borehole) in the 1,000 yr after closure will be addressed in the Site Program 8.3.1.8 (postclosure tectonics).

Design goal for rock-induced load on the waste package. The emplacement hole will be designed and constructed so that the following conditions will be met with a high level of confidence:

1. Less than 0.5 percent of the containers will be breached by anticipated tectonic processes and events during the first 1,000 yr after closure. Drifts and boreholes will be inspected for fault and shear zone, and waste packages will not be emplaced across such regions.

2. For 1,000 yr after closure, the stability analysis will show with a high level of confidence that the rock-induced load on a waste package will be less than 1,000 kg.

3. For 10,000 yr after closure, the stability analysis will show with a moderate level of confidence that the rock-induced load on a waste package will be less than 3,000 kg.

4. Emplacement boreholes will be cleaned of debris before use.

E. Thermal loading of the waste package and the repository layout

The thermal loading of the waste package and the repository layout are interactive parameters. It may be necessary to vary the loading per package and the number of packages per unit area of repository to achieve the desired thermal effects. Thermal loadings that keep the waste package near-field environment above the boiling point of water will assist in achieving the goal set for the amount of water that can contact the waste packages. On the other hand, the thermal loadings must be kept sufficiently low so that waste form temperature limits are not exceeded. These temperature limits are based on the waste form properties and were set to limit degradation of the waste form performance from thermal transients in the early stage of repository history.

The primary information needed to design thermal loadings is the power output of the waste form. Most of the waste that will go into the repository has not yet been generated. Extrapolations of waste age, spent fuel burnup, and other parameters are necessarily uncertain. The design goal for thermal loading is based on two concepts. The first is to maintain adequate flexibility to allow for the uncertainties. The second is the setting of a characterization goal. This goal, combined with a flexible repository layout, will allow the thermal loading during the operational stages of the repository to achieve the desired thermal effects.

Design goal for thermal loading. The design goals for thermal loading include the following:

1. The repository layout will be designed so that the thermal loading characteristics will assist in keeping liquid water from contacting the waste packages for the first 300 yr after closure. It will also ensure that the design-limit temperatures for waste forms are not exceeded.

2. The waste forms will be characterized sufficiently well so that the radionuclide inventory at the time of emplacement will be known to within ±20 percent for each nuclide that represents 5 percent or more of the radioactivity in the packages at any time during the first 1,000 yr after emplacement.

The information to show that part 1 of the goal is met is developed in the resolution of Issue 1.11 (Section 8.3.2.2); part 2 is addressed in Section 8.3.5.10.1 under Information Need 1.5.1.

F. Waste package container material

The selection of the material from which to fabricate the waste package container is important for a variety of reasons. The material choice may be a factor in meeting the performance objective for the containment period and may affect the radionuclide source term for total system performance assessment. The issues related to long-term performance of the container material are discussed under Issue 1.4 (Section 8.3.5.9). This section discusses those aspects of container selection that influence the chemistry of the near-field environment and that influence the design of the waste package.

The effect of the container material on the near-field environment is through the interaction of container corrosion products with the environment. The corrosion rate for the material is determined under Issue 1.4 (Section 8.3.5.9); the effect of the corrosion products on water chemistry is evaluated under Information Need 1.10.4 (Section 8.3.4.2.4). To limit the volume of the corrosion products to be considered, a design goal on the rate of material loss caused by uniform corrosion has been set. The goal is set to provide information on the geometry of the container needed for use in resolving Issue 1.5 (Section 8.3.5.10).

The material choice influences waste package design through a number of considerations, which are evaluated under Information Needs 1.4.1, 1.4.2, and 1.4.3 (Section 8.3.5.9). First, the uniform corrosion rate establishes a minimum thickness of metal for the container. Second, mechanical properties of the container material determine some of the design parameters such as thickness, handling-device shape, and contours of the container. To allow for these considerations, a design goal has been established for the container material.

Design goal for the container material with respect to waste package design and environmental concerns. The container material will be selected so that the following conditions are met with a high level of confidence.

1. The container material will have mechanical properties such that the container will not fail due to mechanical causes when subjected to design basis loads under anticipated conditions for 1,000 yr.

2. The container material will have degradation rates by uniform oxidation and uniform corrosion so that no more than 90 percent of the container wall thickness will be removed by these mechanisms over the first 10,000 yr following repository closure.

The rationale for those conditions and the analyses required to show that these goals will be met are discussed in Section 8.3.5.9 (Information Needs 1.4.1, 1.4.2, and 1.4.3).

Goals for the container material that relate to meeting the containment period performance objective are discussed in Section 8.3.5.9.

G. Waste package fabrication and handling before emplacement

The waste package container material must be capable of being fabricated to design specifications in a reliable manner. The final closure for the container must be capable of being made and inspected under remote operating conditions, with a high level of confidence that defective closures will be detected. The fabrication and closure processes must not degrade the performance of the container material in ways that will preclude meeting the performance objectives discussed under Issue 1.4 (Section 8.3.5.9).

Design goal for fabrication. The fabrication process for the body of the container, including the unique container identification, will not cause an increase in the degradation rate of the material by a corrosion process that might operate in the repository to levels that would cause the performance goals set under Issue 1.4 (Section 8.3.5.9) not to be met.

Design goal for closure. The closure process will be capable of being done and inspected under remote conditions with a reliability such that the container would be capable of passing a standard helium leak test at the level of 1×10^{-7} atm-cm^3/s. The level of undetected defective closures will be shown to be less than 1 percent.

Analyses to show that these goals will be met are discussed under Information Need 1.10.2 (Section 8.3.4.2.2).

Design goal for handling. The surface-handling and emplacement operations might cause damage to the container. To limit such damage, care must be taken during the loading of the container, the closure of the container, any surface-handling and storage operations, and emplacement of the container into the repository.

To avoid damage from handling that affects performance, the following conditions are set:

1. The container will not be allowed to contact corrosive chemicals during the surface-handling and emplacement operations except as needed for surface finishing.

2. Any container that is subjected to an impact load equivalent to a free fall of 10 cm or more during handling will not be emplaced. The 10-cm free-fall condition is tentative.

3. Any container that is scratched so that the metal is thinned by 1 mm or more will not be emplaced.

4. Any container that has experienced an unusual process history that would cause new corrosion considerations to arise will not be emplaced.

These conditions are based on the criterion that the containment function of the waste package will be preserved during handling. The conditions are established to be achievable within the surface facility and repository setting.

H. Alteration to the environment caused by nonwaste package components

One of the largest areas of uncertainty and concern with respect to the package design envelope is the effect of repository construction materials on the local environment of the packages. To remove some of the uncertainties, as part of the performance allocation process, some limits have been established on the allowed effects on the environment from repository construction. These limits can generally be met by suitable choice of construction materials. In some instances, materials with undesirable effects on the vadose water chemistry can be used, as long as it can be shown that the affected water cannot contact a waste package.

The immediate vicinity of the waste package will be influenced by the choice of borehole liner material. Thus, two design goals for the liner material have been set. The other materials that might be present in sufficient quantities to cause major changes to water chemistry are the grout and concrete-type materials used for ground supports and for sealing shafts and boreholes. For vertical emplacement, either a specially designed material will be needed or a hole plug design that does not use conventional grout or concrete will have to be used. (Conventional grouts and concretes result in a very high water pH, which is unacceptable from the point of view of long-term waste form performance.) For horizontal emplacement, conventional materials might be adequate, provided that the hydrologic system is sufficiently well understood to show that the grout-affected water cannot contact waste packages.

Two design goals were set for the borehole liner, and a single unified design goal was set for the alterations to water chemistry for water that might encounter waste packages.

Design goals for the borehole liner. The two design goals for the borehole liner are as follows:

1. The corrosion rate of the borehole liner by uniform corrosion will be within a factor of 2 of that for the container material. This will be demonstrated in analyses done under Information Need 1.4.2 (Section 8.3.5.9.2).

2. The borehole liner shall be a member of the same alloy family as the container material (i.e., if the container material is an austenitic stainless steel, then the liner will also be an austenitic stainless steel). The liner material used in repository designs will reflect this requirement for compatibility (Issue 1.11, Section 8.3.2.2).

These goals are established to avoid significant galvanic effects between the container and borehole liner and to avoid generation of colloids.

Design goal for alteration of water chemistry. Repository engineered barriers and shaft and borehole seals will be designed and constructed so that the changes in water chemistry resulting from interaction of those materials with the vadose water (characterized earlier under item A) for water that might contact a waste package will be within the limits established in Issue 1.4. Analyses to show that this has been achieved are given in resolution of Issues 1.11 (Section 8.3.2.2) and 1.12 (Section 8.3.3.2).

Limits to alteration of water chemistry. Interactive effects between ions in solution and the consequences of these interactions for container and waste form performance require that limits be placed on the extent to which the concentration of certain species may be modified by repository construction materials. The numerical values for these limits are as follows:

Characterization parameters	Test basis
pH:	± 1pH unit
Anions:	+1 mg/L for F^-, Cl^-, and PO_4^{3-}
	+10 mg/L for NO_3^- and SO_4^{2-}
	+50 mg/L for CO_3^{2-} plus HCO_3^-
	+1 mg/L for all other anionic species
Cations:	+1 mg/L for species present at less than that level in the vadose water
	+10 mg/L for CA^{++}, K^+, and Mg^{++}
	+30 mg/L for Na^+
	-5 mg/L for Si^{4+}, no limit to increase
Colloids:	+1 mg/L
Organics:	+1 mg/L
Neutral species:	+1 mg/L

Interrelationships of the information needs

This issue involves development of the reference waste package designs and determination of the effect of those designs on the waste package environment. It also involves establishing that the designs comply with the requirements of 10 CFR 60.135. Because this latter item involves a specific set of requirements, it has been cast as a separate Information Need 1.10.1 (Section 8.3.4.2.1).

The reference waste package designs will be developed from a consideration of our understanding of the service environment. As such, Information Needs 1.10.2 (Section 8.3.4.2.2) and 1.10.4 (Section 8.3.4.2.4) are interactive. Information Need 1.10.3 (Section 8.3.4.2.3) relates to the emplacement configuration. It has been cast as a separate information need to highlight the uncertainties associated with the present situation, which includes both vertical and horizontal emplacement as options, and to facilitate issue resolution when the final emplacement mode is chosen.

When the emplacement mode is chosen, and when the waste package design is completed, the analyses required to satisfy Information Needs 1.10.1 (Section 8.3.4.2.1) and 1.10.4 (Section 8.3.4.2.4) will be performed. The results of these analyses, if favorable, will resolve the issue.

8.3.4.2.1 Information Need 1.10.1: Design information needed to comply with postclosure criteria from 10 CFR 60.135(a) for consideration of the interactions between the waste package and its environment

Technical basis for addressing the information need

The general design criteria contained in 10 CFR 60.135(a) are stated in the context of the in situ properties of the waste package and the interactions between the package and its emplacement environment. These properties and interactions are evaluated to ensure that the function of the waste packages, the performance of the underground facility, or the geologic setting is not compromised.

The criteria require that the design consider a number of factors relating to the performance of the waste packages and their interaction with the environment. The basis for addressing this information need will be to show that the relevant factors have been evaluated in the design.

Link to the technical data chapters and applicable support documents

The work that has been undertaken to date to characterize the performance of the waste package components and the interactions of the waste packages with the near-field environment is discussed in Chapter 7. Specifically, Section 7.4.1 describes the examination of the ambient environment and the changes induced by the introduction of the waste packages. Sections 7.4.2 and 7.4.3 describe the examinations of the performance of the package components under conditions representative of those expected in the repository.

Parameters

The parameters associated with this information need are the relevant postclosure properties and interactions that are stated in 10 CFR 60.135(a)(2) as factors to be considered and include the following:

1. Solubility.
2. Oxidation-reduction reactions.
3. Corrosion.
4. Gas generation.
5. Thermal loads and effects.
6. Mechanical strength and stress.
7. Radiolysis and radiation damage.
8. Radionuclide retardation and leaching.
9. Synergistic interactions.

Interactions and coupled effects involving some of these parameters are also discussed in Section 8.3.2.1.

Logic

The logic to be used in addressing this information need is basically one of integration. The information is developed within other information needs, where the nature of the in situ properties of the waste package and the interactions of the package with the near-field environment are characterized and analyzed.

8.3.4.2.1.1 Design Activity 1.10.1.1: Consideration of 10 CFR 60.135(a) factors

Objectives

This activity will explicitly show that the factors specified in 10 CFR 60.135(a) and listed as parameters for this information need have been considered in the waste package design. The evaluation will identify those factors that could potentially compromise the function of the waste package, the performance of the underground facility, or the geologic setting.

Parameters

The parameters for this activity are given in the list for the information need.

Description

The information to be used in the evaluation will be derived from the studies undertaken in other information needs. Specifically, the information to show that the factors that could potentially compromise the function of the waste package have been considered will be included in the performance analyses done in Information Need 1.4.5 (Section 8.3.5.9.5) and 1.5.4

(Section 8.3.5.10.4). The information to show that the interactions of the package with emplacement environment have been considered will be taken from the studies done in Information Need 1.10.4 (Section 8.3.4.2.4).

8.3.4.2.2 Information Need 1.10.2: Reference waste package designs

Technical basis for addressing information need

Link to the technical data chapters and applicable support document

Conceptual waste package designs are described in Section 7.3. These designs have been developed during the conceptual design phase and include both reference designs (Section 7.3.1) and alternative designs (Section 7.3.2).

Parameters

The parameters that require documentation to fulfill this information need are in two categories: (1) physical characteristics and (2) output characteristics. The parameters are required for all waste forms planned for packaging and disposal. They include the variations in the characteristics that will occur as a result of both the inherent range of waste forms to be accommodated and the anticipated time-dependent variations over the operating life of the repository.

The physical characteristics include

1. Number of packages of each type as a function of time.

2. Internal and external configurations of the packages, with dimensions and tolerances.

3. Package weights and weight distributions.

4. Mechanical and thermal properties of the package component materials.

The output characteristics include

1. Decay-heat generation rates of the waste packages.

2. Ionizing radiation fluxes at the external surfaces of the packages.

Logic

The principal purpose of this information need is to provide a source of reference (and alternative) waste package design data that is traceable to the Yucca Mountain Project technical baseline for use in the analysis of the projected performance of the engineered barrier system. In addition, the

waste package characteristics are needed to support the definition of appropriate materials testing environments, both at laboratory and in situ scales, and to provide design input to the repository facilities, equipment, and operations design activities.

This information need does not require site characterization studies, tests, or analyses. The design information that is collected under this topic is developed as an integral part of the design process. A substantial portion of the information that supports the design process is baselined at the Office of Civilian Radioactive Waste Management Program level. Other baselined input is controlled at the Yucca Mountain Project level in the technical baseline. The detailed waste package design studies and analyses will be documented in the advanced conceptual and license application design reports. Interim design information will be maintained and controlled in the Yucca Mountain Project reference information base.

8.3.4.2.3 Information Need 1.10.3: Reference waste package emplacement configurations

Technical basis for addressing information need

Link to technical data chapters and applicable support documents

The waste emplacement configurations within the repository subsurface facilities that have been considered during the conceptual design phase are described in Chapter 6. The reference for the conceptual design is vertical emplacement of the waste packages in holes constructed in the floor of the emplacement drifts, with a single package installed in each hole. An alternative configuration, with multiple packages emplaced within a single horizontal hole, has also been considered.

In addition to the orientation of the emplacement holes, other details of the configuration need to be determined. The distribution of the thermal output of the waste forms is an important consideration that is necessary to assess the performance of the waste packages and the engineered barrier system. In addition, the physical distribution of the emplaced waste packages is determined by the spacing of the emplacement drifts, the pitch (spacing) of the holes, the dimensions of the holes, and the position of the waste packages within the holes. The conceptual designs of these elements for both emplacement orientations are also described in Chapter 6.

Some of the effects of the emplacement configuration on the performance of the waste package components are discussed in Sections 7.4.2 and 7.4.3.

Parameters

The parameters that require determination to fulfill this information need are in two categories: (1) physical characteristics and (2) output characteristics. The parameters are required to include the variations in the characteristics that will result from the types of waste packages to be

emplaced and the anticipated time-dependent variations in package thermal output at the time of emplacement during the operating life of the repository.

The physical characteristics include

1. Emplacement orientation: vertical or horizontal.

   a. For vertical boreholes:

      i. Borehole diameter.

      ii. Borehole depth.

      iii. Configuration of other emplacement hole components (e.g., liners and shielding plugs).

   b. For horizontal boreholes:

      i. Borehole diameter.

      ii. Borehole length.

      iii. Package spacing in hole.

      iv. Standoff distance from drift to package.

      v. Configuration of other emplacement hole components (e.g., liners and shielding plugs).

2. Emplacement drift layout and dimensions.

3. Emplacement borehole spacing (pitch).

The output characteristics include

1. Planned spatial distribution by waste package types.

   a. Spent fuel.

   b. Glass waste forms from West Valley Defense Project and Defense Waste Processing Facility.

2. Planned spatial distribution by waste package thermal power during repository operating life.

Logic

The principal purpose of this information need is to provide a source of reference (and alternative) repository configuration design data that is traceable to the Yucca Mountain Project technical baseline for use in the analyses of the projected performance of the waste packages and the engineered barrier system. In particular, this information, together with the thermal and hydrologic properties of the host rock, will determine the

near-field temperature distribution as a function of time. In addition, the emplacement configuration characteristics are needed to support the definition of appropriate materials testing environments, both at laboratory and in situ scales, and to provide design input to the waste package design activities.

This information need does not require site characterization studies, tests, or analyses within this issue. The design information collected under this topic is developed as an integral part of the repository design process and is controlled in the Yucca Mountain Project technical baseline. The detailed design studies and analyses will be documented in the advance conceptual and license application design reports. Interim design information will be maintained and controlled in the Yucca Mountain Project reference information base. The design studies and analyses to determine the repository configuration characteristics are described in Section 8.3.2 (Issues 4.4 and 1.11).

8.3.4.2.4 Information Need 1.10.4: Postemplacement near-field environment

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The following sections of the data chapters provide a technical summary of existing data relevant to this information need:

SCP section	Subject
7.1	Emplacement environment
7.4.1.1	Stability of borehole openings
7.4.1.2	Anticipated thermal history
7.4.1.3	Reference water for laboratory studies
7.4.1.4	Radiation field effects
7.4.1.5	Thermal effects on water flow in the vicinity of waste packages
7.4.1.6	Numerical modeling of hydrothermal flow and transport
7.4.1.7	Rock-water interaction
7.4.1.8	Modeling rock-water interaction

The technical data discussed in these sections describe attributes that will influence the thermal history of the repository and establish the extent of chemical interaction expected in the waste package environment. Further

work to address remaining uncertainties discussed in Sections 7.4.1.1, 7.4.1.3, 7.4.1.4, 7.4.1.5, 7.4.1.6, and 7.4.1.7 is outlined in Section 8.3.4.2.4.2.

Parameters

The following parameters will be measured or calculated as a result of the studies planned to satisfy this information need:

1. Near-field thermal history.

2. Postemplacement changes in the near-field mineralogy and fluid chemistry: volumes and compositions of mineralogical and fluid reaction products formed in hydrothermal tests, as a function of temperature, time, fluid composition, and radiation dose. Modeling of the laboratory systems will be carried out for purposes of code validation.

3. Postemplacement, near-field hydrologic properties: definition of the hydrologic properties of representative repository horizon rock, including characteristic curves for single- and two-phase systems, flow pathways in intact and fractured rocks (laboratory and field scale), and modeling of these parameters for code validation.

4. Near-field thermal and mechanical properties: borehole stability as a function of fracture characteristics, rock properties, and thermal environment.

Information that supports these parameters includes work that addresses the following information needs or investigations:

Information need or investigation	Subject
1.4.4	Degradation of containment barriers (Section 8.3.5.9.4)
1.10.3	Reference emplacement configuration (Section 8.3.4.2.3)
1.12	Identification of seals and grouts (Section 8.3.3.2)
8.3.1.2.2	Repository scale hydrologic model
8.3.1.3.4, 8.3.1.3.2	Repository scale mineralogy, petrology, and rock chemistry
8.3.1.3.8	Gaseous radionuclide retardation
8.3.1.15.1	Thermal and mechanical properties of rock

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Logic

To ensure that interactions with the emplacement environment do not compromise the function of the waste packages, the composition of water that may contact the waste packages, the amount of water that may contact the waste packages, and the emplacement hole stability must be established. To provide this information in a form that will allow evaluation of the attributes of the near-field environment, it is necessary to establish within limits the chemical and physical characteristics of the interactive elements in the repository.

Since the water chemistry plays a critical role in determining the performance of the waste package components, goals have been established that define the degree of characterization necessary for water that may contact the waste package.

The attributes that affect water chemistry are

1. Interactive effects caused by the emplacement hole liner and other repository construction materials.

2. Repository thermal loading.

3. Emplacement hole configuration.

4. Radiation dose rate.

5. Near-field hydrologic properties.

6. Mineralogy of the near-field rock.

The planned analyses, evaluations, and activities described in the following section will establish the effects of these attributes. In addition, these activities will establish the credible range of values for individual parameters that relate to water quality, water quantity, and borehole stability. The individual parameters are those discussed in Sections 8.3.4.2.4.1 through 8.3.4.2.4.4, and those parameters that relate to water quality and water quantity in Sections 8.3.5.9 and 8.3.5.10. Once evaluated, the parameters will be used to develop a quantitative model of the anticipated waste package environment. The model of the anticipated environment will consider coupled effects and will explicitly determine the sensitivity of the model to uncertainties in each parameter. In developing the model for the anticipated environment, a range of approaches for evaluating coupled processes will be considered and the relative merits of each method will be documented.

Alternative models and scenarios that consider unanticipated events will also be developed for those scenarios that are credible. These alternative models and scenarios will be based on the degree to which variation is expected in individual parameters. The alternative models and scenarios will be used to evaluate containment and gradual release performance issues, as described in Sections 8.3.5.9 and 8.3.5.10.

The attributes described above will influence the thermal history of the repository and will establish the extent of chemical interaction between water present in the waste package environment, the repository host rock, and the waste package materials.

The stability of the emplacement boreholes must be investigated because instability of the borehole could result in unacceptable loading of the package by rock. Borehole stability considerations will be examined through activities and tests of the near-field waste package environment in the candidate repository horizon as part of the Project exploratory shaft in situ testing program.

Waste package environment field tests will be configured to provide site-specific data on near-field hydrologic, thermal, mechanical, and chemical phenomena during an accelerated thermal cycle in the rock mass. Although near-field hydrologic phenomena (movement of water in rock pores or fractures) are of primary interest, thermal and mechanical phenomena are also of interest because of their roles in driving or influencing water migration. Chemical phenomena are important because of their potential influence on hydrologic behavior and because of possible effects on components of the engineered barrier system.

Engineered barriers (including borehole liners) and shaft and borehole seals may influence water composition. The character of seals is discussed in Section 8.3.3. Borehole liners and the effects of other materials are addressed in the following section describing Study 1.10.4.1.

8.3.4.2.4.1 Study 1.10.4.1: Characterize chemical and mineralogical changes in the postemplacement environment

The objective of this study is to establish, to the degree required in Performance Issues 1.4 and 1.5 (Sections 8.3.5.9 and 8.3.5.10), the compositional features of water that may contact the waste packages. To accomplish this objective, it is necessary to determine the effects of chemical reactions on the rock-water system of the repository horizon over a range of temperatures and chemical conditions that bound the postclosure waste package environment. Seven activities are planned to collect the data needed for this study.

8.3.4.2.4.1.1 Activity 1.10.4.1.1: Rock-water interactions at elevated temperatures

Objectives

The objective of this activity is to establish the identity and abundance of reaction products that form during hydrothermal interaction of tuff and reference ground water at elevated temperatures.

Parameters

The parameters of this activity include

1. Temperature.
2. Compositions of reactant and solid phases.
3. Fluid composition as a function of time.
4. Reactant surface area.
5. Modal abundance of solid reactants and products.

Description

The anticipated conditions for the waste package environment include an unsaturated rock system. Reaction rates in such an environment are exceptionally low, and the identity of solid reaction products can be difficult to establish. Therefore, tests to characterize in detail the chemical behavior of a water-saturated liquid and vapor environment will be conducted to bound the nature of hydrothermal reaction products, to provide a conceptual framework to aid interpretation of work carried out in an unsaturated environment, and to establish reaction characteristics for the unanticipated condition of a saturated environment. Tests and experiments similar to those described in Section 7.4.1.7 will be conducted at elevated temperatures (90 to 250°C) that will span the range of anticipated thermal conditions of the waste package host rock. Studies at lower temperatures are not being considered because reaction rates in geologic materials at such temperatures are too slow to provide meaningful results within the available time. Although it is not expected that significant quantities of liquid water will exist in the waste package environment when the temperature exceeds approximately 100°C, high-temperature (>100°C) studies will be conducted to characterize the stability fields of phases important in the low-temperature tests. These data will also provide information on reaction kinetics and rate laws appropriate for the phases involved in lower-temperature reactions and will provide means to extrapolate reaction behavior to lower temperatures.

The studies will examine the nature of reaction products in hydrothermal systems containing Topopah Spring tuff and water that is believed to be representative of vadose water in the repository horizon. Comparison of the reaction products with mineral assemblages and mineral compositions in natural systems will allow evaluation of the applicability of the laboratory results to the repository environment.

Sample material for the tests will be obtained from the appropriate geologic horizon. Wafers of the sample will be cut, polished on one side, examined using a scanning electron microscope (SEM) and electron microprobe, and mounted in the reaction vessel of a Dickson-type rocking autoclave or other appropriate reaction vessel. If studies of the solid reaction products are not to be undertaken, crushed tuff, rather than a rock wafer, will be placed in the reaction vessel. Sufficient fluid, of the appropriate composition, will be added to the reaction vessel to last the duration of the test. The reaction vessel will then be taken to the temperature and pressure considered for the test. The reaction vessel will be kept at these conditions for the time necessary for the rock-water system to approach equilibrium. Fluid will be periodically extracted from the reaction vessel for

chemical analysis. At completion of the test, the rock wafer will be removed and examined for reaction products in the SEM and the electron microprobe. If crushed rock is used in the test, instead of a rock wafer, the material will be examined by x-ray diffraction and SEM.

8.3.4.2.4.1.2 Activity 1.10.4.1.2: Effect of grout, concrete, and other repository materials on water composition

Objectives

The objective of this activity is to test the rock-water interaction in the presence of concretes, grouts, and other repository materials (Section 8.3.3) when the identity of the other materials is established. The objective of these tests is to determine if the proposed material satisfies the requirements specified in the performance allocation for this issue relating to effects of engineered barriers, shafts, and seals on water chemistry. The parameters and laboratory methods appropriate to this activity will be established when the other materials are identified.

8.3.4.2.4.1.3 Activity 1.10.4.1.3: Composition of vadose water from the waste package environment

Objectives

The objective of this activity is to characterize the composition of vadose water in the unsaturated, preemplacement waste package environment.

Parameters

The parameter of this activity is the chemical composition of vadose water in tuff of the repository horizon.

Description

A test will be conducted to extract pore water from representative devitrified, welded tuff. The extracted fluid will be analyzed using standard inductively coupled plasma and ion chromatography procedures. This test will be designed to determine the method that produces the most representative fluid composition for the environment. Analyses of the collected fluid will be compared with theoretical models of rock-water interaction and known characteristics of vadose fluids in equilibrium with minerals present in the rock, to evaluate whether a particular extraction technique produces uncontaminated fluid. Once an extraction method is selected, vadose water will be extracted from core uncontaminated with drilling fluids and from exploratory shaft material collected at the repository horizon. The need for this activity is discussed in Sections 7.4.1.1, 7.4.1.3, and 7.4.1.7.

This activity will establish the variability of vadose water composition within the repository horizon. This information will define the bounds to be expected on vadose water composition in the pre-emplacement waste package

environment. This activity complements the work of the U.S Geological Survey, which will characterize the regional and stratigraphic variability of pore water chemistry, as described in Section 8.3.1.2.2.8.2.

Design of these tests is in progress.

8.3.4.2.4.1.4 Activity 1.10.4.1.4: Dissolution of phases in the waste package environment

Objectives

The objective of this activity is to determine the dissolution kinetics of the phases present in the waste package environment.

Parameters

The parameters of this activity include

1. Temperature.
2. Solution pH.
3. Mineral composition and structural state.

Description

In rock-water interaction studies, dissolution of reactant phases and the concomitant precipitation of product phases control the rates of chemical reaction. To understand the kinetics of mineral precipitation and to interpret the evolution of the fluid composition in hydrothermal tests, knowledge of the dissolution kinetics of the phases present in the host rock is required. Data on the kinetics of dissolution of phases of interest are sparse and must therefore be obtained through laboratory studies, as discussed in Section 7.4.1.7.

Dissolution studies will be conducted over a range of temperatures and fluid pH to determine the sensitivity of the dissolution kinetics to temperature and variation in the chemistry of the environment. Phases used in the dissolution studies will include the principal constituents of the devitrified, welded tuff and the common secondary phases associated with rock-water interaction as identified in hydrothermal tests and experiments. Tests will also be conducted to determine the degree to which vapor-phase transport and dissolution will occur under conditions anticipated in the waste package environment.

The mineral of interest will be crushed to a specific size range and washed thoroughly to remove adhering fine particles. Brunauer-Emmett-Teller surface area measurements will be conducted to determine the surface area of the material. For tests at temperatures less than 95°C, the sample will then be weighed and placed in small flow-through dissolution cells. Each cell will be attached to a fluid stream of known pH and flow rate. The cell will then be placed in a controlled-temperature environment for specified periods of time. The fluid that passes through the cell will be collected and periodically analyzed for the elements of interest. Statistical analysis of

the results, using transition state theory, will be used to model the kinetics of the dissolution process. Laboratory protocol for dissolution studies at temperatures in excess of 100°C is still in development.

8.3.4.2.4.1.5 Activity 1.10.4.1.5: Effects of radiation on water chemistry

Objectives

The objective of this activity is to determine the composition of water in the presence of a radiation field under postemplacement conditions.

Parameters

The parameters of this activity include

1. Temperature.
2. Radiation dose rate.
3. Degree of water saturation.
4. Nature of solid materials present in addition to tuff.

Description

In water-saturated air, the abundance and composition of the radiolysis products that develop in a radiation field are a sensitive function of the temperature and the radiation dose rate. In addition, chemical reactions may take place between the radiolysis products and any other material present in the system. For example, it remains unclear which chemical reactions occur in the presence of iron and manganese oxides that may influence colloid development, nitrite-to-nitrate ratio, and the relative abundances of other nitrogen-bearing compounds. This activity will determine the chemical composition of the water and air that develops at different radiation dose rates, over a range of temperatures, and in the presence of materials expected in the waste package environment.

Reaction vessels containing tuff, waste package container metal, and reference ground water are placed in a gamma radiation field. The reaction vessels are then subjected to a specified radiation dose rate, at a specific temperature, for an extended period of time. Samples of the solution that develop during the course of the exposure are then chemically analyzed. A matrix of tests over a range of temperatures and radiation dose rates will allow identification of the significance of individual reaction parameters.

The results of these tests are used as input to guide modeling of rock-water interaction in the presence of a radiation field. The rates of dissolution and precipitation of radiolysis products and the identification of solid products formed through interaction of tuff with irradiated fluid provide constraints on the modeling. The geochemical modeling code EQ3/6 (discussed in Section 7.4.4) will be used to extend to long time periods (and to conditions not represented in the matrix of tests) the chemical behavior of the tuff-water system in the presence of radiation and other materials.

8.3.4.2.4.1.6 Activity 1.10.4.1.6: Effects of container and borehole liner corrosion products on water chemistry

Objectives

The objective of this activity is to determine the effect of corrosion products on the composition of water in the package environment.

Parameters

The parameters of this activity include

1. Temperature.
2. Composition and mineralogy of corrosion products.
3. Degree of water saturation.

Description

The effect of corrosion products on the waste package environment and water chemistry will be established through a matrix of long-term tests in which tuff, reference ground water, and metal are commingled at elevated temperatures. The metals used in the test will be partially submerged, if liquid water is present, and will be exposed to the gaseous atmosphere present in the test vessel. Periodic sampling of the fluid phase will be conducted to determine the chemical evolution of the fluid through time. At the conclusion of the tests and experiments, the metal samples and the tuff will be examined by using SEM/electron dispersive spectroscopy to determine the abundance and nature of reactions and corrosion products, their modes of occurrence, and their composition.

8.3.4.2.4.1.7 Activity 1.10.4.1.7: Numerical analysis and modeling of rock-water interaction

Objectives

The objective of this activity is to examine effects and processes in natural systems for time periods and chemical conditions not duplicated by laboratory studies.

Parameters

The parameters of this activity include

1. Temperature.
2. Mineral assemblage.
3. Mineral species surface areas.
4. Reaction times.
5. Fluid composition.

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Description

Laboratory studies are incapable of examining the effects of all the possible values of parameters significant for the system under consideration. Nor can laboratory studies be used to extend directly to periods of many years the behavior of natural systems studied in the laboratory over periods of months. However, the use of numerical studies, in conjunction with judiciously selected tests, can provide the capability to establish the behavior of natural systems for conditions not duplicated by laboratory tests.

The numerical analysis and modeling will be used to predict the results of previously completed tests for characterizing the reaction process. For any geochemical test under consideration, the computer code EQ3/6 (discussed in Section 7.4.4) will use as input the mineralogy of the reactant rock material, the surface area of the reactant solid phases, and the composition of the water. The code then computes (for the temperature of the test and the reaction interval step chosen) the composition of the fluid at each reaction step, the degree of saturation of appropriate mineral phases, and the quantity of minerals precipitated from solution. This approach also allows characterization of reaction processes under conditions not duplicated by the laboratory studies and can be used to extrapolate the results of laboratory studies to repository time and distance scales. The uncertainties in the thermodynamic and kinetics data used in the calculations will be evaluated.

8.3.4.2.4.2 Study 1.10.4.2: Hydrologic properties of waste package environment

The objectives of this study are to establish the hydrologic properties of the near-field repository rock and the effect of thermal perturbation on these hydrologic properties, over the range of anticipated postemplacement conditions. This study will establish the conditions under which fracture flow will predominate over matrix flow and will determine the relative hydrologic importance of gas versus liquid-phase transport under isothermal and polythermal conditions appropriate for the waste package environment. This study will also determine the degree to which thermal effects will modify the ambient hydrologic properties. Isothermal components will provide input for simulation of conditions during the controlled release period and provide partial validation for nonisothermal codes.

Waste package performance assessment calculations will require boundary conditions representing the host rock environment. A hydrothermal flow and transport model will be developed to simulate moisture and contaminant movement in the matrix and fractures of the host rock. The flow model will be composed of the conservation equations for fluid mass, momentum, and energy in a fractured porous medium. Thermodynamic relationships will be included for the water-steam phase changes. Constitutive relationships will include the equation of state for vapor and air components. In addition to flow calculations, this model will also provide the temperature of the surrounding rock mass and the state of saturation for all fluid phases as functions of space and time.

The transport model will use the pore velocities calculated by the flow model and then solve the transport equation for each radionuclide. Transport processes will include advection, molecular diffusion, and dispersion. Radionuclide decay, sorption, and solubility limits also influence the concentrations of radionuclides, and these processes will be included. This model will provide the concentrations of ground-water chemical species of interest to the representation of the waste package environment. In addition, the concentrations of released radionuclide species, both in the ground water and sorbed to the rock matrix, may be determined as a function of time and space.

The flow and transport models will be used to establish the quantity of water that may contact waste containers. Consideration will be given to the range of flow pathways identified in field and laboratory tests and to anticipated and unanticipated hydrologic conditions defined by activities that establish the Yucca Mountain site hydrology (Section 8.3.1.2). These flow and transport models will provide the basis for establishing the extent to which near-field hydrologic properties will contribute to satisfying water quantity performance goals set in Issues 1.4 and 1.5.

Conclusions regarding fluid transport behavior in a thermally perturbed environment will be verified through field studies in the exploratory shaft facility, as described in Sections 7.4.1.1 and 7.4.1.5, and through work under Characterization Program 8.3.1.2. Study 1.10.4.2 consists of three laboratory and modeling activities.

8.3.4.2.4.2.1 Activity 1.10.4.2.1: Single-phase fluid system properties

Objectives

The objectives of this activity are

1. To establish the single-fluid-phase hydrologic properties of fractured and unfractured tuff under isothermal conditions.

2. To establish the single-fluid-phase hydrologic properties of fractured and unfractured tuff in a thermal gradient.

Parameters

The parameters of this activity include

1. Temperature.
2. Relative permeability.
3. Degree of saturation.
4. Nature of the fluid phase.
5. Number of rehydration-dehydration cycles.
6. Resistivity.
7. Magnitude of thermal gradient.

Description

Dehydration-rehydration processes may modify the hydrologic properties of the near-field rock through precipitation-dissolution effects or through induced changes in fracture surface characteristics. The pattern of fluid flow that may develop as a result of heat transfer and mass transport may take several forms, including convective flow and "heat pipe" geometries. Such processes have the potential of developing regions where fluids may condense or areas where transported solutes may concentrate. These processes could change the chemistry, mineralogy, and hydrology of the waste package environment and therefore must be characterized to satisfy Information Need 1.10.4 (Section 8.3.4.2.4).

Fractured and unfractured samples will be used to examine the fluid flow properties of single-phase (gas or liquid) systems. Tests will be run in isothermal conditions and in thermal gradients to determine the fluid flow behavior in different thermal regimes. These tests will be run under pressure conditions that simulate loading at the repository level. These tests will address data needs described in Section 7.4.1.6. The characteristics of fluid flow in these different environments will be documented by using computed impedance tomography. Computed impedance tomography is an imaging technique that uses electrical resistivity measurements taken sequentially around a circumference of a rock core to obtain variations in resistivity within the core. The resistivity measurements may be converted to degree of liquid saturation, thereby providing a two-dimensional map of liquid saturation on a plane normal to the cylinder axis. Modification of fracture surfaces and pores will be documented.

8.3.4.2.4.2.2 Activity 1.10.4.2.2: Two-phase fluid system properties

Objectives

The objectives of this activity are

1. To establish the two-phase hydrologic properties of tuff under isothermal conditions.

2. To establish the two-phase hydrologic properties of tuff in a thermal gradient.

Parameters

The parameters of this activity are

1. Temperature.
2. Relative permeability.
3. Degree of saturation.
4. Gas-to-liquid ratio.
5. Resistivity.
6. Number of rehydration-dehydration cycles.
7. Magnitude of temperature gradient.

Description

Tests in the two-phase system will be designed to establish the effects of a two-phase fluid on the hydrologic properties of the tuff, to allow comparison with results from the single-phase fluid tests. The single-phase and two-phase studies will characterize the tuff-fluid system over the range of conditions anticipated in the postemplacement waste package environment.

The laboratory protocol for the two-phase activities is similar to that for the single-phase activities, with the exception that the ratio of liquid to gas is an additional parameter that will be controlled in the tests. These tests are performed in a pressure vessel under simulated in situ conditions. The work described here addresses needs described in Sections 7.4.1.1, 7.4.1.5, and 7.4.1.6.

8.3.4.2.4.2.3 Activity 1.10.4.2.3: Numerical analysis of flow and transport in laboratory systems

Objectives

The objective of this activity is to use laboratory-scale tests for initial development and validation of the flow and transport code.

Parameters

The parameters of this activity are

1. Temperature.
2. Distribution of liquid-phase saturation.
3. Permeability.
4. Hydraulic conductivity.

Description

The hydrothermal flow model will require validation over a range of conditions sufficient to cover those required in the use of the model. Validation requires that model predictions be compared with controlled tests, from both laboratory and in situ investigations. The laboratory measurements of two-phase flow in rock cores conducted under Study 1.10.4.2 (Section 8.3.4.2.4.2) will partially satisfy the validation needs of the hydrothermal flow model. The primary variables to be used for validation will be the core temperature and saturation distributions. Other properties required will include the thermal properties of the core material. The parameters subject to validation will be the permeability and the expressions used to represent matric potential and relative conductivity as functions of saturation. By using these test results, the model can be tested on one- and two-dimensional systems under controlled but varying thermal and flow conditions. This vali-dation will concentrate on simulation of flow in a small core and, therefore, will provide a limited validation before testing on a scale representative of the waste package environment.

8.3.4.2.4.3 Study 1.10.4.3: Mechanical attributes of the waste package environment

The objectives of this study are to establish the mechanical attributes of the waste package environment host rock. The need for this information is discussed in Section 7.4.1.1 and 7.4.1.2. The mechanical studies will examine the mechanical response of the near-field rock to the engineering and thermal regimes resulting from development of the repository and emplacement of the waste packages. The mechanical properties determine the extent to which borehole wall failure can be expected to load the waste package containers.

8.3.4.2.4.3.1 Activity 1.10.4.3.1: Waste package environment stress field analysis

Objectives

The objective of this activity is to estimate the time-dependent stress field and displacements of the rock in the waste package environment.

Parameters

The parameters of this activity are

1. Emplacement configuration.
2. Repository layout.
3. Temperature fields.
4. Mechanical properties of rock in repository horizon (TSw2), including for example, Young's modulus, Poisson's ration, deformation modulus, coefficient of thermal expansion, and strength-related properties.
5. Fracture (joint) characteristics of rock in repository horizon (TSw2), including for example, shear and normal stiffness, orientation, and frequency and degree of persistence.

Description

The extent to which waste containers can be loaded by rock-induced stresses will be evaluated. One of the potential mechanisms for such loading is slip of discrete blocks of rock along preexisting fractures. Field data describing the attributes of the fractures will be used with repository design information, predicted temperatures, and mechanical properties of the host rock to predict the possible extent and modes of block failure for the range of conditions anticipated in the repository horizon. The integration of the field data with the design specifications for the emplacement geometry, container spacing, and the liner will be accomplished by using computer modeling and, if necessary, model tests.

8.3.4.2.4.4 Study 1.10.4.1: Engineered barrier system field tests

The laboratory tests described in Activities 1.10.4.1.1 through 1.10.4.1.7 (Sections 8.3.4.2.4.1.1 through 8.3.4.2.4.1.7) and 1.10.4.2.1 through 1.10.4.2.3 (Sections 8.3.4.2.4.2.1 through 8.3.4.2.4.2.3) require validation through in situ field tests in the repository horizon to establish the applicability of the laboratory studies to the repository block. These tests will be conducted in the exploratory shaft facilities at the repository horizon. The activities listed below indicate the objectives of the work to be completed and the parameters to be determined. Detailed descriptions of the activities will be available when the indicated test plans are completed. The work described in these activities addresses needs described in Sections 7.4.1.1., 7.4.1.5, and 7.4.1.6. The three activities in this study are described in the following sections.

Before initiation of the in situ tests that support this study, prototype tests to develop and validate the test procedures and protocols are planned. These prototype tests will be conducted in the G-tunnel test facility located in a similar hydrogeologic setting in Rainier Mesa at the Nevada Test Site. The prototype tests are designed to simulate the test conditions and evaluate the installation procedures and performance characteristics of the instrumentation planned for the in situ tests to be deployed in the Yucca Mountain exploratory shaft facility.

8.3.4.2.4.4.1 Activity 1.10.4.4.1: Repository horizon near-field hydrologic properties

Objectives

The objective of this activity is to determine the in situ hydrologic properties of rock in the repository horizon under thermally perturbed conditions.

Parameters

The parameters of this activity are

1. Degree of liquid water saturation.
2. Relative permeability.
3. Matric potential.
4. Fluid flow pathways.
5. Fluid flow rates.
6. Fracture characteristics.
7. Thermal loading.
8. Mechanical and thermal properties of the rock.

Description

Geotechnical and hydrologic instrumentation will be deployed to monitor selected near-field environmental parameters in situ. These measurements will allow characterization of the parameters just enumerated. In addition, laboratory-scale hydrologic studies will be completed, with computed

impedance tomography techniques, on samples obtained from the repository horizon. Comparison of the data obtained from the field studies and laboratory studies with those obtained from earlier laboratory tests will extend the applicability of the laboratory tests to the in situ waste package environment.

8.3.4.2.4.4.2 Activity 1.10.4.4.2: Repository horizon rock-water interaction

Objectives

The objective of this activity is to determine the effect on water chemistry of thermal perturbation of the near-field environment.

Parameters

The parameters of this activity are

1. Temperature.
2. Temperature gradient.
3. Water chemistry.
4. Mineralogical changes.

Description

Geotechnical and hydrologic instrumentation will be deployed to monitor selected near-field environmental parameters in situ. In addition, laboratory tests and analyses will be conducted as described in the test plan. These measurements will provide the background for characterization of the parameters enumerated above. Once established, comparison of these parameters with those obtained from previous laboratory tests will extend the applicability of the laboratory tests to the in situ waste package environment. Pretest and posttest rock and water samples will be analyzed for changes in mineralogy and chemistry. These activities will provide data for integration with laboratory-scale measurements. These activities will address needs described in Sections 7.4.1.1, 7.4.1.5, and 7.4.1.7.

8.3.4.2.4.4.3 Activity 1.10.4.4.3: Numerical analysis of fluid flow and transport in the repository horizon near-field environment

Objectives

The objective of this activity is to validate and calibrate fluid flow, temperature, and transport models by using waste-package-scale field studies.

Parameters

The parameters of this activity are

1. Fracture attributes.

2. Temperature.
3. Degree and distribution of saturation.
4. Time.
5. Sorption.
6. Water composition.
7. Emplacement configuration.
8. Repository layout.
9. Waste package configurations.
10. Waste package heat generation characteristics.

Description

The flow and transport model will require calibration on a scale representative of the waste package environment. Testing on this scale, as described in Activity 1.10.4.4.1 (Section 8.3.4.2.4.4.1), will allow the influence of fractures on the flow of liquid water and steam to be observed. Tests at the repository horizon in the exploratory shaft facility will provide the ability to test the model at a scale approximating the waste package emplacement conditions. To perform this calibration and validation, temperature and degree of liquid saturation of the rock mass and concentration of tracers and sorbed substances must be observed under different simulated emplacement conditions. Other measurements such as pressure of the gas phase in matrix and fractures would be useful but may not be practical. The primary benefit of these tests will be to test the effect of fractures on moisture movement in the rock mass.

The transport capability of the flow and transport model will be used to describe the movement of radionuclides and naturally occurring aqueous chemical constituents in the near field; that is, the first several meters of host rock surrounding an emplacement hole. These calculations will be used respectively in tracking releases and assigning boundary conditions for performance calculations. Therefore, the transport portion of the model must also be validated.

The thermal studies will address the history, magnitude, and nature of the thermal perturbation associated with waste packages in the emplacement configurations under consideration. This history establishes the thermal conditions under which rock-water interaction may occur. The magnitude of the temperature field that develops around a waste package is a complex function that depends on how the packages are spaced within the repository and how much heat the packages dissipate through time. Additional variables include the relative diameters of the borehole and the container and whether the borehole has been lined.

Modeling of the thermal history of the near-field environment will be conducted by using a test matrix consisting of the variables that influence the temperature field of the waste package environment. A computer code for hydrothermal flow in unsaturated rock will be used to evaluate the effect of each variable over the range of conditions anticipated for the repository. The results will be used to establish the thermal behavior of the near-field environment.

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In situ test will be conducted to monitor the movement of sorbing and nonsorbing species. These measurements will include the concentration of species in the pore water as a function of time and space and the concentration of species sorbed onto the tuff matrix at specified times and locations. Calibration of the transport routines will consist of deriving dispersivities and effective diffusion coefficients for the test location. Since measurements will be used to calibrate and validate the transport routines of the hydrothermal model, it will be necessary to design the tests so that several data sets will be available for a given set of geologic parameters.

8.3.4.3 Issue resolution strategy for Issue 2.6: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues?

Regulatory basis for the issue

This issue deals with two aspects of the waste package design considerations. The first relates to the specific criteria explicitly established in the NRC regulations in 10 CFR 60.135. Compliance with these criteria will be addressed by analyses of the designs and comparison with the criteria under Information Needs 2.6.1 and 2.6.2 (Sections 8.3.4.3.1 and 8.3.4.3.2). Information is also needed on the physical characteristics of the spent fuel and high-level waste that is to be accepted into the disposal system. This information will be provided to the Yucca Mountain Project by other elements of the DOE Office of Civilian Radioactive Waste Management (OCRWM) in the form of waste acceptance specifications, receipt rate projections by waste type and characteristics, and other descriptions. This information is expected to be provided in documents controlled within the OCRWM technical baseline and revised periodically to reflect the most current data available. These specifications and characteristics will reflect the regulatory criteria that establish restrictions on the form and content of the wastes to be received, packaged, and disposed of in the repository. Information Need 2.6.3 (Section 8.3.4.3.3) will accumulate the information for use in the waste package design development.

None of the information needed to address the preclosure waste package design criteria mentioned previously requires the acquisition of site characterization data, as it primarily involves information about, or restrictions on, the waste forms and specific criteria for characteristics of the waste packages.

The second part of this issue is much broader in scope and involves the actual development of the waste package designs and the integration of the designs into the repository system. The approach to resolution of this issue is described in the following section.

Approach to resolving the issue

The approach to be used in resolving this issue is similar to that used in the issues that address design of the repository as described in Section 8.3.2. In that section, the requirements that arise in other issues that involve specific aspects of the repository, for both the preclosure and postclosure periods, are consolidated for design purposes within Issue 4.4 (Section 8.3.2.5). The design is developed and placed in the reference information base. Specific design features are then evaluated for consistency with the requirements for performance as required by the other issues. The testing and design activities described in this section are tentative and are subject to change. Any such change will be reported in semiannual progress reports.

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The issues hierarchy (Section 8.2) divides the information needed to develop and evaluate the performance of the waste package designs into five issues, three of which directly address the design aspects. This division, although logical in the context of the regulatory provisions that place different requirements on the waste packages during the preclosure and postclosure periods, results in a complex design management process because the various requirements are imposed on a single set of physical objects. To integrate the waste package design process, the logic shown in Figure 8.3.4.3-1a has been developed.

In this framework, the design criteria and constraints that are derived within Issue 2.6 from the preclosure functional requirements through the performance allocation process are consolidated with the requirements and other design inputs developed in Issue 1.10 (Section 8.3.4.2). An integrated document, the waste package design requirements, is compiled and provides the definitive guidance for development of the designs.

A significant product of the waste package design effort will be the specification of the production processes to be used in the fabrication, closure, and inspection of the containers. A direct supporting element to the design process is therefore identified separately in Issue 4.3 (Section 8.3.4.4), where the evaluation and testing of these production technologies are described.

The design process is planned to progress through multiple phases, starting with an advanced conceptual design phase and continuing through a license application design phase before submission of a license application. During each of these design phases, the design products, including the supporting analyses, will be transferred to the Yucca Mountain Project reference information base. The design information will then be assessed for compliance with the goals imposed by the appropriate performance issues and transferred to the repository design Issue 4.4 (Section 8.3.2.5). Figure 8.3.4.3-1a also shows the decision paths that must be addressed in the event that performance assessments of the designs indicate that revisions are required to achieve the goals. These assessments will be performed both within the design issue and within the performance issues, as determined by the source of the goal.

Table 8.3.4.3-1 lists the major preclosure functions or characteristics that are derived from the regulatory criteria for the waste packages. Performance measures, goals, and levels of confidence are indicated for these functions needed to resolve this issue (2.6).

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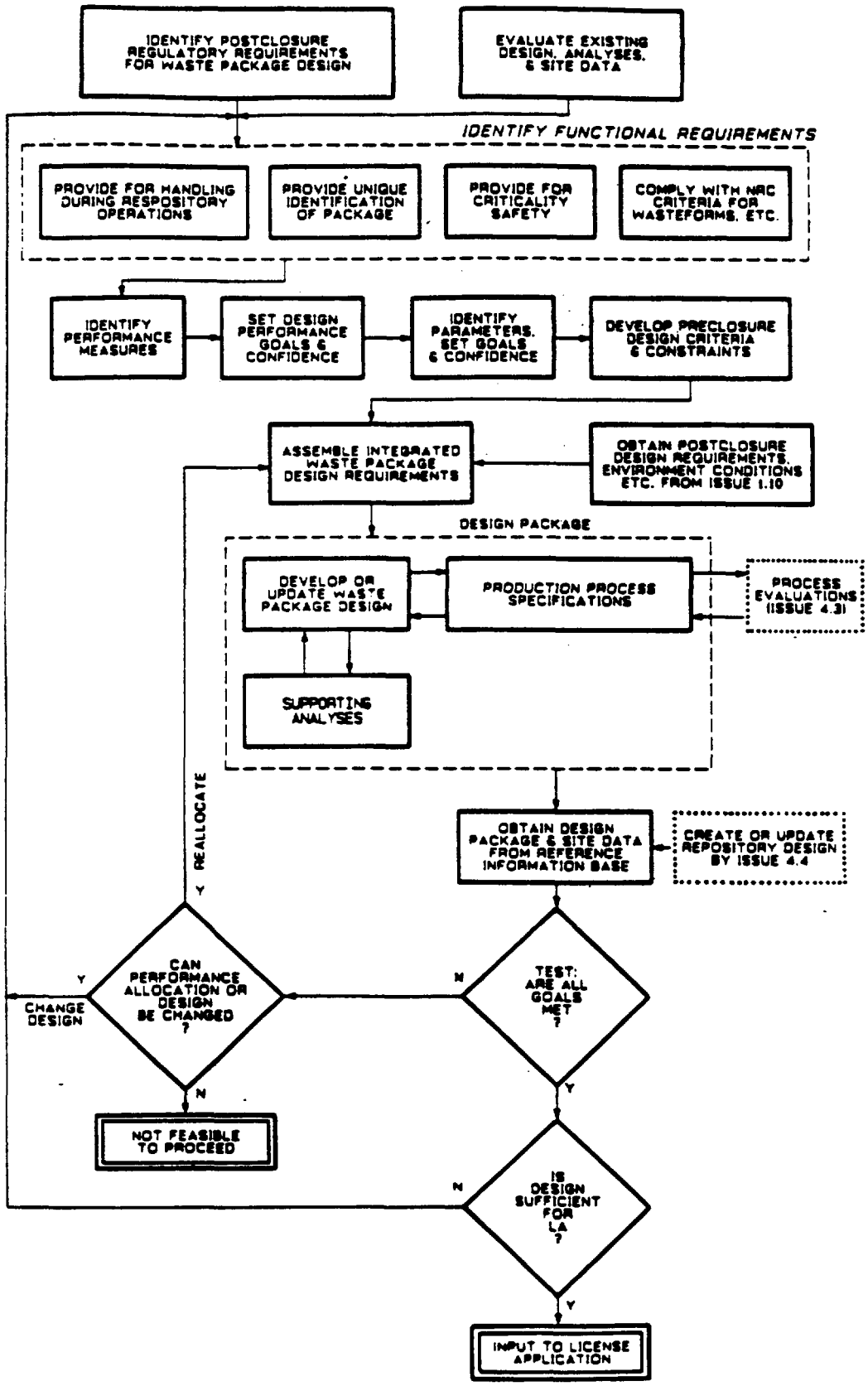

Figure 8.3.4.3-1a. Logic diagram for the resolution of Issue 2.6 (waste package characteristics–preclosure). See Figure 8.3.4.3-1b for legend.

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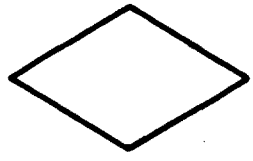
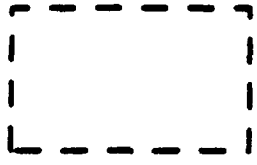
LEGEND

ACTIVITY PERFORMED TO RESOLVE ISSUE

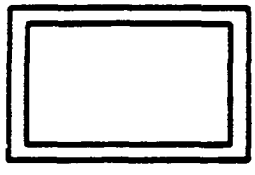


TEST TO DETERMINE SUBSEQUENT ACTIVITY

ACTIVITY PERFORMED BY INDICATED ISSUE



ACTIVITY WITH MULTIPLE SIMILAR ACTIVITIES OR TESTS



DECISION ABOUT ISSUE RESOLUTION

Y - YES
N - NO
LA - LICENSE APPLICATION
NRC - NUCLEAR REGULATORY COMMISSION

Figure 8.3.4.3-1b. Legend for Figure 8.3.4.3-1a.

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Table 8.3.4.3-1. Performance allocation for Issue 2.6 (waste package characteristics--preclosure)

System element	Function or characteristic	Performance measure	Goal	Confidence needed
Waste package	Contain waste during repository operations	Fraction of containers intact at end of preclosure	>99.5% intact	High
	Limit potential criticality in waste packages	Effective neutron multiplication factor (K_{eff})	<0.95	High
	Provide unique identification of packages	Identification legible at end of preclosure	>99% legible	Medium
Waste form	Comply with NRC criteria for acceptance	Waste form characteristics	>99% (Ci) of waste received in compliance with criteria	High
Container	Capable of being handled by repository systems	Package-handling fixtures	100% through emplacement, >95% through preclosure	High

8.3.4.3.1 Information Need 2.6.1: Design information needed to comply with preclosure criteria from 10 CFR 60.135(b) for materials, handling, and identification of waste packages

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The functional requirements, performance criteria, and constraints derived from the regulatory criteria for this information need and used in the conceptual waste package designs are defined in Section 7.2.1.1, generic preclosure requirements. The preliminary allocation of performance to components in response to these requirements is discussed in Section 7.2.3.1, preclosure performance.

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Parameters

The specific waste package design criteria established in 10 CFR 60.135(b)(1) through (4) require that the following parameters be addressed in the design:

1. Explosive, pyrophoric, and chemically reactive materials.
2. Free liquids.
3. Containment during transportation, emplacement, and retrieval.
4. Unique identification.

Logic

The information needed to comply with the criteria of 10 CFR 60.135(b) requires that the waste package designs (together with the characteristics of the waste forms and the preclosure environments that the packages will experience) be analyzed to establish that the criteria will be met. The parameters to be addressed are quite diverse, as are the preclosure environments.

Criteria (1) and (2) in 10 CFR 60.135(b) are limitations on classes of materials in waste packages that could compromise the performance of the packages or other engineered or natural system components. An analysis of the designs, including the waste forms, and the repository operations will be required to show that these classes of materials will not be present or, if present, the quantities will not exceed the criteria.

Criterion (3) is an explicit design requirement that the waste packages maintain waste containment during handling operations. For the waste packages to meet this criterion under all possible loading conditions, the package designs would include structures much stronger than those dictated by any other requirement. An analysis of the containment capability of the waste packages under both normal and off-normal loads will be performed. Loading conditions that result in loss of containment by the packages will be evaluated for significance in view of the repository facility ventilation and other containment systems. These systems are addressed in the information needs under Issue 4.4 (Section 8.3.2.5).

Criterion (4) is an explicit design requirement that each waste package be uniquely identified, with the identifier legible during the preclosure period, consistent with the permanent written records, and that it not impair the integrity of the package. An assessment of the alternatives available for complying with this requirement and an analysis of the selected method will be performed.

The regulatory criteria will be reflected in the waste package design requirements, and the analyses to show that the performance goals have been met will be an integral part of the design activities. The analyses will be documented in the advanced conceptual and license application design reports.

8.3.4.3.2 Information Need 2.6.2: Design information needed to comply with preclosure criteria from 10 CFR 60.135(c) for waste forms

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The functional requirement and performance criterion that has been derived from one of the regulatory criteria for this information need is defined in Section 7.2.1.1, generic preclosure requirements. A brief discussion of the waste form design considerations is included in Section 7.2.3.1, preclosure performance. Additional information related to the waste forms is in Section 7.3.1.1, reference waste form descriptions, and Section 7.4.3, waste form research and testing.

Parameters

The specific high-level waste (HLW) form design criteria established in 10 CFR 60.135(c)(1)-(3) require that the following parameters be addressed:

1. Solidification.
2. Consolidation to limit particulates.
3. Combustibles.

Logic

The criteria established in 10 CFR 60.135(c) prescribe three attributes or limitations on the physical form of the HLW to be disposed in the repository. These are reflected in the parameters listed above.

The information needed to demonstrate compliance with these criteria requires that the HLW form designs be analyzed to establish that the criteria will be met. The physical characteristics of the waste forms to be received at the repository for disposal are determined by the DOE waste acceptance specifications. The approach to determining that the waste forms comply with the criteria will be to compare them with the DOE waste acceptance specifications. Therefore, the approach to determining that the waste forms comply with the criteria will be to compare the waste acceptance requirements and specifications obtained in Information Need 2.6.3 (Section 8.3.4.3.3) with the criteria.

One additional criterion is imposed within this section of the regulations that is not strictly related to waste forms. All HLW must be "placed in sealed containers." Although the DOE acceptance requirements for unreprocessed spent fuel do not include this provision, the criterion will be met by the addition of a sealed container at the repository before emplacement in the underground facility.

This information need will be met by the development of the waste form acceptance specifications (Section 8.3.4.3.3). A documented comparison of these specifications with the regulatory criteria will be presented in the advanced conceptual and license application design reports.

8.3.4.3.3 Information Need 2.6.3: Waste acceptance specifications

Technical basis for addressing the information need

Link to the technical data chapters and applicable supporting documents

Reference is made to the waste acceptance specifications and requirements in Sections 7.2.3.1 and 7.3.1.1 under discussions of preclosure performance and reference waste form descriptions, respectively.

Parameters

The parameters to be addressed in this information need are

1. Acceptance specifications for unreprocessed spent fuel.
2. Acceptance specifications for West Valley high-level waste.
3. Acceptance specifications for DOE defense high-level waste.

Logic

The characteristics of all waste forms to be received at the repository for packaging and disposal are an essential input to the design and development of the geologic disposal system. Therefore an information need has been identified to provide a mechanism within the issues hierarchy for the development and documentation of these characteristics.

The information to be collected falls into two general classes for each waste form. One is the formal waste acceptance specifications that will be developed by the DOE for determining the acceptability of waste into the OCRWM system. These specifications will determine the parameters to be investigated in the waste form performance testing activities and establish the range of variability of the waste forms. Once established, these acceptance specifications are not expected to change significantly.

The other class of information is the baselined projections of the time-dependent characteristics of the waste streams. These projections are the basis of the waste package and repository designs for packaging and handling facilities and equipment, capacities, and receipt rates. This information is expected to change with time as more accurate projections, especially for waste forms that have not been manufactured yet, become available.

The analyses and activities required to provide the waste acceptance specifications and other waste form characteristics are the direct responsibility of the DOE. Technical support will be provided by the Yucca Mountain Project as appropriate to assist in developing the information. The details of these studies and analyses are beyond the scope of the site characterization plan.

8.3.4.4 Issue resolution strategy for Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues?

Regulatory basis for the issue

This issue arises from the provision of 10 CFR 960.5-1, the preclosure system guidelines, that the qualifying conditions require that the repository operation be demonstrated as feasible on the basis of reasonably available technology. The waste packages are a "product" of the repository operation and therefore must be technically feasible on the same basis.

In addition to their technical feasibility, the processes selected for producing the waste packages affect the design of the packages, the design and operation of the repository surface facilities where they are produced, and the performance of the packages after they are emplaced in the repository subsurface facilities.

Rather than differentiate between the feasibility, package and facility design, and package performance aspects of the production processes and describe the plans for each separately, the planned activities to provide information for all these topics are addressed in this issue.

Approach to resolving the issue

Several production technologies are required to fabricate, assemble, and inspect the waste packages. These processes, in addition to being reasonably available, must be responsive to the performance-derived requirements for the waste packages and relevant to the design concepts. Thus, this issue (4.3) is closely coupled to the waste package design requirements document and the design concepts that are generated as a part of Issue 2.6 (Section 8.3.4.3). The relationship between these issues is shown in Figure 8.3.4.4-1. To minimize the interfaces between this issue and other design issues (both for the repository and the waste package), this issue interacts directly only with Issue 2.6.

Interactions with the other design issues are implemented within Issue 2.6 through the Yucca Mountain Project reference information base. These interactions are shown in Figure 8.3.4.4-1.

The approach to resolving this issue will involve a set of studies directed at identifying and evaluating production processes in each of the technology areas. Selection criteria for each technology will be established. Candidate processes will be identified and evaluated against the selection criteria. The leading candidate processes will be used to produce representative test specimens. These test specimens will be analyzed to determine their properties, and the properties will be compared with the criteria derived from the performance requirements. Process selection will then be made on bases that will include performance, as well as other criteria such as reliability, adaptability to repository facility operations, and cost. The final step in the studies will be the use of the selected processes to produce full-scale prototype components and assemblies, including testing of the prototypes to demonstrate both feasibility and compliance with the requirements. The testing and design activities described in this

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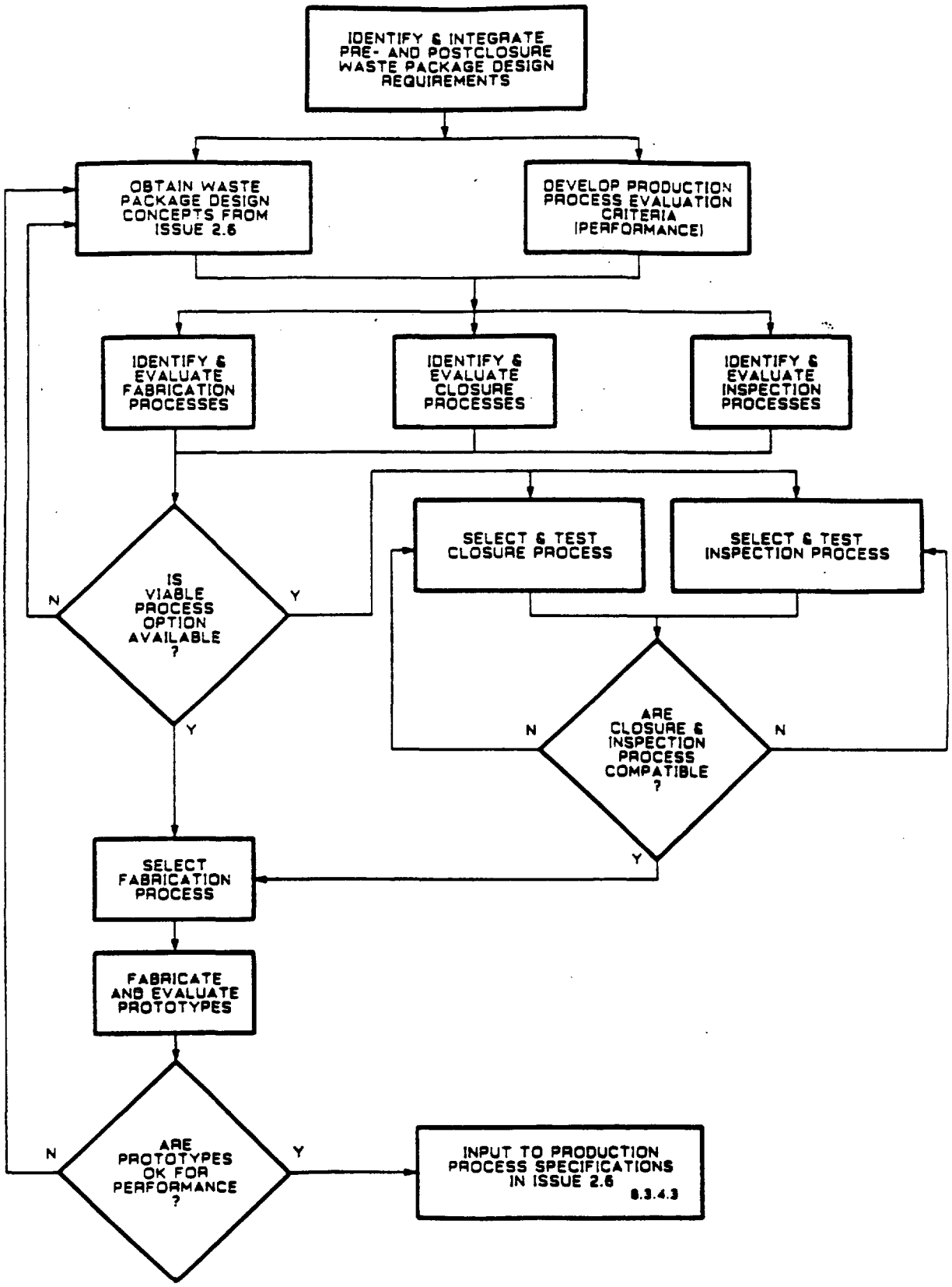

Figure 8.3.4.4-1. Logic diagram for the resolution of Issue 4.3 (waste package production technologies).

section are tentative and are subject to change. Any such change will be reported in semiannual progress reports.

8.3.4.4.1 Information Need 4.3.1: Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

This information need has only an indirect relationship to the characteristics of the site. That relationship is established through the need for the processes selected for production to be responsive to the requirements placed on the waste package design by the anticipated service environment and the performance of the package components. The existing data on this environment is summarized in Section 7.1 and discussed further in Section 7.4.1. The implications of the production processes on the performance of the package components are discussed briefly in Section 7.4.2. A brief discussion of the required processes is found in Section 7.3.1.4.

Parameters

The general parameters to be addressed in this information need are the waste package production technologies. Within each of the technologies, specific parameters associated with the identification, testing, evaluation, selection, and demonstration of the processes are defined. These specific parameters are identified in the activity that addresses each technology.

Logic

The logic to be followed in developing the production technologies is described in the issue resolution section for this issue and follows the conventional approach to production engineering activities as shown in Figure 8.3.4.4-1.

8.3.4.4.1.1 Design Activity 4.3.1.1: Waste package fabrication process development

Objectives

The objective of this activity is to determine, by using the logical sequence described for this issue, the processes to be used in fabricating the nonwaste form components of the waste packages.

Parameters

The parameters of this activity involving fabrication technologies are

1. Requirements and selection criteria.
2. Candidate process identification.

3. Process testing.
4. Process evaluation.
5. Process selection.
6. Prototype fabrication and testing.

Description

Fabrication is defined as those processes required to produce the package components other than the waste forms. These components are assumed to be produced at commercial facilities and, after inspection to ensure compliance with procurement specifications, delivered to the repository for assembly. The processes to be used may include production of container and other component materials; forming and joining processes such as rolling, welding, casting, forging, extruding, or combinations of these; heat treating; nondestructive testing and inspection; and packaging, shipping, and storage.

Each of the applicable process steps will be evaluated, and a process will be selected and demonstrated as necessary to show compliance with the requirements established for each package component.

8.3.4.4.1.2 Design Activity 4.3.1.2: Waste package closure process development

Objectives

The objective of this activity is to determine, by using the logical sequence described for this issue, the process to be used in the final closure of the waste package containers.

Parameters

The parameters of this activity involving closure technologies are

1. Requirements and selection criteria.
2. Candidate process identification.
3. Process testing.
4. Process evaluation.
5. Process selection.
6. Full-scale demonstration.

Description

The closure process is required to provide a high-integrity seal of the containers. The closure must be performed under hot cell conditions by equipment operated by remote control. Additional requirements will be imposed by the need for a highly reliable process that can be qualified on the basis of monitored process variables and remote equipment maintenance. The process may be a conventional joining process or may require developments of the state of the art.

The candidate closure processes will be evaluated, and a process will be selected and demonstrated as necessary to show compliance with the requirements established for final package closure.

8.3.4.4.1.3 Design Activity 4.3.1.3: Waste package closure inspection process development

Objectives

The objective of this activity is to determine, by using the logical sequence described for this issue, the process to be used in the inspection of the final closure of the waste package containers.

Parameters

The parameters of this activity involving inspection technology are

1. Requirements and selection criteria.
2. Candidate process identification.
3. Process testing.
4. Process evaluation.
5. Process selection.
6. Prototype subsystem design and specification.

Description

Following the final closure of the waste package containers, the integrity of the closure will require a verification by a nondestructive inspection. This inspection process, which will also be made by equipment operated by remote control, must operate with high reliability to ensure adequate defect detection and yet avoid false rejections. The high ionizing radiation field present will limit the alternatives available for this process.

The candidate closure inspection processes will be evaluated, and a process will be selected and demonstrated as necessary to show compliance with the requirements established for closure inspection. An inspection subsystem will be designed and specified for this process.

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8.3.5 PERFORMANCE ASSESSMENT PROGRAM

This section describes the Yucca Mountain Project (formerly the Nevada Nuclear Waste Storage Investigations (NNWSI) Project) performance assessment program for both the preclosure and postclosure time periods. Section 8.3.5.1 provides an overview of the strategy for preclosure performance assessment. The site data needs and the design activities necessary to demonstrate compliance with the performance objective for maintaining an option of waste retrieval are presented in Section 8.3.5.2 (Issue 2.4). Site and design information necessary to perform radiological safety assessments are described in Sections 8.3.5.3 through 8.3.5.5. Section 8.3.5.3 (Issue 2.1) addresses public exposure under normal conditions, and Section 8.3.5.4 (Issue 2.2) addresses worker exposure under normal conditions. Section 8.3.5.5 (Issue 2.3) describes the approach to assessments of radiological safety under accidental conditions.

Sections 8.3.5.6 and 8.3.5.7 (Issues 2.5 and 4.1) differ from the previous sections, in that they address the site data requirements for supporting higher level findings on the DOE general siting guidelines (10 CFR Part 960). These findings are required at the time of selection of the first repository site.

Section 8.3.5.8 describes the overall strategy for postclosure performance assessment. The approach to demonstrating compliance and the site data needed for the waste package containment performance objective are described in Section 8.3.5.9 (Issue 1.4). Site data needs and planned activities for assessing compliance with the release rate limits for the engineered barrier system are presented in Section 8.3.5.10 (Issue 1.5). Section 8.3.5.11 describes the general plans for assessing seal system performance. Site data needs required to establish that the pre-waste-emplacement ground-water travel time is at least 1,000 years are described in Section 8.3.5.12 (Issue 1.6). Activities to generate the necessary calculational models and to identify the likely flow paths are also described in Section 8.3.5.12. Section 8.3.5.13 (Issue 1.1) describes the plans for complying with the requirements for assessing total repository system performance. The site data needed, as well as the activities planned to develop appropriate calculational models and identify potentially significant release scenarios are described. Sections 8.3.5.14 and 8.3.5.15 describe the site data needs and the plans for activities to demonstrate compliance with the requirements for limiting radiation doses to man (Issue 1.2) and for protection of special sources of ground water (Issue 1.3).

The approach to be taken in addressing the NRC requirements for performance confirmation is described in Section 8.3.5.16 (Issue 1.7). Section 8.3.5.17 (Issue 1.8) describes the strategy for addressing the favorable and potentially adverse conditions in the NRC siting criteria. The close interaction between assessment of total system performance in Section 8.3.5.13 (Issue 1.1) and this section is highlighted in the discussion. Section 8.3.5.18 (Issue 1.9), like Sections 8.3.5.6 and 8.3.5.7, describes the approach developed to comply with the requirements for higher level findings on the DOE general siting guidelines. Section 8.3.5.18 specifically addresses higher level findings for the postclosure technical guidelines. Finally, Sections 8.3.5.19 and 8.3.5.20 describe the analytical techniques already developed and those still requiring development.

8.3.5.1 Strategy for Preclosure Performance Assessment

During the repository preclosure period, performance assessment is synonymous with safety assessment. Safety assessment involves assessment of the risks and hazards to which the repository workers and the general public may be exposed as a result of the activities that will be carried out at the repository before its permanent closure.

Preclosure safety assessment is a major component of the overall licensing strategy, providing a mechanism for resolving Key Issue 2. The uses of preclosure safety assessment include (1) providing guidance to design by determining the need for preventive and mitigative measures for reducing the effects of potential accidents, as well as providing guidance to improve or modify repository operating procedures; (2) demonstrating compliance with regulatory requirements (10 CFR Part 60, 40 CFR Part 191, and 10 CFR Part 20) and with DOE orders; (3) identifying the structures, systems, and components important to safety for supporting the identification of the Q-List items; (4) supporting demonstration of compliance with DOE siting guidelines and NRC siting criteria by providing preclosure safety assessment result; and (5) providing information to the general public on preclosure repository safety.

The general categories of risks that will be considered within the scope of preclosure safety assessment include (1) radiation effects on repository personnel and the public from accidents and routine operations, (2) nonradiological effects on repository personnel and the public from accidents and routine operations, and (3) economic costs of accidents. For the resolution of Key Issue 2, however, only radiological safety will be considered. Nonradiological safety assessment and economic costs accidents will be considered for the resolution of Key Issue 4. The economic analyses will address costs of actual risks but not perceived risks.

The preclosure safety assessment will address risks during the following preclosure activities:

1. Construction of surface facilities and subsurface excavations.

2. Operations, including (a) receipt, handling, and preparation of spent fuel and other wastes in surface facilities for emplacement; (b) emplacement of wastes in the underground facility; and (c) monitoring and maintenance of activities before the repository is permanently closed.

3. Retrieval operations, if required.

4. Decommissioning, including the removal of the surface facilities and the permanent sealing of underground facilities.

The DOE plans to include many types of safety analyses within the overall structure of the analytical techniques of safety assessment. For the analyses performed for the Yucca Mountain Project, the DOE is developing a preclosure risk assessment methodology (PRAM) that will establish procedures on assessment methods, computer codes, assumptions, and data bases. Section 8.3.5.1.1 overviews the PRAM program, Section 8.3.5.1.2

identifies how information required to conduct a preclosure safety assessment will be obtained, Section 8.3.5.1.3 covers the uses of PRAM for both radiological and nonradiological accidents, and Section 8.3.5.1.4 covers the applicability of PRAM to routine operations.

8.3.5.1.1 Overview of the PRAM program

The PRAM program is illustrated in Figure 8.3.5.1-1. The program addresses four elements of safety assessment, including (1) major considerations for performing a preclosure safety assessment, (2) analytical approaches for assessing safety, (3) safety assessment results, and (4) end uses of preclosure safety assessment. A preclosure risk assessment methodology program (PRAM) will implement this process and further develop the safety assessment process as the repository program progresses.

Passage of the National Waste Policy Amendments Act of 1987 (NWPAA, 1987) has reduced the need for PRAM to provide for uniformity among analyses for various sites. Although the exact evolution of the PRAM program is not completely defined at this time, important uses for the program remain, including (1) providing tradeoff analyses for considering various risk categories, (2) providing a fully integrated program to assist the design, and (3) providing for consistency of analyses related to other elements of the waste disposal system, i.e., the monitored retrievable storage and transportation.

For the repository, the major considerations that will be addressed by the PRAM program include (1) repository design phases, (2) preclosure operation phases, (3) a spectrum of risk categories, (4) end uses of the safety assessment results by the Office of Civilian Radioactive Waste Management, and (5) data needed for assessing repository safety.

The PRAM program will address two design phases of the repository: the advanced conceptual design (ACD) and the license application design (LAD). This will include further development of the Q-List Methodology, which has been established for assessing the conceptual design (CD). The preclosure activities that will be addressed include construction, operation, potential retrieval, and decommissioning. The spectrum of risk categories that may be considered includes the following:

1. RAP--radiological risk from accidents to the public.
2. RAW--radiological risk from accidents to the essential workers.
3. RRP--radiological risk from routine operations to the public.
4. RRW--radiological risk from routine operations to the workers.
5. NAP--nonradiological risk from accidents to the public.
6. NAW--nonradiological risk from accidents to the workers.
7. NRP--nonradiological risk from routine operations to the public.
8. NRW--nonradiological risk from routine operations to the workers.
9. COSTR--economic risk from radiological accidents.
10. COSTN--economic risk from nonradiological accidents.

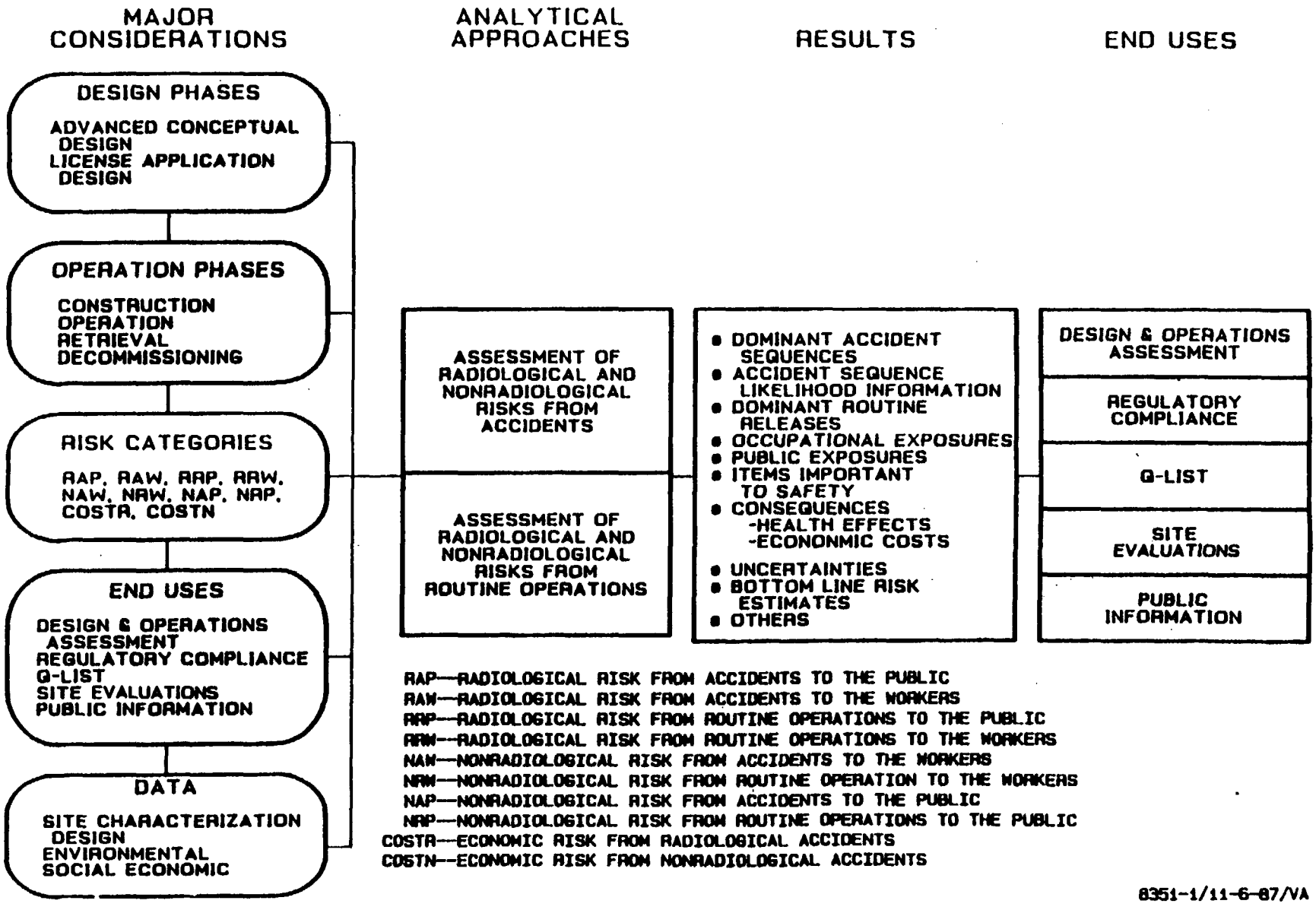

Figure 8.3.5.1-1. Overview of the PRAM program for the high-level waste repository.

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For resolving issues related to regulatory requirements for siting and licensing, the appropriate risk categories to be addressed in the SCP include RAP, RAW, RRP, and RRW. Nevertheless, the PRAM program will address all risk categories necessary to meet the needs of all end users. The applications of the risk categories to the various Office of Civilian Radioactive Waste Management end uses is illustrated in Figure 8.3.5.1-2.

The results used to support these applications will include (1) dominant accident sequences from each phase of repository operation; (2) accident sequence likelihood information; (3) information on dominant routine releases; (4) occupational exposures; (5) items important to safety; (6) consequence results, including health effects and economic costs; (7) estimates of the uncertainties in the safety assessment results; and (8) bottom-line risk estimates. The PRAM program will further define the results for supporting each end use.

The PRAM program will develop detailed analytical approaches for addressing each risk category. In developing the analytical approaches, the major considerations will be addressed collectively to reflect their interdependence.

A general description of the radiological and nonradiological risks that can result from accidents and routine operations during repository construction, operation, retrieval, and decommissioning is briefly provided in the following paragraphs.

Construction--accidents

Because significant quantities of radioactive materials will not be present at locations where construction is taking place (e.g., the excavation and waste emplacement areas of the underground facilities will be separated), no significant radiological effects are expected from construction-related accidents. Accidents during construction of the surface facilities should be typical of any large construction project. These accidents will primarily affect the workers. Some public effects are possible from construction accidents, but these would be principally associated with the transportation of construction materials to the site. Accidents during construction of the mined portion of the repository should be typical of any large underground construction project and will primarily affect workers and have little or no public effects.

Construction--routine activities

There may be radiological risks to both the public and the worker during routine construction of the mined portion of the repository. These mining operations will result in releases into the atmosphere of some natural radioactive materials that are present in the host rock. Some data exists on the amount of radioactive material present in the air in underground mines. These data have been used to make preliminary estimates of the airborne radionuclides and other particulates that would be present in the mine air and, therefore, available for the miners to breathe and for release from the mine to the atmosphere. The repository mining operation will also require that large amounts of the host rock material be stored on the surface during the construction and operational phases of the repository. This practice

END USE

	DESIGN AND OPERATIONS ASSESSMENT	REGULATORY COMPLIANCE	IDENTIFICATION OF Q-LIST ITEMS	SITE EVALUATIONS	PUBLIC INFORMATION
RADIOLOGICAL RISK FROM ACCIDENTS TO THE PUBLIC	X	X	X	X	X
RADIOLOGICAL RISK FROM ACCIDENTS TO THE ESSENTIAL WORKERS	X	X		X	X
RADIOLOGICAL RISK FROM ROUTINE OPERATIONS TO THE PUBLIC	X	X		X	X
RADIOLOGICAL RISK FROM ROUTINE OPERATIONS TO THE WORKERS	X	X		X	X
NONRADIOLOGICAL RISK FROM ACCIDENTS TO THE WORKERS	X	X		X	X
NONRADIOLOGICAL RISK FROM ROUTINE OPERATION TO THE WORKERS	X	X		X	X
NONRADIOLOGICAL RISK FROM ACCIDENTS TO THE PUBLIC	X			X	X
NONRADIOLOGICAL RISK FROM ROUTINE OPERATIONS TO THE PUBLIC	X			X	X
ECONOMIC RISK FROM RADIOLOGICAL ACCIDENTS	X			X	X
ECONOMIC RISK FROM NONRADIOLOGICAL ACCIDENTS	X			X	X

USED FOR RESOLVING PRECLOSURE RADIOLOGICAL SAFETY ASSESSMENT ISSUES

X RISK APPLIES TO END USE

Figure 8.3.5.1-2. The applications of risk categories to end uses.

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could also result in release of radioactive constituents of the host rock to the biosphere. In addition, small quantities of radioactive material will be used during construction for nondestructive testing, etc. These sources are not expected to impact the public and are expected only to have a minor impact on repository workers.

Operation--accidents

The potential accidents during waste repository operations can have both radiological and nonradiological impacts that may affect both workers and the public. Radiological risks to the public from accidents during repository operation are those traditionally addressed in risk assessment studies. Small "industrial" type accidents could expose workers to both radiological and nonradiological hazards. Some accidents could cause significant damage to the facility and exposure of workers, but probably not result in significant offsite releases. Very unlikely accidents might cause significant offsite releases, but preliminary analyses indicate that such events are either very rare or not credible.

Operation--routine

Workers will receive routine radiation exposures from handling radioactive wastes. Small amounts of radioactive material may be released as routine effluents from the facility at levels well within regulatory limits. There may also be small releases of fugitive dust from mined material stored at the surface.

Retrieval--accidents

Risks during retrieval will be characterized using methods similar to those applied to estimate risks from the operation phase of the repository.

Retrieval--routine operations

Risks during retrieval will be characterized using methods similar to those applied to estimate risk during operations, although retrieval is expected to be more complicated than emplacement.

Decommissioning--accidents

Radiological risks from accidents during decommissioning are expected to be small due to the relatively limited quantities of residual radioactive material expected to be present in the surface facilities. Nonradiological accident risks during decommissioning should be similar to nonradiological risks from accidents during construction.

Decommissioning--routine operations

Workers will be exposed routinely to low levels of radiation during the decommissioning operations and could be exposed to dust and other potential nonradiological hazards. These risks are expected to be small. No significant routine offsite effluents are expected.

8.3.5.1.2 Identifying information needs

A great deal of information is required to conduct an assessment of the risk categories identified in Sections 8.3.5.1 and 8.3.5.1.1. This information includes physical property values, design descriptions and objectives, and analytical tools. The resolution strategies for performance Issues 2.1 through 2.3 provide a comprehensive and systematic process for determining the required information. As shown in Sections 8.3.5.3 through 8.3.5.5, most of this information is associated with the design of engineered systems and does not require site characterization, environmental monitoring, or socioeconomic monitoring activities. Instead, the goals and expected ranges for this design-related information will be developed as an integral part of the normal design and safety assessment processes. For the information to be obtained from site characterization or from the collection of environmental and socioeconomic data, the parameter attributes that will be measured and the methods of satisfying the information needs are contained in study plans appropriate for the discipline or subject area of interest.

The general analytical strategies and approaches for assessing preclosure radiological safety are described in Sections 8.3.5.1.3 and 8.3.5.1.4. The analytical approaches fall within two broad categories: (1) the assessment of radiological risks from accidents and (2) the assessment of radiological risks from routine operations. These two general safety assessment analytical approaches may also be applicable to the other risk categories.

8.3.5.1.3 General analytical approach for assessing radiological risks from accidents

The general analytical approach for the assessment of radiological risks from accidents to the public and workers is illustrated in Figure 8.3.5.1-3. As pointed out in Section 8.3.5.1.1, preclosure safety assessment can be performed at any design phase (e.g., conceptual, advanced conceptual, or license application design phases), although its specificity is clearly a function of the level of detail of the available design and operations information. The analytical steps are briefly described below; their results are applicable to risk categories RAP (radiological risks from accidents to the public) and RAW (radiological risks from accidents to the workers). The inclusion of the appropriate analytical steps and the depth of analysis of each step at each design assessment phase will depend on the design and operations information, the available analytical data, and the intended end use.

Step 1: Repository familiarization and identification of initiating events

The objectives of step 1 are (1) to identify and describe the physical configurations and processes of the repository systems and support systems to be modeled, and the dependencies among them, and (2) to identify the accident initiating events to be considered in the risk assessment. The system description information includes surface and underground facility layout, engineering diagrams, and operating procedures. Engineering diagrams include process flow, functional, component-status (during standby, operation and

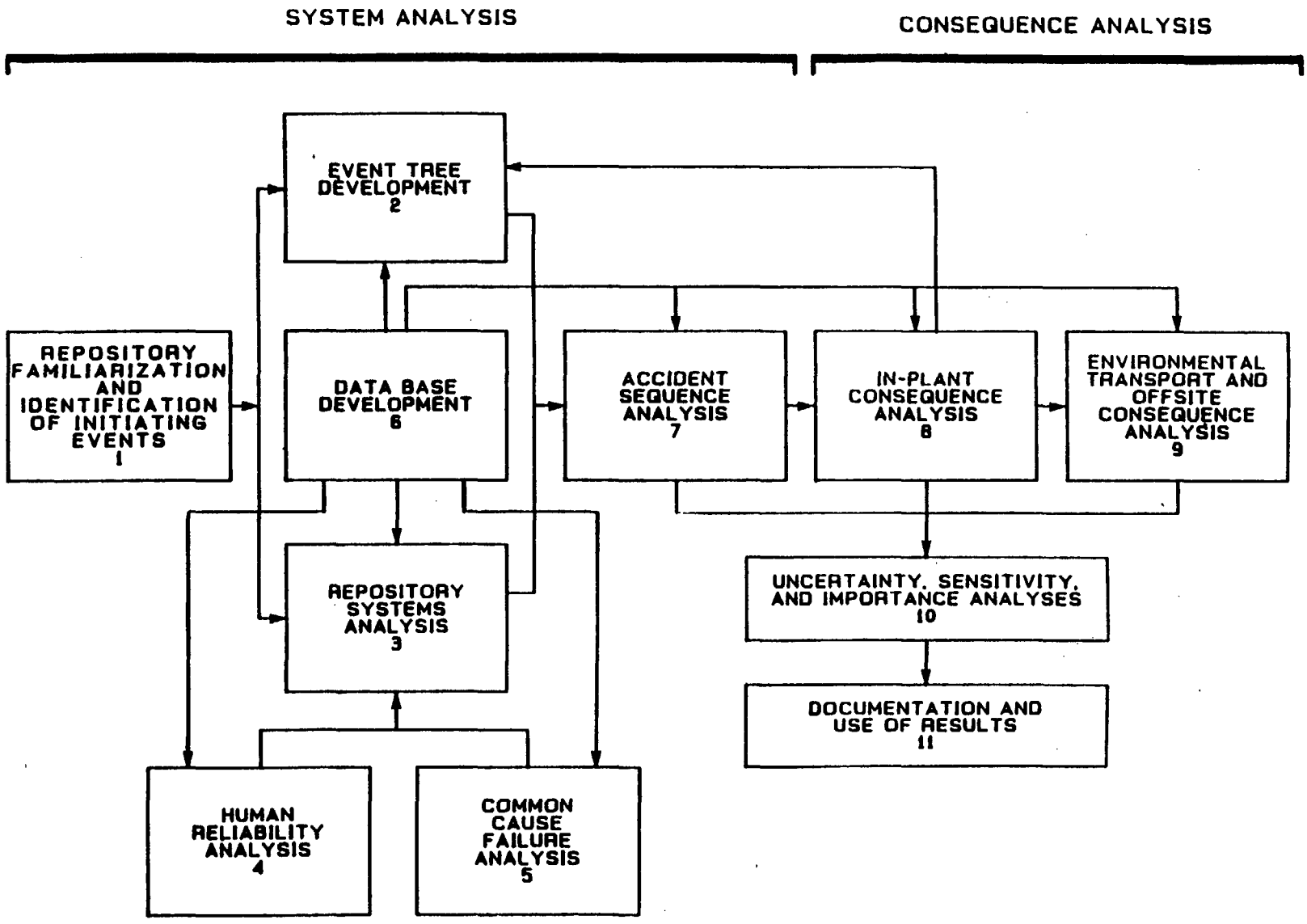

Figure 8.3.5.1-3. Analytical steps for assessing radiological risks from accidents. (The numbers in the diagram are keyed to text discussion.)

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maintenance) and instrumentation. The information gained from this step will be used to model the systems and support systems in step 3 (repository systems analysis).

After the physical configuration and processes of the repository systems and support systems are described, the potential accident initiating events that could challenge the equipment and operations of the repository are identified. The identification of the initiating events will be based on previous studies and a detailed examination of the repository design and activities to be performed during construction, operation, retrieval, and decommissioning. The types of initiating events will include external natural phenomena (e.g., earthquakes), external man-caused phenomena (e.g., airplane crash), equipment failure (e.g., crane drops), and human error (e.g., transporter accident). The PRAM program will identify a list of initiating events that are generally applicable to a repository and estimate their probability of occurrence. The PRAM program will also establish guidelines on the identification of site-specific initiating events and the threshold probabilities for establishing the credible initiating events.

Step 2: Event tree development

The objective of step 2 is to identify the potential accident sequences that could occur following the initiating events. Accident sequences are commonly identified using an event tree modeling approach. Given each credible initiating event identified in Step 1, an event tree model will be constructed to identify a set of accident sequences based on the response of the surface and subsurface systems, repository processes, and reactions of the operator to the initiating event. The potential accidents are screened, usually through an iterative process based on their estimated frequency of occurrence (computed in step 7) and consequences (computed in steps 8 and 9). From the iteration process, a set of dominant accident sequences can be determined. The dominant accident sequences can be used to develop design basis accidents (DBAs) that complement the set of DBAs that may be required by regulatory authorities. DBAs are the postulated accidents and resulting conditions for which the confinement structures, systems, and components must meet their functional goals. For the advanced conceptual and license application design phases, the PRAM program will establish the methods and assumptions for event tree modeling and a common naming scheme for the repository systems and support systems.

Step 3: Repository systems analysis

The objective of step 3 is to develop the reliability models for the repository systems and support systems to be analyzed. As shown in Figure 8.3.5.1-3, the information needed for this step is obtained from step 1 (repository familiarization and identification of initiating events); step 4 (human reliability analysis); step 5 (common cause failure analysis); and step 6 (data base development). These system logic models are necessary for the quantification of the accident sequences to be performed in step 7 (accident sequence analysis). The PRAM program will establish the appropriate reliability modeling techniques for a repository. The appropriate level of analysis will depend on the design phase and input from steps 1, 4, 5, and 6. Potential techniques include fault-tree analysis, failure mode and effects analysis (FMEA), GO methodology, and reliability block diagram.

[Note: GO methodology computes probability that a system exists in each of a few states.] Most likely, a combination of reliability techniques (e.g., fault-tree analysis with FMEA) will be recommended by the PRAM program.

Step 4: Human reliability analysis

The objectives of step 4 are (1) to identify the human errors to be included in the preclosure safety assessment, (2) to provide the probability estimates for these errors, and (3) to assist in the inclusion of human recovery actions to mitigate the consequences of accidents. Human reliability analysis (HRA) has direct input to step 3 and will provide insights on how to improve design and to use certain types of procedures and operator training. The PRAM program will establish the appropriate HRA methods, computer codes, and assumptions for each design phase. HRA data will be developed under step 6 (data base development). The level of HRA effort will depend on the level of design information.

Step 5: Common cause failure analysis

The objective of step 5 is to identify the failures of multiple equipment items occurring from a single cause that is common to all equipment items, for example, a loss of electric power can cause failures of several repository systems. The results of this step will be used in step 3. The level of detail of common cause failure analysis (CCFA) will depend on the level of design information. Areas of CCFA that need to be addressed include common cause accident initiating events (e.g., floods, fire, and loss of electric power), intersystem dependencies (to be treated at the event tree level), and intercomponent dependencies (to be treated at the lower logic modeling level, e.g., fault tree). The PRAM program will establish the appropriate methods, computer codes, and assumptions to be used for a repository. CCFA data will be developed as part of step 6.

Step 6: Data base development

The objective of step 6 is to develop the data bases for the analytical steps of the preclosure safety assessment. As shown in Figure 8.3.5.1-3, data are needed for steps 3, 4, 5, 7, 8, and 9. The PRAM program will develop the data bases that are generally applicable to a repository. As part of the development of data, the PRAM program will establish estimates of (1) initiating event frequencies; (2) component failure, repair, test, and maintenance parameters; (3) human reliability; (4) common cause failures; and (5) data used in consequence analysis. The PRAM program will also establish the methods and assumptions for modifying the generic data for a repository and for treating data uncertainty. Much of the activity in this step will occur as part of steps 1 through 5 and 7 through 9. The data base will be used in the documentation and control of the data used in the analysis.

Step 7: Accident sequence analysis

The objective of step 7 is to quantify the frequency of occurrence of the accident sequences identified from event tree development (step 2) by linking the system logic models (step 3) and using the data developed in step 6 for quantification. Each accident sequence is transformed into a

mathematical expression, represented in Boolean algebra, which is composed of minimal cut sets. Using the Boolean equation, an estimate of the frequency of occurrence of the accident sequence can be computed, uncertainty and sensitivity analyses can be performed (step 10), and an importance analysis (also in step 10) can be performed to identify structures, systems, and components important to safety for supporting the formulation of the Q-List items. As mentioned in step 3, the analysis of the results from steps 3, 4, and 9 will use an iterative process to identify the dominant accident sequences that complement the set of DBAs developed in response to regulatory requirements. The PRAM program will establish the methods, computer codes, and assumptions on (1) Boolean equation reductions, (2) the probability threshold for minimal cutsets, (3) the treatment of human recovery, and (4) the frequency threshold for identifying dominant accident sequences. In addition, PRAM will establish the screening process for identifying and incorporating accident sequences, including low probability/high consequence sequences into more general release categories to facilitate subsequent consequence analyses.

Step 8: In-plant consequence analysis

The objective of step 8 is to determine the accident consequences within the repository site boundary, including the surface and underground facilities. These consequences include exposure of essential workers and economic costs from radiological accidents.

In-plant consequence analysis will be performed for the selected design basis accidents and the full set of dominant accident sequences, or both. A consequence model representing the course of events from accident initiator to personnel exposure will be developed for the surface and underground facilities. Computer codes and analytical models will be used to describe the accident radionuclide release mechanisms, the resulting source term, radionuclide transport from the surface and underground facilities to the surface release points, exposure of essential workers, and economic losses due to accidents. The PRAM program will develop the methods, computer codes, and assumptions to ensure that consistency is maintained throughout the program.

Step 9: Environmental transport and offsite consequence analysis

The objective of step 9 is to estimate accident consequences outside the repository site boundary. These consequences include health effects on the general public and economic costs resulting from the radiological accidents.

Refinement of the release categories will be established based on results from steps 7 and 8 to minimize the offsite consequence analysis effort. The PRAM program will provide guidance for establishing the methods, computer codes, and assumptions for air and water dispersion, pathways to man, dosimetry, health effects, and economic models to ensure program consistency. The data will be developed in step 6.

Step 10: Uncertainty, sensitivity, and importance analyses

Each of the three analyses of step 10 has its own objective. The objective of an uncertainty analysis is to estimate the uncertainty in the results due to uncertainty in the parameters and models. Such uncertainties as those in the accident sequence likelihood estimates (step 7), in the releases to the environment (step 8), and in the risk to the public health and safety (step 9) can be computed. The objective of a sensitivity analysis, which is often a useful adjunct to uncertainty analysis, is to determine how much the output of an analysis changes with respect to variation in the input. The objective of the importance analysis is to identify and rank the important accident sequences, system failures, component failures, and human errors with regard to the accident sequence likelihood estimates. The importance analysis will identify the structures, systems, and components important to safety and will be used to help formulate the Q-List items for the advanced conceptual and license application phases of design. The PRAM program will develop overall methods for combining the uncertainties and sensitivities from the various analytical steps and establish the methods for importance analysis to support the preparation of the Q-List items.

Step 11: Documentation and use of results

The objective of step 11 is to document the safety assessment methodology and results. The PRAM program will develop an annotated outline for the documentation of the safety assessment results by a repository project. A preclosure safety assessment will be prepared to support the advanced conceptual design compliance with siting requirements. The safety assessment results will be based on the advanced conceptual design information. A more detailed preclosure safety assessment will be prepared to support the preparation of the safety analysis report and the environmental impact statement. It will be based on the license application design information.

Safety assessment results from the analytical approaches described in this section and Section 8.3.5.1.4 can be used to improve the preclosure repository safety. An important principle of safety is that it is better to prevent or reduce the frequency of occurrence of an accident than to mitigate its consequences. When appropriate, preventive safety measures will be incorporated into the repository design as it matures. Selection of preventive measures will be based on the results from the accident sequence analysis (step 7), with additional safety insights from uncertainty, sensitivity, and importance analyses (step 10).

Safety assessment results can also be used to improve preclosure repository safety by identifying mitigative measures. Given accidents of various probabilities and consequences, which together constitute the incremental risk or significance of the event, it is possible to identify design and procedural measures that can reduce the risk. Those measures taken to lessen the consequences of potential accidents are termed mitigating features. Recommendations of mitigative measures will be based on results from accident sequence analysis (step 7) and consequence analyses (steps 8 and 9), with additional insights from uncertainty, sensitivity, and importance analyses (step 10).

8.3.5.1.4 General analytical approach for assessing radiological risks from routine operations

Public radiological safety

The general approach to resolving Issue 2.1 (public radiological exposures--normal conditions) is discussed in Section 8.3.5.3 and depicted in Figure 8.3.5.3-2 of that section. The general approach for assessing public radiological safety is shown in the box labeled "public radiological safety assessment package" in Figure 8.3.5.3-2. The following provides a step-by-step discussion of the analytical approach.

Step 1: Design evaluation

The design package and site data are obtained from the reference information base (RIB), and the repository design features related to the radiological safety of the public during normal operations are evaluated. The following discusses the types of information that are investigated during this design evaluation. The high level waste (HLW) throughput (schedule and amount of waste received per year) is an important controlling factor in the design of the repository process and storage facilities (e.g., hot-cell structure and lag storage). Direct radiation that can be emitted from the central process area and the amount of routine radioactive effluents will be directly related to the amount of HLW on hand and being processed. These sources of potential doses to the public also depend on how processes are conducted for such activities as waste receipt, lag storage, waste handling and consolidation, transport of waste containers and possible heat treating of spent fuel assemblies. Public exposure to radiation sources from such activities will also be controlled by administrative procedures (e.g., limits on frequency of tasks and time in storage). Attributes of the repository design that will play a major role in controlling direct radiation and release of radioactive effluents to the unrestricted area include such features as

1. Barrier and shield thicknesses, composition, and distance from the source and the maximally exposed individual.

2. Containment and ventilation system characteristics (e.g., repository and hot-cell layout, differential pressures between areas, openings, air locks, and filters).

3. Containment characteristics of the waste form (i.e., fuel elements, waste package, etc.)

4. Radioactive material release point characteristics (e.g., stack height, diameter, exit velocity, temperature, and distance from unrestricted area).

In addition, as part of the regulatory performance verification requirements, specific systems and operational controls will be needed to verify that the repository design and operation will maintain the annual radiation dose to the public to less than the regulatory limits. Types of systems that must be provided include (1) gaseous, particulate, and liquid effluent monitoring and control equipment, (2) effluent sampling and measuring equipment,

(3) environmental surveillance equipment, and (4) emergency response features. Design of these systems will be incorporated in the normal repository design process. The information needed for this design evaluation will be the product of the design process and will generally not depend directly on the site characterization activities. However, data on background radiological constituents and dust characteristics may affect the design of monitoring equipment. Data on dust characteristics are discussed in Section 8.3.2.4 (nonradiological health and safety) and only mentioned here because worker health concerns require more extensive data on dust.

Step 2: Identification of radiation source characteristics

Potential sources of radiation that can contribute to the dose to the maximally exposed individual in the unrestricted area can be categorized as (1) resulting from repository operations, (2) resulting from operation of offsite facilities, and (3) resulting from miscellaneous operations. Examples of radiation sources resulting from repository operations are receipt of HLW shipping casks, releases during spent fuel consolidation, transport of HLW containers, and naturally occurring radionuclides. An example of radiation resulting from the operation of nearby offsite facilities is the routine release of radioactive material from a nearby nuclear fuel cycle facility, if any.

The specific information needed about the potential source terms includes radionuclides involved, quantity and concentration, decay radiation and energies, and physical and chemical forms. General information needed about the source terms for dose evaluation include

1. Planned repository operational details (e.g., scheduled HLW throughput and inventories, generated low-level waste (LLW) and transport rates, and normal effluent release rates).

2. Repository design features (e.g., radionuclide barriers, normal effluent release locations, layout distances, containment, leakage, and filtration details).

3. Environmental details (e.g., pathways for transport or dispersion of radioactive materials through the soil, air, and water to vegetation, animals, and the public, and location of relevant offsite facilities and their radionuclide release rates).

4. Natural radionuclide sources (e.g., radon emanation rate).

Depending on the characteristics of the source terms, the information needs will be satisfied by either the site characterization program, the repository design process, or the environmental and socioeconomic sampling and monitoring programs. Development of the analytical tools needed to evaluate potential adverse public impacts of the source terms will be coordinated with the preclosure risk assessment methodology (PRAM) program requirements and recommendations.

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Step 3: Radionuclide transport evaluation

The next element in the public radiological safety assessment package is radionuclide transport evaluation following release to the environment of radioactive material from normal repository activities. Radioactive releases to the environment from offsite facilities must also be considered since these releases can contribute to the dose to the public in the repository unrestricted area.

The pathways for the initial concentration of radionuclides released from the repository central process area and offsite facilities to the public in the unrestricted area need to be described. The possible pathways to the public can be directly through the air, water, and soil, or indirectly through vegetation and animals.

The dispersion of airborne radioactive materials can result in (1) radionuclide concentrations in the air that can cause an external dose by direct radiation or an internal dose through inhalation or (2) ground deposition of radioactive material. Similarly, dispersion of waterborne radioactive effluents can result in an external dose by direct radiation, an internal dose through drinking of the water, or the deposition of radioactive material. Radionuclides deposited on the ground, plants, or riverbanks can cause a direct radiation dose but, more importantly, they can enter the food chain through uptake and bioaccumulation in plants and animals. Examples would be eating cattle that grazed on local grass or eating grain irrigated with local water.

Analytical tools in the form of dispersion and pathway models will be required to perform the radionuclide transport evaluation. Meteorological data (e.g., wind speed and direction and atmospheric stability) will be needed as input to the dispersion model. This need for site data will be satisfied by the site characterization program. Specific data (e.g., type of crops raised and bioaccumulation of radionuclides in plants and animals) will be required for the food chain pathway models. This data need will be addressed by the socioeconomic and environmental monitoring program.

Step 4: Public radiation exposure calculation

The last step in the analysis is the evaluation of radiological exposure that quantifies the maximum dose to the public postulated from the normal operation of the repository and offsite facilities.

The maximum dose to an individual at the nearest unrestricted location is normally considered the greatest potential adverse impact and is used as the basis for calculations. The furthest distance the unrestricted area can be from the repository is 5 km. The Bureau of Land Management limits occupancy at this location. Occupancy at a site about 15 km away from the repository will be assumed to be 24 hours per day, 365 days per year. Individuals are conservatively assumed to do such things as drink local water, eat local animals and fish, eat foodstuffs grown using local water, and spend recreational time in local water bodies. Analytical models will be used to quantify the public dose. The following types of analytical tools will be needed:

1. Building ventilation, filtration, and leakage models.
2. Radiation shielding models.
3. Atmospheric dispersion models.
4. Radiological impact models for transportation of LLW.
5. Food chain pathways models.
6. Radiological consequence assessment models.

The information needed to calculate doses using these analytical tools will be provided as discussed in the previous steps. This information will be the product of the site characterization program, the socioeconomic and environmental monitoring program, and the normal repository design process. Following is a list of some technical guidance documents that will be evaluated for applicability to the development of the previously mentioned analytical tools. A list of analytical tools that are available for use is contained in Section 8.3.5.19 (completed analytical techniques). Further discussions of analytical tools still needed are contained in Section 8.3.5.20 (techniques requiring development).

1. Regulatory Guide 1.21--Measuring, Evaluating, and Reporting Radio activity in Solid Waste and Release of Radioactivity in Liquid and Gaseous Effluents From Light-Water-Cooled Nuclear Power Plants (Revision 1, June 1974) (AEC, 1974).

2. Regulatory Guide 1.23--Onsite Meteorological Programs (NRC, 1980).

3. Regulatory Guide 1.109--Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purposes of Evaluating Compliance With 10 CFR 50, Appendix I (Revision 1, October 1977) (NRC, 1977a).

4. Regulatory Guide 1.111--Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases From Light-Water-Cooled Reactors (Revision 1, July 1977) (NRC, 1977c).

5. Regulatory Guide 1.112--Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents From Light-Water-Cooled Power Reactors (Revision O-R, May 1977) (NRC, 1976b).

6. Regulatory Guide 1.113--Estimating Aquatic Dispersion of Effluents From Accidental and Routine Reactor Releases for the Purpose of Implementing Appendix I (Revision 1, April 1977) (NRC, 1977b).

7. Safety Series No. 58--Concepts and Examples of Safety Analyses for Radioactive Waste Repositories in Continental Geological Formations (IAEA, 1983a).

8. Safety Series No. 60--Criteria for Underground Disposal of Solid Radioactive Waste (IAEA, 1983b).

9. Safety Series No. 68--Performance Assessment for Underground Radioactive Waste Disposal Systems (IAEA, 1985).

10. DOE/EP-0023--A Guide for Environmental Radiological Surveillance at U.S. Department of Energy Installations (July 1981) (Corley and Denham, 1981).

11. DOE/EP-0096--A Guide for Effluent Radiological Measurements at DOE Installations (April 1982). (Corley and Corbit, 1983).

Worker radiological safety

The general approach to resolving Issue 2.2 (worker radiological safety--normal conditions) is discussed in Section 8.3.5.4 and depicted in Figure 8.3.5.4-2. The general approach for assessing worker radiological safety is shown in the box labeled "worker radiological safety assessment package" and is discussed here.

The following discussion provides a step-by-step explanation of the general approach to predict worker radiation doses during the normal operation of the repository.

Step 1: Design evaluation

The design package and site data are obtained from the reference information base (RIB), and the repository design features related to the radiological safety of the worker during normal operations are evaluated. The following text discusses the types of information that are investigated during this design evaluation. The high-level waste (HLW) throughout (schedule and amount of waste received per year) is an important controlling factor in the design of the repository process and storage facilities (e.g., hot-cell structure and lag storage) and, hence, in the radiation doses predicted for workers. Direct radiation that can be emitted from the central process area and the amount of routine radioactive effluents will be directly related to the amount of HLW on hand and being processed. These sources of potential dose to the workers also depend on how processes are conducted for such activities as waste receipt, lag storage, waste handling and consolidation, and transport of waste containers. Worker radiation doses from such activities will be controlled principally by design features and administrative procedures (e.g., limits on frequency of tasks and time in storage), which will be a secondary control on worker exposure. Attributes of the repository design that will play a major role in controlling direct radiation or release of radioactive effluents to the restricted area include such features as

1. Operations plan parameters such as number of workers present and time to complete tasks.

2. Remote-handling equipment used for tasks in high radiation or high frequency tasks.

3. Maintenance requirements of remote-handling and hot-cell equipment.

4. Barrier and shield thicknesses, composition, and distance to workers from the source.

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5. Containment and ventilation system characteristics (e.g., repository and hot-cell layout, differential pressures between areas, openings, air locks, and filters).

6. Radioactive material release point characteristics (e.g., stack height, diameter, exit velocity, temperature, and location within the restricted area).

In addition, as part of the regulatory performance verification requirements, specific systems and operational controls will be needed to verify that the repository design and operation does maintain annual radiation doses to the workers to less than the regulatory limits. Examples of the systems that must be provided include gaseous and liquid effluent sampling and measuring equipment, area radiation and airborne monitoring equipment, and personnel and area dosimetry equipment. Design of these systems will be incorporated in the normal repository design process. The information needed for this design evaluation will be the product of the design process and will not depend directly on the site characterization activities.

Step 2: Identification of radiation source characteristics

Potential sources of radiation that can contribute to worker exposure in the restricted area can be categorized as (1) resulting from repository operations or (2) miscellaneous operations. Examples of radiation sources resulting from repository operations are receipt of HLW shipping casks, releases during spent fuel consolidation, transport of HLW containers, direct radiation from storage of disposal containers, direct radiation from emplacement activities, and naturally occurring radionuclides. Other miscellaneous operations that are potential radiation sources include treatment and transportation of site-generated low-level waste (LLW) and gamma and neutron radiation-producing equipment used in construction and nondestructive testing.

The specific information needed about the potential source terms includes the radionuclides involved and the quantity and concentration, decay radiation and energies, and physical and chemical forms of these radionuclides. General information needed about the source terms for dose evaluation include

1. Planned repository operational details (e.g., scheduled HLW throughput and inventories, LLW generation and transport rates, and normal effluent release rates).

2. Repository design features (e.g., radionuclide barriers, normal effluent release locations, layout distances, containment, leakage, and filtration details).

3. Environmental details (e.g., pathways for transport or dispersion of radioactive materials through the air).

4. Natural radionuclide sources (e.g., concentrations in tuff and ground water at the repository location).

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Depending on the characteristics of the source terms, the information needs will be satisfied by the site characterization program (e.g., naturally occurring radionuclides), the repository design process (e.g., HLW and site-generated waste), or the environmental and socioeconomic monitoring programs (e.g., offsite installations and background radiation). Development of the analytical tools needed to evaluate potential adverse impacts of the source terms on worker safety will be coordinated with the PRAM program requirements and recommendations.

Step 3: Radionuclide transport evaluation

The third element in the worker radiological safety assessment package is radionuclide transport evaluation following release from containment systems or repository facilities of radioactive material as a result of normal repository activities. The dispersion of airborne radioactive materials can result in radionuclide concentrations in the air that can cause an external dose by direct radiation or an internal dose through inhalation, or result in ground deposition of radioactive material. The dominant pathway for occupational exposure to airborne radionuclides is expected to be from radionuclides entrained in repository airstreams. Analysis of this pathway will require data on the radionuclide source terms, air volumetric flow rates, air patterns, and location of workers and length of occupancy. Analytical tools will be required for determining direct radiation dose rates in all areas of the repository, as well as for determining ventilation leakage and filtration of airborne radionuclides in the repository airstreams.

Analytical tools in the form of dispersion and pathway models also will be required to perform the radionuclide transport evaluation for restricted areas outside the facility. Meteorological data (e.g., wind speed, wind direction, and atmospheric stability) in the vicinity of the repository buildings, as well as repository design information, will be needed as input to the dispersion model. This information need will be satisfied by Characterization Program 8.3.1.12 (meteorology).

Step 4: Worker radiation exposure calculation

The last step in the analysis is the radiological exposure evaluation that quantifies the dose to the individual worker from routine operations of the repository and offsite installations. The quantification of radiation doses will be performed by the use of accepted analytical models and knowledge of the various design features as input into the models. Some design features needed include

1. The processes and activities necessary for the functioning of the repository.

2. The layout and physical design features (i.e., location of processes and activities, wall thickness and material, personnel occupied areas, source location and storage, transport, and personnel corridors).

3. The repository throughput of radioactive materials.

4. The source terms (i.e., radionuclides involved, low-level waste generated, material quantities, material form (solid, liquid, particulate, or gaseous), container parameters, and industrial sources).

5. Duration and frequency of tasks.

6. The number of workers involved.

Accepted analytical methods for the calculation of personnel doses will be selected or developed as part of the preclosure safety assessment activities consistent with the methodology described in this section. Computer models will be used to evaluate the potential of direct and indirect radiation doses to workers where appropriate. Design-limiting assumptions will be specified for the code input parameters (e.g., radionuclide sources). The following types of analytical tools will be needed:

1. Repository operations models.
2. Building ventilation, filtration, and leakage models.
3. Radiation shielding models.
4. Atmospheric dispersion models.
5. LLW treatment and transportation radiological impact models.
6. Radiological consequences assessment models.

The information needed to calculate doses using these analytical tools will be provided as discussed in the previous steps. This information will be the product of the site characterization program, the socioeconomic and environmental monitoring program, and the normal repository design process. The following list indicates some technical guidance documents that might be applicable to the development of the analytical tools. A list of analytical tools available for use is contained in Section 8.3.5.19 (completed analytical techniques). Further discussions of analytical tools still needed are contained in Section 8.3.5.20 (techniques requiring development).

1. Regulatory Guide 1.169--Concrete Radiation Shields for Nuclear Power Plants (December 1973) (NRC, 1973)

2. Regulatory Guide 8.19--Occupational Radiation Dose Assessment in Light-Water-Reactor Power Plants-Design Stage Man-Rem Estimates (Rev. 1, July 1979) (NRC, 1979a).

3. Safety Series No. 58--Concepts and Examples of Safety Analyses for Radioactive Waste Repositories in Continental Geological Formations, (IAEA, 1983a).

4. Safety Series No. 60--Criteria for Underground Disposal of Solid Radioactive Waste (IAEA, 1983b).

5. Safety Series No. 68--Performance Assessment for Underground Radioactive Waste Disposal Systems (IAEA, 1985).

6. DOE/EV/1830-T5--A Guide to Reducing Radiation Exposures to As Low As Reasonably Achievable (ALARA) (Kathren et al., 1980).

7. DOE Order 6430.1--General Design Criteria Manual, as applicable (December 1983) (DOE, 1983a).