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YMP/CM-0011

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

SITE CHARACTERIZATION PROGRAM BASELINE

REVISION 1

VOLUME 5 OF 5

102.8

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
CI No. CI.11.0000/CI.13.0000
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 5

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

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

UNITED STATES DEPARTMENT OF ENERGY
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT OFFICE

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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 ___)

Implementation 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 Baldwin for DG Horton Date: 3/28/91

[8] Disposition Authority

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

[9] Effective Date: 3/28/91

6 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
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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

MAR 20 1991

Distribution--Memorandum dated

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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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8.3.5.17 Issue resolution strategy for Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?

Regulatory basis for the issue

Postclosure Performance Issue 1.8 addresses the NRC siting criteria. These criteria, set forth in 10 CFR 60.122, consist of two sets of conditions that describe human activities and natural conditions, processes, and events. The first set (10 CFR 60.122(b)) encompasses eight favorable conditions (FCs) that could enhance the ability of a site to meet the performance objectives relating to the isolation of waste if they were present at the site. These favorable conditions are shown in Table 8.3.5.17-1. The second set (10 CFR 60.122(c)) encompasses 24 conditions (potentially adverse conditions, or PACs) that could adversely affect the ability of a site to meet the performance objectives relating to the isolation of waste if they were present at the site. These potentially adverse conditions are shown in Table 8.3.5.17-2.

The siting criteria also include requirements for the demonstrations that must be made regarding these conditions. For each potentially adverse condition determined to be present, the NRC requires that the following be demonstrated:

(i) The potentially adverse human activity or natural condition has been adequately investigated, including the extent to which the condition may be present and still be undetected, taking into account the degree of resolution achieved by the investigations; and

(ii) The effect of the potentially adverse human activity or natural-condition on the site has been adequately evaluated using analyses which are sensitive to the potentially adverse human activity or natural condition and assumptions which are not likely to underestimate its effect; and

(iii) (A) The potentially adverse human activity or natural condition is shown by analysis pursuant to paragraph (a)(2)(ii) of this

(iii) (A) The potentially adverse human activity or natural condition is shown by analysis pursuant to paragraph (a)(2)(ii) of this section not to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste, or

(B) The effect of the potentially adverse human activity or natural condition is compensated by the presence of a combination of the favorable characteristics so that the performance objectives relating to isolation of the waste are met, or

(C) The potentially adverse human activity or natural condition can be remedied.

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Table 8.3.5.17-1. Favorable conditions, Performance Issue 1.8 (Nuclear Regulatory Commission siting criteria)[a]

Favorable condition	Text of the condition
1	The nature and rates of tectonic, hydrogeologic, geochemical, and geomorphic processes (or any of such processes) operating within the geologic setting during the Quaternary Period, when projected, would not affect or would favorably affect the ability of the geologic repository to isolate the waste.
2	For disposal in the saturated zone, hydrogeologic conditions that provide - (i) A host rock with low horizontal and vertical permeability; (ii) Downward or dominantly horizontal hydraulic gradient in the host rock and immediately surrounding hydrogeologic units; and (iii) Low vertical permeability and low hydraulic gradient between the host rock and the surrounding hydrogeologic units.
3	Geochemical conditions that - (i) Promote precipitation or sorption of radionuclides; (ii) Inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides; or (iii) Inhibit the transport of radionuclides by particulates, colloids, and complexes.
4	Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having equal or increased capacity to inhibit radionuclide migration.
5	Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface. (The ground surface shall be deemed to be the elevation of the lowest point on the surface above the disturbed zone.)
6	A low population density within the geologic setting and a controlled area that is remote from population centers.

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Table 8.3.5.17-1. Favorable conditions, Performance Issue 1.8 (Nuclear Regulatory Commission siting criteria)[a] (continued)

Favorable condition	Text of the condition
7	Pre-waste-emplacement travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 yr.
8	For disposal in the unsaturated zone, hydrogeologic conditions that provide- (i) Low moisture flux in the host rock and in the overlying and underlying hydrogeologic units; (ii) A water table sufficiently below the underground facility such that fully saturated voids contiguous with the water table do not encounter the underground facility; (iii) A laterally extensive low-permeability hydrogeologic unit above the host rock that would inhibit the downward movement of water or divert downward moving water to a location beyond the limits of the underground facility; (iv) A host rock that provides for free drainage; or (v) A climatic regime in which the average annual historic precipitation is a small percentage of the average annual potential evapotranspiration.

[a]Quoted from 10 CFR 60.122(b).

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Table 8.3.5.17-2. Potentially adverse conditions, Performance Issue 1.8 (Nuclear Regulatory Commission siting criteria)[a]

Potentially adverse condition	Text of the condition
1	Potential for flooding of the underground facility, whether resulting from the occupancy and modification of floodplains or from the failure of existing or planned man-made surface water impoundments.
2	Potential for forseeable human activity to adversely affect the ground-water flow system, such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity or construction of large scale surface water impoundments.
3	Potential for natural phenomena such as landslides, subsidence, or volcanic activity cf such magnitude that large-scale surface water impoundments could be created that could change the regional ground-water flow system and thereby adversely affect the performance of the geologic repository.
4	Structural deformation, such as uplift, subsidence, folding or faulting, that may adversely affect the regional ground-water flow system.
5	Potential for changes in hydrologic conditions that would affect the migration of radionuclides to the accessible environment, such as changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.
6	Potential for changes in hydrologic conditions resulting from reasonably forseeable climatic changes.

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Table 8.3.5.17-2. Potentially adverse conditions, Performance Issue 1.8 (Nuclear Regulatory Commission siting criteria)[a] (continued)

Potentially adverse condition	Text of the condition
7	Ground-water conditions in the host rock, including chemical composition, high ionic strength, or ranges of Eh-pH, that could increase the solubility or chemical reactivity of the engineered barrier system.
8	Geochemical processes that would reduce sorption of radionuclides, result in degradation of the rock strength, or adversely affect the performance of the engineered barrier system.
9	Ground-water conditions in the host rock that are not reducing.
10	Evidence of dissolutioning such as breccia pipes, dissolution cavities or brine pockets.
11	Structural deformation, such as uplift, subsidence, folding, and faulting, during the Quaternary Period.
12	Earthquakes that have occurred historically that if they were to be repeated could affect the site significantly.
13	Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.
14	More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.
15	Evidence of igneous activity since the start of the Quaternary Period.
16	Evidence of extreme erosion during the Quaternary Period.

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Table 8.3.5.17-2. Potentially adverse conditions, Performance Issue 1.8 (Nuclear Regulatory Commission siting criteria)[a] (continued)

Potentially adverse condition	Text of the condition
17	The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such a form that: (i) Economic extraction is currently feasible or potentially feasible during the forseeable future; or (ii) Such materials have a greater gross value or net value than the average for areas of similar size that are representative of and located within the geologic setting.
18	Evidence of subsurface mining for resources within the site.
19	Evidence of drilling for any purpose within the site.
20	Rock or ground-water conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and ramps/shafts.
21	Geomechanical properties that do not permit design of underground openings that will remain stable through permanent closure.
22	Potential for the water table to rise sufficiently so as to cause saturation of an underground facility located in the unsaturated zone.
23	Potential for existing or future perched water bodies that may saturate portions of the underground facility or provide a faster flow path from an underground facility located in the unsaturated zone to the accessible environment.

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Table 8.3.5.17-2. Potentially adverse conditions, Performance Issue 1.8 (Nuclear Regulatory Commission siting criteria)[a] (continued)

Potentially adverse condition	Text of the condition
24	Potential for the movement of radionuclides in a gaseous state through air-filled pore spaces of an unsaturated geologic medium to the accessible environment.

[a]Quoted from 10 CFR 60.122(c).

The demonstration requirements for the favorable conditions are not as explicit as the requirements for the potentially adverse conditions. The NRC, in 10 CFR 60.122(a)(1), requires that

> A geologic setting shall exhibit an appropriate combination of the... [favorable conditions]...so that, together with the engineered barrier system, the favorable conditions present are sufficient to provide reasonable assurance that the performance objectives relating to isolation of the waste will be met.

This requirement from 10 CFR Part 60 indicates that a site judged suitable for a repository does not necessarily have all favorable conditions. To demonstrate that the combination of conditions is appropriate, the safety analysis report in the license application to the NRC is required to contain "analyses to determine the degree to which each of the favorable and potentially adverse conditions, if present, has been characterized, and the extent to which it contributes to or detracts from isolation" (60.21(c)(1)(ii)(B)). For those potentially adverse conditions that could detract from isolation, the NRC allows a site to rely on the favorable conditions present at the site to compensate for the potentially adverse conditions (60.122(a)(2)(iii)(B)). Thus, the presence of favorable conditions is expected to contribute substantially to the demonstration of reasonable assurance, and their functions in enhancing isolation will be included explicitly, whenever it is feasible to do so, in calculations demonstrating compliance with the performance objectives.

Approach to resolving the issue

Because 10 CFR 60.122 addresses two kinds of conditions, two strategies for resolving this issue have been developed and are described in the following section. The first addresses the demonstrations required for the potentially adverse conditions, and the second addresses the demonstrations required for the favorable conditions. There is a strong tie between these strategies and the strategy for resolving Issue 1.1 (Section 8.3.5.13). Issue 1.1 addresses the NRC's overall system performance objective (10 CFR 60.112).

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Significant processes and events will be investigated through the assessments of compliance with the performance objective. These significant processes and events, including natural features existing at the site and various alternative conceptual models, will be taken into account by developing scenarios that specify a sequence of processes and events potentially resulting in significant impacts on the repository system elements important to waste isolation.

The DOE intends to evaluate in the overall system performance assessment only those natural processes and events and human activities that are sufficiently credible to warrant consideration. Generally, categories of natural processes and events and human activities that can be shown to have a likelihood of less then one chance in 10,000 of occurring in the first 10,000 yr after permanent closure will be excluded from the postclosure performance assessment. These processes, events and activities however, will be investigated, as necessary, during site characterization to validate such a determination of credibility of occurrence.

Scenarios will be developed for undisturbed conditions (those conditions that are caused by likely natural events) and for disturbed conditions (those conditions that are caused by unlikely yet sufficient credible events). The term "scenario class" is used in the resolution strategy of Issue 1.1 to group those scenarios involving similar types of events and processes. The scenarios for undisturbed conditions are grouped into the normal-scenario class (sometimes referred to as the "expected case", anticipated case", and "undisturbed case"). The scenarios for undisturbed conditions are grouped into a number of distruptive-scenario classes. The screening of future events and processes and the development of scenarios and scenario classes is described in detail in the resolution strategy of Issue 1.1 (Section 8.3.5.13).

The strategies for Issue 1.8 (Section 8.3.5.17) ensure that the scenarios and scenario classes overall system performance assessment conducted through the resolution of Issue 1.1 consider the site characteristics with which the NRC is concerned, specifically the favorable and potentially adverse conditions of 10 CFR 60.122. To conduct a realistic performance assessment, Issue 1.1 will rely upon input from Issue 1.5 (engineered barrier system release rates), which must in turn consider the site conditions specified in 10 CFR 60.122. The strategy for resolving Issue 1.1 is discussed in detail in Section 8.3.5.13.

Issue 1.8 has many similarities to Issue 1.1; the two issues take many of the same site conditions into account, and both deal with the effects of site conditions on the isolation of the waste. They do not, however, have to be structured identically. Although each of the two issues will require both quantitative and qualitative arguments for resolution, the DOE expects that the resolution of Issue 1.8 will rely more heavily on expert geotechnical judgment. The resolution of Issue 1.1 will result in a definitive quantitative demonstration of compliance by the construction of the cumulative complementary distribution function. This resolution will rely on qualitative reasoning primarily for the justification of the conceptual models it uses and for showing the reasonable assurance required by 10 CFR 60.101. Because 10 CFR 60.122 makes explicit reference to meeting the waste-isolation performance objectives, the resolution of Issue 1.8 cannot be wholly qualita-

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tive. It can, however, be a forum for full expression of sound qualitative technical judgment on the site's ability to isolate waste. The DOE expects that such judgments can frequently be made without recourse to complex calculations of releases to the accessible environment; for example, modeling of ground-water flow may be used to address increases in water-table elevations and in infiltration. Such simpler calculations and the use of expert geotechnical judgment will play important roles in the resolution of Issue 1.8.

Strategy for addressing the potentially adverse conditions

In 10 CFR 60.122 the NRC states that these conditions are potentially adverse if they are characteristic of the controlled area or may affect isolation within the controlled area. If present, these conditions could significantly affect the ability of a site to meet the performance objectives relating to isolation of waste. Therefore, each PAC must be investigated to determine whether the condition is present at the Yucca Mountain site, what effects the PAC could have on the site's ability to isolate waste, and whether the effects, if any, are significant.

Figure 8.3.5.17-1 shows the major steps that the DOE intends to take in resolving Issue 1.8 for each potentially adverse condition (PAC) listed in 10 CFR 60.122. The figure, which is an expansion of the general issue resolution strategy shown in Section 8.1, outlines the licensing strategy and the subsequent steps that will lead to the final resolution of Issue 1.8 for each PAC. As explained in detail below, certain steps in the licensing strategy--i.e., the steps up to the collection of site characterization data--were carried out in preparing this section and have been used in the development of the site characterization program presented in other parts of Section 8.3.

The following detailed explanation of Figure 8.3.5.17-1 describes the steps and the reasoning behind them. The explanation is intended to guide the reader's understanding of the detailed discussions presented later in Section 8.3.5.17 that explain how the licensing-strategy decisions were made for each PAC. To keep the section as concise as possible, those detailed discussions omit many of the general principles that underlie the strategy. The following explanation supplies those principles. The steps in the figure are numbered to aid the reader in following the explanation.

The first step in the licensing strategy for dealing with each PAC is to adopt a tentative strategy on whether the license application will show that the PAC is present at the Yucca Mountain site (step 1). This decision has been based on the evidence currently available to the DOE. As Section 8.1 explains in detail, the tentative decisions adopted in the development of licensing strategies will be changed if evidence acquired in the future shows them to be technically unsound. For now they are simply a basis for planning site characterization.

<u>Strategy for addressing PACs with preliminary findings not present at the site</u>--The major branch on the right side of Figure 8.3.5.17-1 shows the steps to be followed to test the hypothesis that a PAC is not present at the site. If the available data show conclusively that the condition is not present (step 2), the issue will be resolved simply by reporting those data

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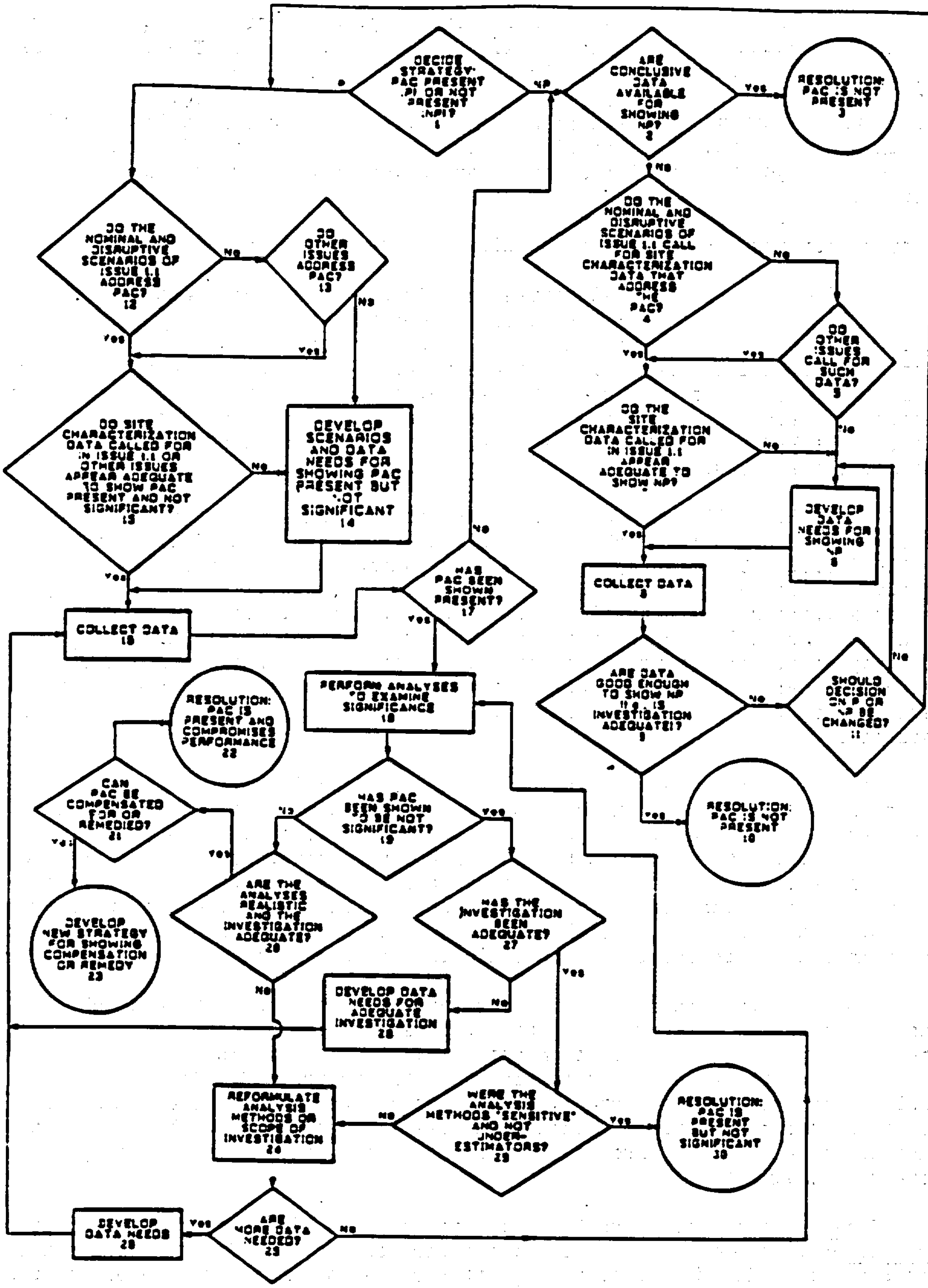

Figure 8.3.5.17-1. Logic diagram for resolving Issue 1.8 for potentially adverse conditions (PACs). The text discussion is keyed to the numbers in this logic diagram.

(step 3). If the available data are not conclusive, the strategy will follow the remainder of the major branch.

Step 4 shown in Figure 8.3.5.17-1 is an examination of the performance allocation in Issue 1.1. The reason for this step and for two other steps near it in the diagram (5, 6) is the following: a major premise of the licensing strategy for Issue 1.8 is that most of the data needed for resolution are already called for by other issues. Issue 1.1 (total-system performance) is the principal issue that calls for data needed in resolving Issue 1.8 because it is the issue that must consider all the credible scenarios for future events and processes at the site. The list of PACs in 10 CFR 60.122 includes many conditions that might serve as initiating events for credible disruptive scenarios, and for that reason Issue 1.1 has used the list in allocating performance for the assessment of such scenarios. Furthermore, the allocation of performance for the scenarios has relied on the technical judgment of both performance-assessment and geoscience personnel; this effort has been intended to make the allocations in Issue 1.1 responsive to the data needs of Issue 1.8, as well as to the need to address the overall system performance objective adequately.

Thus, Step 4 in Figure 8.3.5.17-1 is a decision on whether the performance allocation for the nominal and disruptive scenarios in Issue 1.1 calls for the data needed for testing the hypothesis that the PAC is not present. If such data are not called for in Issue 1.1, other issues are examined to see whether they address the PAC by calling for the needed data (step 5). If no issue that addresses the PAC is found, the strategy calls for a separate development of data needs for testing the hypothesis that the PAC is not present (step 6).

If Issue 1.1 or some other issue addresses the PAC, the licensing strategy for Issue 1.8 proceeds by examining the allocation made in that issue (step 7). If the site characterization information called for there is judged to be adequate for testing the hypothesis that the PAC is not present, the allocation is adopted as the licensing strategy for collecting the data needed for resolving the PAC (step 8). As the detailed descriptions of the licensing strategy for each PAC show, Issue 1.1 usually contains an adequate allocation because the PACs were specifically used in constructing the strategy for its resolution. If the allocation is judged inadequate, the strategy requires a separate development of the data needed for resolution (step 6). (The DOE has carried out the work described in the steps leading to this point, and the results are described in the detailed discussion of the strategy for each PAC.) Data called for by the licensing strategy will be collected through the site characterization program (described in other sections of the SCP); the diagram shows this collection in a single box (step 8).

Beginning with step 9, Figure 8.3.5.17-1 describes additional actions that may need to be taken for any given PAC. The DOE will decide whether the data are adequate for testing the hypothesis that the PAC is not present (step 9). In other words, the DOE will decide whether the investigation that provided the data is likely to be judged adequate in the licensing proceedings. If the investigation is found adequate, the DOE will consider the issue resolved (step 10). If the investigation is not found adequate, the DOE must decide (step 11) whether the information suggests a change in

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the overall strategy for the PAC: should the strategy be to test the hypothesis that the PAC is present? If the answer is yes, the steps to be followed appear in the left branch of Figure 8.3.5.17-1, beginning with step 12. If the answer is no, the DOE will develop new data needs that will provide an adequate investigation of the PAC (step 6), and the collection of additional data (step 8) will begin.

Demonstration strategy for PACs present at the site--For PACs known or suspected to be present at the site, 10 CFR 60.122 offers three options for demonstrating that they do not compromise the ability of the site to isolate the waste. Currently, however, the DOE feels that all the PACs that might be present can be shown to meet the particular option allowing for the PACs to be shown "not to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste." The strategy shown as the major branch on the left side of Figure 8.3.5.17-1 assumes that those PACs will be treated in the license application according to that option. Figure 8.3.5.17-1 uses the word "significant" as a short form to refer to the option. The possible use of the other two choices appears in the strategy much later--to be used if evidence suggests that the site characterization data will not demonstrate insignificance.

The first steps in the left branch of Figure 8.3.5.17-1 are similar to the first steps in the right branch. The strategy calls first for an examination of Issue 1.1 to see whether the PAC is addressed in the nominal and disruptive scenarios there (step 12); for the reasons explained above, Issue 1.1 is a likely issue in which to find considerations of PACs because it uses the PACs in identifying the scenarios that are credible at the site. If the PAC is not addressed there, other issues are examined to see whether they address the PAC (step 13). If no issue addresses it, the DOE will develop a new performance allocation--i.e., a scenario and the set of data needed for showing the presence and significance of the PAC (step 14).

If an issue is found to address the PAC, the performance allocation in the issue is examined to see whether the data it calls for appear adequate for determining the presence and significance of the PAC (step 15). If the data appear adequate, they are adopted for resolving Issue 1.8. If they do not, the DOE constructs a new performance allocation based on the strategy for showing the presence of the PAC and determining its significance (step 14). (The work described in the steps leading to this point has been done, and the results are described in the explanation of the strategy for each PAC). The data called for by the licensing strategy will be collected as part of the site characterization program described in other sections of the SCP (step 16).

The remainder of the left branch of Figure 8.3.5.17-1 describes the issue-resolution steps that the DOE expects to take after site characterization has provided the needed information. The collected data may show that, contrary to the expectation embodied in the licensing strategy, the PAC is not present at the site (step 17). If it is not present, the DOE will change the strategy for dealing with the PAC, and the figure therefore shows a decision that leads to the major right branch of the diagram (step 2).

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The statements of some PACs in 10 CFR 60.122 do not refer simply to the presence of a condition; for such a PAC to be shown present, the condition must be shown to adversely affect the performance of a repository. For example, PAC 5 refers not simply to the presence of a potential for changes in hydrologic conditions but to the presence of a potential for changes "that would affect the migration of radionuclides to the accessible environment." Such PACs cannot be shown to be present in step 17 alone. Their presence can be shown only after subsequent steps in the strategy have examined their effect on performance, which, as explained above, Figure 8.3.5.17-1 refers to as their "significance."

If step 17 has failed to show that the PAC is not present at the site, the DOE will use the site characterization information in analyses intended to determine whether the PAC is significant in the sense of 10 CFR 60.122 (step 18). These analyses will not necessarily trace the contribution of the PAC to the full cumulative complementary distribution function (CCDF) required for resolving Issue 1.1 (Section 8.3.5.13). An elaborate model of the total system will be used in deriving the CCDF, but it will often be possible to use simpler models of the system or its subsystems to see whether the presence of a PAC changes the characteristics (e.g., the performance parameters) of the site enough to affect waste isolation. The analyses of significance will include sensitivity and uncertainty studies in order to provide confidence that the conclusions derived from the system or subsystem analyses are justified by the data they use and the assumptions they make. Step 18 in Figure 8.3.5.17-1 represents the performance of these analyses.

All these analyses--(calculations using total-system models or simpler subsystem models, sensitivity studies, uncertainty studies)--will contribute to the decision on whether the PAC is significant. That decision, shown as step 19 in the figure, will rely on both the results of the analyses and expert professional judgment in the technical fields appropriate to studies of the PAC. Whether the decision is that the PAC is or is not significant, several steps remain in the strategy before the issue can be resolved, and Figure 8.3.5.17-1 shows a separate branch for each of the two outcomes.

If the analyses fail to show that the PAC is not significant, the analyses themselves must be examined to make sure that the methods they use are realistic representations of the effects of the PAC (step 20). The reason such an examination is necessary is that many analyses of repository performance will make conservative assumptions intended to overestimate adverse effects. Such assumptions are usually appropriate for licensing decisions because they contribute to the required reasonable assurance that the performance objectives will be met. Moreover, they generally make the analyses easier to perform and easier to understand than the complex analyses that are less conservative but more realistic. If these assumptions are overly conservative, however, predictions based on them could overestimate the effects of a PAC so severely that the actual effects of the PAC would be obscured. Before concluding that a PAC has significant effects on performance, therefore, the DOE would examine the methods used in the analyses of significance to be sure that they are realistic enough to give reliable predictions. Figure 8.3.5.17-1 shows this step (20) as a decision in the issue-resolution strategy. Step 20 also shows an examination of whether the site characterization investigations have been adequate for the determination of significance. If the analyses are found realistic and the investigations

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adequate, the DOE will abandon the strategy of showing that the PAC is present and not significant.

The next step, shown in Figure 8.3.5.17-1, is to decide whether the strategy should adopt either of the other two options--remediation or compensation by a combination of favorable conditions--for showing that the PAC does not compromise waste isolation (step 21). If neither option appears feasible for the PAC, the DOE expects to interpret the analyses as showing that the PAC is present and does indeed compromise performance (step 22). If one of the options appears feasible, the DOE expects, as shown in the diagram, to develop a new strategy showing that remediation or compensation can be demonstrated and that the PAC will not compromise performance (step 23).

If, on the other hand, either the analyses or the investigation is found unacceptable, the strategy calls for the DOE to reformulate the analysis methods or the scope of the investigations in an attempt to make the decision on significance better reflect the conditions at the site (step 24). As Figure 8.3.5.17-1 shows, such a step would be followed by a decision on whether the new methods or the new scope requires that additional data be collected (step 25). If more data are needed, new data needs are developed (step 26), and the strategy calls for a reiteration through the collection of data. If more data are not needed, the strategy calls for the question of significance to be revisited through new calculations (step 18).

If the analyses of significance show the PAC to be not significant, the strategy calls for answers to two further questions that express requirements of 10 CFR 60.122. The question shown first in Figure 8.3.5.17-1 asks whether the investigations have been adequate (step 27). The DOE expects that this question will be answered primarily through expert review of the data-collection program; the regulations give no guidance on how the adequacy is to be assessed. If the answer to this question is no, new data needs will be developed to ensure that the program is adequate (step 28). If the answer is yes, the strategy proceeds to the second question.

The second question addresses the requirement in 10 CFR 60.122(a)(2)(ii) that the evaluation of the PAC be done with analyses that are sensitive to "the potentially adverse human activity or natural condition" and that use assumptions that "are not likely to underestimate its effect" (step 29). The DOE expects to perform sensitivity analyses as adjuncts to the analyses of significance. This work will demonstrate that the methods are sensitive in the sense required, and it will contribute to a demonstration that the effects have not been underestimated. Further examination of the answer to this question will come from expert review of the analyses themselves.

If the answer to the second question is no, the strategy calls for the cycle of reformulating the analysis methods and investigations (step 24), possibly collecting more data (steps 25, 26, and 16), and again evaluating the significance of the PAC (step 18). If the answer is yes, the PAC will have been shown to be present but not to significantly affect the ability of the site to isolate waste (step 30).

It should be emphasized that the DOE does not expect to perform steps 20, 27, and 29 only in the strict order shown in Figure 8.3.5.17-1. The

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questions of adequacy and realism will not, for example, be left unexamined until the analyses have been finished. These questions will be considered throughout site characterization as the DOE constructs and manages a program that will produce the information needed for the license application. The actual order of these steps is somewhat arbitrary; the important point to be drawn from the figure is that they must all be completed before Issue 1.8 can be resolved.

Strategy for favorable conditions

Figure 8.3.5.17-2 shows the major steps that the DOE intends to take in resolving Issue 1.8 for each favorable condition (FC) listed in 10 CFR 60.122. The figure, which is an expansion of the general issue-resolution strategy shown in Section 8.1, outlines the licensing strategy and the subsequent steps that will lead to the final resolution of Issue 1.8 for each FC. The steps in the licensing strategy--i.e., the steps up to the collection of site characterization data--were carried out in preparing this section, and have been used in the development of the site characterization program presented in other parts of Section 8.3.

The following detailed explanation of the figure describes all the steps and the reasoning behind them. The explanation is intended to guide the reader's understanding of the detailed discussions that, later in Section 8.3.5.17, explain how the licensing-strategy decisions were made for each FC. To keep the section as concise as possible, those detailed discussions omit many of the general principles that underlie the strategy they follow. The following explanation supplies those principles. The steps in the figure are numbered to aid the reader in following the explanation.

The first step in the licensing strategy for dealing with each FC is to adopt a tentative strategy on whether the license application will show that the FC is present at the Yucca Mountain site (step 1). This decision has been based on the evidence currently available to the DOE. As Section 8.1 explains in detail, the tentative decisions adopted for licensing strategies will be changed if evidence acquired in the future shows them to be technically unsound. For now they are simply a basis for planning site characterization.

If the DOE adopts a strategy for showing that the FC is not present at the site, no further action is planned (step 2). As far as the FC is concerned, Issue 1.8 will have been resolved, and the FC will be assumed in the license application to be not present at the site.

If the DOE adopts a strategy for testing the hypothesis that the FC is present at the site, several steps remain to be carried out before the issue can be resolved. The strategy calls first for an examination of Issue 1.1 to see whether the performance allocation there calls for site characterization data that can be used in determining whether the FC is present. As discussed in the explanation of the strategy diagram for potentially adverse conditions (Figure 8.3.5.17-1), the reason for this step and for two other steps near it in the diagram is the following: a major premise of the licensing strategy for Issue 1.8 is that most of the data needed for resolution are already called for by other issues. Issue 1.1 (total system performance) is the principal issue that calls for data needed in resolving Issue 1.8. It is

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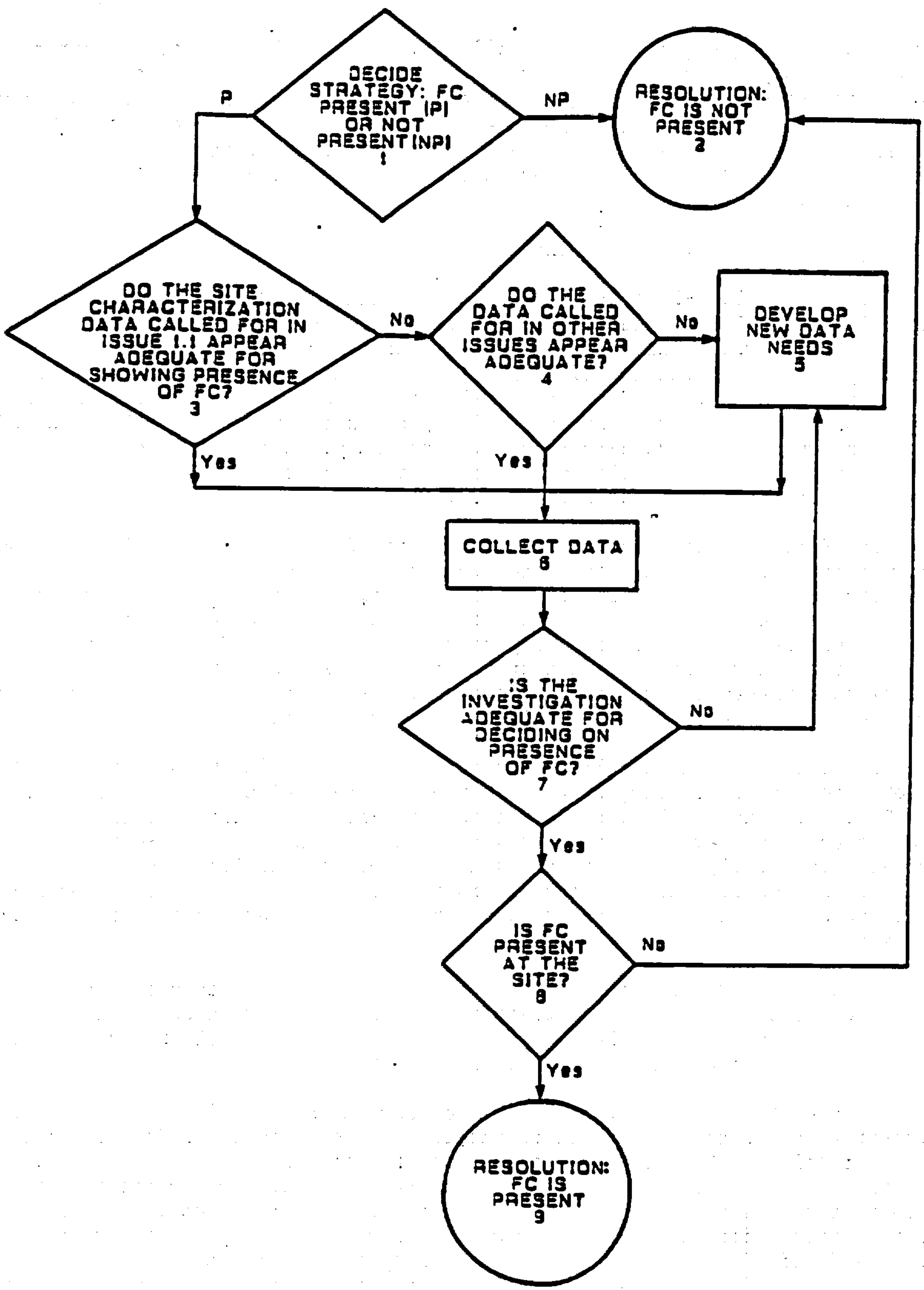

Figure 8.3.5.17-2. Logic diagram for resolving Issue 1.8 for favorable conditions (FCs). The text discussion is keyed to the numbers in this diagram

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particularly important to the strategy for dealing with FCs. The list of FCs in 10 CFR 60.122 includes many conditions that are expected to contribute to the performance of the Yucca Mountain site; these conditions are included in the scenarios that Issue 1.1 has developed for allocating performance to the elements of the site that will contribute to isolating the emplaced waste. This allocation of performance has relied on the technical judgment of both performance assessment and geoscience personnel; this reliance has been important in making sure that the allocations in Issue 1.1 are responsive to the qualitative as well as the quantitative data needs of Issue 1.8.

The next step in Figure 8.3.5.17-2, therefore, is a decision on whether the site characterization data called for in the performance allocation for Issue 1.1 appear adequate for testing the hypothesis that the FC is present (step 3). If these data appear adequate, they are adopted as the licensing strategy for collecting the data that will determine the presence or absence of the FC. If the data in Issue 1.1 do not appear adequate, other issues are examined to see whether they call for the needed data (step 4). If no issue that addresses the FC is found, the strategy calls for a separate development of data needs for testing if the FC is present (step 5). Site characterization can then proceed to collect the needed data (step 6). The steps shown in Figure 8.3.5.17-2 up to the collection of data have been carried out and are reported later in this section. In actual practice, as the detailed descriptions of the individual FCs point out, the data called for by Issue 1.1 have proved sufficient for defining the strategy for dealing with each FC.

After the site characterization program has collected the data called for in the licensing strategy, the DOE examines the investigation that provided the data to decide whether the investigation is adequate for a conclusive decision on the presence or absence of the FC. This decision will be based on expert judgment after a careful review of the site studies (step 7). If the investigation is found to have been inadequate, the DOE will develop a new set of data needs for deciding on the presence or absence of the FC, as the figure shows in a return to an earlier step (5). It should be emphasized that the DOE will not actually wait until after site characterization to examine the adequacy of the investigation. Such examination is a part of planning the investigations, and it will continue through the site characterization period. As shown in Figure 8.3.5.17-2, however, an examination for adequacy must precede the determination of the presence or absence of the FC.

If the investigation is found to have been adequate, the DOE will proceed to decide whether the FC is present or absent at the site (step 8). This decision will be made primarily through expert judgment and peer review, which will, of course, be aided by the quantitative data collected in response to the calls made by the licensing strategy. If the FC is determined in this way not to be present, Issue 1.8 will have been resolved for the FC: the DOE, as shown in the diagram, will conclude that, contrary to the tentative position adopted for the licensing strategy, the FC is not present at the site (step 2). If the determination is that the FC is present, Issue 1.8 will also have been resolved and the license application will present the analyses to show that the FC is present at the site (step 9). These analyses will explicitly take into account the functions of the

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FCs in enhancing isolation; they are also expected to use the presence of FCs in contributing to the demonstration of reasonable assurance.

Discussion of the potentially adverse conditions

This section presents individual discussions of the PACs listed in 10 CFR 60.122. For each PAC the discussion identifies the tentative strategy (present or not present) called for in step 1 of Figure 8.3.5.17-1. The potential effects of the PAC and their expected significance on performance are discussed, and the site characterization data needed for addressing the PAC are specified. The general method for identifying the needed data is similar for each PAC; it is explained here to avoid repeating it in each discussion.

As mentioned in the text accompanying the logic diagram for dealing with PACs (Figure 8.3.5.17-1), a preliminary set of scenarios has been developed for Issue 1.1, which covers the overall performance objective on cumulative radionuclide release to the accessible environment. Because the number of different scenarios could be unmanageably large, they have been grouped into scenario classes; the scenarios within a class can be dealt with similarly and require similar data for this evaluation. These classes help to focus the site characterization program on potentially significant processes and events that may affect the ability of the geologic repository to meet the system performance objective. A scenario class (the nominal case) has been developed for undisturbed conditions due to likely expected natural events, processes, and conditions. Other scenario classes have been developed for disturbed conditions, i.e., those due to unlikely yet credible natural events and human activity. The preliminary set of nominal and disturbed scenario classes are discussed in detail in Section 8.3.5.13.

The preliminary set of nominal and disturbed scenario classes focus on the particular events and processes that are considered credible and potentially significant for the Yucca Mountain site. The PACs specified in the siting criteria of 10 CFR 60.122 were taken into consideration in developing the preliminary set; each PAC can be associated with one or more of the scenario classes. Through the resolution strategy for Issue 1.1 performance measures and goals consistent with meeting the overall system performance objective have been selected to evaluate these scenario classes. Parameters and tentative parameter goals needed to guide site characterization and to evaluate these performance measures have also been identified. (Section 8.1 explains the special meanings used in performance allocation for such terms as "performance measure," "goal," and "parameter.") The values chosen for the parameter goals are consistent with the performance-measure goals in the following sense: if the parameter goals are achieved, the performance-measure goals will probably also be achieved. In other words, the calculation of cumulative release to the accessible environment is likely to show compliance with the overall performance objective if the site characterization data provide confidence that the parameter goals have been met.

Because they were set for consistency with the overall performance objective, the goals for the parameters in a particular scenario class are suitable for addressing the testing needed for the PACs associated with that scenario class. The data needs for each scenario class have been derived from the performance parameters, which address effects on waste isolation; for this reason, they are considered appropriate for guiding the testing needed to determine the significance of the PACs associated with those scenario classes. The application of this method for deriving data needs is discussed for each PAC individually in this section.

This discussion reports a comparison of each PAC with the relevant scenario classes (i.e., the comparison called for in steps 4, 7, 12, and 15 of Figure 8.3.5.17-1). This comparison uses available information and the tentative strategy in examining the nominal and disruptive scenarios to identify the relevant data needs.

Information to determine the performance parameters for these scenario classes will be obtained in the characterization programs. The complete specification of the data needs for each potentially adverse condition, therefore, includes (in addition to the relevant scenario classes, performance parameters, and goals) the SCP sections that describe the characterization programs to obtain the information needed to determine the parameters. The following discussions of the PACs contain tables that summarize this specification.

The postclosure characterization programs are discussed in detail in Section 8.3.1 according to the following topical breakdown: geohydrology, geochemistry, rock characteristics, climate, erosion, dissolution, tectonics, and human interference. These topical areas may be addressed in more than one potentially adverse condition depending on the actual wording found in 10 CFR 60.122. Some readers may be interested in determining which potentially adverse conditions are of interest to particular technical disciplines. To assist such readers, the following is a general guide stating the topical breakdown in terms of the potentially adverse conditions they treat. Geohydrology data are requested by PACs 1 to 8, 11 to 15, and 22 to 24; geochemistry data by PACs 7 to 9 and 24; rock-characteristics data by PACs 4, 5, 7, 8, 11 to 14, 20, and 21; climate data by PACs 5, 6, 22, and 23; erosion data by PAC 16; dissolution data by PAC 10; tectonics data by PACs 3 to 5, 7, 8, 11 to 15, 22, and 23; and human interference data by PACs 2, 5, 9, 17 to 19, and 22.

<u>Potentially adverse condition 1</u>: Potential for flooding of the underground facility, whether resulting from the occupancy and modification of floodplains or from the failure of existing or planned man-made surface water impoundments.

This PAC addresses a condition occurring before closure that could affect postclosure performance (statements of consideration, (NRC, 1981c) 10 CFR Part 60). Flooding of the underground facility during the preclosure period could result in conditions, such as standing pools of water, that could adversely affect the performance of the waste package.

Because of the rugged terrain and meteorological conditions at the Yucca Mountain site, local intense flooding occurs periodically in the normally dry washes draining down from the Yucca Mountain ridge (Section 3.2.1). Preliminary investigations of the 100- and 500-yr floods have determined that the 100-yr flood would not exceed the banks of incised channels of Fortymile Wash or its major tributaries (Yucca, Drill Hole, and Busted Butte washes). The 500-yr flood, however, could exceed the banks of Busted Butte and Drill Hole washes. The available evidence, therefore, suggests that this PAC may be present. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

This PAC is expected to be fully addressed by design of the systems that will take into account the probable maximum flood (PMF) (Section 6.1.2.6). This method has been successfully used by the U.S. Army Corps of Engineers for dam design and by the nuclear power industry for protection of safety-related facilities. The underground entries at the repository site will be protected against the PMF by diverting the upland runoff. Also, finish grade elevations will be set above the PMF levels.

Site characterization data will be collected in support of the design activities that will provide for this protection from preclosure flooding. Those data are also, therefore, the data to be used in the resolution of PAC 1. They are developed and presented in Section 8.3.2.5, which also lists the site characterization activities for collecting the data. The needed information consists of the surface-hydrology data that will permit descriptions of the 5-, 25-, 50-, 100-, and 500-yr floods, the PMF, and the corresponding areas of inundation. As explained in Section 8.3.2.5, these data are stream flow rates, quantities, durations for surface water systems at the site, and descriptions of channel morphology.

Because PAC 1 will be addressed by the design of the repository system, its resolution, unlike that of most other PACs, does not depend on data called for by Issue 1.1. The strategy for resolving Issue 1.1 does not call for explicit modeling of preclosure flooding of the underground repository. Neither the nominal-case scenario nor the disturbed-performance scenario classes include such flooding. If it is determined later that such a scenario class should be developed, the information needed to evaluate it could be found in the data needs of the scenario classes that address increased moisture flux through the repository (scenario class C-1) and water-table rise (scenario class C-2). These two scenario classes are discussed in Section 8.3.5.13.

<u>Potentially adverse condition 2</u>: Potential for forseeable human activity to adversely affect the ground-water flow system, such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity or construction of large scale surface water impoundments.

This PAC is concerned with future human activities that could alter the ground-water flow system to adversely affect the waste-isolation capabilities of a site. Isolation could be adversely affected, for example, by decreasing the ground-water travel time to the accessible environment, thereby increasing the rate of transport to the accessible environment of radionuclides

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dissolved in the ground water. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Assessing the potential for human activity at a site presents special problems because of the dependence upon future, unpredictable activities of humans (Section 8.3.1.9). Quantitative estimates of the absolute probability of human activities (e.g., ground-water withdrawal) in the distant future may not be feasible. The treatment of such events and processes will, however, follow an approach similar to that for the natural processes and events: the effects of potentially adverse human activities will be evaluated, appropriate scenario classes will be developed, and relative probabilities and consequence for these scenarios will be estimated. The data needed for resolving PAC 2 and other conditions produced by human activity can be found among the scenario classes of Section 8.3.5.13.

In the evaluation of future human activities that could affect post-closure performance (in the overall system performance assessment), the following were identified as credible potential future activities at the Yucca Mountain site: exploratory drilling, extensive irrigation near the controlled area, the construction of large-scale surface water impoundments near the controlled area, extensive surface or subsurface mining near the controlled area, and extensive ground-water withdrawal near the controlled area.

Preliminary disturbed-performance scenario classes have been developed for these activities. In the development of the scenario classes, it was concluded that significant adverse effects in the ground-water flow system due to exploratory drilling are not sufficiently credible to warrant consideration. For the other credible human activities, it was concluded that potentially significant effects on the ground-water flow system could include an increase in percolation flux through the unsaturated zone, an increase in the ground-water-table altitude, and an increase in head gradients.

No scenario classes have been developed explicitly for subsurface injection of fluids and underground pumped storage. Subsurface injection of fluids and underground pumped storage are not considered to be credible events at the Yucca Mountain site. The presence of ground-water resources at the site preclude subsurface injection of fluids, and the geohydrologic conditions at Yucca Mountain are not conducive to underground pumped storage. The DOE has judged that additional site data are not needed to demonstrate that these human activities are not likely to occur and are, therefore, not likely to adversely affect repository performance.

No scenario classes have been developed to explicitly address military activities. The strain generated from large-scale weapons testing may have an effect on the hydrologic conditions at the site; however, these effects are expected to be less significant than those from natural seismic activity (Section 1.4). The seismic effects of weapons testing are considered to be bounded by the scenario classes for tectonic disturbances (see, for example, the discussions of PACs 3, 4, and 11).

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Table 8.3.5.17-3 lists the scenario classes associated with this PAC that are being investigated in the system performance assessments. The performance parameters associated with these scenario classes are also shown. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-3. Table 8.3.5.17-3 also references the section that discusses the data to be collected and the associated studies and activities.

<u>Potentially adverse condition 3</u>: Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitude that large-scale surface water impoundments could be created that could change the regional ground-water flow system and thereby adversely affect the performance of the geologic repository.

This PAC is concerned with naturally formed surface-water impoundments that could adversely affect postclosure performance at a site. For example, if surface-water impoundments were to form, an increase in percolation through the unsaturated zone, and subsequently an increase in radionuclide transport rate, could result.

There is no substantial evidence of large-scale, rapid episodes of mass wasting, such as rock slides, debris avalanches, and earth flows, at the site (Section 1.1.3); thus, no disruptive scenario class was developed to explicitly address this process. Volcanic and tectonic processes, on the other hand, are believed to have the potential to alter the topography in such a way that surface-water impoundments could form over the next 10,000 yr. The available information, however, indicates that these events are not likely to adversely affect the performance of the geologic repository. Therefore, the strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Additional information is required for testing the presence or absence of this PAC. Information to be obtained in the site characterization program with regard to the effect of natural surface-water impoundments is defined by disturbed-performance scenario classes. The relevant scenario classes defined in Section 8.3.5.13 are identified in Table 8.3.5.17-4, which also gives the associated parameters and goals. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-4. Table 8.3.5.17-4 also references the section that discusses the data to be collected and the associated studies and activities.

<u>Potentially adverse condition 4</u>: Structural deformation, such as uplift, subsidence, folding or faulting, that may adversely affect the regional ground-water flow system.

This PAC is concerned with future structural deformation and tectonic activity that could affect the regional ground-water flow system in such a way that a site's ability to isolate waste would be impaired. The flow system could, for example, be disrupted if tectonic processes could increase

Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2[a] (page 1 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Extensive irrigation is conducted near the C-area[c]	Expected magnitude of flux change due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Area irrigated, net water consumption, and crop and evapotranspiration rates	8.3.1.9.3.2.2(D), 8.3.1.9.3.2
			Infiltration rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8 or 8.3.1.2.2.9
	Expected magnitude of change in head gradients of the saturated zone in C-area due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Area irrigated, net water consumption, and crop and evapotranspiration rates	8.3.1.9.3.2.2(D), 8.3.1.9.3.2
			Infiltration rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8 or 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3

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Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2[a] (page 2 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Extensive irrigation is conducted near the C-area (continued)	Expected magnitude of change in level of water table under C-area due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Area irrigated, net water consumption, and crop and evapotranspiration rates	8.3.1.9.3.2.2(D), 8.3.1.9.3.2
			Infiltration rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8 or 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Extensive ground-water withdrawal occurs near C-area	Expected magnitude of change in water-table level under C-area due to extensive ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Locations, hydrostratigraphic sources, and rates of withdrawal	8.3.1.9.2.2, 8.3.1.16.2.1
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Expected magnitude of changes in gradient of water table under C-area due to ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Locations, hydrostratigraphic sources, and rates of withdrawal	8.3.1.9.2.2, 8.3.1.16.2.1

Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2[a] (page 3 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Extensive ground-water withdrawal occurs near C-area (continued)			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Extensive surface or subsurface mining occurs near C-area	Expected magnitude of change in water-table level under C-area due to mine water use or mine dewatering near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 (No change expected)	
			Rates and locations of dewatering	8.3.1.9.3.2.2
			Saturated-zone flow model	8.3.1.2.3.3.3
	Expected magnitude of change in gradient of water table under C-area due to extensive surface or subsurface mining near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 (No change expected)	8.3.1.9.3.2.2
			Rates and locations of dewatering	8.3.1.9.3.2.2
			Saturated-zone flow model	8.3.1.2.3.3.3
Large scale surface-water impoundments are constructed near the C-area	Expected magnitude of flux change due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 (No change expected)	
			Area, depth, flow input, rate of impoundment	8.3.1.9.3.2.2(D), 8.3.1.9.3.2

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Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2[a] (page 4 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Large scale surface-water impoundments are constructed near the C-area (continued)			Infiltration/ percolation rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8 or 8.3.1.2.2.9
	Expected magnitude of change in water-table level under C-area due to placement of artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 (No change expected)	8.3.1.9.3.2.2(D), 8.3.1.9.3.2.2
			Area, depth, flow input, rate of impoundment	8.3.1.9.3.2
			Infiltration/ percolation rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8 or 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.3.3.3
	Expected magnitude of changes in head gradients of the saturated zone in C-area due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 (No change expected)	8.3.1.9.3.2.2(D), 8.3.1.9.3.2.2
			Area, depth, flow input, rate of impoundment	8.3.1.9.3.2
			Infiltration/ percolation rates	8.3.1.2.2.1.2

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Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2[a] (page 5 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Large scale surface-water impoundments are constructed near the C-area (continued)			Unsaturated-zone flow model Saturated-zone flow models	8.3.1.2.2.8 or 8.3.1.2.2.9 8.3.1.2.3.3.3

[a]Information on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.

[b]Study or activity directly addresses scenario.

[c]C-area = the controlled area (i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area).

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Table 8.3.5.17-4. Scenario classes and parameters associated with potentially adverse condition 3[a] (page 1 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on fault creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on a fault in the C-area[c] in 10,000 yr	$<10^{-1}$	8.3.1.8 Vertical slip rate and recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.4.3
	Probability of changing dip by >2° in 10,000 yr by faulting	$<10^{-4}$	8.3.1.8 Rates of vertical slip and tilting	8.3.1.17.4.6.2
	Effect of faulting on flux	Faulting will not affect flux because of low slip rates	8.3.1.8 Locations of faults	8.3.1.8.3.1.4, 8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12
			Runoff estimates	8.3.1.5.2.2.1
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9

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Table 8.3.5.17-4. Scenario classes and parameters associated with potentially adverse condition 3[a] (page 2 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	Annual probability of volcanic events within C-area	$<10^{-5}$/yr	8.3.1.8 Probability of volcanic event	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of volcanic event on topography and flow rates	Topographic changes are not great enough to affect flux	8.3.1.8 Topographic effects of eruptions	8.3.1.8.1.2.1, 8.3.1.8.1.2.2

[a]Information on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.

[b]Study or activity directly addresses scenario.

[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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the percolation flux through the repository horizon, increase the altitude of the ground-water table, change the head gradients in the saturated zone, or create surficial discharge points within the boundaries of the accessible environment.

Quaternary rupture on 32 faults within an 1,100-km^2 area surrounding the site has been documented, with evidence of movement on 5 of the faults within the past 270,000 yr (Section 1.3.2). Also, the region is currently undergoing active lateral crustal extension. Local patterns of uplift, tilting, and subsidence near Yucca Mountain are typical of shallow crustal response to regional extension and attendant volcanic activity in the Great Basin (Section 1.3.2.4).

According to the available information, these conditions are not likely to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Additional information is required for evaluating the presence or absence of this PAC. Faulting, folding, uplift, or subsidence that could affect the ground-water flow system in such a way as to significantly increase the probability of cumulative releases to the accessible environment was found unlikely yet credible during the development of the scenario classes for disturbed performance of the geologic repository (see Section 8.3.5.13). The nominal-case scenario includes these tectonic processes only at their expected rates, which would not produce significant effects. Therefore, the information needed to investigate such effects is to be obtained in terms of scenario classes for unlikely natural events. Table 8.3.5.17-5 lists the scenario classes similar to those that will be considered in the overall system performance assessment, and the performance parameters that will be addressed. To address this PAC explicitly, the tectonic scenario classes listed in Table 8.3.5.17-5 will be considered on a broader, regional scale, rather than the controlled-area scale that is addressed in the total system performance assessment. Table 8.3.5.17-5 also lists the site characterization data to be collected to address this PAC and the associated studies or activities in the SCP. These data will be used to evaluate the effects of tectonic processes on the regional flow regime (such as water-table rises and flow-path changes). If these processes appear to produce significant changes in the larger-scale flow system, the effects on local flow-system behavior will be evaluated along with their effects on meeting the site-related parameter goals listed in the table. As explained in the introduction to the PAC discussions, these goals are those associated with the scenario classes developed for the total-system performance assessments (Section 8.3.5.13).

Table 8.3.5.17-5. Scenario classes and parameters associated with potentially adverse condition 4[a] (page 1 of 4)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Episodic offset on faults causes local changes in rock hydrologic properties thereby destroying existing barriers to flow or creating new conduits for drainage	Annual probability of faulting events on Quaternary faults within 0.5 km of C-area[c] boundary	$<10^{-4}$ per year	8.3.1.8 Locations, slip rates and recurrence intervals for Quaternary faults at the site and in the region	8.3.1.8.3.3.2(D), 8.3.1.17.4.3, 8.3.1.17.4.4, 8.3.1.17.4.5, 8.3.1.17.4.6.2, 8.3.1.17.4.7, 8.3.1.17.4.2
	Effects of fault motion on local permeabilities and effective porosities	Change in fracture permeability is less than a factor of 2; fracture porosity decreases	8.3.1.8 Evidence of episodic rock-property changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.4, 8.3.1.4.2.2.5, 8.3.1.2.1.4, 8.3.1.2.3.1, 8.3.1.2.3.3
Offset on fault creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on a fault in the C-area in 10,000 yr	$<10^{-1}$	8.3.1.8 Offsets, slip rates, and recurrence intervals for Quaternary faults at the site and in the region	8.3.1.8.3.1.5(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12

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Table 8.3.5.17-5. Scenario classes and parameters associated with potentially adverse condition 4[a] (page 2 of 4)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on fault creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds (continued)	Probability of changing dip by >2° in 10,000 yr by faulting	$<10^{-4}$ per 10,000 yr	8.3.1.8	
			Rates of vertical slip and tilting at the site and in the region	8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12
	Effect of faulting on flux in the C-area	Faulting will not affect flux because of low slip rate	8.3.1.8	
			Locations of faults in the C-area and in the region	8.3.1.8.3.1.4, 8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12
			Runoff estimates	8.3.1.5.2.2.1
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3

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Table 8.3.5.17-5. Scenario classes and parameters associated with potentially adverse condition 4[a] (page 3 of 4)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in the creation of a perched aquifer, a rise in the water table, or a change in hydraulic gradients	Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8	
			Offsets, slip rates, and recurrence intervals for Quaternary faults at the site and in the region	8.3.1.8.3.1.5(D), 8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in the creation of a perched aquifer, a rise in the water table, or a change in hydraulic gradients (continued)	Effects of fault offsets on water-table levels	Water table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.8	
			Locations of faults in C-area and in region	8.3.1.8.3.1.4, 8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Effects of fault offsets on hydraulic gradients	Show gradients change less than a factor of 4	8.3.1.8	
			Locations of faults in C-area and in region	8.3.1.8.3.1.4, 8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3

Table 8.3.5.17-5. Scenario classes and parameters associated with potentially adverse condition 4[a] (page 4 of 4)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Episodic changes in strain in the rock mass due to faulting cause changes in water-table level	Probability that strain-induced changes increase water-table level to >850 m mean sea level	$<10^{-5}$/yr	8.3.1.8 Magnitudes and rates of strain changes in region, relation of hydraulic properties to strain	8.3.1.8.3.2.3(D), 8.3.1.17.4.8.1, 8.3.1.17.4.8.4, 8.3.1.17.4.12.1, 8.3.1.8.3.3.3, 8.3.1.8.1.4.4
			Saturated-zone flow model	8.3.1.8.3.3.3
Tectonic folding changes dip of tuff beds in C-area, thereby changing flux	Probability of changing dip by >2° in 10,000 yr by folding	$<10^{-4}$ per 10,000 yr	8.3.1.8 Rates of folding in region	8.3.1.8.3.1.7(D), 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Uplift or subsidence changes drainage, thereby changing flux	Probability of exceeding 30-m elevation change in 10,000 yr	$<10^{-4}$ per 10,000 yr	8.3.1.8 Rates of uplift and subsidence in region	8.3.1.8.3.1.7(D), 8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3

[a]Information on scenario classes, performance parameters, and tentative parameters is from Section 8.3.5.13.

[b]Study or activity directly addresses scenario.

[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of trolled area.

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Potentially adverse condition 5: Potential for changes in hydrologic conditions that would affect the migration of radionuclides to the accessible environment, such as changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.

This PAC is concerned with future changes in hydrologic conditions that could adversely affect the isolation capabilities of the site. Changes in hydrologic conditions could, for example, reduce the ground-water travel time, thereby increasing the rate of radionuclide transport to the accessible environment.

As discussed in Sections 8.3.5.12 and 8.3.5.13, hydrologic properties at the Yucca Mountain site could be altered by a number of mechanisms, including tectonic processes and events, climatic changes, and human activities. Hydrologic changes that could affect the migration of radionuclides to the accessible environment include increases in percolation flux through the repository horizon, increases in the altitude of the ground-water table, alteration of rock-mass hydrologic properties, the creation of surficial discharge points within the boundaries of the accessible environment, and changes in head gradients in the saturated zone. According to current information, changes of sufficient magnitude to significantly affect the migration of radionuclides are not likely. Therefore, the strategy for resolution of this PAC is to demonstrate that this condition is not present at the Yucca Mountain site.

The effects of tectonic processes, climate changes, and human activities on the ground-water flow system were evaluated with regard to each of the mechanisms previously specified in the development of the scenario classes. The potential for the changes in hydrologic conditions that are likely to occur are considered in the nominal-case scenario in Section 8.3.5.13. The unlikely, disruptive changes are considered in the disturbed-performance scenario classes, from which the information needs to address this PAC follow. Table 8.3.5.17-6 lists the scenario classes from which a potentially significant effect on the ground-water flow system may result and gives the performance parameters associated with these scenario classes. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-6. Table 8.3.5.17-6 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 6: Potential for changes in hydrologic conditions resulting from reasonably forseeable climatic changes.

This PAC is concerned with future foreseeable climatic conditions that could adversely affect the isolation capabilities of a site by disrupting the hydrologic conditions at the site. Changes in hydrologic conditions could

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 1 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Climatic change causes increase in infiltration over C-area[c]	Expected magnitude of flux change due to climatic changes over next 10,000 yr	Expected flux change will be <0.5 mm/yr	8.3.1.5.2	
			Future-climate model	8.3.1.5.2.2.2(D), 8.3.1.5.1.6
			Infiltration characteristics	8.3.1.2.2.1
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
Climatic change causes an increase in level of water table	Expected magnitude of change in water-table level due to climatic changes over the next 10,000 yr	Expected magnitude of change in water-table level will not bring water table to within 100 m of repository horizon in 10,000 yr	8.3.1.5.2	
			Future-climate model	8.3.1.5.2.2.3(D), 8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5
Climatic change causes appearance of surficial discharge points within C-area	Expected locations of surficial discharge points within C-area over the next 10,000 yr	No surficial discharge points could appear within C-area, given	8.3.1.5.2	
			Future-climate model	8.3.1.5.2.2.3(D), 8.3.1.5.1.6
			Saturated-zone recharge/flow	8.3.1.2.3.3

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 2 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Climatic change causes appearance of surficial discharge points within C-area (continued)		a water-table rise of less than 160 m	models	
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5
Climatic change causes an increase in the gradient of the water table within the C-area	Expected magnitude of change in water-table gradient due to climatic change over the next 10,000 yr	Change will be less than 4 times current value	8.3.1.5.2	
			Future-climate model	8.3.1.5.2.2.3(D), 8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 3 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Extensive irrigation is conducted near the C-area	Expected magnitude of flux change due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Net water consumption rates Cropland evapotranspiration rates	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
	Expected magnitude of change in level of water table under C-area due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Net water consumption rates, cropland evapotranspirtation	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Expected magnitude of change in head gradients of saturated zone in C-area due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Net water consumption rates, cropland evapotranspiration	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 4 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Extensive irrigation is conducted near the C-area (continued)			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Large scale surface-water impoundments are constructed near the C-area	Expected magnitude of flux change due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Impoundment characteristics	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
	Expected magnitude of change in water-table level under C-area due to placement of artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Impoundment characteristics	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Expected magnitude of changes in head gradients of saturated zone in C-area due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Impoundment characteristics	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 5 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Extensive surface or subsurface mining occurs near C-area	Expected magnitude of change in water-table level under C-area due to mine water use or mine dewatering near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Locations of mining and dewatering rates	8.3.1.9.3.2.2
			Saturated-zone flow model	8.3.1.2.3.3.3
	Expected magnitude of changes in gradient of water table under C-area due to extensive surface or subsurface mining near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Locations of mining and dewatering rates	8.3.1.9.3.2.2
			Saturated-zone flow model	8.3.1.2.3.3.3
Extensive ground-water withdrawal occurs near C-area	Expected magnitude of change in water-table level due to extensive ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Locations and rates of expected withdrawals	8.3.1.9.3.2.1(D)
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Expected magnitude of changes in gradient of water-table under C-area due to ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Locations and rates of expected withdrawals	8.3.1.9.3.2.1(D)
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 6 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	Annual probability of volcanic events within C-area	$<10^{-5}$/yr	8.3.1.8 Probability of volcanic event	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of a volcanic event on topography and flow rates	Topographic changes are not great enough to affect flux	8.3.1.8 Topographic effects of eruption	8.3.1.8.1.2.1, 8.3.1.8.1.2.2
Igneous intrusion causes barrier to flow or thermal effects that alter water-table level	Annual probability of igneous intrusion within 0.5 km of C-area boundary	$<10^{-5}$/yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Barrier-to-flow effects of igneous intrusion on water-table levels	Water-table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Thermal effects of igneous intrusions on water-table levels	Water-table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 7 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Igneous intrusion causes barrier to flow or thermal effects that alter water-table level (continued)			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
			Thermal effects near intrusion	8.3.1.2.3.3.3
	Thermal effects of igneous intrusions on hydraulic gradients	Gradient change less than a factor of 4	8.3.1.8	
			Thermal effects near intrusion	8.3.1.2.3.3.3
Igneous intrusions, such as a sill, result in a change in flux	Annual probability of igneous intrusion in in the C-area	$<10^{-5}$/yr	8.3.1.8	
			Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of an igneous intrusion on flux	Igneous intrusion will not affect flux because of depth, location, and extent of intrusion	8.3.1.8	
			Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow model	8.3.1.2.3.3

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 8 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Igneous intrusion causes changes in rock hydrologic properties	Annual probability of igneous intrusions within 0.5 km of C-area boundary	$<10^{-5}$/yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.3.1 (D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of igneous intrusions on local permeabilities and effective porosities	No significant changes in rock hydrologic properties	8.3.1.8 Locations and geometry of possible intrusions	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Effects of intrusions on hydraulic properties	8.3.1.8.3.3.1
Offset on fault creates impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on a fault in the C-area in 10,000 yr	$<10^{-1}$	8.3.1.8 Vertical slip recurrence intervals	8.3.1.8.3.1.5 (D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Probability of changing dip by >2° in 10,000 yr by faulting	$<10^{-4}$	8.3.1.8 Rates of vertical slip and tilting	8.3.1.17.4.6.2
	Effects of faulting on flux	Faulting will not affect flux because of low slip rate	8.3.1.8 Unsaturated-zone flow model	8.3.1.8.3.1.4, 8.3.1.2.2.8, 8.3.1.2.2.9

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 9 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in either the creation of a perched aquifer or a rise in the water table (or a change in hydraulic gradients)	Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8 Slip rates and recurrence intervals	8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Effects of fault offsets on water-table levels and hydraulic gradients	Water table will not rise to within 100 m of repository horizon in 10,000 yr Gradients change less than a factor of 4	8.3.1.8 Fault location and geometry Unsaturated-zone flow model Saturated-zone flow model Quaternary water levels	8.3.1.8.3.2.5, 8.3.1.17.3.1 8.3.1.2.2.6, 8.3.1.2.2.8, 8.3.1.2.2.9 8.3.1.2.1.4.4, 8.3.1.2.3.3.3 8.3.1.5.2.1.5
Episodic offset on faults causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow, or creating new conduits for drainage	Annual probability of faulting events on Quaternary faults within 0.5 km of C-area boundary	$<10^{-4}$/yr	8.3.1.8 Slip rates and recurrence intervals	8.3.1.8.3.3.2(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 10 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Episodic offset on faults causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow, or creating new conduits for drainage (continued)	Effects of fault motion on local permeabilities and effective porosities	Change in fracture permeability is less than a factor of 2; fracture porosity increases	8.3.1.8 Evidence of episodic rock-property changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.4, 8.3.1.4.2.2.5
Folding, uplift, or subsidence lowers repository with respect to water table	Probability that repository will be lowered relative to water table by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates of subsidence	8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3
			Rates of folding	8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Uplift or subsidence changes drainage, thereby changing flux	Probability of exceeding 30-m elevation change in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates of uplift and subsidence	8.3.1.8.3.1.7(D), 8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 11 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Tectonic folding changes dip of tuff beds in C-area, thereby changing flux	Probability of changing dip by >2° in 10,000 yr by folding	$<10^{-4}$	8.3.1.8 Rates of folding	8.3.1.8.3.1.7(D), 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Changes in stress or strain in C-area resulting from episodic faulting, folding, or uplift cause changes in the hydrologic properties of the rock mass	Effects of changes of stress or strain on hydrologic properties of the rock mass	Changes in conductivity and porosity of rock mass are less than a factor of 2	8.3.1.8 In situ stress field Magnitude of stress change Stress-strain relationships Relation of hydraulic properties to strain	8.3.1.8.3.3.3(D), 8.3.1.17.4.8.1 8.3.1.17.4.8.4 8.3.1.4.2.1.3 8.3.1.8.3.3.3
Episodic changes in strain in the rock mass due to faulting cause changes in water-table level	Probability that strain-induced changes increase potentiometric level to greater than 850 m mean sea level	$<10^{-8}$/yr	8.3.1.8 In situ stress field Magnitude of stress change Stress-strain relationships	8.3.1.8.3.3.3(D), 8.3.1.17.4.8.1 8.3.1.17.4.8.4 8.3.1.4.2.1.3

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5[a] (page 12 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Episodic changes in strain in the rock mass due to faulting cause changes in water-table level (continued)			Relation of hydraulic properties to strain	8.3.1.8.3.3.3, 8.3.1.17.4.12.1
			Rate of stress change	8.3.1.8.3.2.3(D)
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3

[a]Information on scenario classes, performance parameters, and tentative goals is from Section 8.3.5.13.

[b]Study or activity directly addresses scenario.

[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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result in a decrease in the ground-water travel time from the repository horizon to the boundary of the accessible environment, thereby possibly increasing radionuclide transport to the accessible environment.

On the basis of current information, climatic changes are likely at the Yucca Mountain site during the next 10,000 yr. Such changes are expected to alter hydrologic conditions to some degree. However, changes sufficient to affect significantly the ability of the geologic repository to meet the performance objectives relating to waste isolation are not likely. That is, changes in the percolation flux, the water-table level in the vicinity of the controlled area, the head gradient in the saturated zone, or the discharge conditions due to reasonably forseeable climatic changes are not likely to significantly affect the performance of the repository.

If the wording of this PAC included an evaluation of the significance of the effect on isolation the strategy for the PAC resolution would be to test the hypothesis that this condition is not present; however, since the PAC, as stated, refers only to the potential for climate-induced hydrologic changes, the strategy for resolution is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The changes in hydrologic conditions that are likely to result from climatic changes are included in the nominal scenario class. In addition, disruptive scenario classes for climatic changes that will be investigated for the resolution of Issue 1.1 are summarized in Table 8.3.5.17-7. The parameters needed to evaluate these disruptive scenarios will be used to evaluate this condition. The goals for these parameters are also shown in this table. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-7. This table also references the section that discusses the data to be collected and the associated studies and activities.

<u>Potentially adverse condition 7</u>: Ground-water conditions in the host rock, including chemical composition, high ionic strength, or ranges of Eh-pH, that could increase the solubility or chemical reactivity of the engineered barrier system.

This PAC is concerned with ground-water conditions that could adversely affect the performance of the engineered barrier system (EBS). The EBS consists of the waste form, the waste container, and an air gap separating the waste container from the borehole wall. Ground-water conditions in a host rock could have an effect on the degradation rate of the waste packages (the waste form and the waste containers) and thus on radionuclide release rates from the EBS. This release rate is directly related to the source term to be used in determining releases to the accessible environment.

The corrosion rate of the metallic barriers and the release rates from the waste form are affected by the pH and oxidation-reduction conditions as well as composition of the fluids contacting the waste package. Site data to be collected to address this PAC include the major ion composition of the

Table 8.3.5.17-7. Scenario classes and parameters associated with potentially adverse condition 6[a] (page 1 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Climatic change causes increase in infiltration over C-area[c]	Expected magnitude of flux change due to climatic changes over next 10,000 yr	Expected flux change will be <0.5 mm/yr	8.3.1.5.2 Future-climate model	8.3.1.5.2.2.2 (D) 8.3.1.5.1.6
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
Climatic change causes an increase in level of water table	Expected magnitude of change in water-table level due to climatic changes over the next 10,000 yr	Water table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.5.2 Future-climate model	8.3.1.5.2.2.3 (D) 8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5

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Table 8.3.5.17-7. Scenario classes and parameters associated with potentially adverse condition 6[a] (page 2 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Climatic change causes appearance of surficial discharge points within C-area	Expected locations of surficial discharge points within C-area over the next 10,000 yr	No surficial discharge points could appear within C-area, given a water-table rise of less than 160 m	8.3.1.5.2	8.3.1.5.2.2.3(D)
			Future-climate model	8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5
Climatic change causes an increase in the gradient of the water-table within the C-area	Expected magnitude of change in water-table gradient due to climatic change over the next 10,000 yr	Change will be less than 4 times current value	8.3.1.5.2	8.3.1.5.2.2.3(D)
			Future-climate model	8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5

Table 8.3.5.17-7. Scenario classes and parameters associated with potentially adverse condition 6[a] (page 3 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Climatic change causes an increase in the gradient of the water-table within the C-area (continued)			Quaternary discharge areas Analog recharge data Distribution, origin, and age of vein deposits	8.3.1.5.2.1.3 8.3.1.5.2.1.4 8.3.1.5.2.1.5

[a]The information on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.

[b]Study or activity directly addresses scenario.

[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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unsaturated-zone ground waters and the thermal stability of the minerals in the host rock. These data will be used to develop a ground-water model that will be used to show that near-field geochemical processes will not adversely affect EBS performance. During characterization, the ground-water chemistry of the unsaturated zone will be analyzed to ensure that the chemistry falls within the range considered in the testing programs supporting EBS design. The geochemical modeling to reliably predict the emplacement environment will consider the interactions of the host rock and ground waters under expected conditions. The EBS design or material selection may have to be modified if adverse effects are indicated. In addition, ground water is not expected to come into contact with, and thus will not affect, the waste container during the 300-yr containment period. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

The nominal (undisturbed-performance) scenario class in Section 8.3.5.13 takes into account the full range of potential geochemical conditions, i.e., variations in ground-water composition. The EBS design is also based on this range. The information generated through this evaluation of the nominal case will therefore provide the confirmation necessary to evaluate this PAC. This information is summarized in Table 8.3.5.17-8.

<u>Potentially adverse condition 8</u>: Geochemical processes that would reduce sorption of radionuclides, result in degradation of the rock strength, or adversely affect the performance of the engineered barrier system.

This PAC is concerned with conditions that could significantly affect the site geochemical characteristics related to the transport of radionuclides and performance of the engineered-barrier system (EBS). These conditions could result from the thermal effects of the emplaced waste or from tectonic or human activities that could significantly change the ground-water composition by introducing ground water or other fluids into the isolation system. In principle, tectonic activity could also alter the mineralogic characteristics along the likely radionuclide transport pathways or create new pathways with different mineralogic characteristics; such effects are expected to be minor.

The expected thermal effects of waste emplacement may affect minerals in the tuffs, producing phase changes that may, in turn, affect sorptive properties. Sorption could also be affected by disturbance to ground-water chemistry. These geochemical processes that affect the sorptive mineralogy are expected to occur at rates too slow to significantly affect the sorptive capacity of the tuffs in the time frame of concern to a repository. In addition, any alteration of glass that did occur in the tuffs is expected to produce sorptive mineral phases, thereby producing an increase in sorptive capacity.

At present, geochemical process are not expected to significantly affect rock strength during the postclosure period. Fracturing of the tuffs due to chemical changes (e.g., dehydration and phase transitions) in the rocks is not expected under the range of thermal conditions predicted. Furthermore,

Table 8.3.5.17-8. Scenario classes and parameters associated with potentially adverse condition 7[a] (page 1 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Nominal case	Distribution coefficients (K_ds) for Sr, Cs, Pu, Am, C, U, Np, Tc, Zr, I, and Cm in unsaturated-zone units below repository and above water table	$K_d \geq 0$ for I and C. $K_d \geq 0.1$ for other elements under expected temperature range	8.3.1.3 Saturated- and unsaturated-zone sorptive properties	8.3.1.3.4(D)
			Solubility of radionuclides	8.3.1.3.5(D)
			Rock-unit mineralogy, petrology, and chemistry	8.3.1.3.2(D)
			Fracture-filling mineralogy	8.3.1.3.2(D)
			Unsaturated- and saturated-zone ground-water chemistry	8.3.1.3.1(D)
	Liquid constrictivity/tortuosity factor		Unsaturated- and saturated-zone dispersive and diffusive properties	8.3.1.3.6(D)

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Table 8.3.5.17-8. Scenario classes and parameters associated with potentially adverse condition 7[a] (page 2 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Nominal case (continued)			Retardation potential changes over 10,000 yr	8.3.1.3.7(D)

[a]Information on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.
[b]Study or activity directly addresses scenario.

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the waste package is being designed to withstand the impacts that could occur from falling rock, and the information needs for the design are addressed in Issue 1.10 (Section 8.3.4.2).

The engineered-barrier system could be affected if the chemical characteristics of the ground water contacting it were to be disturbed significantly. No currently operating geochemical processes are thought, however, to have a potential for significantly affecting the EBS.

The available data do not, therefore, support a statement that the geochemical processes described in the PAC are operating at the site. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

In the development of the preliminary scenario classes, changes of this type were grouped into two categories: changes in the geochemical conditions due to likely events (for example, to the heat generated by the emplaced wastes) and disturbances to the geochemical conditions due to unlikely natural events. The former category is addressed by information needs for the nominal-case scenario class, and the latter is addressed by certain disturbed-performance scenario classes. Table 8.3.5.17-9 lists the relevant scenarios that will be considered in the overall system performance assessment to address the concern of this PAC. Scenarios concerning surface-water impoundments, irrigation, and mining near the controlled area are not considered to have credible significant effects on geochemical processes (sorption) at the site. They are not listed in Table 8.3.5.17-9. The performance parameters, for which values will be obtained during site characterization, are shown in the table; the site characterization data to be collected to address this PAC are listed by parameter category or set. Table 8.3.5.17-9 also references the section that discusses the data and the associated studies and activities.

The principal geochemical data that will be collected to address this PAC include the stability of sorptive minerals in the tuffs under both the ambient and the postemplacement thermal conditions and ground-water compositions. The sorptive behavior of the tuffs will be determined under a range of conditions intended to cover the effects of expected and unexpected events on the variables controlling sorption properties.

Potentially adverse condition 9: Ground-water conditions in the host rock that are not reducing.

This PAC is concerned with oxidizing ground-water conditions in the host rock because such conditions may be less favorable then chemically reducing conditions with regard to sorption and solubility relationships for radionuclides that exhibit sensitivity to oxidation-reduction conditions.

Because the host rock at the Yucca Mountain site is located in the unsaturated zone, the ground water in the host rock is oxidizing. It is expected that this condition can be shown not to significantly affect performance, because any potentially adverse effects it may theoretically cause will be compensated for by the low water flux through the repository and the sorptive capacity of the host rock and surrounding units. The

Table 8.3.5.17-9. Scenario classes and parameters associated with potentially adverse condition 8[a] (page 1 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Nominal case	Distribution coefficients (K_ds) for Sr, Cs, Pu, Am, C, U, Np, Tc, Zr, I, and Cm in unsaturated-zone units below repository but above water table	$K_d \geq 0$ for I and C. $K_d \geq 0.1$ for other elements under expected temperature range	8.3.1.3	
			Saturated- and unsaturated-zone sorptive properties	8.3.1.3.4(D)
			Solubility of radionuclides	8.3.1.3.5(D)
			Rock-unit mineralogy, petrology, and chemistry	8.3.1.3.2(D)
			Fracture-filling mineralogy	8.3.1.3.2(D)
			Unsaturated- and saturated-zone ground-water chemistry	8.3.1.3.1(D)
	Liquid constrictivity/ tortuosity factor		Unsaturated- and saturated-zone dispersive and diffusive properties	8.3.1.3.6(D)
			Retardation potential changes over 10,000 yr	8.3 1.3.7(D)

Table 8.3.5.17-9. Scenario classes and parameters associated with potentially adverse condition 8[a] (page 2 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Igneous intrusions cause changes in rock geochemical properties	Annual probability of igneous intrusions within 0.5 km of C-area[c] boundary	$<10^{-5}$/yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.4.1.1(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of igneous intrusions on local rock geochemical properties	Potential changes in mineralogy will not be extensive	8.3.1.8 Locations and geometry of intrusions Mineralogic changes	8.3.1.3.3, 8.3.1.8.1.2.1, 8.3.1.17.4.12.1 8.3.1.3.2.2.2, 8.3.1.8.5.2.2
Tectonic processes cause changes in ground-water table or movement that results in mineralogic changes in C-area	Degree of mineralogic change in the controlled area resulting from changes in water-table level or flow paths in 10,000 yr	Adverse changes in mineralogy will not occur	8.3.1.8 Probability and magnitude of mineralogic changes Rate of mineral alteration	8.3.1.8.4.1.4(D), 8.3.1.8.3.2.2, 8.3.1.8.3.2.3, 8.3.1.8.3.2.4, 8.3.1.8.3.2.6 8.3.1.3.2.2.1, 8.3.1.3.3.3, 8.3.1.3.3.4
Offset on a fault changes potential radionuclide travel pathway to one with different geochemical properties	Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8 Offsets, slip rates, and recurrence intervals	8.3.1.8.4.1.3(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2

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Table 8.3.5.17-9. Scenario classes and parameters associated with potentially adverse condition 8[a] (page 3 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on a fault changes potential radionuclide travel pathway to one with different geochemical properties (continued)	Effects of fault offset on travel pathway	Significant changes will not occur	8.3.1.8 Unsaturated-zone flow model Saturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9 8.3.1.2.3.3.3
Offset on a fault causes changes in movement of ground water that result in mineralogical changes along the fault zone	Probability of movement within 2 km of surface and location of Quaternary faults in C-area	$<10^{-4}$/yr per fault	8.3.1.8 Locations of faults, slip rates, and recurrence intervals	8.3.1.8.4.1.2(D), 8.3.1.17.4.6.1, 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Degree of mineralogic change in fault zone in 10,000 yr	Adverse changes in mineralogy will not occur	8.3.1.8 Nature and age of mineralogic changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.5, 8.3.1.3.2

[a]Information on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.

[b]Study or activity directly addresses scenario.

[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The information needed to address this condition (natural processes and waste-emplacement effects) will be generated through the evaluation of the nominal-case scenario class defined in Section 8.3.5.13. This information is summarized in Table 8.3.5.17-10.

Potentially adverse condition 10: Evidence of dissolutioning such as breccia pipes, dissolution cavities or brine pockets.

The available information is sufficient to conclude that this potentially adverse condition is not present at the Yucca Mountain site. There are no known dissolution features within the potential host rock or the other rock units at the sites (DOE, 1986b), and the minerals that make up the host rock (alkali feldspar, quartz, cristobalite, and tridymite) are not prone to dissolution in any significant quantities.

Because the available information appears adequate to address this PAC, no further characterization is needed. No scenario classes associated with dissolutioning will be developed as a part of the evaluation of the geologic repository with respect to the overall system performance objective.

Potentially adverse condition 11: Structural deformation, such as uplift, subsidence, folding, and faulting, during the Quaternary Period.

This PAC is concerned with future structural deformation, similar to the observed Quaternary deformation, that could adversely affect a repository system in such a way that the isolation capabilities of a site would be impaired. For example, structural deformation could affect radionuclide transport rates from the repository horizon to the boundaries of the accessible environment, if the hydrologic conditions or geochemical characteristics along the transport path were adversely affected.

Quaternary rupture on 32 faults within an 1,100-km^2 area surrounding the site has been documented (Section 1.3.2). In addition, Quaternary activity has been observed on faults near Yucca Mountain. The region is currently undergoing active lateral crustal extension in response to regional extension within the Great Basin (Section 1.3.2.4). The rate is, however, considered to be low. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The potential effects of structural deformation on the ground-water flow system are addressed by PACs 4 and 5. Tables 8.3.5.17-5 (PAC 4) and 8.3.5.17-6 (PAC 5) summarize the information needed to evaluate these

Table 8.3.5.17-10. Scenario classes and parameters associated with potentially adverse condition 9[a] (page 1 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Nominal case	Distribution coefficients (K_ds) for Sr, Cs, Pu, Am, C, U, Np, Tc, Zr, I, and Cm in unsaturated-zone units below repository and above water table	$K_d \geq 0$ for I and C $K_d \geq 0.1$ for other elements under expected temperature range	8.3.1.3 Saturated- and unsaturated-zone sorptive properties	8.3.1.3.4(D)
			Solubility of radionuclides	8.3.1.3.5(D)
			Rock-unit mineralogy, petrology, and chemistry	8.3.1.3.2(D)
			Fracture-filling mineralogy	8.3.1.3.2(D)
			Unsaturated- and saturated-zone ground-water chemistry	8.3.1.3.1(D)
	Liquid constrictivity/ tortuosity factor		Unsaturated- and saturated-zone dispersive and diffusive properties	8.3.1.3.6(D)

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Table 8.3.5.17-10. Scenario classes and parameters associated with potentially adverse condition 9[a] (page 2 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Nominal case (continued)			Retardation potential changes over 10,000 yr	8.3.1.3.7(D)

[a]Scenario classes, performance parameters, and tentative parameter goals are from Section 8.3.5.13.
[b]Study or activity directly addresses scenario.

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effects. Table 8.3.5.17-11 repeats this information and also includes the information regarding the effects of tectonic activity on waste packages and the geochemical conditions important to waste isolation. The table lists the performance parameters for those scenarios relevant to the effects of tectonic activity, such as faulting, on waste isolation. The characterization programs that will provide the information needed to determine these parameters are also listed in Table 8.3.5.17-11.

Potentially adverse condition 12: Earthquakes that have occurred historically that if they were to be repeated could affect the site significantly.

This PAC is concerned with historic earthquakes that, if they reoccurred in the future, could adversely affect the postclosure performance of a geologic repository.

The Yucca Mountain site is located in the southern Great Basin, a seismically active region (Section 1.4). The pattern of regional seismicity, as defined by historical epicenters within 400 km of Yucca Mountain, consists of the north-south-trending Nevada-California seismic belt, the southern end of the Intermountain seismic belt in southwestern Utah, and the diffuse East-West seismic belt encompassing the Nevada Test Site. Six major historical earthquakes ($M \geq 6.5$) have occurred in the Nevada-California seismic belt, and two have occurred on or near the San Andreas fault. The nearest major earthquake (1872 Owens Valley) was about 150 km west of Yucca Mountain. Yucca Mountain itself is located in a quiescent area characterized by few hypocenters and low seismic-energy density, and the historical record of the region suggests that past seismic activity, if repeated, would not be expected to significantly affect the postclosure performance of a geologic repository. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

The historical record is limited. Therefore, detailed geologic investigations will be combined with ongoing earthquake monitoring activities to assess the effects of future earthquakes at the site. Additional information to strengthen the strategy is included in Table 8.3.5.17-11 (PAC 11). This table lists the scenario classes associated with fault movement and ground motion developed in Section 8.3.5.13. The performance parameters needed to evaluate these phenomena and the characterization programs that will provide the information to develop these parameters are also listed in this table.

Potentially adverse condition 13: Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.

Like PAC 12, PAC 13 is concerned with the potential for seismic activity, including ground motion and faulting, that could adversely affect the performance of the repository in the postclosure period. The information needed for this PAC is the same as that for PAC 12 and will be investigated through PAC 11. The information needs for this PAC are defined in Table 8.3.5.17-11 (PAC 11). The available information is insufficient to determine whether future seismic activity is likely to be more frequent or of higher

Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11[a] (page 1 of 7)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Changes in stress or strain in C-area[c] resulting from episodic faulting, folding, or uplift cause changes in the hydrologic properties of the rock mass	Effects of changes of stress or strain on hydrologic properties of the rock mass	Changes in conductivity and porosity of rock mass are less than a factor of 2	8.3.1.8	
			In situ stress field	8.3.1.17.4.8.1
			Relation of hydraulic properties to strain	8.3.1.8.3.3.3(D)
Episodic changes in strain in the rock mass due to faulting cause changes in water-table level	Probability that strain-induced changes increase potentiometric level to > 850 m mean sea level	$<10^{-8}$/yr	8.3.1.8	
			In situ stress field	8.3.1.17.4.8.1
			Relation of hydraulic properties to strain	8.3.1.8.3.3.3(D)
			Rate of stress change	8.3.1.8.3.2.3(D), 8.3.1.17.4.12.1
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Offset on fault creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on faults in the C-area in 10,000 yr	$<10^{-1}$	8.3.1.8	
			Vertical slip rate and recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2

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Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11[a] (page 2 of 7)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on fault creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds (continued)	Probability of changing dip by > 2° in 10,000 yr by faulting	$<10^{-4}$	8.3.1.8 Rates of vertical slip and tilting	8.3.1.17.4.6.2
	Effects of faulting on flux	Faulting will not affect flux because of low slip rate	8.3.1.8 Unsaturated-zone flow model	8.3.1.8.3.1.4, 8.3.1.2.2.8, 8.3.1.2.2.9
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in the creation of a perched aquifer, a rise in the water table, or a change in hydraulic gradients	Probability of total offsets >2.0 m in 10,000 yr on faults within C-area	$<10^{-1}$	8.3.1.8 Slip rates and recurrence intervals	8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Effects of fault offset on water-table levels and hydraulic gradients	Water table will not rise to within 100 m of repository horizon in 10,000 yr Gradients change less than a factor of 4	8.3.1.8 Fault location and geometry Unsaturated-zone flow model Saturated-zone flow model Quaternary water levels	8.3.1.8.3.2.5, 8.3.1.17.3.1 8.3.1.2.2.8, 8.3.1.2.2.9 8.3.1.2.1.4.4, 8.3.1.5.3.3.3 8.3.1.5.2.1.5

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Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11[a] (page 3 of 7)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Episodic offset on faults causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow, or creating barriers to flow, or creating new conduits for drainage	Annual probability of faulting events on Quaternary faults within 0.5 km of C-area boundary	$<10^{-4}$/yr	8.3.1.8 Slip rates and recurrence intervals	8.3.1.8.3.3.2(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Effects of fault motion on local permeabilities and effective porosities	Change in fracture permeability is less than factor of 2; and fracture porosity decreases	8.3.1.8 Evidence of episodic rock-property changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.4, 8.3.1.4.2.2.5
Offset on a fault changes potential travel pathway to one with different geochemical properties	Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8 Offsets, slip rates, and recurrence intervals	8.3.1.8.4.1.3(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Effects of fault offset on travel pathway	Significant changes will not occur	8.3.1.8 Unsaturated-zone flow model Saturated-zone flow model	8.3.1.2.2.2.8, 8.3.1.2.2.9 8.3.1.2.3.3.3

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Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11[a] (page 4 of 7)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on a fault causes changes in movement of ground-water that result in mineralogical changes along the fault zone	Probability of movement within 2 km of surface and location of Quaternary faults in C-area	$<10^{-4}$/yr per fault	8.3.1.8 Locations of Quaternary faults in C-area	8.3.1.8.4.1.2(D), 8.3.1.17.4.6.1
			Slip rates and recurrence intervals	8.3.1.8.3.1.3, 8.3.1.17.4.6
	Degree of mineralogic change in fault zone in 10,000 yr	Adverse changes in mineralogy will not occur	8.3.1.8 Nature and age of mineralogic changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.5
Uplift or subsidence changes drainage, thereby changing flux	Probability of exceeding 30-m elevation change in 10,000 yr	$<10^{-4}$ per 10,000 yr	8.3.1.8 Rates uplift and subsidence	8.3.1.8.3.1.7(D), 8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3

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Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11[a] (page 5 of 7)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Tectonic folding changes dip of tuff beds in C-area, thereby changing flux	Probability of changing dip by >2° in 10,000 yr by folding	$<10^{-4}$ per 10,000 yr	8.3.1.8 Rates of folding	8.3.1.8.3.1.7(D), 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Folding, uplift, or subsidence lowers repository with respect to water table	Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates of subsidence Rates of folding	8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Tectonic processes cause changes in water table or movement that results in mineralogic changes in C-area	Degree of mineralogic change in the controlled area resulting from changes in water-table level or flow paths in 10,000 yr	Adverse changes in mineralogy will not occur	8.3.1.8 Probability and magnitude of hydrologic changes Rate of mineral alteration	8.3.1.8.4.1.4(D), 8.3.1.8.3.2.2, 8.3.1.8.3.2.3, 8.3.1.8.3.2.4, 8.3.1.8.3.2.6 8.3.1.3.2.2.1, 8.3.1.3.3.2, 8.3.1.3.3.3

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Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11[a] (page 6 of 7)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on one or more faults intersects waste package and causes failure[d]	Number of waste packages affected by fault penetrating repository	Less than 0.5% of waste packages intersected by a single fault, with a 95% probability	8.3.1.8 Characteristics of faults that penetrate repository, width and orientation of Quaternary faults, number of waste packages affected by a fault	8.3.2.2.7, 8.3.1.3.3.1, 8.3.1.17.4.2, 8.3.1.17.4.6.1, 8.3.1.17.4.6.2
	Probability of faulting with displacement over 5 cm in repository	Annual probability less than 10^{-4} of faulting with displacement over 5 cm		
Ground motion causes spalling or failure and closes air gap around waste packages[d]	Expected ground motion at emplacement boreholes in 1,000-yr period	Probability of exceeding ground motion values <0.1 in 1,000 yr	8.3.1.17 Probability of ground motion	8.3.1.17.3.5.2, 8.3.1.17.3.6.2

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Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11[a] (page 7 of 7)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Folding or distributed shear causes waste-emplacement-borehole deformation and results in waste-package failure[d]	Rate of deformation due to folding or distributed shearing in repository horizon	Waste-emplacement boreholes will be subject to <0.005 shear strain in 1,000 yr as a result of folding or deformation	8.3.1.8 Nature and age of folding in repository	8.3.1.4.2.2.1, 8.3.1.4.3.2, 8.3.1.17.4.12.1, 8.3.1.8.2.1.2

[a]Scenario classes, performance parameters, and parameter goals are from Section 8.3.5.13, except where noted.

[b]Study or activity directly addresses scenario.

[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

[d]Scenario class, performance parameter, and parameter goal are from Section 8.3.2.2.

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magnitude than historic seismicity. The maximum earthquake magnitude in the historical record and the record of Quaternary faulting within the geologic setting are assumed to be the strongest indicators of future earthquake potential for the postclosure time frame. Difficulty in interpreting the Quaternary faulting record suggests that the historical record may not reveal the largest earthquake that could occur at Yucca Mountain. Given this interpretation, it is possible that the geologic setting of the Yucca Mountain site may experience earthquakes of higher magnitude or frequency than have been historically observed. The strategy for resolution of this PAC is to demonstrate that although the condition may be present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste. The characterization work that will provide the information needed for resolving this PAC is listed in Table 8.3.5.17-11.

Potentially adverse condition 14: More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.

This PAC is concerned with the potential for future seismic activity to adversely affect the postclosure performance of a geologic repository. The frequency and magnitude of earthquakes at Yucca Mountain during the several years of close monitoring is the same as or less than that for the southern Basin and Range Province. Furthermore, it is not expected that future seismicity at the site will be more frequent or of higher magnitude than is typical of the region in which the geologic setting is located. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

The information needed to evaluate this PAC is identical to that needed for PACs 12 and 13, and the information needs for this PAC are included in Table 8.3.5.17-11 (PAC 11). Data to be collected to address PAC 11 are expected to be adequate for resolving PAC 14.

Potentially adverse condition 15: Evidence of igneous activity since the start of the Quaternary Period.

This PAC is concerned with igneous activity during the next 10,000 yr that could adversely affect the performance of a repository system. Igneous activity could cause direct releases of radionuclides to the accessible environment as a result of an extrusive event. Igneous activity could also affect releases indirectly by disrupting the geohydrologic conditions at a site (increasing the ground-water table altitude, increasing percolation flux through the repository horizon, changing head gradients in the saturated zone, or creating surficial discharge points within the accessible environment) or altering the rock-mass hydrologic or geochemical characteristics along the potential radionuclide transport pathways.

Although the volcanic rocks in the region of Yucca Mountain are predominately silicic tuffs and rhyolite domes formed during middle Tertiary, the youngest volcanic rocks are mostly basalt flows. These basalts were probably formed as recently as approximately 15,000 yr ago (Crowe and Turrin, 1988; Crowe et al, 1988; Wells et al, 1988); however, the dating methods have significant uncertainties. These basalts were formed in isolated Strombolian eruptions of small volume and short duration. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The likelihood and extent of igneous activity during the next 10,000 yr and its effects on site characteristics will be investigated during site characterization. Table 8.3.5.17-12 shows the scenario classes associated with igneous activity that will be considered in the overall system performance assessment. The table also lists the performance parameters for which values will be obtained during site characterization. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-12. Table 8.3.5.17-12 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 16: Evidence of extreme erosion during the Quaternary Period.

This potentially adverse condition is concerned with the potential for erosional processes to adversely affect the isolation capabilities of the site. Repository performance could be directly affected through denudation of the underground facility or indirectly affected through disturbance of the hydrologic system, such as the creation of new ground-water discharge points within the controlled area.

Erosional processes in the area of Yucca Mountain site have been, and continue to be, dominated by a general pattern of upland erosion, piedmont transport, and basin deposition (Section 1.1.3.3.2). Average downwasting rates over the past 1 to 5 million years have been 0.5 to 2.0 cm per thousand years. Assuming that these rates would continue, the total downwasting would amount to a maximum of approximately 20 cm during the next 10,000 yr. Large-scale rapid mass wasting has not played a major role in the erosional regime at the site. Although generally stable, episodes of rapid erosion have occurred locally in areas of concentrated fluvial activity. In these areas, rates of stream incision, averaged over the past 0.15 to 0.3 million years, range from 5.3 to 37.5 cm per thousand years. These rates would amount to a maximum of approximately 3.8 m over the next 10,000 yr. Therefore, it is not likely that erosion would significantly affect the ability of the Yucca Mountain site to meet the performance objectives related to waste isolation. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Because of these low rates, disturbed-performance scenario classes associated with erosional processes have not been developed for the Yucca Mountain site. Furthermore, no information needs associated with the nominal-case scenario are identified for erosion. The underground facility will be at least 200 m below the surface at all points. Therefore, direct releases resulting from denudation are considered to be not credible during the next 10,000 yr. Even the rates associated with stream incision are not expected to affect the ground-water flow important to waste isolation. Although erosion-related site data are limited, no new site data are necessary to address this condition. Some erosion data will be collected for

Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15[a] (page 1 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Igneous intrusion penetrating repository resulting in failure of waste packages[c]	Probability of igneous intrusion penetrating repository	Annual probability less than 10^{-5}	8.3.1.8 Probability of intrusion	8.3.1.8.2.1.1(D), 8.3.1.8.1.1.4
	Effects of igneous intrusion penetrating repository	Less than 5% of waste packages disrupted	8.3.1.8 Geometry of intrusions	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Number of waste packages disrupted	8.3.1.8.1.2.1, 8.3.2.2.6.2, 8.3.2.2.7.1
Volcanic eruption penetrates repository and causes direct releases to the accessible environment	Annual probability of volcanic eruption that penetrates the repository	$<10^{-6}$/yr	8.3.1.8 Probability of eruption	8.3.1.8.1.2(D), 8.3.1.8.1.1.4
	Effects of volcanic eruption penetrating repository, including area of repository disrupted	Given occurrence, <0.1% of repository area disrupted with a conditional probability of <0.1 of being exceeded in 10,000 yr	8.3.1.8 Effects of eruption	8.3.1.8.1.2.1, 8.3.1.8.1.2.2

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Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15[a] (page 2 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	Annual probability of volcanic events within C-area[d]	$<10^{-5}$/yr	8.3.1.8 Probability of volcanic event	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of a volcanic event on topography and flow rates	Show topographic changes are not great enough to affect flux	8.3.1.8 Topographic effects of eruption	8.3.1.8.1.2.1, 8.3.1.8.1.2.2
Igneous intrusion, such as a sill, that could result in a significant change in average flux	Annual probability of igneous intrusion in the C-area	Show $<10^{-5}$/yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of an igneous intrusion on flux	Show igneous intrusion will not affect flux because of depth, location, and extent of intrusion	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow model	8.3.1.2.3.3

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Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15[a] (page 3 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Igneous intrusion causes barrier to flow or thermal effects that alter water-table level (or hydraulic gradients)	Annual probability of an igneous intrusion within 0.5 km of C-area boundary	$<10^{-5}$/yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Barrier-to-flow effects of igneous intrusions on water-table levels	Water table will not rise to within 100 m of repository horizon within 10,000 yr	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Thermal effects of igneous intrusions on water-table levels	Water table will not rise to within 100 m of repository horizon within 10,000 yr	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Thermal effects of igneous intrusions on hydraulic gradients	Gradients change less than a factor of 4	8.3.1.8 Thermal effects near intrusion	8.3.1.8.1.2.1

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Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15[a] (page 4 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Igneous intrusions cause changes in rock hydrologic properties	Annual probability of igneous instrusions within 0.5 km of C-area boundary	$<10^{-5}$/yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.3.1(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of igneous intrusions on local permeabilities and effective porosities	No significant changes in rock hydrologic properties	8.3.1.8 Locations and geometry of possible intrusions	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Effects of intrusions on hydraulic properties	8.3.1.8.3.3.1
Igneous intrusions cause changes in rock geochemical properties	Annual probability of igneous intrusions within 0.5 km of C-area boundary	$<10^{-5}$/yr	8.3.1.8 Probability of igneous intrusions	8.3.1.8.4.1.1(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1

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Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15[a] (page 5 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Igneous intrusions cause changes in rock geochemical properties (continued)	Effects of igneous intrusions on local rock geochemical properties	Potential changes in mineralogy will not be extensive	8.3.1.8 Mineralogic changes	8.3.1.8.5.2.2
			Rates of mineral alteration	8.3.1.3.2.2.1, 8.3.1.3.3.2, 8.3.1.3.3.3

[a]Scenario classes, performance parameters, and parameter goals are from Section 8.3.5.13, except as noted.

[b]Study or activity directly addresses the scenario.

[c]Scenario class, performance parameter, and parameter goal are from 8.3.2.2.

[d]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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purposes other than characterizing extreme erosion (Section 8.3.1.6), and these data will be used to test the hypothesis that this PAC is not present at the site.

Potentially adverse condition 17: The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such a form that: (i) Economic extraction is currently feasible or potentially feasible during the forseeable future; or (ii) Such materials have a greater gross value or net value than the average for areas of similar size that are representative of and located within the geologic setting.

This PAC is concerned with the potential for future human activities associated with resource exploration and exploitation at the site that could adversely affect the isolation capabilities of the site. Such activities include exploratory drilling, surface and subsurface mining, and ground-water withdrawal. These activities could result in direct radionuclide releases to the accessible environment if radioactive material were brought up to the surface along with the resource or in the course of exploration. The activities could also indirectly affect isolation if the geohydrologic or geochemical conditions of the site were disturbed.

There are no known occurrences of economic mineral resources at the Yucca Mountain site (Section 1.7). Preliminary analyses of drill-core samples at Yucca Mountain suggest there are no mineral occurrences in any significant abundance that could be economically feasible to extract in the near future. Comparison of the site with similar regions, where mineral resources have been found, indicates that there are some similarities in rock types and depositional environments for economic minerals; however, the occurrences at Yucca Mountain are not expected to be unique or of a higher value. The potential for energy resources (uranium, oil, gas, and geothermal resources) at the site is considered very low. Deep boreholes in the region have failed to detect the presence of any significant quantities of hydrocarbons. Most of the southern Great Basin, including the Yucca Mountain site, has a potential for low- to moderate-temperature geothermal development, data from wells at Yucca Mountain, however, suggest low heat flow would preclude geothermal energy development at the site.

Ground-water resources exist near the Yucca Mountain site. The extent of the resource is unknown; however, the limited ground-water resources in southern Nevada make the ground-water resources proximal to the site attractive for future extraction. The ground-water resources within the site, however, are not considered feasible for economic extraction because of depth to the ground water, topographic conditions, land-use restrictions at the repository site, and the expected availability of ground-water resources outside of the controlled-area boundary. Ground-water withdrawal near the controlled area is discussed in PAC 2.

The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

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The potential for human activities that are associated with resource exploration and extraction at the Yucca Mountain site and their effects on the site characteristics will be investigated during site characterization (Section 8.3.1.9). Scenario classes associated with human activities have been developed for this purpose. Table 8.3.5.17-13 shows the scenario classes that will be evaluated in the overall system performance assessment and the performance parameters associated with those scenarios for which values will be obtained. Because of the unpredictable nature of human activities, goals cannot be set for many of these parameters (see Section 8.3.5.13 and the discussion of PAC 2). Nevertheless, investigations will be conducted to obtain information needed to evaluate these parameters, and these investigations are also listed in this table. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-13. Table 8.3.5.17-13 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 18: Evidence of subsurface mining for resources within the site.

This potentially adverse condition is concerned with the potential for past or present mining-related activities to adversely affect the performance of a repository. There is no evidence of mining activity within 10 km of the Yucca Mountain site (Section 1.6.4). Surface exploration of the area found no evidence of abandoned underground mines, surface mines, or prospecting drillholes.

The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site. The available evidence is sufficient to address this PAC, and no additional site data are called for. Information needed to evaluate future mining activities is identified in Table 8.3.5.17-13.

Potentially adverse condition 19: Evidence of drilling for any purpose within the site.

This PAC is concerned with the potential for past or present drilling to adversely affect the performance of a repository, e.g., by providing pathways for transport of radionuclides from the repository.

A study has been made of the available records, and all the area within a 10-km radius around the perimeter drift outline has been physically examined during surface mapping operations. A total of 184 drillholes within the 10-km radius has been reported (Section 1.6.1). Two of these drillholes, the J-12 and J-13 water wells, were completed for water supply for the Nuclear Rocket Development Station work in 1957 and 1963, respectively. The other 182 holes were drilled under the control of the Nevada Test Site Operations Office for the Project during exploratory work to investigate the site. If the wording of this PAC related the significance of drillholes to the ability of the site to isolate waste, the strategy for PAC resolution would be to test the hypothesis that the PAC is not present; however, since the PAC, as stated, refers only to evidence of drilling, the strategy for PAC resolution is to demonstrate that although the condition is present, it will

Table 8.3.5.17-13. Scenario classes and parameters associated with potentially adverse condition 17[a]

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Exploratory drilling intercepts a waste package and brings waste up with core or cuttings	Presence and readability of C-area[c] markers over next 10,000 yr	>50% chance that markers are readable over next 10,000 yr	8.3.1.9	
			Rates of processes decreasing survival period, visibility, or readability of markers	8.3.1.9.3.1.1(D), 8.3.1.9.1.1
	Expected drilling rate (number of boreholes/km^2/yr) in C-area over the next 10,000 yr	Expected drilling rate $\leq 3 \times 10^{-4}$/km^2/yr	8.3.1.9	
			Types and locations of inferred resources	8.3.1.9.2.1
			Expected exploratory methods	8.3.1.9.3.1.1
	Distribution of depths of exploratory drillings	No goal (human activity)	8.3.1.9	
			Expected exploratory methods	8.3.1.9.2.1, 8.3.1.9.3.1.1
	Distribution of diameters of exploratory drill holes	No goal (human activity)	8.3.1.9	
			Expected exploratory methods	8.3.1.9.2.1, 8.3.1.9.3.1.1

[a]Scenario classes, performance parameters, and parameter goals are from Section 8.3.5.13.
[b]Study or activity directly addresses the scenario.
[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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not affect significantly the ability of the geologic repository to meet the performance objective relating to isolation of the waste.

Scenarios associated with drilling for purposes other than those of previous drilling activities at the site will be investigated in the overall system performance assessment. These scenario classes are discussed by PAC 17, and the information needed to evaluate this PAC is identified in Table 8.3.5.17-13.

<u>Potentially adverse condition 20</u>: Rock or ground-water conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and ramps/shafts.

This PAC is concerned with a preclosure condition that could affect postclosure performance. According to the NRC's statements of consideration for 10 CFR Part 60 (NRC, 1981c), complex engineering measures are not inherently unacceptable. The concern lies in the reliability of the measures. Preclosure failure of such measures could conceivably affect postclosure performance, for example, through collapse of underground openings or flooding of the repository. The isolation capability of the repository system during the postclosure period could then be inferior to that which would exist if closure had been intentional.

Presently available data indicate that measures beyond those that are accepted mining practices would not be required to compensate for unfavorable rock characteristics (Chapters 2 and 6) and ground-water conditions (Chapter 3). The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Rock characteristics will be investigated further during site characterization to satisfy the information needs of both design and performance issues. However, no other information associated with particular scenario classes has been identified for this PAC. Present rock and ground-water conditions are included in the nominal-case scenario class as described in Section 8.3.5.13. Additional studies beyond those described in the sections cited above are presently believed not to be necessary.

<u>Potentially adverse condition 21</u>: Geomechanical properties that do not permit design of underground openings that will remain stable through permanent closure.

This PAC is concerned with a preclosure condition that could affect postclosure performance. Failure of an underground opening during the preclosure period could result in the enlargement of existing fractures or opening of new fractures that could potentially affect radionuclide transport. In addition, fracturing due to failure of an underground opening could potentially increase the amount of ground water reaching the waste package.

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No measures beyond those generally acceptable in the mining industry are expected to be required to maintain stable underground openings through the preclosure period (Chapter 6). The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Additional studies beyond those described for the nominal-case scenario class (Sections 8.3.5.13, 8.3.2.2, and 8.3.2.5) are presently believed not to be necessary. The final plans for maintaining stable underground openings will be presented as part of the license application design.

Potentially adverse condition 22: Potential for the water table to rise sufficiently so as to cause saturation of an underground facility located in the unsaturated zone.

This PAC is concerned with the saturation of an underground facility initially located in the unsaturated zone. A water-table rise that would flood an underground facility could result from climatic conditions (also considered in PAC 6), human activity (also considered in PAC 2), or tectonic processes or events (also considered in PACs 3 and 5).

Climate change, human activities, structural deformation, and igneous activity are all possible at the site. The effects of these processes are not, however, expected to produce a water-table rise high enough to saturate the underground repository. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Table 8.3.5.17-14 shows the scenarios that will be considered in the overall system performance assessment and that address water-table rise during the postclosure period. The table also shows the performance parameters for which values will be obtained during site characterization to address these scenarios. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-14. Table 8.3.5.17-14 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 23: Potential for existing or future perched water bodies that may saturate portions of the underground facility or provide a faster flow path from an underground facility located in the unsaturated zone to the accessible environment.

This PAC is concerned with perched-water bodies that could affect the transport of radionuclides by increasing flux through the unsaturated zone. These perched-water bodies could result from structural deformation at a site or from a climate change that produces a significant increase in infiltration.

Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22[a] (page 1 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Climate change causes an increase in level of water table	Expected magnitude of change in water-table level due to climatic changes over the next 10,000 yr	Water table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.5 Future-climate model	8.3.1.5.2.2.3(D), 8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Paleodischarge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Vein-deposit distribution, age, and origin	8.3.1.5.2.1.5
Extensive irrigation is conducted near the C-area[c]	Expected magnitude of change in level of water table under C-area due to extensive irrigation near near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9 Irrigation characteristics	8.3.1.9.3.2.2(D), 8.3.1.9.3.2
			Infiltration rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow model	8.3.1.2.3.3.3

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Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22[a] (page 2 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Large-scale surface-water impoundments are constructed near the C-area	Expected magnitude of change in water-table level due to placement of artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9	
			Impoundment characteristics	8.3.1.9.3.2.2(D), 8.3.1.9.3.2
			Infiltration rates	8.3.1.2.2.1.1
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9
			Saturated-zone flow model	8.3.1.2.3.3.3
Extensive surface or subsurface mining occurs near C-area	Expected magnitude of change in water-table level due to mine water use or mine dewatering near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9	8.3.1.9.3.2
Extensive ground-water withdrawal occurs near C-area	Expected magnitude of change in water-table level due to extensive ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9	8.3.1.9.3.2.1(D), 8.3.1.9.2.2

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Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22[a] (page 3 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Episodic changes in strain in the rock mass due to faulting cause changes in water-table level	Probability that strain-induced changes increase potentiometric level to > 850 m mean sea level	$<10^{-5}$/yr	8.3.1.8 Magnitudes and rates of strain, relation of properties to strain	8.3.1.8.3.2.3(D), 8.3.1.17.4.8.1, 8.3.1.17.4.8.4, 8.3.1.8.3.3.3
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Folding, uplift, or subsidence lowers repository with respect to water table	Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates of subsidence	8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3
			Rates of folding	8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in a rise in the water table	Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8 Offsets, slip rates, and recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.1.2

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Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22[a] (page 4 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in a rise in the water table (continued)	Effects of fault offset on water-table levels	Water table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.8 Locations of faults Saturated-zone flow model	8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12, 8.3.1.2.3.3.3
Igneous intrusion causes barrier to flow or thermal effects that alter water-table level	Annual probability of igneous intrusion within 0.5 km of C-area boundary	Show < 10^{-5}/yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Barrier-to-flow effects of igneous intrusion on water-table levels	Water table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.8 Locations and geometry of possible intrusions at site Saturated-zone flow model	8.3.1.8.1.2.1, 8.3.1.17.4.12.1 8.3.1.2.1.4.4, 8.3.1.2.3.3.3

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Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22[a] (page 5 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Igneous intrusion causes barrier to flow or thermal effects that alter water-table level (continued)	Thermal effects of igneous intrusions on water-table levels	Water table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
			Thermal effects near intrusive bodies	8.3.1.8.1.2.1

[a]Scenario classes, performance parameters, and parameter goals are from Section 8.3.5.13.
[b]Study or activity directly addresses the scenario.
[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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The site is located in the southern Great Basin, a tectonically active region (Section 1.3); however, the effects of tectonism are not expected to create perched-water bodies that could saturate portions of the underground repository. Although the potential for existing perched-water bodies at the site cannot be ruled out on the basis of currently available information, it is unlikely that large bodies exist, because they have not been encountered in the program-related drilling performed to date. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Table 8.3.5.17-15 shows the scenarios that have been identified that could create perched-water bodies in the unsaturated zone at the site. These scenarios are being considered in the overall system performance assessment. The table also shows the performance parameters for which values will be obtained during site characterization. The categories and sets of site characterization data to be collected to address this PAC are listed in Table 8.3.5.17-15. Table 8.3.5.17-15 also references the section that discusses the data to be collected and the associated studies and activities.

Existing perched-water bodies, if any, at the site will be identified by the program of hydrologic testing and modeling proposed for the site. The development of an unsaturated-zone flow model, using the data from the hydrologic testing program, will support an evaluation of the potential for perched-water bodies to have formed at the site under present conditions.

Potentially adverse condition 24: Potential for the movement of radionuclides in a gaseous state through air-filled pore spaces of an unsaturated geologic medium to the accessible environment.

Gaseous transport has been identified as a potentially significant transport mechanism for a repository located in the unsaturated zone (Section 8.3.5.13). Carbon-14 is expected to be the most important radionuclide species to be transported in this mode. The total-system performance assessment is therefore investigating gas-phase C-14 releases from the waste form and the characteristics and mechanisms of gas-phase transport of C-14 in the unsaturated rock units overlying the repository in the nominal-case scenario class (Section 8.3.5.13).

Available evidence suggests that this condition may be present. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The information needs for the nominal-case scenario relevant to movement of C-14 in the gaseous state in the unsaturated zone are summarized in Table 8.3.5.17-16. The investigations supporting those information needs are also listed in this table. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-16. Table 8.3.5.17-16 also references the section that discusses the data to be collected and the associated studies and activities.

Table 8.3.5.17-15. Scenario classes and parameters associated with potentially adverse condition 23[a] (page 1 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on fault creates impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on a fault in the C-area[c] in 10,000 yr	$<10^{-1}$	8.3.1.8 Offsets, vertical slip rates, and recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12
	Probability of changing dip by >2 in 10,000 yr by faulting	$<10^{-4}$	8.3.1.8 Rates of vertical slip and tilting	8.3.1.17.4.6.2
	Effect of faulting on flux	Faulting will not affect flux because of low slip rate	8.3.1.8 Unsaturated-zone flow model	8.3.1.8.3.1.4, 8.3.1.2.2.8, 8.3.1.2.2.9
Offset on fault juxtaposes transmissive and nontransmissive units, resulting in the creation of a perched aquifer or a rise in the water table	Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8 Offsets, vertical slip rates, and recurrence intervals	8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12

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Table 8.3.5.17-15. Scenario classes and parameters associated with potentially adverse condition 23[a] (page 2 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Offset on fault juxtaposes transmissive and nontransmissive units, resulting in the creation of a perched aquifer or a rise in the water table (continued)	Effects of fault offsets on water-table levels	Water table will not rise to within 100 m of repository horizon in 10,000 yr	8.3.1.8	
			Credible offsets	8.3.1.8.3.1.3
			Hydraulic properties of faults	8.3.1.8.3.3.2
			Unsaturated-zone flow model	8.3.1.8.3.1.4, 8.3.1.2.2.8, 8.3.1.2.2.9
Climatic change causes increase in infiltration over C-area	Expected magnitude of flux change due to climatic change over next 10,000 yr	Flux change will be <0.5 mm/yr	8.3.1.5.2	
			Future-climate model	8.3.1.5.2.2.2, 8.3.1.5.1.6
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.8, 8.3.1.2.2.9

[a]Scenario classes, performance parameters, and parameter goals are from Section 8.3.5.13.
[b]Study or activity directly addresses scenario.
[c]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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Table 8.3.5.17-16. Scenario classes and parameters associated with potentially adverse condition 24[a]

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D)[b] or associated study or activity
Nominal case (undisturbed performance)	Fraction of carbon-14 that could be released as carbon-14 dioxide	<10% of inventory at closure	8.3.5.10.4 Model of spent-fuel release	8.3.5.10.3.3.1(D)
	Mean residence time of released carbon-14 dioxide in unsaturated-zone units	Show residence time less than 10,000 yr	8.3.1.2.2, 8.3.1.3.8.2 Gas composition, transport mechanisms, flow paths, water chemistry and physics	8.3.1.2.2.3, 8.3.1.3.8.1.1(D), 8.3.1.3.8.1.2(D)

[a]Scenario classes, performance parameters, and parameter goals are from Section 8.3.5.13.
[b]Study or activity directly addresses scenario.

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Discussion of the favorable conditions

This section provides individual discussions of the favorable conditions (FCs) listed in 10 CFR 60.122. For each FC, the discussion identifies thetentative strategy (present or not present) called for in Step 1 of Figure 8.3.5.17-2. Also, the potential contribution of the FC to performance is discussed, and the site characterization data needed for addressing the FC are identified.

Favorable condition 1: The nature and rates of tectonic, hydrogeologic, geochemical, and geomorphic processes (and any of such processes) operating within the geologic setting during the Quaternary Period, when projected, would not affect or would favorably affect the ability of the geologic repository to isolate waste.

Available evidence indicates that there were several processes operating during the Quaternary that, if projected into the future, would contribute to isolating waste. Certain geochemical conditions, for example, would retard the transport of radionuclides to the accessible environment. These geochemical processes include the sorbing of radionuclides by the mineralogic assemblages along the flow path and the precipitating of radionuclides out of solution. Also, the rates of erosional processes during the Quaternary were relatively low and, if continued into the future, would not disrupt the performance of the repository system. The strategy for resolving this FC with respect to these Quaternary processes is to demonstrate that they would favorably affect the ability of the repository to isolate waste.

Some aspects of the tectonic setting, however, could be disruptive if they were to continue into the future. Both faulting and volcanic activity were present within the geologic setting during the Quaternary and, depending on the extent of these processes, could adversely affect the hydrologic system by raising the water table level, changing the flow path through the unsaturated zone, changing gradients in the saturated zone, or creating surficial discharge points within the controlled area. Also, the hydrologic system within the geologic setting during the Quaternary, though generally favorable, was influenced by cyclic fluctuations in precipitation. This resulted in sometimes greater flux and higher water-table altitudes than presently exist. If these tectonic and hydrogeologic conditions were to reoccur in the future, ground-water travel time to the accessible environment could be decreased and subsequently the rate of radionuclide transport increased. The strategy for resolving this FC with respect to these potentially disruptive processes is to demonstrate that they will not affect the ability of the repository to isolate waste.

The overall strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. The various programs that are planned for site characterization will investigate the processes operating within the setting during the Quaternary and use the information as a basis for predicting future processes, events, and conditions. Overall, the geologic setting is expected to exhibit sufficient favorable characteristics to ensure waste isolation. The descriptions of the various site conditions

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are given in Chapters 1 through 5, and the discussions of the various characterization programs are given in Section 8.3.1. The data needed to evaluate the effects of the potentially disruptive conditions are discussed above in the issue-resolution strategies for PACs.

<u>Favorable condition 2</u>: For disposal in the saturated zone, hydrogeologic conditions that provide: (i) a host rock with low horizontal and vertical permeability, (ii) downward or dominantly horizontal hydraulic gradient in the host rock and surrounding hydrogeologic units, and (iii) low vertical permeability and low hydraulic potential between the host rock and surrounding hydrogeologic units.

Because disposal at the Yucca Mountain site will be in the unsaturated zone, this favorable condition is not present at the site.

<u>Favorable condition 3</u>: Geochemical conditions that: (i) promote precipitation or sorption of radionuclides, (ii) inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides, or (iii) inhibit the transport of radionuclides by particulates, colloids, and complexes.

Favorable condition 3 is concerned with conditions that would reduce radionuclide transport through precipitation or sorption. This condition is also concerned with the absence of conditions that would interfere with these processes. These conditions include the formation of or transport by particulates, colloids, and organic and inorganic complexes.

Available evidence indicates that some aspects of favorable condition 3 are expected to exist at the Yucca Mountain site. Conditions present at the site are expected to promote precipitation of some radionuclides. Present evidence indicates that many radionuclide oxides are least soluble in solutions of neutral pH (6-8). Water samples taken from wells near the site have pH values in this range. Conditions at the site are also expected to promote the sorption of radionuclides. Highly sorbing zeolitic and clay minerals are common in the tuffaceous beds of Calico Hills that underlie the proposed repository horizon. The hydrologic flow path from the proposed host rock is expected to be downward through the unsaturated Calico Hills to the saturated zone, and sorptive processes are expected to retard migrating radionuclides.

Insufficient information is available at this time to state a definite expectation regarding the formation of colloids, particulates, or complexes. Colloids may form and there may be a potential for the transport of radionuclides as colloids or as complexes or by particulates, but the relative significance or importance of these processes is not yet determined.

The strategy for resolving this FC is to demonstrate that the condition is present at the Yucca Mountain site. The geochemistry test program will investigate radionuclide sorption and solubility. Furthermore, the test program will investigate the formation and stability of radiocolloids, the sorption of radionuclides on particulates and colloid material, and the

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potential for transport and retardation of particulates and colloids. The test program will provide the necessary information to determine the potential for radionuclide retardation, and this information will be used in determining compliance with the waste-isolation performance objective (10 CFR 60.112, Issue 1.1, Section 8.3.5.13).

The investigations that address favorable condition 3 fall into two categories. The first category of investigations study (1) radionuclide sorption in a nonadvective and advective system and (2) the solubility of radionuclides. Investigations and studies in this category are

1. Investigation 8.3.1.3.4 (radionuclide retardation by sorption processes) including Studies 8.3.1.3.4.1 through 8.3.1.3.4.3.

2. Investigation 8.3.1.3.5 (radionuclide retardation by precipitation processes) including Studies 8.3.1.3.5.1 and 8.3.1.3.5.2.

3. Investigation 8.3.1.3.6 (radionuclide dispersion, diffusion, and advection) including Studies 8.3.1.3.6.1 and 8.3.1.3.6.2.

The second category includes investigations that study (1) radiocolloid formation and stability, (2) sorption of radionuclides by particulates or colloids, (3) the transport of radionuclides (retardation) in general and transport by colloids or particulates, and (4) the overall potential for radionuclide retardation. Investigations and studies in this category are

1. Investigation 8.3.1.3.4 (radionuclide retardation by sorption processes) including Study 8.3.1.3.4.1 and Activity 8.3.1.3.4.1.4 (sorption by particulates and colloids).

2. Investigation 8.3.1.3.5 (radionuclide retardation by precipitation processes) including Study 8.3.1.3.5.1 (colloid formation).

3. Investigation 8.3.1.3.6 (radionuclide dispersion, diffusion, and advection) including Studies 8.3.1.3.6.1 and 8.3.1.3.6.2 (transport processes) and Activity 8.3.1.3.6.1.5 (filtration particulate transport).

4. Investigation 8.3.1.3.7 (radionuclide retardation by all processes) including Study 8.3.1.3.7.1 (retardation sensitivity analysis).

The descriptions of these investigations provide detailed discussions of the studies and their interrelationships. Equally informative is the overview to the geochemistry test program (Section 8.2).

<u>Favorable condition 4</u>: Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having equal or increased capacity to inhibit radionuclide migration.

Under expected repository conditions, the present high radionuclide-retardation capacity of the tuff units at Yucca Mountain is not expected to be significantly degraded and may, in fact, be increased. Zeolitic minerals (clinoptilolite and mordenite) are expected to contribute most to inhibiting

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radionuclide migration through sorptive processes. Most of the sorptive zeolites are located below the proposed repository horizon and are not expected to be significantly altered under the expected postemplacement thermal loading.

The minerals that could be affected by thermal loads include feldspar-silica assemblages, the heulandite-smectite assemblage, and volcanic glass. Feldspar-silica assemblages have a low sorbing capacity that is unlikely to decrease significantly under expected repository conditions. The heulandite-smectite assemblage, which together with volcanic glass comprises approximately 2 percent of the host rock, might be affected by the increase in temperature. However, the potential loss of sorption from alteration of these zeolites in the host rock represents a very small proportion of the total sorption potential of the zeolites in the underlying Calico Hills unit, where the thermal effects of the waste are expected to be much lower than in the host rock. Studies of volcanic glass alteration suggest that the glassy rock could alter to silica-feldspar-zeolite-smectite assemblages. The high sorptive properties of the zeolite-smectite assemblages could possibly enhance the overall sorptive capacities along radionuclide migration pathways.

The strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. The geochemistry test program will investigate the mineral assemblages already present at Yucca Mountain in order to adequately characterize the potential for future mineral alteration. The test program will (1) evaluate the present ground-water composition to establish the rock, mineral, and water interactions; (2) establish the alteration history of the minerals present at Yucca Mountain; (3) experimentally investigate mineral stability; (4) establish the thermodynamic data base for mineral alteration; and (5) develop a conceptual model of mineral evolution that would allow a prediction of potential future changes in mineralogy due to the expected thermal loading. The potential mineral changes will be assessed in terms of the sensitivity of radionuclide retardation to potential mineral changes, particularly changes in sorptive minerals. The portions of the geochemistry test program that will provide this information are

1. Investigation 8.3.1.3.1 (water chemistry) including Study 8.3.1.3.1.1 (ground-water chemistry model).

2. Investigation 8.3.1.3.2 (mineralogy, petrology, and rock chemistry) including Study 8.3.1.3.2.2 (alteration history) and Activities 8.3.1.3.2.2.1 (past alteration) and 8.3.1.3.2.2.2 (heating experiments on sorbing minerals).

3. Investigation 8.3.1.3.3 (mineral and glass stability) including Studies 8.3.1.3.3.1 through 8.3.1.3.3.3 (the thermodynamic and kinetic experimental and theoretical work to develop a conceptual model of mineral evolution).

4. Investigation 8.3.1.3.7 (radionuclide retardation by all processes).

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Favorable condition 5: Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface. (The ground surface shall be deemed to be the elevation of the lowest point on the surface above the disturbed zone.)

The unsaturated, densely welded, devitrified portion of the Topopah Spring has been selected as the preferred repository horizon. The ranking criteria used to select the horizon included (1) ground-water travel time, (2) allowable gross thermal loading, (3) excavation stability, and (4) relative economics. In the primary area, only 50 percent of the waste could be emplaced at least 300 m below the ground surface. The strategy for resolving this FC is to claim that it is not present at the Yucca Mountain site. It will not be investigated further.

Favorable condition 6: A low population density within the geologic setting and a controlled area that is remote from population centers.

The Yucca Mountain site is located in a county with a population density of 0.5 person per square mile. This is substantially less than the average for the continental United States, which is 76 persons per square mile. Also, the controlled area is located 137 km (85 mi) by air from the city of Las Vegas, Nevada, the nearest highly populated area.

The strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. The identification of additional information that might be necessary to address population density and distribution concerns, and subsequently provide additional evidence regarding this favorable condition, is outside the scope of this document. Information required to address population density and distribution concerns will be identified through environmental scoping hearings and presented in the environmental impact statement.

Favorable condition 7: Pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 yr.

Preliminary calculations of the ground-water travel time from the disturbed zone to the accessible environment have been made. Using an upper bound of 0.5 mm/yr for flux through the repository horizon, the mean travel time was calculated to be approximately 43,400 yr, with a range of 9,500 yr to 80,200 yr. These calculations were based on available data and the current understanding of the geohydrologic flow system.

The strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. Additional data are needed to refine the unsaturated- and saturated-zone models so that more accurate calculations can be made. Issue 1.6 (Section 8.3.5.12) addresses the NRC performance objective for pre-waste-emplacement ground-water travel time (10 CFR 60.113). This objective requires that the ground-water travel time from the disturbed zone to the accessible environment be at least 1,000 yr for a site to be

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acceptable. The strategy to demonstrate compliance with the objective, thereby resolving Issue 1.6, is presented in Section 8.3.5.12. The information needs identified in the strategy for Issue 1.6 are expected to be sufficient to determine the extent to which this favorable condition is present at Yucca Mountain, i.e., the extent to which the ground-water travel time exceeds 1,000 yr. This information is given in Section 8.3.5.12.

Favorable condition 8: For disposal in the unsaturated zone, hydrogeologic conditions that provide: (i) low and nearly constant moisture flux in the host rock and in the overlying and underlying hydrogeologic units, (ii) a water table sufficiently below the underground facility such that fully saturated voids continuous with the water table do not encounter the underground facility, (iii) a laterally extensive low-permeability hydrogeologic unit above the host rock that would inhibit the downward movement of water or divert downward moving water to a location beyond the limits of the underground facility, (iv) a host rock that provides for free drainage, or (v) a climatic regime in which the average annual historic precipitation is a small percentage of the average annual potential evapotranspiration.

The strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. Each part of the favorable condition will be discussed individually.

(i) Low and nearly constant moisture flux

This favorable characteristic is not expected to exist at the Yucca Mountain site. The moisture flux at the site is expected to be low; however, the actual magnitude of the flux is expected to vary throughout the host rock and overlying and underlying units. This variation results from variations in the matrix and fracture characteristics of the different rock units. Also, structural features such as fault zones result in areas of higher than average moisture flux.

(ii) Extent of fully saturated voids

Saturated void spaces in the unsaturated zone consist of the capillary fringe above the water table and any saturated fractures that extend from the water table upward. The zone of continuous, fully saturated voids (capillary fringe and saturated fractures) is not expected to extend above the top of the Calico Hills nonwelded unit below the repository host rock.

Current data indicate that in the area of Yucca Mountain, the water table is approximately 500 to 750 m below the ground surface. The proposed repository horizon is the densely welded, divitrified portion of the Topopah Spring Member of the Paintbrush tuff. This horizon is approximately 200 to 400 m above the water table.

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(iii) Lateral diversion of infiltration

Preliminary evidence suggests that the downward movement of water will not be diverted completely beyond the limits of the underground facility. It is expected, however, that lateral diversion could occur to some extent, thus reducing the overall downward flux through the repository.

The combination of contrasting welded, highly fractured units and nonwelded, porous units with the general 3 to 8 eastward dip of the units could promote lateral diversion to some degree. The nonwelded, highly porous unit of the Paintbrush Tuff overlies the welded, highly fractured Topopah Spring unit. Because the permeability of the Topopah Spring unit is much less than the permeability of the nonwelded unit, a permeability barrier is expected at the contact. Because the pores of the overlying unit are much smaller than the fractures of the Topopah Spring unit, a capillary barrier is also expected. These barriers, together with the dip of the beds, could result in a general, eastward lateral diversion.

Structural features of high permeability could disrupt this lateral movement, however. The Ghost Dance fault, for example, could act as a conduit for downward flow through the repository horizon. The extent to which these conditions are present needs further investigation to determine their likelihood and significance.

(iv) Free drainage

It is expected that the host rock would be freely draining if flux through the host rock were to increase sufficiently to cause fracture flow. The welded Topopah Spring unit is highly fractured, which results in a high bulk permeability. Although matrix flow predominates at lower fluxes, fracture flow would be expected at higher rates. Existing drill-hole data support a position that the fractured, welded tuff is continuous beneath the site; thus, free drainage would be expected throughout the host rock.

(v) Precipitation less than evapotranspiration

Meteorological recording stations at Yucca Mountain have not been in operation long enough to provide historically significant precipitation records. Data available from nearby recording stations (Yucca Flat and Beatty) indicate average annual precipitation values of 145 and 114 mm. The actual precipitation at Yucca Mountain is expected to be slightly higher. Taking into account the terrain and high elevation of Yucca Mountain, the average annual precipitation has been estimated to be approximately 150 mm. Potential evapotranspiration has been estimated by empirical methods to be approximately 630 mm/yr. This results in an average annual precipitation that is roughly 20 percent of the evapotranspiration.

The concerns of favorable condition 8 will be investigated through the geohydrology test program (Section 8.3.1.2). The concerns of the first four parts of this condition are included in the investigation of the unsaturated-zone hydrologic properties and conditions. These properties, shown in tabular form in Section 8.3.1.2, include fracture and matrix permeability, flux, flow velocities, matric potentials, moisture content, and infiltration rates. Collecting data on these properties will allow more quantitative

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analyses of the first four parts of this FC. The concerns of the fifth part, precipitation and evapotranspiration at Yucca Mountain, will be investigated through the meteorology test program (Section 8.3.1.12). The information made available through these test programs for the resolution of other issues is expected to be sufficient to determine the extent to which each aspect of this favorable condition is present and could contribute to waste isolation.

Interrelationships of the information needs

The strategies for making the demonstrations required by 10 CFR 60.122 for the potentially adverse conditions and the favorable conditions rely on the investigations and assessments of other issues, as explained in the preceding discussion. All information necessary to make these demonstrations is expected to be identified and obtained through the activities of these other issues. Because the purpose of the demonstrations required for the conditions is to show that the performance objectives can be met given the conditions present at the site, it is also expected that the goals and levels of confidence identified by the other issues are suitable for resolution of this issue. Therefore, there are no information needs identified specifically for this issue.

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8.3.5.18 Issue resolution strategy for Issue 1.9: (a) Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the postclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for geohydrology, geochemistry, rock characteristics, climatic changes, erosion, dissolution, tectonics and human interference; and (b) can the comparative evaluations required by 10 CFR 960.3-1-5 be made?

The DOE has established a set of siting guidelines to be used as a basis for evaluating the suitability of potential repository sites during the site selection process.* These siting guidelines, which are set forth in 10 CFR Part 960, are separated into two categories: those that address postclosure conditions (10 CFR 960.4) and those that address preclosure conditions (10 CFR 960.5). The manner in which the siting guidelines must be addressed during the siting process is described by DOE implementation guidelines (10 CFR 960.3).

In addition to the preclosure and postclosure guidelines, 10 CFR Part 960 describes two evaluations that will predict radionuclide releases to the accessible environment under expected conditions during the next 100,000 yr (10 CFR 960.3-1-5). These evaluations were intended to compare the expected postclosure performance of candidate sites. Given the passage of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987), such comparisons are no longer required, although the evaluation will still be performed. The first evaluation will emphasize the performance of the natural barriers; the second will emphasize the performance of the total system.

Issue 1.9 is concerned with the DOE's postclosure guidelines (Issue 1.9(a)) and the two evaluations of repository performance over 100,000 yr (Issue 1.9(b)). The discussion that follows explains how the guidelines and the evaluations will be addressed and how the necessary information will be made available. Because the guidelines and the comparative evaluations are distinct, this issue will be described in two parts.

Regulatory basis for Issue 1.9(a) of the postclosure siting guidelines

The postclosure siting guidelines consist of a system guideline and eight technical guidelines. The system guideline is concerned with the effect of the geologic setting of a site as a whole on postclosure performance of the repository system. Each technical guideline, however, is concerned with the effect of some specific aspect of the setting on postclosure performance. Each guideline has a qualifying condition that must be met for a site to be acceptable. In addition, five of the technical guidelines have at least one disqualifying condition. A site is unacceptable if any one of the disqualifying conditions is found to be present. The technical guidelines also identify favorable conditions and potentially adverse conditions that describe characteristics of the setting that, if present, could contribute to or detract from the postclosure performance of a site.

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*Passage of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987) may impact the manner in which this process is implemented.

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The implementation guidelines require that the qualifying and disqualifying conditions of the system and technical guidelines be evaluated and that specific findings be made for each condition at principal decision points in the siting process. These findings are stated in 10 CFR Part 960, Appendix III, and are shown in Table 8.3.5.18-1.

There are four levels of findings. Disqualifying and qualifying conditions both require a lower-level and a higher-level finding. Lower-level findings must be made to determine if a site may be nominated as suitable for characterization or recommended as a candidate site for characterization. Higher-level findings, however, must be made to determine if a site may be recommended for the development of a repository. Disqualifying conditions require Level 1 and Level 2 findings, and qualifying conditions require Level 3 and Level 4 findings. Each level has both a positive finding and a negative finding associated with it.

Table 8.3.5.18-2 shows the findings previously made for the postclosure guideline qualifying and disqualifying conditions. These findings and the evidence supporting them are given in the Yucca Mountain environmental assessment (DOE, 1986b). The available evidence was sufficient to support positive higher-level findings for the qualifying and disqualifying conditions of the dissolution technical guideline and positive lower-level findings for the qualifying and disqualifying conditions of the other postclosure technical guidelines and the postclosure system guideline. To determine if the Yucca Mountain site is suitable for the development of a repository, therefore, higher-level findings must be made for the remaining qualifying and disqualifying conditions.

The DOE siting guidelines do not require any findings similar to lower-level or higher-level findings to be made for the favorable or potentially adverse conditions of the technical guidelines. As stated in the Supplementary Information for 10 CFR Part 960, Overview of the Guidelines (DOE, 1984c), these conditions were intended to be used to predict the suitability of a site and provide a preliminary indication of system performance before the start of detailed site characterization studies. These conditions were considered and used in the identification of potentially acceptable sites, and in the nomination and recommendation of sites as suitable for characterization. By the completion of site characterization, however, sufficient data will be available to directly evaluate site performance against the qualifying conditions of the system and technical guidelines. Therefore, the favorable and potentially adverse conditions will not be considered in specific terms as they were for the environmental assessment (DOE, 1986b).

<u>Approach to resolving Issue 1.9(a)</u>

To resolve Issue 1.9(a), sufficient evidence must be available to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with postclosure repository performance. Each of the qualifying conditions makes reference either directly or through the system guideline to regulatory requirements of the NRC (specifically, 10 CFR Part 60). To support higher-level findings for the qualifying conditions, evidence must show that the geologic setting as a

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Table 8.3.5.18-1. Findings for qualifying and disqualifying conditions

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Disqualifying condition--lower-level findings

Level 1 (a) The evidence does not support a finding that the site is disqualified.

(b) The evidence supports a finding that the site is disqualified.

Disqualifying condition--higher-level findings

Level 2 (a) The evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified.

(b) The evidence supports a finding that the site is disqualified or is likely to be disqualified.

Qualifying condition--lower-level findings

Level 3 (a) The evidence does not support a finding that the site is not likely to meet the qualifying condition.

(b) The evidence supports a finding that the site is not likely to meet the qualifying condition, and therefore the site is disqualified.

Qualifying condition--higher-level findings

Level 4 (a) The evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.

(b) The evidence supports a finding that the site cannot meet the qualifying condition or is unlikely to be able to meet the qualifying condition, and therefore the site is disqualified.

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Table 8.3.5.18-2. Preliminary findings on postclosure system and technical guidelines[a]

Postclosure guideline (10 CFR 960)		Preliminary finding[b]
960.4-1	Postclosure system	
(a)	Qualifying condition	Level 3(a)
960.4-2-1	Geohydrology	
(a)	Qualifying condition	Level 3(a)
(d)	Disqualifying condition	Level 1(a)
960.4-2-2	Geochemistry	
(a)	Qualifying condition	Level 3(a)
960.4-2-3	Rock characteristics	
(a)	Qualifying condition	Level 3(a)
960.4-2-4	Climate	
(a)	Qualifying condition	Level 3(a)
960.4-2-5	Erosion	
(a)	Qualifying condition	Level 3(a)
(d)	Disqualifying condition	Level 1(a)
960.4-2-6	Dissolution	
(a)	Qualifying condition	Level 4(a)
(d)	Disqualifying condition	Level 2(a)
960.4-2-7	Tectonics	
(a)	Qualifying condition	Level 3(a)
(d)	Disqualifying condition	Level 1(a)
960.4-2-8-1	Natural resources	
(a)	Qualifying condition	Level 3(a)
(d)(1)	Disqualifying condition	Level 1(a)
(d)(2)	Disqualifying condition	Level 1(a)
960.4-2-8-2	Site ownership and control	
(a)	Qualifying condition	Level 3(a)

[a]Preliminary findings from DOE (1986b).
[b]See Table 8.3.5.18-1 for an explanation of the finding levels.

whole (for the system guideline) and the various aspects of the setting (for the technical guidelines) will not prevent compliance with the NRC regulations. The disqualifying conditions are also related to NRC regulations, but not always as explicitly as the qualifying conditions.

Figure 8.3.5.18-1 shows the strategy for resolving Issue 1.9(a). The first step is to eliminate from further consideration the qualifying and disqualifying conditions for which higher-level findings have already been made. This is the case for the qualifying and disqualifying conditions of the dissolution technical guideline. Next, for each remaining condition, it is determined whether the evidence presently available is sufficient to support a higher-level finding. This evidence consists of the information presented in the Yucca Mountain environmental assessment (DOE, 1986b) and in Chapters 1 through 7 of the SCP. If the evidence is sufficient, the finding and the evidence are documented.

For the qualifying and disqualifying conditions for which there is not adequate evidence available, the planned site characterization studies are reviewed to determine if the conditions will be investigated. This is accomplished by evaluating the resolution strategies of the other postclosure performance issues that assess the ability of the site to comply with the NRC's postclosure regulatory requirements (10 CFR Part 60) (Issues 1.1 through 1.6). As discussed previously, each qualifying and disqualifying condition is linked to NRC regulatory requirements. Evidence to support a higher-level finding will be generated through evaluations of compliance with the referenced NRC regulatory requirements. If the concerns of the qualifying and immediately disqualifying conditions are being considered in the resolution strategies of the issues that assess compliance with the regulations, it can be expected that the evidence to support higher-level findings will be made available through the information and analyses that support resolution of these other issues.

After ensuring that the qualifying and disqualifying conditions will be investigated, the information necessary to evaluate resolution of the other postclosure performance issues will be obtained during site characterization. The results will be evaluated over the course of site characterization to determine if sufficient evidence is available to support higher-level findings. If the evidence is deemed sufficient at any point, the findings and the evidence will be documented. If the evidence shows that a negative higher-level finding must be made for any one of the conditions (i.e., that a disqualifying condition is present or that a qualifying condition is not present), then the site will be immediately disqualified. This evaluation will continue until positive higher-level findings can be supported for all the conditions or until a negative higher-level finding must be made.

If, in evaluating the results of the assessments, insufficient information is found to support either a positive or a negative higher-level finding for a qualifying or disqualifying condition, additional data and analyses may be necessary to satisfy existing information needs. The resolution strategies of the appropriate performance issues will be reviewed to determine if, in fact, the condition was adequately considered and the information needs satisfied. If not, the strategies for the appropriate performance issues will be revised, and new information needs will be identified as necessary,

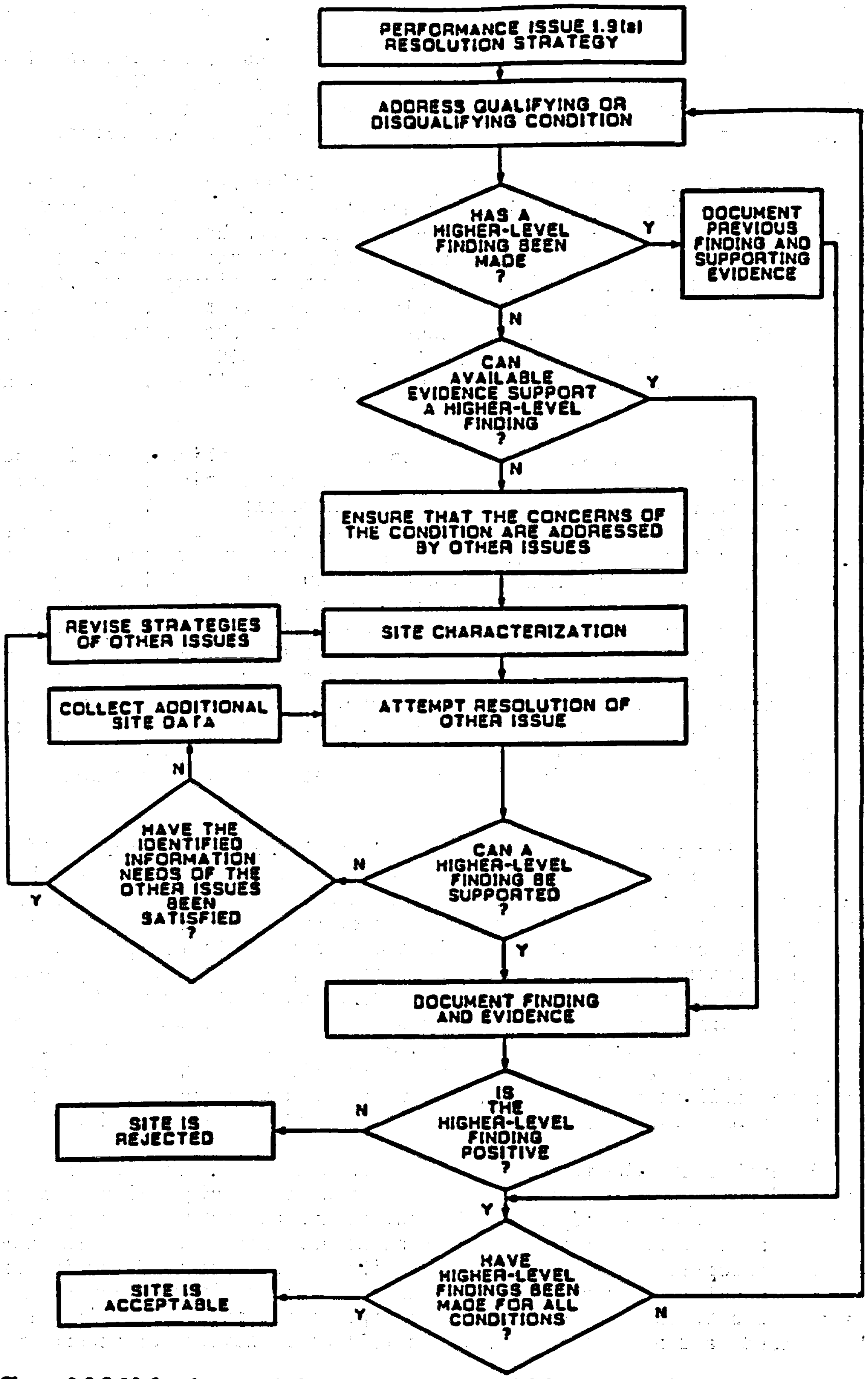

Figure 8.3.5.18-1. Issue resolution strategy for Issue 1.9(a) (postclosure higher-level findings).

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additional data will be collected, and compliance will be reassessed. This process continues until there is sufficient evidence to support either a positive or a negative higher-level finding for every qualifying and disqualifying condition.

As discussed previously, findings are not required for the favorable conditions or the potentially adverse conditions at this stage in the siting process. Site conditions that may favorably affect performance will be considered only to the extent necessary in the assessment of compliance with the NRC regulations (Issues 1.1 through 1.6; total system performance, individual protection, ground-water protection, containment by waste package, engineered barrier system release rates, and ground-water travel time, respectively). However, since the potentially adverse conditions describe processes or events that could adversely affect postclosure performance, it would be prudent to ensure that they are being considered in the appropriate performance assessments performed in support of the other performance issues. The concerns of the potentially adverse conditions of 10 CFR Part 960 are very similar to the concerns of the potentially adverse conditions of the NRC's siting criteria (10 CFR 60.122), which are addressed by Issue 1.8 (Section 8.3.5.17). The strategy for addressing the potentially adverse conditions of the NRC siting criteria is to link each of the conditions to the site characteristics and disruptive scenarios being considered in the assessments of postclosure performance of the total repository system (Issue 1.1, Section 8.3.5.13) and the engineered barrier system (Issue 1.4, Section 8.3.5.9, and Issue 1.5, Section 8.3.5.10). This will ensure that the effects on postclosure performance of each of the potentially adverse conditions of the NRC siting criteria will be evaluated. Because of the similarity of the NRC's potentially adverse conditions to the DOE's potentially adverse conditions, the DOE's analysis indicates that the information and evaluations performed to support resolution of Issue 1.8 (NRC siting criteria) will ensure that the effects of the DOE's potentially adverse conditions on postclosure performance will be adequately evaluated.

The following is a discussion of the qualifying condition of the postclosure system guideline and of each of the qualifying and disqualifying conditions of the postclosure technical guidelines. The ties of each condition to the NRC regulations are explained, and the postclosure performance issue resolution strategies that will be relied upon are identified. The information relevant to each guideline, which will be collected during site characterization and used in the resolution of the other issues, is also given.

System guideline qualifying condition

The qualifying condition of the postclosure system guideline is stated in 10 CFR 960.4-1(a) as follows:

> The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60

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This qualifying condition is concerned with the overall compatibility of the geologic setting with the isolation of waste. To satisfy this condition, evidence must demonstrate that the characteristics of the geologic setting were investigated and that they do not prevent compliance with the EPA's requirements for the physical separation of radioactive waste from the accessible environment after closure (40 CFR Part 191, Subpart B, as implemented by 10 CFR 60.112) or prevent the use of engineered barriers to ensure compliance with these requirements or those separate requirements established by the NRC for particular barriers (10 CFR 60.113).

The requirements of 40 CFR Part 191, Subpart B, as implemented by 10 CFR Part 60, are addressed through Issues 1.1, 1.2, and 1.3. Issue 1.1 assesses radioactive releases to the accessible environment during the next 10,000 yr (40 CFR 191.13, as implemented by 10 CFR 60.112). Issue 1.2 evaluates individual doses in the accessible environment (40 CFR 191.15). Issue 1.3 is concerned with the protection of special sources of ground water (40 CFR 191.16).

The NRC's requirements for particular barriers after permanent closure are contained in 10 CFR 60.113, which establishes the requirements for the performance of the engineered barrier system with respect to waste package containment period, limits on the rate of releases from the engineered barrier system, and requirements for the geologic setting with respect to the pre-waste-emplacement ground-water travel time. These requirements are addressed by Issues 1.4, 1.5, and 1.6, respectively.

The information that will be used to support a higher-level finding for this qualifying condition, therefore, is a compilation of all the site characteristics identified and evaluated through the issue resolution strategies of Issues 1.1 through 1.6, and evidence that these site characteristics will not prevent the resolution of these six issues.

Issues 1.1, 1.2, and 1.3 are discussed in Sections 8.3.5.13, 8.3.5.14, and 8.3.5.15. Issues 1.4, 1.5, and 1.6 are discussed in Section 8.3.5.9, 8.3.5.10 and 8.3.5.12. The site information that will be considered and evaluated in the resolution of these issues is described in these sections. Collectively, this represents the information upon which a higher-level finding for the system guideline qualifying condition will be based. The higher-level findings, however, may be made before all of the information that will support resolution of these issues in the license application becomes available.

Geohydrology technical guideline

The geohydrology technical guideline has one qualifying condition and one disqualifying condition.

<u>Qualifying condition</u>. The qualifying condition for the geohydrology technical guideline is stated in 10 CFR 960.4-2-1(a) as follows:

> The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with

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(1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

The qualifying condition for the geohydrology technical guideline requires that the present and expected geohydrologic setting permit compliance with the postclosure system guideline qualifying condition (Section 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of that qualifying condition are addressed by Issues 1.1 through 1.6.

The geohydrology qualifying condition also specifically requires that the geohydrologic setting permit compliance with the requirements of 10 CFR 60.113: radionuclide containment within the waste package, limits on allowable releases from the engineered barrier system, and a minimum pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment. These three performance requirements are addressed by Issues 1.4, 1.5, and 1.6 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12), respectively.

The evidence to support a higher-level finding for this qualifying condition, therefore, will be made available through the analyses used to evaluate resolution of Issues 1.1 through 1.6. The evidence will show how the geohydrologic setting was considered in these evaluations and that these characteristics will not prevent the resolution of these issues. Table 8.3.5.18-3 shows the general present and expected characteristics of the geohydrologic setting that will be considered by each issue. A more detailed discussion of how these characteristics will be evaluated in the resolution of each issue is presented in the SCP section addressing that issue.

<u>Disqualifying condition</u>. The disqualifying condition for the geohydrology technical guideline is stated in 10 CFR 960.4-2-1(d) as follows:

> A site shall be disqualified if the pre-waste emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 yr along any pathway of likely and significant radionuclide travel.

This disqualifying condition is essentially the same as the NRC's pre-waste emplacement ground-water travel time objective, stated in 10 CFR 60.113(a)(2). Issue 1.6 addresses the NRC's ground-water travel time objective. In the process of resolving Issue 1.6, the site information and the calculational models necessary to determine the ground-water travel times and ultimately demonstrate compliance with the objective will be compiled. All the information necessary to support a higher level finding for the geohydrology disqualifying condition, therefore, will be provided by Issue 1.6. This information is discussed in greater detail in Section 8.3.5.12.

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Table 8.3.5.18-3. Geohydrologic characteristics considered in making a higher-level finding for the qualifying condition of the geohydrology technical guideline, and issues for which the information will be obtained

Issue	Information
1.1	Same characteristics as used by Issue 1.6 below Disruptive conditions Increase in percolation flux Change in water-table altitude Change in saturated-zone head gradients Creation of surficial discharge points
1.2	Same characteristics as used by Issue 1.6 below
1.3	Regional hydrogeologic reconnaissance of the site Regional ground-water flow system Ground-water uses Site hydrogeologic system Aquifer communication Aquifer contamination potential
1.4	Water flow mechanism in the host rock Quantity of water flow in contact with waste packages
1.5	Water flow mechanism in the host rock Quantity of water flow in contact with waste packages
1.6	Unsaturated zone characteristics Flux Moisture content Pressure head (matric potential) Saturation Moisture retention curve Permeability Saturated zone characteristics Flux Pressure head Saturated permeability Aquifer geometry Water-table altitude

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Geochemistry technical guideline

The geochemistry technical guideline has one qualifying condition and no disqualifying conditions.

Qualifying condition. The qualifying condition for the geochemistry technical guideline is stated in 10 CFR 960.4-2-2(a) as follows:

> The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

The qualifying condition for the geochemistry technical guideline requires that the present and expected geochemical setting permit compliance with the postclosure system guideline qualifying condition (Section 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of the system guideline qualifying condition are addressed by Issues 1.1 through 1.6.

The geochemistry qualifying condition also specifically requires that the geochemical setting permit compliance with the requirements of 10 CFR 60.113: radionuclide containment within the waste package, limits on allowable releases from the engineered barrier system, and a minimum pre-waste emplacement ground-water travel time from the underground facility to the accessible environment. These three performance requirements are addressed by Issues 1.4, 1.5, and 1.6 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12), respectively.

The evidence to support a higher-level finding for this qualifying condition, therefore, will be made available through the analyses used to evaluate the resolution of Issues 1.1 through 1.6. The evidence will show how the geochemical setting was considered and that these characteristics will not prevent the resolution of these issues. Table 8.3.5.18-4 shows the general present and expected characteristics of the geochemical setting that will be considered during the resolution of each issue. A more detailed discussion of how these characteristics will be evaluated in the resolution of each issue is presented in the SCP section addressing that issue.

Rock characteristics technical guideline

The rock characteristics technical guideline has one qualifying condition and no disqualifying conditions.

Qualifying condition. The qualifying condition for the rock characteristics technical guideline is stated in 10 CFR 960.4-2-3(a) as follows:

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Table 8.3.5.18-4. Geochemical characteristics considered in making a higher-level finding for the qualifying condition of the geochemistry technical guideline, and issues for which the information will be obtained

Issue	Information

1.1	Coupling factors and radionuclide retardation factors
	Gas-phase carbon-14 transport characteristics
	Disruptive conditions
	    Change in ground-water chemistry
	    Change in unsaturated zone K_d values
	    Change in saturated zone K_d values

1.2	Coupling factors and radionuclide retardation factors Gas-phase carbon-14 transport characteristics
1.3	No geochemistry information needed
1.4	Ground-water chemistry in host rock
1.5	Ground-water chemistry in host rock
1.6	No geochemistry information needed

> The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

The qualifying condition for the rock characteristics technical guideline requires that the present and expected characteristics of the host rock and surrounding units permit compliance with the postclosure system guideline qualifying condition (Section 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of that qualifying condition are addressed by Issues 1.1 through 1.6.

The rock characteristics qualifying condition also specifically requires that the rock characteristics permit compliance with the requirements of 10 CFR 60.113: radionuclide containment within the waste package, limits on allowable releases from the engineered barrier system, and a minimum pre-

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waste emplacement ground-water travel time from the underground facility to the accessible environment. These three performance requirements are addressed by Issues 1.4, 1.5, and 1.6 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12), respectively.

The evidence to support a higher-level finding for this qualifying condition, therefore, will be made available through the analyses used to evaluate resolution of Issues 1.1 through 1.6. The evidence will show how the rock characteristics of the geologic setting were considered in these evaluations. Table 8.3.5.18-5 shows the present and expected rock characteristics of the geologic setting that will be considered by each issue. A more detailed discussion of how these characteristics will be evaluated in the resolution of each issue is presented in the SCP section addressing that issue.

Climatic changes technical guideline

The climatic changes technical guideline has one qualifying condition and no disqualifying conditions.

Qualifying condition. The qualifying condition for the climatic changes technical guideline is stated in 10 CFR 960.4-2-4(a) as follows:

> The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

Table 8.3.5.18-5. Rock characteristics considered in making a higher-level finding for the qualifying condition of the rock characteristics technical guideline, and issues for which the information will be obtained

Issue	Information
1.1	Unsaturated zone characteristics Effective porosity Location of geologic unit contacts Fault zone characteristics Bulk density Fracture frequency

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Issue	Information
	Saturated zone characteristics Effective thickness Effective porosity Fracture compressibility Matrix-fracture interface constrictivity-tortuousity factors Fracture frequency Fault zone characteristics
1.2	Same characteristics as those used by Issue 1.1
1.3	No rock characteristics information required
1.4	No rock characteristics information required
1.5	No rock characteristics information required
1.6	Unsaturated zone characteristics In situ temperature Bulk density Effective porosity Hydrologic unit contact altitudes Fault displacement Fault locations
	Saturated zone characteristics Bulk density Effective porosity Aquifer geometry Lithologic unit contact altitudes Fault displacement Fault locations Fracture characteristics

The future climatic conditions at the site are expected to have some effect on the geohydrologic characteristics of the site during the next 10,000 yr. The qualifying condition for the climatic-changes technical guideline requires that the future climatic conditions, both expected and unexpected, permit compliance with the postclosure system guideline qualifying condition (10 CFR 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of the postclosure system guideline qualifying condition are addressed by Issues 1.1 through 1.6.

Future climatic conditions will be investigated during site characterization to establish the potential for unexpected disruptive changes to the hydrologic system as a result of unexpected, yet credible, climatic condi-

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tions. These unexpected changes in the geohydrologic setting will be factored into the evaluations for resolution of Issue 1.1.

The requirements of 40 CFR 191.13, 40 CFR 191.15, and 40 CFR 191.16, which are addressed by Issues 1.1, 1.2, and 1.3, and of 10 CFR 60.113, which is addressed by Issues 1.4, 1.5, and 1.6, are concerned with the undisturbed expected performance of the repository system. Future expected climatic conditions will be factored into the resolution of these issues through the evaluation of the expected geohydrologic setting. Issue 1.1 must also take disruptive processes and events into account.

The evidence to support a higher-level finding will consist of demonstrations that future climatic conditions, both expected and unexpected, have been investigated and that these conditions will not prevent the resolution of Issues 1.1 through 1.5. Table 8.3.5.18-6 shows the effects of future unexpected disruptive climatic conditions that will be considered specifically during the resolution of Issue 1.1. The way in which these effects will be evaluated in the resolution of Issue 1.1 is discussed in Section 8.3.5.13. As stated previously, the effects of expected conditions will be incorporated in the resolution of the other issues through the development and evaluation of the expected geohydrologic setting.

Erosion technical guideline

The erosion technical guideline has one qualifying condition and one disqualifying condition.

Qualifying condition. The qualifying condition for the erosion technical guideline is stated in 10 CFR 960.4-2-5(a) as follows:

> The site shall allow the underground facility to be placed at a depth such that the erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

Hypothetically, future erosional processes could affect the transport of radionuclides to the accessible environment by decreasing the thickness of the overburden, or by creating surficial discharge points between the underground facility and the boundary of the accessible environment. The qualifying condition for the erosion technical guideline requires that the future erosional processes, both expected and unexpected, permit compliance with the postclosure system guideline qualifying condition (10 CFR 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of the postclosure system guideline qualifying condition are addressed by Issues 1.1 through 1.6.

The requirements of 40 CFR 191.13, 40 CFR 191.15, and 40 CFR 191.16, which are addressed by Issues 1.1, 1.2, and 1.3, and of 10 CFR 60.113, which are addressed by Issues 1.4 and 1.5, are concerned with the undisturbed expected performance of the repository system (the requirement of 10 CFR

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Table 8.3.5.18-6. Effects of future climatic conditions considered in making a higher-level finding for the qualifying condition of the climatic change technical guideline and in the resolution of Issue 1.1

Issue	Information
1.1	Disruptive conditions: Change in infiltration through host rock Change in water table altitude Change in saturated-zone head gradients Creation of surficial discharge points

60.113 addressed by Issue 1.6 considers pre-emplacement conditions). Future expected erosional processes will be investigated during site characterization and will be factored into the resolution of these issues through the evaluation of the expected geohydrologic setting and rock characteristics. Issue 1.11 must also take into account disruptive processes and events. As discussed in Section 8.3.5.13, erosion has been considered in the identification of disruptive scenarios. Erosional processes at the Yucca Mountain site have been evaluated and no disruptive scenarios associated with erosional processes have been found that are credible at the site during the next 10,000 yr. Evidence to support this position is presented in Chapter 1.

Disqualifying condition. The disqualifying condition for the erosion technical guideline is stated in 10 CFR 960.4-2-5(d) as follows:

> The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 m below the directly overlying ground surface.

A positive higher-level finding can be made for the disqualifying condition on erosion on the basis of the geologic unit selected for the repository location and the conceptual design for the repository, which place the repository at a depth in excess of 200 m from the overlying ground surface (Chapter 6).

Dissolution technical guideline

The dissolution technical guideline has one qualifying condition and one disqualifying condition. The qualifying condition is stated in 10 CFR 960.4-2-6(a) as follows:

> The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of dissolution within the

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> geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

The disqualifying condition is stated in 10 CFR 960.4-2-6(d) as follows:

> The site will be disqualified if it is likely that, during the first 10,000 yr after closure, active dissolution, as predicted on the basis of the geologic record, would result in a loss of waste isolation.

Positive higher-level findings have been made previously for these two conditions for the Yucca Mountain site. The evidence supporting these higher-level findings is presented in Chapter 6 of the Yucca Mountain environmental assessment (DOE, 1986b). Since higher-level findings have been made, the dissolution technical guideline does not need to be considered further.

Tectonics technical guideline

The tectonics technical guideline has one qualifying condition and one disqualifying condition.

Qualifying condition. The qualifying condition for the tectonics technical guideline is stated in 10 CFR 960.4-2-7(a) as follows:

> The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

Future tectonic activity at the site is expected to have some effect on the geohydrologic and rock characteristics of the site during the next 10,000 yr. The qualifying condition for the tectonics technical guideline requires that future tectonic activity, both expected and unexpected, permit compliance with the postclosure system guideline qualifying condition (10 CFR 960.4-1). Predictions of future tectonic activity will be based on the evidence of such activity during the Quaternary. As explained in the discussion of the system guideline qualifying condition, the requirements of the postclosure system guideline qualifying condition are addressed by Issues 1.1 through 1.6.

Future tectonic activity will be investigated during site characterization to establish the potential for unexpected disruptive changes to the expected conditions as a result of unexpected, yet credible, tectonic events and processes.

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The requirements of 40 CFR 191.13, 40 CFR 191.15, and 40 CFR 191.16, which are addressed by Issues 1.1, 1.2, and 1.3, and of 10 CFR 60.113, which are addressed by Issues 1.4 and 1.5, are concerned with the undisturbed expected performance of the repository system (the requirement of 10 CFR 60.113 addressed by Issue 1.6 considers pre-emplacement conditions). Future likely tectonic activity will be factored into the resolution of these issues through the evaluation of the expected geohydrologic and rock characteristics. Issue 1.1 must also take disruptive processes and events into account.

The evidence to support a higher-level finding will consist of demonstrations that the potential for future tectonic activity has been investigated and that any such activity will not prevent the resolution of this issue. Table 8.3.5.18-7 shows the effects of future disruptive tectonic activity that will be considered during the resolution of Issue 1.1. The way in which these effects will be evaluated in the resolution of Issue 1.1 is discussed in Section 8.3.5.13.

Disqualifying condition. The disqualifying condition for the tectonics technical guideline is stated in 10 CFR 960.4-2-7(d) as follows:

A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur.

This disqualifying condition is concerned with future fault movement or other tectonics-related ground motion disrupting the geologic setting during the next 10,000 yr such that isolation will be adversely affected. The DOE defines isolation in 10 CFR 960.2 as "inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits." The prescribed limits are those limits set forth by the EPA in 40 CFR Part 191, Appendix A and implemented by 10 CFR 60.112. The effects of fault movement or other ground motion on waste isolation will be evaluated as part of the evaluation of the tectonics guideline qualifying condition for expected performance.

Human interference technical guideline

This technical guideline has two parts. The first part is concerned with natural resources and has one qualifying condition and two disqualifying conditions. The second part is concerned with site ownership and control, and has one qualifying condition.

Natural resources qualifying condition. The natural resources qualifying condition of the human interference technical guideline is stated in 10 CFR 960.4-2-8-1(a) as follows:

This site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology-- the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be

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Table 8.3.5.18-7. Effects of future tectonic activity considered in making a higher-level finding for the qualifying condition of the tectonics technical guideline and in the resolution of Issue 1.1

Issue	Information
1.1	Structural deformation
	Rupturing waste packages
	Increasing water table altitude
	Increasing percolation flux
	Altering hydraulic gradients
	Diverting flow pathways
	Igneous activity
	Causing direct releases
	Rupturing waste packages
	Altering hydraulic gradients
	Diverting flow pathways
	Increasing water table altitude
	Ground motion
	Closure of borehole air gap

likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

The presence of natural resources at a site has the potential to encourage activities that could interfere with the isolation of waste. Human activities could result in direct releases, if the waste containers were penetrated and waste brought to the surface, or could affect isolation in other ways, such as a shortening of travel pathways by ground-water removal. The natural resource qualifying condition requires that the extent of natural resources at the site be such that retrieval activities in the future would not be likely, so that compliance with the postclosure system guideline would not be prevented. As explained, the requirements of the system guideline are addressed by Issues 1.1 through 1.6.

The requirements of 40 CFR 191.15 and 40 CFR 191.16, which are addressed by Issues 1.2 and 1.3, and of 10 CFR 60.113, which are addressed by Issues 1.4, 1.5, and 1.6, are only concerned with the undisturbed performance of the repository system (the requirement of 10 CFR 60.113 addressed by Issue 1.6 considers pre-waste-emplacement conditions). Since human intrusion due to the potential for natural resources is considered a disruptive scenario, the evidence to support a higher-level finding for this qualifying condition will be made available through the information and analyses used to support resolution of Issue 1.1, which will consider the long-term performance of the

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system and take disruptive processes and events into account. The evidence will consist of demonstrations that the potential for future human interference has been investigated and will not prevent the resolution of this issue. Table 8.3.5.18-8 shows the future human activities that will be considered during the resolution of Issue 1.1. The way in which these effects will be evaluated in the resolution of Issue 1.1 is discussed in Section 8.3.5.13.

Natural resources disqualifying conditions. There are two disqualifying conditions for the natural resources section of the human interference technical guideline. They are stated in 10 CFR 960.4-2-8-1(d) as follows:

A site shall be disqualified if

1. Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment; or

2. Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation.

This disqualifying condition is essentially the inverse of the natural resources qualifying condition discussed previously. (In establishing the disruptive scenarios associated with human activities that could occur at the site, previous exploration, mining, and extraction activities are investigated.) Therefore, the same evidence that will support a higher-level finding for the qualifying condition will be sufficient to support a higher-level finding for this disqualifying condition.

Site ownership and control technical guideline

Site ownership and control qualifying condition. The site ownership and control qualifying condition of the human interference technical guideline is stated in 10 CFR 960.4-2-8-2(a) as follows:

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

The concern of this qualifying condition is an institutional one related to acquiring sufficient land for the controlled area in compliance with the requirements of 10 CFR 60.121. DOE ownership and control of this land is expected to decrease the potential for future human interference activities. The institutional concerns of this guideline condition are outside the scope of site characterization as defined by the Nuclear Waste Policy Act (NWPA, 1983) and, hence, are outside the scope of the SCP. The issue of land acquisition will be addressed in future environmental program planning (see Section 8.3.1.11).

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Table 8.3.5.18-8. Effects of human activities considered in making a higher-level finding for the qualifying condition of the human interference technical guideline and in the resolution of Issue 1.1

Issue	Information
1.1	Irrigation Change in flux through repository horizon Change in water-table altitude Change in saturated-zone head gradients
	Ground-water withdrawal Change in water-table altitude Change in saturated-zone head gradients
	Surface and subsurface mining Change in water-table altitude Change in saturated-zone head gradients
	Construction of surface water impoundments Change in flux through repository horizon Change in water-table altitude Change in saturated-zone head gradients
	Exploratory drilling Potential for and effects of interception of waste by exploratory drilling

Regulatory basis for Issue 1.9(b) of the postclosure siting guideline

Comparative evaluations of postclosure performance, as stipulated in 10 CFR 960.3-1-5, are no longer needed as the result of the passage of the NWPAA (NWPAA, 1987). Following the characterization of the Yucca Mountain site and before recommending the site for the development of a repository, the DOE will nevertheless evaluate the postclosure performance of the repository system. The NRC implementation guidelines (10 CFR 960.3-1-5) will be followed in making these evaluations. The guidelines state that "predicted releases of radionuclides to the accessible environment" will be evaluated by combining "releases of different radionuclides...by the methods specified in Appendix A of 40 CFR Part 191."

Two evaluations are required to predict releases for 100,000 yr after repository closure. The first evaluation will emphasize the performance of the natural barriers at the site. The second evaluation will (1) consider the expected performance of the repository system; (2) be based on the expected performance of waste packages and waste forms, in compliance with the requirements of 10 CFR 60.113, and on the expected hydrologic and

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geochemical conditions at the site; and (3) take credit for the expected performance of all other engineered components of the repository system.

In making these evaluations, the DOE will only consider natural processes and events that are considered likely to occur or exist at the site over the next 100,000 yr.

Approach to resolving Issue 1.9(b)

Issue 1.1 addresses the NRC's overall system performance objective (10 CFR 60.112). For the resolution of Issue 1.1, an assessment of the total system performance will be made to predict the performance of the total repository system over the next 10,000 yr. This assessment will consider both undisturbed and disturbed conditions. Undisturbed conditions are those processes and events that have a probability greater than 0.1 of occurring or existing at the site during the next 10,000 yr. Disturbed conditions are those processes and events that have a probability between 0.1 and 0.0001 of occurring or existing during the next 10,000 yr at the site. Processes and events that have a probability of less than 0.0001 of occurring or existing at the site during the next 10,000 yr are considered incredible and will not be considered.

Scenario classes have been identified to describe the events and processes. These scenario classes are described in Section 8.3.5.13. Through the resolution strategy of Issue 1.1, performance measures and parameters have been identified to address the scenario classes.

To resolve Issue 1.9(b), the DOE will rely on the same strategy used to resolve Issue 1.1, with a few modifications. The nominal scenario class, the class describing undisturbed conditions, will be expanded to include those processes and events that have a probability of greater than 0.1 of occurring during the next 100,000 yr. This means that certain scenario classes considered to represent disturbed conditions over the 10,000-yr performance period may fall within the nominal scenario class for the 100,000-yr performance period. The same total system model and submodels used to resolve Issue 1.1 will be used for Issue 1.9(b), however, additional information may be necessary. Disturbed scenario classes--those within a probability of less than 0.1 of occurring at the site during the next 100,000 yr--are considered to be incredible and need not be considered.

Figure 8.3.5.18-2 shows this strategy. The first step is to evaluate the nominal and disturbed-performance scenario classes that are being considered in the assessment of the 10,000-yr performance of Issue 1.1. Those conditions that are within the 10,000-yr nominal-performance scenario class will also be considered in the nominal-performance scenario class for the 100,000-yr evaluation. In addition, the 100,000 yr nominal scenario class may need to be expanded because (1) some of the disturbed-performance scenario classes of the 10,000-yr assessment may become part of the nominal-performance scenario class of the 100,000-yr evaluation, and (2) some events and processes eliminated from consideration in the 10,000-yr assessment may need to be considered in the 100,000-yr nominal-performance scenario class. In both cases, this will depend upon the probability of occurrence of the events of these scenario classes, i.e., if the probability of realization during the next 100,000 yr is greater than 0.1. The determination of events

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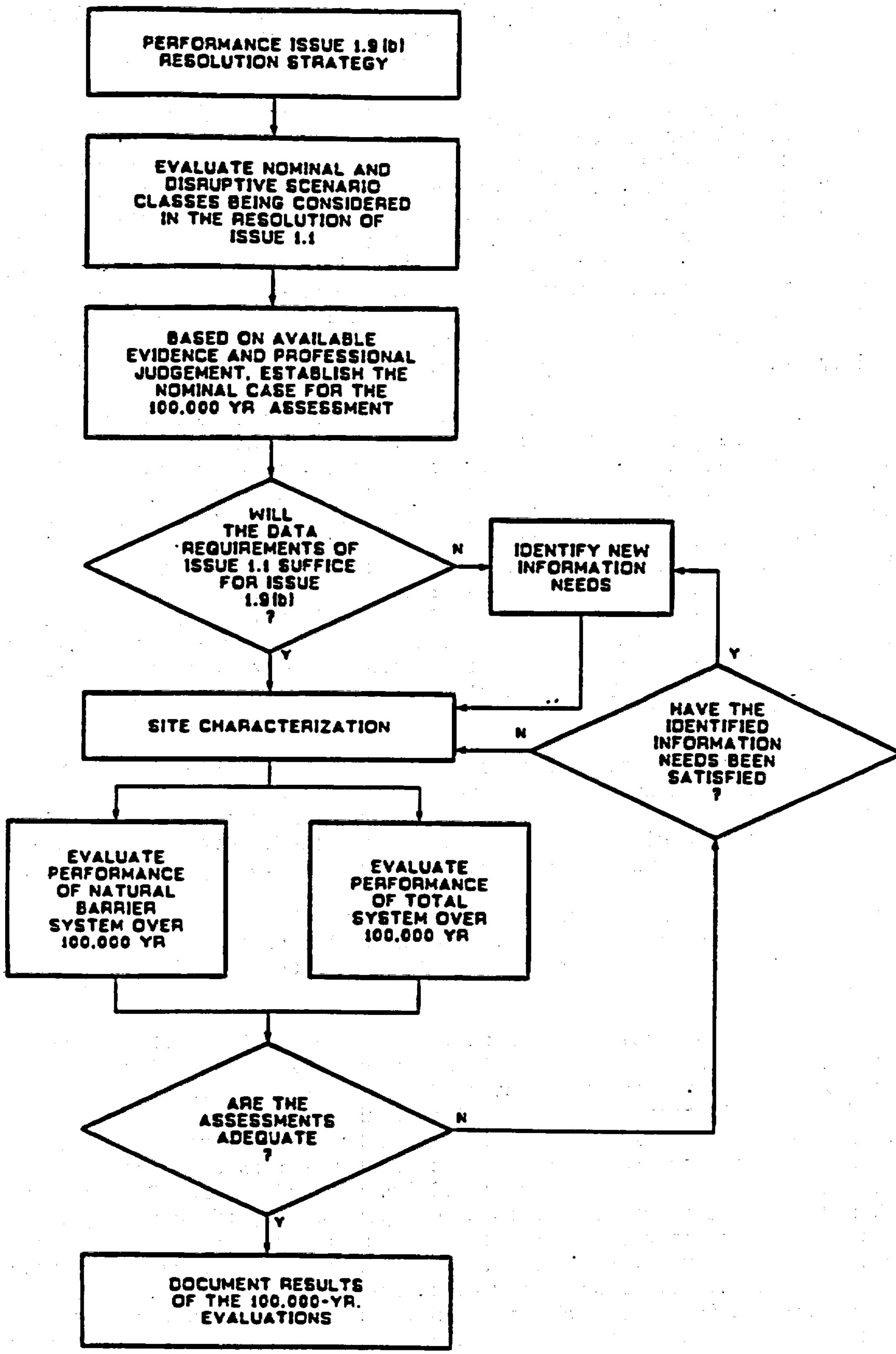

Figure 8.3.5.18-2. Resolution strategy for Issue 1.9(b).

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and processes that need to be considered, as in the assessment of 10,000-yr performance, are identified based on available evidence and professional judgment and will be revised as necessary based on new information.

The next step, once the nominal performance scenario class of events and processes is established, is to determine what information is required to evaluate the scenario class and assess the performance of the repository during the next 100,000 yr. This is accomplished by evaluating the data requirements of Issue 1.1. As mentioned previously, the models used in the 10,000-yr performance are sufficient to evaluate 100,000-yr performance. The only additional information would be the information needed to address events and processes that were not included in either the nominal or disturbed-performance scenario classes of Issue 1.1, or the information necessary to address events or processes over 100,000 yr that would not be adequately addressed by data for the 10,000-yr period.

Once these data needs are established, site characterization is conducted. The necessary information is collected during this phase, and the 100,000-yr performance of the repository is assessed, based on the 100,000-yr nominal-performance scenario class and using the same techniques, models, etc., as those used in the resolution of Issue 1.1. With respect to a radionuclide source term, two evaluations are made, in accordance with 10 CFR 960.3-1-5. The first will assess the performance of the repository system, using as a source term a range of release rates bounded by a factor of ten above and below the rates specified in 10 CFR 60.113, thus emphasizing the isolation capabilities of the site's natural barriers. The second assessment will use as a radionuclide source term the actual expected performance of the engineered barrier system. This will allow full assessment of all aspects of the repository system at the site.

If during these evaluations insufficient information is available to assess the 100,000-yr performance, the data base will be reviewed. If the information identified is found adequate, but the data to satisfy the information needs are not, additional data will be collected. Otherwise, additional information needs may be necessary to assess 100,000-yr performance.

This reevaluation will continue until a satisfactory assessment of 100,000-yr performance is attained. The results of both evaluations will then be documented and used in the recommendation of the site for development of a repository.

The steps of this resolution strategy have been completed through the identification of information needs. It has been determined, using the same information, evaluations, and judgment used in constructing the scenario classes of Issue 1.1, that the only conditions that need to be added to the nominal-performance scenario class of Issue 1.1 to form the nominal-performance scenario class for Issue 1.9(b) are those conditions associated with climatic events and processes. Over the 10,000-yr period, the DOE has determined that disruptive climatic changes have a probability of occurring of less than 0.1 and are therefore considered in the disturbed-performance scenario classes. However, over the 100,000-yr period these changes are expected to have a probability of occurring of greater than 0.1, and therefore need to be included in the 100,000-yr nominal-performance scenario class. The tectonic events and processes that were determined to have a probability

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of realization of less than 0.1 during the next 10,000 yr (and are, therefore, included in the disturbed-performance scenario classes of Issue 1.1) are expected to also have a probability of realization of less than 0.1 for the 100,000-yr period and hence need not be considered. Also, the disturbed-performance scenario classes of Issue 1.1 that were associated with human activities need not be considered in the 100,000-yr assessments since they are not natural events or processes. As for the other events and processes that were part of the nominal-performance scenario class of Issue 1.1 and will also be part of the nominal-performance scenario class of Issue 1.9(b), the information required for the 10,000-yr assessment will be sufficient for the 100,000-yr assessment.

The information needed to supplement that information required by Issue 1.1 to assess 100,000-yr performance is shown in Table 8.3.5.18-9. This information will be obtained through the climate test program (Section 8.3.1.5). This information, with the information and analyses of Issue 1.1, is expected to be sufficient to make the two 100,000-yr performance evaluations as required by 10 CFR 960.3-1-5. In addition, the data required to evaluate the tectonic-related disturbed-performance scenario classes of Issue 1.1 will provide evidence to support the position that, over the 100,000-yr period, tectonic events would not be part of the nominal-performance scenario class. As mentioned, the positions taken with regard to the events and processes included in the 100,000-yr nominal-performance scenario class will be modified as necessary as new site data becomes available.

Table 8.3.5.18-9. Scenarios and parameters associated with the 10,000-yr disturbed-performance scenario class that need to be added to the 100,000-yr nominal-performance scenario class (page 1 of 2)

Scenario class (from Section 8.3.5.13)	Performance parameter (adapted from Section 8.3.5.13)	Tentative parameter goal (adapted from Section 8.3.5.13)	SCP section and parameter category or set	Direct or associated study or activity[a]
Climatic change causes increase in infiltration over controlled area[b]	Expected magnitude of flux change due to climatic changes over next 100,000 yr	Show expected flux change will be less than 5 mm	8.3.1.5.2	8.3.1.5.2.2.2(D)
			Future climate model	8.3.1.5.1.6
			Infiltration characteristics	8.3.1.2.2.1
			Unsaturated-zone flow model	8.3.1.2.2.9
Climatic change causes an increase in altitude of water table	Expected magnitude of change in water-table level due to climatic changes over the next 100,000 yr	Show expected magnitude of water-table rise will be less than 100 m	8.3.1.5.2	8.3.1.5.2.2.3(D)
			Future climate model	8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5

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Table 8.3.5.18-9. Scenarios and parameters associated with the 10,000-yr disturbed-performance scenario class that need to be added to the 100,000-yr nominal-performance scenario class (page 2 of 2)

Scenario class (from Section 8.3.5.13)	Performance parameter (adapted from Section 8.3.5.13)	Tentative parameter goal (adapted from Section 8.3.5.13)	SCP section and parameter category or set	Direct or associated study or activity[a]
Climatic change causes appearance of surficial discharge points within controlled area	Expected locations of surficial discharge points within the controlled area over the next 100,000 yr; magnitude of discharge at each location	Show that no surficial discharge points could appear within controlled area, given a water-table rise less than 160 m	Same as information given for an increase in altitude of water table	
Climatic change causes an increase in the gradient of the water-table within the controlled area	Expected magnitude of change in water-table gradient due to climatic change over the next 100,000 yr	Show average gradient to controlled area boundary will be less than 2×10^{-3}	Same as information given for an increase in altitude of water table	

[a](D) indicates the study or activity directly addressing the scenario.
[b]The controlled area is the actual area chosen according to the 40 CFR 191.12 definition of controlled area.

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8.3.5.19 Substantially completed analytical techniques

Postclosure performance assessments by the Yucca Mountain Project will evaluate the potential for containment and isolation of waste emplaced in the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain as discussed in Issues 1.1 through 1.9 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12 through 8.3.5.18). The objective of the postclosure performance assessments is to determine whether the Yucca Mountain repository system is such that the regulatory standards set forth in 10 CFR 960.4, 10 CFR 60.112, 10 CFR 60.113, 40 CFR 191.13, 40 CFR 191.14, and 40 CFR 191.15 can be met.

Preclosure performance assessments will evaluate the potential for constructing and operating a repository in the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain, as discussed in Section 6.4 and addressed by Issues 2.1 through 2.5 and Issue 4.1 (Sections 8.3.5.2 through 8.3.5.6). The objective of the preclosure performance assessments is to determine if the repository system is such that the standards set forth in 10 CFR 960.5, 10 CFR 60.111, 40 CFR 191 Part A, and 10 CFR Part 20 can be met.

Over the next few years, preclosure and postclosure performance assessments will be made using many mathematical and numerical analytical techniques that have already been developed. Analytical techniques considered substantially completed are those that already exist and could be used, with little additional work or only minor modifications, to conduct performance assessment analyses. These analytical techniques have not yet been fully verified and validated for application to the conditions that exist at the Yucca Mountain Project repository site. The need for verification and validation of analytical techniques depends upon the intended application and the specific nature of the techniques. Preliminary verification is currently in progress, as discussed in this section. Validation activities have been initiated but, for the most part, are still being developed, as discussed in Section 8.3.5.20.

Those techniques that are substantially completed and available are summarized here for postclosure and preclosure performance issues. Section 8.3.5.20 describes plans to verify the accuracy of the techniques and to validate the models that are based on these techniques and also discusses the techniques that still require significant development.

8.3.5.19.1 Postclosure performance-assessment analytical techniques

Computer codes that have been developed and are found suitable for use in assessing the postclosure performance of a repository at the Yucca Mountain site are listed in Table 8.3.5.19-1. These computer codes fall into four broad categories, depending on the physical processes and conceptual models they incorporate: (1) those suitable for assessing the performance of the waste package; (2) those suitable for assessing the behavior of the rock and the water in the repository environment, where heat effects are important and cannot be completely decoupled from the geomechanical and hydrological calculations; (3) those suitable for assessing site behavior on a scale at which temperature effects do not have to be accounted for directly; and (4) those suitable for assessing the behavior of the entire repository system

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Table 8.3.5.19-1. Computer codes for use in performance assessment

Performance assessment task	Performance measures	Type of analysis	Potential codes[a]	Related issue in which the code may be used[b]
Waste package	Canister temperature	Conductive and convective heat and mass transfer	ADINAT, NORIA, COYOTE, ARRAY F, TACO2D	1.4
	Waste containment time, waste release rate	Material degradation, dissolution, decay, leaching Geochemistry	WAPPA, ORIGEN2, MORSE-L, NIKE2D, EQ3/EQ6, PANDORA, PHR81	1.4, 1.5
Repository	Rock stress-strain, displacement, permeability changes	Rock stress and fracture alterations induced by excavation; thermal loads, moisture changes; backfilling	ADINAT, SPECTROM 31, SPECTROM 41, JAC2D	1.4, 1.5, 1.6
	Unsaturated water travel times, radionuclide release rates	Water flow in unsaturated media; coupled water and heat flow; coupled water flow and radionuclide migration	NORIA/FEMTRAN, NAFE/TRACR3D, TOUGH	1.5, 1.6
Site	Ground-water travel time	Probabilistic analysis of ground-water travel time distributions along flow paths at Yucca Mountain	GWTT	1.6
	Unsaturated and saturated water and radionuclide transport	Water flow paths; radionuclide migration	SAGUARO/FEMTRAN, TRUST/TRUMP, NWFT, TRACR3D, ISOQUOD, MDOC, VSFAST,	1.1, 1.2, 1.3, 1.6
	Dose to man	Biosphere transport and human uptake	FABLM, DACRIN	1.2
Total integrated system	Radionuclide release Ground-water contamination Individual dose	Simple systems model of water flow in unsaturated media; leaching; flow and migration in unsaturated media; flow and migration in saturated media	TOSPAC, NWFT, SPARTAN	1.1, 1.2, 1.3
	Dose to man	Biosphere transport and human uptake	FABLM, DACRIN,	2
	Atmospheric transport	Inhalation dose at accessible environment boundary	AIRDOS-EPA	1.2

[a]The list of potential codes does not exclude use of other codes.
[b]Issues 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6 are discussed in Sections 8.3.5.13, 8.3.5.14, 8.3.5.15, 8.3.5.9, 8.3.5.10, and 8.3.5.12, respectively.

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and for probabilistic calculations of total releases to the accessible environment. The fourth category includes simplified versions of some of the models in the first three categories. In addition to the computer codes listed in Table 8.3.5.19-1, some simple analytical techniques, such as hand calculations, may be used in performance-assessment analyses. The information needs under each postclosure performance issue discussed in Sections 8.3.5.9 through 8.3.5.17 contain the descriptions of the analyses that will be done. Therefore, the last column entry in Table 8.3.5.19-1 lists the issue(s) that the code might be used to resolve so that the reader can determine what analyses might be done using these codes.

Table 8.3.5.19-2 briefly describes each code, its documentation, and its availability for use by the Yucca Mountain Project. There are three reasons for listing several codes for each type of application: (1) where closed-form analytic solutions do not exist and while benchmarking activities are ongoing, several codes whose performance can be compared are needed for verification exercises; (2) the complexity (i.e., dimensions, level of detailed physical parameter descriptions, etc.) of the analyses that must be done have not yet been determined; and (3) the specific capabilities of the codes are usually different.

8.3.5.19.2 Preclosure performance-assessment analytical techniques

Computer codes that could be used in constructing models to assess the preclosure safety of the Yucca Mountain repository site are listed in Table 8.3.5.19-3. These computer codes fall into two broad categories: preclosure repository-systems analyses and preclosure repository-consequence analyses. Computer codes for preclosure repository-systems analyses perform (1) initiating-event identification and quantification such as for criticality, fire, seismic activity, and flood; (2) systems-reliability studies such as analyses of fault trees and failure modes and effects; (3) human-reliability analysis; (4) common-cause failure analysis; (5) accident-sequence quantification; and (6) uncertainty, sensitivity, and importance analyses. Computer codes for preclosure repository-consequence analyses include (1) source-term characterization, (2) in-repository-consequence analysis, (3) environmental transport and offsite-consequence analyses, and (4) uncertainty and sensitivity analyses. In addition to the computer codes listed in Table 8.3.5.19-3, some simple analytical techniques, such as hand calculations, may be used in preclosure safety assessment. The last column in Table 8.3.5.19-3 lists the issues in which the codes may be used. Table 8.3.5.19-4 gives a brief description of each code identified as a potential code to be used by the Yucca Mountain Project and its status. The preclosure risk assessment methodology (PRAM) program is designed to assess the Yucca Mountain Project computer codes, as well as codes from other sources to determine the most appropriate computer codes to be used.

Unlike the computer codes used for postclosure performance assessment, most of the computer codes used in preclosure safety assessment are adopted from codes used for other nuclear-safety assessments (e.g., assessments of reactors). Compilation and evaluation of such codes can be found in the following references: Hoffman et al. (1977), Mauro et al. (1977), Mills and Vogt (1983), Till and Meyer (1983), NCRP (1984), Elder et al. (1986), Parks

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Table 8.3.5.19-2 Brief description of codes from Table 8.3.5.19-1 (page 1 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by Yucca Mountain Project[a]
ADINAT 1,2,3d	Linear, nonlinear, transient, steady state, thermal conduction	Temperature, space-dependent variation of heat, thermal conductivity; boiling model; multiple layers; anisotropic properties, generates input to SANDIA-ADINA	Bathe 1975; 1977	SNLA (a,o)
AIRDOS-EPA	Predictions of radionuclide concentrations in air, rates of deposition, intake rates, and doses	Modified Gaussian plume equation, Nuclear Regulatory Commission terrestrial food-chain models, dose-conversion factors	Moore et al., 1979	SNLA (a)
ARRAY F 3D	Thermal conduction and radiation; solutions by superposition of exponentially decaying point sources	Analytic solution of a heat source in an infinite medium; all material properties constant	Klett et al., 1980	SNLA (a,o)
COYOTE	Linear and nonlinear transient heat conduction with energy sources	Temperature, time, and space-dependent variation of specific heat and thermal conductivity; boiling in partially saturated media approximated through latent heat consideration; multiple material layers; jointed rock model	Gartling, 1982	SNLA (a,o)
DACRIN	Organ dose to man from acute or chronic inhalation of radioactive aerosols	ICRP Task Group Organ Models; atmospheric dispersion; effective radiation doses to organs and the gastrointestinal tract	Houston et al., 1974	PNL (a)
EQ3/EQ6	EQ3: Equilibrium distribution of chemical species in an aqueous solution; saturation state of fluid with respect to minerals. EQ6: Mass transfer and effects of heating and cooling of the aqueous solutions; irreversible reaction in rock-water system	EQ3: Fixed temperature and pressure; empirical models of minerals in stable phase assemblage; EQ6: Reaction path models include precipitation, reaction progress in open/closed system	Wolery, 1979	LLNL (a,o,d)
FEMTRAN	Convective, dispersive, and diffusive transport of dissolved constituents; sorption, first order decay; development with first order decay complete; decay chain capabilities in developmental stage	Unsaturated porous media; retardation by sorption; chemical reactions, decay, moisture-dependent retardation factor; assumes local equilibrium for sorption	Martinez, 1985	SNLA (a,o,d)

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Table 8.3.5.19-2 Brief description of codes from Table 8.3.5.19-1 (page 2 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by Yucca Mountain Project[a]
GWTT	Probability distributions of ground-water travel times along distribution of flow paths, simplified Darcy's law in both matrix and fractures	Frequency distribution for saturated conductivity; effective porosity in multilayers throughout repository; implicit assumptions for correlation lengths; probability distribution functions generated for flow paths; probability distribution functions calculated for areally integrated ground-water travel times	Sinnock et al., 1986	SNLA (o)
HDOC	Two-phase nonlinear mass and heat transport in porous media, radionuclide decay; method of dynamics of contours	Transient, 1D, nonlinear flow; solute transport includes advection and diffusion with decay and retardation of radionuclides		Los Alamos (a,o,d)
ISOQUOD	Regional saturated hydrologic analysis of aquifier systems in multilayered media	Heterogeneous, multidimensional saturated media, Darcy's law applied with transient leakage coefficient, storage/sink terms, transmissivity	Pinder, 1976	SNLA (o)
JAC2D	Linear and nonlinear static stress analysis of 2D solids	Temperature-dependent, elastoplastic strain hardening; temperature-dependent secondary creep, soil with thermal loading, jointed rock with thermal loading	Thomas, 1982	SNLA (o,d)
MORSE-L	Atomic displacements from slowing of alpha particles and fission fragments; attenuation and absorbed dose rate from gamma rays	Gamma-ray interaction with atoms in water, metal barrier, and waste to produce alpha particles and spontaneous fission	Wilcox, 1972	LLNL (o)
NIKE2D	Stress in waste package from external loads, thermal expansion and thermal gradients, volume expansion of corrosion products, residual stress from fabrication	Mechanical and thermal stress, yielding, and unstable crack propagation	Hallquist, 1983	LLNL (o)
NORIA	Transport of water, water vapor, air and energy through partially saturated porous media; four nonlinear parabolic equations solved simultaneously	Material properties either constant or function of dependent and independent variables through user-defined subroutines; ideal gas law	Bixler, 1985	SNLA (a,o,d)

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Table 8.3.5.19-2 Brief description of codes from Table 8.3.5.19-1 (page 3 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by Yucca Mountain Project[a]
NWFT	Flow and transport in saturated porous media	2D network representation of 1D paths for flow and transport of 3-member decay chains; properties vary between flow segments, constant along each segment	Campbell et al., 1980	SNLA (a,o)
ORIGEN2	Time-dependent compositions radiation, spectra, and hazard indices, etc., based on fuel burnup and decay	Bateman equations, secular equilibria where appropriate; space- and spectrum-averaged cross sections; one-group flux		SNLA (a)
PABLM	Internal doses and dose commitments to man for acute or chronic ingestion of radionuclides	ICRP models for doses by ingestion for population or maximum individual for air pathway	Napier et al., 1980	SNLA (a); PNL (a)
PANDORA	Physical and chemical degradation of waste package barriers, radionuclide flux	Radiation, thermal, mechanical corrosion, and leach models; 1D flow and transport in porous media	O'Connell and Drach, 1986	LLNL (d)
PHR81	Geochemical speciation and mass transfer	Ion association model; pH, redox-potential, mass transfer functions of reaction progress equilibrium; solid phases, distribution of aqueous species, saturation state of aqueous phase with respect to mineral phase; temperature variations		Los Alamos (a)
SAGUARO	Richard's equation for flow through partially saturated porous media using Darcy's law; capillary effects; assumes single-phase incompressible fluid; includes energy transport by conduction, convection, dispersion; development complete on all but vapor transport	Pressure, temperature, time, and space-dependent specific heat, thermal conductivity and internal heat generation, moisture content, permeability; moisture-dependent permeability; thermal expansion, multiple material layers, anisotropic material properties	Eaton et al., 1983; Gartling and Hickox, 1982	SNLA (a,o,d)

Table 8.3.5.19-2. Brief description of codes from Table 8.3.5.19-1 (page 4 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by Yucca Mountain Project[a]
SPARTAN	Water flow and radionuclide transport through dual porosity media; Darcy's law and convective transport of sorbing radionuclides	Release rates, cumulative releases, and ratios of releases to Environmental Protection Agency standards calculated as functions of geometry, repository area, flow path, water flux, effective porosity, initial inventory, water solubility, canister lifetime, and retardation factors	Lin, 1985	SNLA (o)
SPECTROM41 and SPECTROM31	Thermoplastic and plastic analyses of stresses, displacement, plasticity zones and failure zones due to extraction and canister emplacement in a repository	Nonisotropic, 3D elastic and thermal properties; ubiquitous joint element; failure modes include Von Mises and Mohr-Couloumb-Drucker-Prager	Svalstad, 1983	RESPEC (o)
TACO2D	Transient and steady-state thermal conduction in 2D		Burns, 1982	LLNL (o)
TOSPAC	Infiltration through unsaturated porous media, radionuclide decay and leaching, saturated and unsaturated flow and transports of decaying radionuclides in porous media	1D space-dependent material properties; 3-member decay chains; solubility-limited leaching, assumed source dissolution and diffusion model; equilibrium adsorption; dispersive, diffusive, convective transport	Peters et al., 1986	SNLA (o)
TOUGH	Transport of water, water vapor, and heat in partially saturated porous media	Transient, 3D non-linear flow, liquid water, pore gas, water vapor, heat, variably saturated	Pruess and Wang, 1984	LBL (o), LLNL (a,o,d), USGS (a)
TRACR3D	Saturated and unsaturated, fractured and porous media; multicomponent ground-water flow and radionuclide migration	Transient, 3D, nonlinear flow, one- or two-phases (air and water), tracer in one phase, molecular dispersion, radioactive decay, adsorption, capillary pressure, buoyancy, spatial variation of material properties, saturated and unsaturated seepage from fractures	Travis, 1984	Los Alamos (a,o,d)
TRUMP	Diffusive-advective transport of sorbing radionuclides	Transient, 1, 2, or 3D molecular diffusion and advection of radioactive tracers in single phase, equilibrium sorption		LBL (a,o)

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Table 8.3.5.19-2 Brief description of codes from Table 8.3.5.19-1 (page 5 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by Yucca Mountain Project[a]
TRUST	Conservation of fluid mass in variably saturated, deformable porous medium	Permeability, compressibility nonlinearly related to stress; permeability, saturation related to pore water pressure in unsaturated zone	Reisenauer et al., 1982	LBL (a,o,d)
VSFAST	Saturated and unsaturated, water flow in porous media; radionuclide migration	Transient, 2D, nonlinear flow, single solute, decay, adsorption		USGS (o)
NAFE	Two-phase nonlinear mass and heat transport in porous media	Transient, 2D, nonlinear flow; anisotropic properties; equations of state for liquid and vapor water; multicomponent (air and water)	Travis, 1985	Los Alamos (o)
WAPPA	Physical and chemical degradation of waste package barriers, radionuclide flux	Radiation, thermal, mechanical corrosion, and leach models	INTERA, 1983	LLNL (a,o,d), SNLA (a,o)

[a]Abbreviations as follows: SNLA = Sandia National Laboratories, Albuquerque; LBL = Lawrence Berkeley Laboratory; LLNL = Lawrence Livermore National Laboratory; Los Alamos = Los Alamos National Laboratory; USGS = U.S. Geological Survey; INTERA = INTERA Environmental Consultants, Inc.; RESPEC = RESPEC, Inc.; PNL = Pacific Northwest Laboratories; a = codes available; o = codes operational; d = codes under development.

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Table 8.3.5.19-3. Examples of computer codes for use in preclosure safety assessment

Categories of preclosure safety assessment	Type of analysis	Potential codes	Issue in which the code may be used[a]
Systems analyses	Criticality	KENO-IV	2.1, 2.2
	Systems reliability	SETS	2.3
	Shielding code	ANISN	2.1, 2.2, 2.3
Consequence analyses	Source-term characterization	ORIGEN-2	2.1, 2.2, 2.3
	Public exposures	GASDOSE	2.1
	Public exposures	AIRDOS-EPA	2.1, 2.2
	Public exposures	CRRIS system	2.1, 2.2, 2.3
	Public exposures	DACRIN	2.3

[a]Issues 2.1, 2.2, and 2.3 are discussed in Sections 8.3.5.3, 8.3.5.4, and 8.3.5.5, respectively.

Table 8.3.5.19-4. Brief description of codes from Table 8.3.5.19-3

Code name	Code description	Status of documentation	Status of use by Yucca Mountain Project
AIRDOS-EPA	Routine-release dose consequences (Clean Air Act compliance)	User manual extant; no verification; some limited validation	Under evaluation
ANISN	Discrete-ordinate for shielding	User manual extant; no verification and validation data	Used in preparation of existing project documentation
CRRIS	New Environmental Protection Agency radioactive-release dose consequences	Documentation in preparation; limited verification and validation	Under evaluation
DACRIN	Accident-release, airborne-pathway dose consequences	User manual extant; limited validation only	Under evaluation
GASDOSE	See AIRDOS-EPA	Proprietary	Used in preparation of existing project documentation
KENO-IV	Monte-Carlo criticality and shielding	User manual extant; has been validated	Under evaluation
ORIGEN-2	Radionuclide inventory of spent fuel	User manual extant; verification and validation underway	Under evaluation
SETS	Fault-tree and event-tree analysis	User manual extant; no verification and validation data	Under evaluation

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et al. (1987), and Ayer et al. (1988). Since these computer codes have been used extensively in safety assessment, they do not require extensive verification and validation. Some exceptions to this statement are the ORIGEN-type codes, which are used by all the waste-management subsystems, and the computer codes developed specifically for repository applications, such as computer codes to model the consequences inside the surface and underground facilities.

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8.3.5.20 Analytical techniques requiring significant development

Sections 8.3.5.20.1 and 8.3.5.20.2 discuss (1) the need to develop analytical techniques for those areas where well-developed methods (as discussed in Section 8.3.5.19) are currently not available and (2) the verification of computer codes and the validation of models on which the methods are based. Historically, analytical techniques have played a central role in estimating the performance of nuclear facilities for the purpose of demonstrating regulatory compliance. As a consequence, special quality-assurance requirements have been placed on these techniques, per 10 CFR 60.152, and the licensing assessments of high-level waste repository system performance must use analytical techniques certified in accordance with these requirements. Therefore, it is expected that both completed techniques (Section 8.3.5.19) and techniques to be developed (Section 8.3.5.20.1) may require some degree of verification and validation beyond what has been done for previous applications to make them suitable for repository applications.

8.3.5.20.1 Analytical techniques

The analytical techniques that require significant development are those for which analysis approaches are still being formulated, solution methods are still being developed, or codes are still being written or tested. Among the analytical techniques that still require significant development are those that are expected to be used to estimate the performance measures that are to be compared with regulatory requirements. These system performance assessment techniques include

1. Simplified physical models that will be used in the probabilistic analyses of total system performance.

2. Techniques for implementing statistical methods that will be used to do probabilistic estimates of ground-water travel time, release rates from the engineered-barrier systems, and cumulative releases to the accessible environment, as described in Sections 8.3.5.12.2, 8.3.5.10.3, and 8.3.5.13.4, respectively.

3. Systematic techniques that will be used for screening scenarios, as described in Section 8.3.5.13.3.

In addition, the analytical techniques described in Tables 8.3.5.19-1 and 8.3.5.19-2 in Section 8.3.5.19 may require more development if validation or site characterization activities show that the models fail to adequately simulate conditions at the site.

Some analytical techniques will be used specifically in the assessments of preclosure safety during repository construction, operation, retrieval (if required), and permanent closure. Those that may require significant development for preclosure safety assessment will be determined by the preclosure risk assessment methodology (PRAM) program, as described in Section 8.3.5.1. Preclosure safety assessments are expected to use existing analytical techniques with minor modification. A potential area that may require development is source-term characterization.

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A number of methods and practices that will be useful in assessing the postclosure performance of a repository might be termed "analytical techniques"; they are discussed in other sections of the SCP. For example, Section 8.3.5.13 describes the selection and characterization of scenarios for releases of radioactive material from the total repository system. The section also explains in detail the basic construction of complementary cumulative distribution functions for assessing these releases. As described in Section 8.3.5.13, the assessment of releases will require some special-purpose models in addition to the models described in Section 8.3.5.19. Sensitivity and uncertainty analyses will also be an important part of the performance assessments and will provide guidance for site characterization. Preliminary sensitivity and uncertainty work has been done, and some important results are described in the detailed performance allocations throughout Section 8.3.5.

8.3.5.20.2 Plans for verification and validation

Verification and validation activities are intended to reduce and evaluate the uncertainty in estimates of repository performance that are based on predictive models, thereby enhancing the confidence in the accuracy of predictions. Verification studies are used to demonstrate that the numerical values produced by a computational procedure correspond to the mathematical formulas on which they are based. Verification becomes especially important for complex computer codes using advanced numerical methods to solve systems of equations. Validation is an attempt to demonstrate that a mathematical representation of repository performance will adequately replicate the actual performance of the repository. The DOE will provide an explanation, during licensing, of the verification and validation activities that were used to support the performance assessment models. Emphasis will be given to those models used (1) to assess the postclosure performance of the natural and engineered barriers and their effectiveness in controlling the release of radioactive material (taking into account both anticipated and unanticipated processes and events) and (2) to assess favorable and potentially adverse conditions at the site.

The preliminary plans for verification and validation are discussed in the following sections. Although these plans are general, they demonstrate how validation enters the site characterization program that addresses the needs identified in the performance allocation process. Detailed plans are being developed that will describe (1) the overall procedure for verification of computer codes and (2) the overall strategy for the validation of models. The validation strategy will address how the data from site characterization and performance confirmation will be used in validation, how data from natural or other analogues will be used, and how peer review will be used in the validation process.

8.3.5.20.3 Verification of analytical techniques

Verification of codes, according to the guidelines in NUREG-0856 (Silling, 1982), is the "assurance that a computer code correctly performs the operations specified in a numerical model." This definition includes any analysis method, however simple (e.g., semianalytic computer code for calculating a single-valued, uniquely determined algebraic expression) or complex (a numerical computer code). For the purposes of this discussion, the analytical techniques addressed in this section are those computer codes used to implement mathematical models.

All computer codes used for final performance assessments of the suitability of the Yucca Mountain site will be verified to demonstrate that they correctly implement the mathematical and numerical procedures on which they are based. The extent to which verification will be pursued depends on (1) the extent to which verification has been previously done, documented, and certified software control procedures subsequently followed; (2) whether the code has been previously used and accepted in other nuclear facility licensing application; and (3) the importance of the code to the demonstration of regulatory compliance. The codes to be verified include the completed codes described in Section 8.3.5.19 and the groups of analytical codes described in this section (8.3.5.20).

The numerical accuracy and stability of the hydrologic and radionuclide transport codes will be verified by comparison with analytic solutions and by benchmarking against other computer codes. If the verification process reveals that the mathematical model has been inaccurately incorporated into the numerical code or that the existing codes have insufficient capabilities, then additional code-development work may be needed. A comprehensive set of verification steps would include the following:

1. The use of numerical-analysis techniques to define the limits of code accuracy in terms of methods of solution, discretization, and parameter ranges.

2. The testing of numerical accuracy and solution sensitivities by comparison with analytical solutions wherever possible.

3. The revision or modification of computer codes as necessary to ensure sufficient accuracy and stability.

4. The performance of benchmarking comparisons of codes on problems typical of those required by the issue or issues the codes are intended to address. These comparisons are to be made by the Yucca Mountain Project, using these codes and the data obtained from site characterization of Yucca Mountain, and will be coordinated with the analyses performed for Issues 1.1 through 1.6 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12 through 8.3.5.16).

5. The documentation of the verification activities according to the guidelines in NUREG-0856 (Silling, 1982) as implemented in the Yucca Mountain Project.

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COVE: a Yucca Mountain Project benchmarking activity

Not all applications of codes are amenable to testing of numerical accuracy by comparison with analytical solutions. Therefore, the code verification (COVE) activity has been initiated for benchmarking the water flow and radionuclide-transport codes being used for performance assessments. The goals of the COVE activity are to (1) demonstrate and compare the numerical accuracy and sensitivity of selected codes, (2) identify and resolve problems in running typical performance assessment calculations using this code, and (3) evaluate the computer resources needed for running these codes. The following benchmarking problems have been defined:

1. Isothermal transport of water and radionuclides through homogeneous, variably saturated tuff (COVE 1).

2. Isothermal transport through layered, variably saturated tuff (COVE 2).

3. Nonisothermal transport of water, vapor, air, and heat in fractured, welded tuff (COVE 3).

4. Isothermal transport of water and radionuclides through saturated tuff.

Other benchmarking problems may be defined, as required, during the code verification process.

COVE 1 was the first step in benchmarking some of the performance-assessment codes. Isothermal calculations for the COVE 1 benchmarking have been completed using the hydrologic flow codes SAGUARO, TRUST, and GWVIP; the radionuclide codes FEMTRAN and TRUMP; and the coupled flow and transport code TRACR3D. The COVE 1 participants are listed in Table 8.3.5.20-1. Hayden (1985) presents the results of the three cases of the benchmarking problem solved for COVE 1, a comparison of the results, questions raised regarding sensitivities to modeling techniques, and conclusions drawn regarding the status and numerical sensitivities of the codes.

Work is currently in progress on both COVE 2 and COVE 3. The goals of COVE 2 and COVE 3 are the same as for COVE 1. However, the emphasis in COVE 2 and 3 is on modeling site-scale problems of the type that will be required for performance-assessment calculations. Both one- and two-dimensional problems have been defined under both isothermal and nonisothermal conditions. Isothermal water flow through several layers of unsaturated tuff with different hydrologic properties is modeled in COVE 2. The participants in COVE 2 and the codes they are using are listed in Table 8.3.5.20-2.

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Table 8.3.5.20-1. Participants and codes used in the COVE 1 benchmarking exercise

Participant	Code
Los Alamos National Laboratory	TRACR3D
Lawrence Berkeley Laboratory	TRUST/TRUMP
Pacific Northwest Laboratories	TRUST
Sandia National Laboratories	SAGUARO/FEMTRAN
Environmental Consultants, Inc.	GWVIP

Table 8.3.5.20-2. Participants and codes used in the COVE 2 benchmarking exercise

Participant	Code
Los Alamos National Laboratory	HDOC/TRACR3D
Lawrence Berkeley Laboratory	TRUST
Sandia National Laboratories	SAGUARO/NORIA/TOSPAC

In COVE 3, temperatures and saturation profiles are being calculated in a nonisothermal condition in tuff, using hydrologic properties that may be similar to the Topopah Spring Member. These simulations examine expected post-waste-emplacement conditions in the near field. The participants in COVE 3 and the codes they are using are listed in Table 8.3.5.20-3. The COVE 2 and 3 activities will be fully documented in Yucca Mountain Project reports.

Table 8.3.5.20-3. Participants and codes used in the COVE 3 benchmarking exercise

Participant	Code
Lawrence Berkeley Laboratory	TOUGH
Sandia National Laboratories	NORIA
Lawrence Livermore National Laboratory	WAFE

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International code verification and model-validation activities

The Yucca Mountain Project is participating in two international code comparison projects to supplement its benchmarking activities. These comparisons address problems designed to test a number of aspects of the exercised codes. Participation also provides independent assessment and peer review. Results of the comparisons aid the establishment of the general applicability, acceptability, and flexibility of the exercised codes.

The Hydrologic Code Intercomparison (HYDROCOIN) project examines hydrologic models and codes and their uses in performance assessments of nuclear waste repositories. The International Nuclide Transportation Code Intercomparison (INTRACOIN) study examines models and codes that describe the transport of radionuclides in geologic media.

Both HYDROCOIN and INTRACOIN have three principal activities:

1. Level 1, benchmarking and verification of codes.

2. Level 2, validation of models.

3. Level 3, sensitivity and uncertainty analyses of models and codes.

Several level 1 benchmarking analyses, on test cases that may be pertinent to Yucca Mountain, have been performed for both projects by Yucca Mountain Project participants. The results are documented in the INTRACOIN Final Report for Level 1 (1986) and in the HYDROCOIN report prepared by Cole (1986).

8.3.5.20.4 Model validation

Overview

This section presents the DOE approach to dealing with the complex task of model validation by defining what validation is, describing the need for model validation in the repository program, and describing activities that may be useful in supporting the validation effort. In general, validation is an important part of the investigative effort that is to create the record upon which the NRC is to base its licensing decision. Validation thus addresses the competence of the performance assessment effort. Evaluating and documenting the quality of site and laboratory data, interpreting that data, and certifying the appropriateness of uses made of that data is also important in establishing the credibility of the performance assessment effort, and is sometimes referred to as data validation. For the purposes of this discussion, however, the meaning of validation is restricted to establishing the soundness of specific computer models and the legitimacy of specific applications being made of those models.

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Definitions

Before discussing some of the aspects of the DOE validation strategy and program, some of the terminology that will be used will be clarified to avoid semantic difficulties.

Performance assessment

Performance assessment is the process of quantitatively evaluating system, subsystem, or component behavior relative to the containment or isolation of radioactive waste, to support the development of a high-level waste repository and to determine compliance with quantitative safety criteria.

Performance assessment refers to evaluations of risks and hazards to workers and the public in the preclosure phase of the repository (Section 8.3.5.1) and refers to evaluations of the behavior of the repository for the postclosure phase (Section 8.3.5.8). In particular, as articulated in Section 8.3.5.8, postclosure performance assessment addresses the resolution of Key Issue 1 in the issues hierarchy, which parallels the regulatory system-performance requirements. Thus, performance assessment is a type of systematic safety analysis that is used to (1) predict potential health and safety effects, (2) depict these effects in terms of magnitude and likelihood, (3) compare the results to acceptability standards, and (4) document the process and results in an appropriate and usable format.

Conceptual model

A conceptual model is an abstraction of the relationships among the system and its component subsystems, processes, geometric structures, and bounding environmental conditions. The conceptual model is a set of these relationships, selected from among a larger set of possible relationships and conditions, that is sufficient to describe the system for the intended application of the model to a preclosure safety or postclosure waste isolation assessment. Ideally, these relationships and their alternatives are expressed in terms of testable hypotheses.

Model

A model is a representation of a system that implements the conceptual model in terms of quantitatively linking key features or aspects of the conceptual model with important behaviors, such as containment and isolation. A quantitative model may range in complexity from simple, closed-form analytical solutions of one or more governing equations to numerical models that rely on sophisticated and complex computer codes and resources. Of necessity, mathematical models will only be applied to problems that are mathematically well posed, meaning that a solution does exist.

Code

A code is a sequence of mathematical expressions and computer instructions written so that a computer can implement those instructions and

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solve the mathematical expressions as directed. A code, with appropriate data, implements the model, and running the code quantifies the predictions of the model.

Validation

The concept of validation was defined by the International Atomic Energy Agency (IAEA, 1982) as follows:

> A conceptual model and the computer code derived from it are "validated" when it is confirmed that the conceptual model and the derived computer code provide a good representation of the actual processes occurring in the real system. Validation is thus carried out by comparison of calculations with field observations and experimental measurements.

This definition is adequate for many cases but is not strictly appropriate for the long-term and large-scale postclosure system performance predictions that cannot be compared with field measurements or replicated in a laboratory. The definition does, however, separate the validation problem into two aspects: (1) ascertaining when the model has achieved a good representation of the system and (2) comparing predictive results to appropriate observations and experimental results.

<u>Validation in the repository program</u>

Reasons for validation

In the repository program, the record that will be provided by the DOE to support the NRC's licensing decision-making will consist in large part of information from the site characterization and design programs. The laboratory and field studies of these two programs will, however, be used to support one of the most important parts of the license application, the predictive modeling that is to be done to demonstrate regulatory compliance related to Key Issue 1. Many types of scientific investigations will be used to create the data bases needed to support the predictive modeling effort. Empirical field and laboratory data will be used in modeling as the basis for (1) formulating the conceptual model and its component hypotheses, (2) evaluating the conceptual model in terms of selecting between competing hypotheses, which includes selecting alternative processes, and (3) evaluating the predictive validity of the model that implements the conceptual model.

The record that the DOE places before the NRC as part of its license application must address the appropriateness and quality of the data, including the data that is used to support the building of predictive models. The record must also show that all lines of code constituting a predictive model have been verified in terms of their correct implementation of the mathematical expressions embodied, as described in Section 8.3.5.19. In addition, validation, or the demonstration of the correctness of the conceptualization of the system being modeled and of the implementation of that conceptualization in a predictive model, must also be addressed in the record because validation is a fundamental part of the scientific process of building and demonstrating the competence of a quantitative predictive model.

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Limitations on validation

As noted previously in the definition of validation, the estimate of postclosure repository performance resulting from a performance assessment cannot be compared to experimental measures of system performance. In other words, direct experimental corroboration of models via full-scale, full-duration testing is not feasible because of the time scales over which the repository is required to isolate waste (10,000 yr) and the length scales for which performance measures are specified (kilometers). In addition, the performance of the waste disposal system must be estimated for a variety of potential future scenarios, further complicating the ability to design experiments that yield results to which long-term system behavior predictions can meaningfully be compared.

In terms of the postclosure aspects of the repository performance assessment program, the role of model validation is to demonstrate the state or performance of the repository system to within some acceptable limits of uncertainty. The sources of uncertainty in a repository system model derive from (1) uncertainties associated with the conceptual model on which the system model is based, (2) measurement errors and sparse data, (3) intrinsic heterogeneities of internal system properties or processes, and (4) uncertainty in the future environmental setting of the repository (adapted from Dettinger and Wilson, 1981). The sparsity of data is, in part, a consequence of the need to limit characterization of the site so as to "limit adverse effects on the long-term performance of the geologic repository to the extent practical." (10 CFR 60.15(d)(1))

To achieve an adequate degree of validation, appropriate data from scientific investigations and from the design effort are needed to ensure that system descriptions and modeling assumptions are appropriate and adequate, and peer reviews may be necessary to assess the competence of the scientific investigations and judge the uses made of results. Difficulties exist in the application of the results of scientific investigations to the validation of postclosure predictive modeling. For example, in a hydrogeologic system in which ground-water flow velocity is small (less than 1 mm/yr (0.04 in./yr)), direct measurement of mechanical dispersivity on the scale of 1 to 10 km (0.6 to 6 mi) will not be possible because a field experiment would have to be run for thousands of years to yield pertinent data. Thus, some of the data sparsity that contributes to the overall uncertainty of the predictive model is irreducible, and peer reviews may be needed to judge whether or not the residual uncertainty allows the predictive result to meet regulatory requirements with reasonable assurance.

That the validity of regulatory compliance calculations cannot be established in the sense that prediction is compared with observation is acknowledged by the U.S. Environmental Protection Agency (EPA) in its 40 CFR Part 191, where Paragraph 191.13 (b) says in part

> Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 191.13 (a) will be achieved.

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[Note: 191.13 (a) specifies the 10,000 year containment requirement and that compliance is to be shown through performance assessments.]

Similarly, the NRC discusses the evidence that may support a regulatory compliance calculation in terms that also recognize that the nature of these long-term projections of system performance limits their certainty and hence limits the degree to which validity can be established. The NRC's 10 CFR Part 60, Paragraph 60.101(a)(2) states in part

> Proof of the future performance of engineered barrier systems and the geologic setting over time periods of many hundreds or many thousands of years is not to be had in the ordinary sense of the word. For such long term objectives and criteria, what is required is reasonable assurance, making allowance for the time period, hazards, and uncertainties involved, that the outcome will be in conformance with those objectives and criteria.

Others have recognized the difficulties inherent in validating complex environmental models, even those for which some level of comparison with system performance is possible (Gass, 1983; Sargent, 1987). Cale and Shugart (1980) and Eisenberg et al. (1987) point out that partial validation of a model may be feasible and will enhance model credibility.

Validation is application dependent, and thus must be performed for the particular circumstances of the problem under consideration. This application-dependence of model validation has been recognized by the EPA in its published protocols for validating an application of a specific, well-documented and accepted model used in air-pollution studies addressing regulatory siting criteria (EPA, 1987).

The application-dependence of validation was also addressed by Eisenberg et al. (1987) but from a different perspective. In terms of setting priorities for validation activities, for example, it was suggested that the priority given to the validation of a model be determined by the role the model has in evaluating safe operation. This is equivalent to the priority the model has in demonstrating compliance with the EPA system performance requirement and the NRC subsystem performance requirements. Thus, the importance of a given validation effort is linked to the importance of the given application to the overall demonstration of regulatory compliance, and resources will be allocated accordingly.

Finally, Brinberg and McGrath (1985) conclude that one of the difficulties associated with model validation is that the nature of the validation need, and even the meaning of validation, may change at different stages of the modeling and research process. Similarly, Eisenberg et al. (1987) suggest that the NRC's 10 CFR Part 60, Subpart F, which mandates a performance confirmation period, provides time for this type of continuous feedback process for model confirmation beyond what is achieved at licensing. This, in turn, suggests that at the time of permanent closure there is a need for a more comprehensive validation to accompany the assessments addressing the postclosure performance requirements than there was for the more preliminary phases of the licensing process.

8.3.5.20.5 Validation program

Scientific validation activities

The DOE goal for validating performance assessment models is to use all appropriate means to ensure that modeling results are accurate within an acceptable degree of uncertainty and that regulatory requirements are satisfied with reasonable assurance. The validation approach is still being formulated in detail for specific aspects of the requisite compliance demonstrations, but the approach would include applying the models to predict the outcomes of specific scientific investigations. The NRC has suggested that in terms of the long-term postclosure performance objectives imposed by the regulations:

> Demonstration of compliance with such objectives and criteria will involve the use of data from accelerated tests and predictive models that are supported by such measures as field and laboratory tests, monitoring data and natural analog studies. (10 CFR Part 60, Paragraph 60.101(a)(2))

These are scientific investigations and other activities that can be carried out on a human time scale, and will be carried out to support resolution of the questions addressed in validation. A more complete list would include

1. Laboratory experiments.

2. Field investigation, i.e., monitoring, in situ tests in the exploratory shaft facility, field tests, and studies that are part of the surface-based studies at the site.

3. Analog studies, i.e., natural, anthropogenic, and laboratory analogs.

4. Numerical or synthetic modeling experiments.

5. Theoretical scoping studies and asymptotic bounding estimates.

The investigations and activities that may provide useful information for validation each have positive aspects and limitations, as has been discussed elsewhere (Eisenberg et al., 1987). Many of the site characterization activities outlined in Section 8.3.1 may be used to support model validation. These activities and their relationship to the testing of alternative conceptual models are described in Section 8.3.1.1 and Tables 8.3.1.2-2a and -2b, 8.3.1.3-2, 8.3.1.4-2, 8.3.1.5-3, 8.3.1.8-7 and -8, 8.3.1.9-3, 8.3.1.15-2, and 8.3.1.17-7 and -8.

Performance assessment models are planned to be subjected to impartial and critical peer review throughout their inception, development, testing, and repository system application. Testing would include the model's application to predicting the outcomes of appropriate investigations and activities as listed above, and would also include the sensitivity and uncertainty analyses performed to describe the characteristics of the model and to quantify some of the uncertainty in its predictive results.

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Hypothesis testing

As noted in the definition of "conceptual model," a conceptual model is developed from hypotheses and, where appropriate, competing or counter-hypotheses. Experiments can be constructed that will attempt to falsify a hypothesis or that will allow discrimination between competing hypotheses. The pursuit of this type of experimental validation of the component hypotheses of a conceptual model is called "hypothesis testing."

A conceptualization of a complex system would have numerous component hypotheses and numerous counter-hypotheses that can be experimentally evaluated. This implies that a program of hypothesis testing, and where possible elimination, is a necessary part of formulating a provisional conceptual model for a system. The hypothesis testing program is discussed in Section 8.3.1.

A conceptual model is developed on the basis of many sources of data and evidence. It is desirable that the conceptual model be consistent with as many of these sources of data and evidence as possible. The conceptual model must also be complete in the sense that at a minimum it must provide hypotheses that address the important aspects of system performance. Generally, conceptual models that describe more aspects of system behavior are more desirable. Section 8.3.1 discusses the evaluation of the adequacy of conceptual models. Questions that will be addressed in such evaluations are to include the following:

1. Are the repository system and its subsystems described accurately enough with respect to the enclosing environmental setting (i.e., the geologic framework, the hydrologic regime, and the boundary and initial conditions)?

2. Are the physicochemical and other processes governing repository performance properly identified and incorporated into the performance assessment conceptual models and quantitative models?

3. Are systems dynamics and responses to changing conditions, both evolutionary and disruptive, capable of being addressed by both the conceptual and quantitative models?

Since the degree of knowledge concerning a system would improve with time, new data or observations may become available that may conflict with aspects of the provisional conceptual model. Thus, conceptual model development will be an evolving and iterative process of model modification, testing, and refinement, as described by Mankin et al. (1977).

International validation programs

Some validation activities are currently being pursued by the DOE through the international cooperative validation study, INTRAVAL.

INTRAVAL was established in October 1987 by the Swedish Nuclear Power Inspectorate in Stockholm, with cooperation from the Nuclear Energy Agency in Paris and the participating nations. The project is a cooperative effort to validate geosphere transport models by using experimental, field, and natural

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analog studies. The problems, or test cases, being considered in INTRAVAL include transport problems in porous rock, fractures, and fractured rock masses in saturated and unsaturated flow. The DOE participation consists of teams that are to solve selected field cases and conduct an unsaturated zone laboratory and field experiment that has been selected for inclusion in the INTRAVAL project.

Peer review

Peer review will be formalized through the establishment of applicability and review criteria before conducting a review. These criteria and the procedures that are to be followed in the review may be set by the designated review bodies. In establishing these criteria, the review body will consider the implications of the modeling under review in terms of system safety and performance. The criteria will be specific to the comparisons at hand, taking into account the characteristics, limitations, and uncertainties in both the modeling and experimental results. The final determination of modeling adequacy will also address whether or not, taking into account all uncertainties, there is a sufficient basis for judging that the regulatory requirement being addressed will be met with reasonable assurance. A negative finding, as described in Figure 1 of Eisenberg and Van Luik (1987), requires reconsideration of system data, design, and performance allocations, as well as of the modeling.

Peer review will address model construction and implementation in order to be able to assess the adequacy of the model as an appropriate representation of the repository system or its subsystems, which is a part of validation by definition. As noted by Eisenberg et al. (1987), the following issues must be addressed:

1. Are the repository system and its important subsystems described accurately enough in terms of geometry and physical parameters?

2. Are the internal operating conditions (temperature, pressure, etc.) and external states of nature adequately described for the repository and its important subsystems?

3. Are the physicochemical processes that are important in determining system performance identified for the repository and its important subsystems?

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8.4 PLANNED SITE CHARACTERIZATION ACTIVITIES AND POTENTIAL PERFORMANCE IMPACTS

This section presents the plans for surface-based activities (including drilling, trenching, and site preparation) and for subsurface excavations related to implementing the site characterization program described in Section 8.3. Also provided are background information on the DOE approach to site characterization, the rationale for the proposed testing configuration, the relationship of that configuration to the repository conceptual design, and the potential impact of the testing activities on the integrity of the site. Further, this section presents information on related topics derived from recent interactions between the DOE and the NRC. Information presented includes the approach to characterizing the primary barrier to radionuclide migration (the Calico Hills Formation), a description of the exploratory shaft facility (ESF) design and surface-based testing activities with evaluations of interferences between tests, and a discussion of the bases for selecting exploratory shaft facility locations and the potential impact of these locations on site characterization and long-term impacts on postclosure performance.

This section is divided into three subsections. Section 8.4.1 presents background information on the approach adopted by the DOE to guide the characterization program, gives the approach to incorporating the requirements of 10 CFR Part 60 in the development of the testing program, and discusses the concepts of flow in the unsaturated zone. An understanding of the concepts of unsaturated-zone flow is a prerequisite for understanding the potential impacts of testing activities on site integrity. Section 8.4.2 presents the rationale for the planned testing, describes the surface testing and the underground test facility, and evaluates the effectiveness of the proposed configuration in terms of test-to-test and construction-to-test interferences and compatibility of the ESF with the repository design. Section 8.4.3 evaluates the impact of the testing configuration on the integrity of the site by considering its potential impacts on the postclosure performance objectives.

There are important ties between the information presented in this chapter and the quality assurance program that governs the activities related to characterization and design. A quality assurance program compatible with 10 CFR 60 Subpart G will be in place before undertaking new site characterization work to ensure that, as a minimum, items important to safety, barriers important to waste isolation, and activities that could affect the performance of either are designed, investigated, or carried out under appropriate quality assurance controls. The site characterization program activities have the potential to affect natural barriers important to waste isolation; assessment of this potential is a primary topic of Section 8.4. Assessments to determine those barriers that are important to waste isolation are summarized in Section 6.1.5 of the SCP; they are presently based primarily on the results of the performance allocation process described in Sections 8.2 and 8.3. The list of activities that have the potential to affect natural barriers important to isolation is given in Section 8.6 of the SCP and these activities are a recurrent topic in Section 8.4.

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With respect to potential preclosure impacts, site characterization activities are not expected to have any adverse impacts on structures, systems, and components important to safety. These structures, systems, and components, which are identified in Section 6.1.4 of the SCP, will be constructed after site characterization activities have been completed. The repository designers can consider the possible effects of these activities and if any adverse effects are identified, they can be mitigated in the design. Therefore, the discussion of potential impacts from site characterization activities throughout Section 8.4 focuses on postclosure performance.

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8.4.1 INTRODUCTION

This section is divided into three subsections. The first section, 8.4.1.1, describes the phased approach (DOE, 1991a) adopted by the DOE to guide the site characterization program. This approach provides for the continual evaluation of the adequacy of the testing configuration and the impacts of the testing activities on site integrity. Next, the approach for incorporating the requirements of 10 CFR Part 60 in the development of the site characterization program is presented in Section 8.4.1.2. Finally, Section 8.4.1.3 discusses the concepts of unsaturated flow and their application to Yucca Mountain. The unsaturated zone is the primary element that the DOE expects to rely on in demonstrating the waste-isolation capabilities of the site. Thus, an understanding of the concepts of unsaturated-zone flow is a prerequisite for understanding the potential impacts of testing activities on site integrity.

8.4.1.1 Phased approach to implementing site characterization activities

In managing the implementation of the site characterization program, the DOE must continually evaluate the adequacy of the testing configuration and the impacts of the testing activities on the integrity of the site. This means that regular evaluations will be made of such factors as (1) the potential for interference (test-to-test, construction-to-test, etc.) that could affect the integrity of data being collected; (2) the representativeness of the testing program; (3) the potential for significant adverse impacts on the isolation features of the site; and (4) the design features that reduce the potential for interference and impacts. Consequently, the DOE has established a phased approach to implementing the ESF portion of the site characterization program in which periodic evaluations using available data are made to determine the prudence of proceeding with the next phase of activities.

Information from the periodic evaluations will be used to modify or refine the construction and testing activities associated with ESF, thereby incorporating the most recent knowledge of the in situ characteristics at Yucca Mountain. The reviews discussed above will supplement the reviews that are part of the process for completion of individual testing activities. The DOE's approach to implementing site characterization activities provides several well-defined opportunities to reevaluate the conclusions drawn in this section and reassess their validity in light of better information than that which is currently available. The information to be gained during the site characterization activities following issuance of the SCP is expected to be better in the sense that uncertainty will be reduced, assumptions and models will be confirmed or modified, design concepts will be refined, system interfaces and performance will be better understood, and the quality assurance program will place stricter controls on aspects of the program.

The progression of characterization and design activities naturally improves the program data bases in several respects. First, the DOE has an expressed commitment to receive NRC acceptance of its QA program before beginning new characterization activities. The data acquired under such an approved program typically will be more readily acceptable to the NRC staff

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than data drawn heavily from journal literature or collected under QA programs not approved by the NRC. Collection of data during characterization activities following issuance of the SCP will strengthen the statistical bases for data sets as well as fill in gaps in sparse or limited data sets. Such data will be reported in semiannual progress reports to inform the NRC and the State of the results of characterization activities. It is prudent to plan to use that data to reaffirm the assumptions, data, analyses and conclusions that form the bases for Section 8.4.

As the data collection programs progress, ongoing design activities lead to a refined understanding of system interfaces; likewise, performance modeling activities and the assumptions and models upon which they are based are refined. The improved understanding of the design and the improved capability to verbally model performance that accompany the collection of additional data provide the means to reevaluate the conclusions that are contained in this section. The DOE is firmly committed to such reevaluations and plans to report on their results in semiannual progress reports. The actual reevaluations are envisioned to be a nearly continuous process throughout characterization; as noted previously, however, a total reevaluation of the results reported in Section 8.4 is planned before development of the main test level facility. The evaluations provided in this section and those included in the planned reviews focus on the effectiveness of the testing program to obtain needed information. The evaluations include determining if the activities will provide representative data of the site as a whole, if there is a potential for interference between or among construction and testing activities, and if the activities have a potential impact on the ability of the site to meet the postclosure performance objective.

The evaluations of the ESF summarized in the following sections of 8.4 address the location of the ramps/shafts, the layout of the underground facility, and the construction and testing operation. Assessments are made of interferences between ramps/shafts, interferences between ramps/shaft and facility construction and the tests, interferences between tests, and the integration of the ESF with the repository design. The postclosure impacts are assessed by evaluating the impact of the excavations on the unsaturated flow system. Primary emphasis is given to the potential for fluid movement in or near the excavation and consideration of the types of materials used in the construction and testing operations. This information is used to examine the rationale for the ESF layout and, in turn, is incorporated into the design process to modify the configuration if necessary. Similar evaluations are performed for surface-based testing activities, thereby allowing appropriate definition of construction activities and controls on the drilling operations. In addition, these evaluations allow the identification of specific data necessary to refine the analyses. This provides guidance to the site characterization activities by identifying those data to be confirmed early in the testing program.

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8.4.1.2 Incorporation of 10 CFR Part 60 in the development of the site characterization program

The development of the site characterization program and the evaluation of the impact of site characterization activities on the integrity of the site have been based on numerous regulations and requirements. These requirements have been considered in the development of Section 8.4, the definition of the site investigations, and the design of the exploratory shaft facility. In 10 CFR Part 60, the NRC prescribes the technical criteria applicable to the licensing of a geologic repository. Many subparts of 10 CFR Part 60 must be considered during site characterization to ensure that the proposed characterization activities will not only allow the DOE to obtain the necessary data for a license application, but also to ensure that the activities will be carried out in a manner consistent with meeting licensing requirements for maintaining site integrity and consistency with the repository design. This section summarizes the site characterization activities, including the drilling and construction activities, and evaluates those activities to determine if they are consistent with the requirements of 10 CFR Part 60. This section (8.4.1.2) identifies those portions of 10 CFR Part 60 directly considered in developing Section 8.4; identifies in general terms the influence these regulations have had on the planned characterization activities and testing; and directs the reader to specific sections containing additional information on how the regulation has been considered. The design of the exploratory shaft facility has also incorporated the requirements of 10 CFR Part 60 by making these requirements a formal part of the design requirements and design control process. These requirements are contained in Appendix E of the Waste Management System Requirements (WMSR) Volume IV (DOE, 1991b) and Section 3.0 of the Yucca Mountain Mined Geologic Disposal System Requirements (SR) (DOE, 1991c). The design control process is further discussed in Section 8.4.2.3.3.

At this very early stage of planning a repository, the most directly applicable sections of 10 CFR Part 60 are related to the preapplication review discussions in Subpart B (Licenses). The requirements for a site characterization plan are established in Section 60.16 of 10 CFR Part 60, while Sections 60.15 and 60.17 of 10 CFR Part 60 establish the requirements for the characterization program content and scope. A summary of the principal requirements of these CFR sections that directly affect site characterization planning and performance impact evaluation is provided in Table 8.4.1-1. These sections recognize three important concepts that form the basis for the descriptions and evaluations presented in Section 8.4:

1. The need to balance the testing program for site characterization with the necessity to limit the potential impacts of site characterization on barriers relied on to meet the NRC postclosure performance objectives.

2. The need to have plans for controlling the potential adverse impacts of the characterization activities.

3. The need to integrate the planned site characterization activities with the design of the repository.

Table 8.4.1-1. Principal requirements of 10 CFR Part 60 affecting site characterization planning and performance impact evaluation related to discussions in Section 8.4 (page 1 of 2)

10 CFR 60 Citation	Principal requirements	8.4 Section
Subpart B		
60.15 Site characterization	The U.S. Department of Energy shall conduct site characterization program	
	(a) Prior to license application	
	(b) Including in situ exploration and testing at depths waste would be emplaced	8.4.2.1.4 and 8.4.2.3.3
	(d) The program of site characterization shall be conducted in accordance with:	
	(1) Limiting adverse effects on the long-term performance of the geologic repository to the extent practical	8.4.3.3
	(2) Limiting number of exploratory boreholes and shafts to the extent practical consistent with obtaining the information needed for site characterization	8.4.2.1.4 and 8.4.3.3.3
	(3) Locating to the extent practical exploratory boreholes and shafts in the geologic repository operations area to where shafts or large unexcavated pillars are planned for the underground facility	8.4.2.1.4, 8.4.2.3.4.3, and 8.4.3.3

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Table 8.4.1-1. Principal requirements of 10 CFR Part 60 affecting site characterization planning and performance impact evaluation related to discussions in Section 8.4 (page 2 of 2)

10 CFR 60 Citation	Principal requirements	8.4 Section
60.15 Site characterization (continued)	(4) Planning and coordinating subsurface exploratory drilling, excavation, and in situ testing with geologic repository operations area design and construction	8.4.2.3.6.3
60.17 Contents of site characterization plan (SCP)	SCP shall contain	
	(a) General plan for site characterization activities to include:	
	(2) Description of site characterization activities including	
	(i) Extent of planned excavations	8.4.2.3.3
	(ii) Plans for onsite testing with radioactive materials	8.4.2.3.1 and 8.4.2.2.2
	(iii) Plans for investigation that may affect capability to isolate waste	8.4.2.1 and 8.4.3.2.5
	(iv) Plans to control adverse impacts of site characterization activities important to safety or waste isolation	8.4.2.1.2 and 8.4.2.3.6

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Section 8.4.2 summarizes the testing program for site characterization from the more detailed information in Section 8.3.1 and emphasizes those aspects of the characterization program that could potentially impact barriers relied on to meet the NRC postclosure performance objectives. Section 8.4.2 also describes the construction activities and operations needed at the site to carry out the site characterization program and discusses the control of adverse impacts and integration with repository design. The final section (8.4.3), then describes the potential impacts of the site characterization activities on postclosure performance.

Sections 60.15 and 60.17 of 10 CFR Part 60 have been incorporated into the planning of the site characterization program. Consideration of the requirements has impacted the planning of the surface-based drilling program with regard to the extent of characterization within the repository block (i.e., number of exploratory boreholes), the drilling methods to be used (i.e., dry, wet, mist), the drilling depth of boreholes, the construction controls to be used, the sequence in which the holes are to be drilled, and the consistency of proposed locations with the repository design.

For the ESF design and planned operations, the requirements of these sections of 10 CFR Part 60 have been applied to the establishment of controls on selected operations (i.e., construction and water use), the evaluation of the location and configuration of the facility relative to long-term performance, and the integration of the ESF and repository layouts to ensure compatibility between the proposed exploration and the conceptual design of the repository. The specific sections of Section 8.4 in which the various criteria in 10 CFR 60.15 and 60.17 have been considered are identified in Table 8.4.1-1.

In the preceding discussion, the term "performance" is used in the sense of the ability of the repository system to meet the postclosure performance objectives identified by the NRC. Four postclosure performance objectives are identified in 10 CFR 60 Subpart E in 60.112 and 60.113. These post-closure performance objectives are summarized in Table 8.4.1-2, together with the location of the related discussion in Section 8.4. The discussions in Section 8.4.3 evaluate whether the site characterization activities are consistent with meeting the postclosure performance objectives. The post-closure performance objectives have impacted the planned characterization program and operations principally by providing constraints including such factors as the proposed construction methods, the controls to be placed on those methods, and the ramp/shaft locations.

In addition to the direct guidance for site characterization and the definition of the postclosure performance objectives, 10 CFR Part 60 provides other technical criteria in Subpart E. These include specific requirements to be placed on the repository facility to further ensure public health and safety during the postclosure phase. In those instances in which a direct linkage can be demonstrated, it is considered appropriate to evaluate the potential impacts of site characterization on the capability to ultimately comply with other selected requirements in Subpart E. The additional technical criteria from Subpart E considered in the evaluations in 8.4 are identified in Table 8.4.1-3. Note that several of the criteria presented in Subpart E do not appear in the list of those considered in Table 8.4.1-3. This is generally because those criteria are not viewed as being closely

Table 8.4.1-2. Postclosure performance objectives from 10 CFR Part 60 related to discussions in Section 8.4 (page 1 of 2)

10 CFR 60 Citation	Principal objectives	8.4 Section
Subpart E		
60.112	Overall system performance objective for the geologic repository after permanent closure (postclosure performance objectives)	8.4.3.3.1
	Select geologic setting and design engineered barrier system, and shafts, boreholes and their seals to assure that releases of radioactive material conform to Environmental Protection Agency standards for both anticipated and unanticipated processes and events	
60.113	Performance of particular barriers after permanent closure (postclosure performance objectives) For anticipated processes and events	
	(a) (1) Substantially complete containment within waste package for 300-1000 years after closure (a)(1)(ii)(A) -- assuming anticipated processes and events	8.4.3.3.2
	Release rate from engineered barrier system after containment period shall not exceed one part in 100,000 per year of 1,000 year inventory (a)(1)(ii)(B)	8.4.3.3.3

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Table 8.4.1-2. Postclosure performance objectives from 10 CFR Part 60 related to discussions in Section 8.4 (page 2 of 2)

10 CFR 60 Citation	Principal objectives	8.4 Section
	Geologic setting	
	(a)(2) Locate repository so that pre-waste-emplacement ground water travel time along fastest path of likely radionuclide travel from disturbed zone to accessible environment is at least 1,000 years	8.4.3.3.4

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Table 8.4.1-3. Technical criteria from 10 CFR Part 60 related to discussions in Section 8.4 (page 1 of 3)

10 CFR 60 Citation	Principal objectives	8.4 Section
Subpart E		
60.133	Additional design criteria for the underground facility	
	(a) General criteria for underground facility	
	(1) Orientations, geometry, layout, and depth of the underground facility and design of engineered barriers that are part of the underground facility shall contribute to containment and isolation	8.4.2.3.3 8.4.2.3.4 8.4.3.3
	(2) Design underground facility so that effects of credible disruptive events during operations, such as flooding, fires and explosions, will not spread through the facility	8.4.2.3.3 8.4.2.3.4 8.4.3.2.4 8.4.3.3
	(b) Flexibility of design	
	Design underground facility with sufficient flexibility to allow adjustments to accommodate site specific conditions	8.4.2.3.6.4
	(c) Retrieval of waste	
	Design underground facility to permit retrieval of waste in accordance with 60.111	8.4.2.3.6.3

Table 8.4.1-3. Technical criteria for 10 CFR Part 60 related to discussions in Section 8.4 (page 2 of 3)

10 CFR 60 Citation	Principal objectives	8.4 Section
60.133 (continued)	(d) Control of water and gas	
	Design of underground facility for control of water or gas intrusion	8.4.2.3.3 8.4.2.3.4 8.4.3.3
	(e) Underground openings	
	(1) Design underground openings so operations can be carried out safely and retrievability option maintained	8.4.2.3.3 8.4.2.3.4 8.4.2.3.6.3
	(2) Design underground openings to reduce potential for deleterious rock movement or fracturing of overlying or surrounding rock	8.4.2.3
	(f) Rock excavation	
	Design of underground facility to incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water to contact waste packages or radionuclide migration to the accessible environment	8.4.2.3.3 8.4.3.3
	(h) Engineered barriers	
	Design engineered barriers to assist geologic system in meeting postclosure performance objectives	8.4.3.3.2 8.4.3.3.3

Table 8.4.1-3. Technical criteria for 10 CFR Part 60 related to discussions in Section 8.4 (page 3 of 3)

10 CFR 60 Citation	Principal objectives	8.4 Section
60.133 (continued)	(i) Thermal loads	
	Design underground facility to meet performance objectives considering predicted thermal and thermomechanical response of host rock, and surrounding strata, ground water system	8.4.3.2.1.4 8.4.3.2.4
60.134	Design of seals for shafts and boreholes	
	(a) General design criterion	
	Seals shall be designed so that following permanent closure they do not become pathways that compromise ability to meet performance objectives	8.4.3.3.1 (8.3.3.1) (8.3.3.2)
60.137	General repository operations area designed to permit implementation of performance confirmation program that meets requirements of subpart F	8.4.2.3.6.2 8.4.2.3.6.4
Subpart F		
60.140	General requirements	
	(b) Timing	
	Performance confirmation will start during site characterization and continue until permanent closure	
	(d) Constraint	
	Not adversely affected ability of repository to meet performance objectives	

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related to postclosure performance impacts of the site characterization program. In general, those sections of Subpart E that have not been addressed directly in Section 8.4 include 10 CFR 60.131 (general design criteria for the general repository operations area), 10 CFR 60.132 (additional design criteria for surface facilities), and portions of 10 CFR 60.133 (additional design criteria for underground facility), of 10 CFR 60.134 (design of seals for shafts and boreholes), and 10 CFR 60.135 (design criteria for the waste package).

The significance of the criteria in 10 CFR 60.133, 60.134, and 60.137 to the site characterization program has generally been to add some specificity to several of the impact evaluations. For example, specific evaluations of (1) the flexibility of the design to accommodate site-specific conditions encountered in construction, (2) the control of water and gas, (3) excavation methods and allocation of a dedicated testing area consistent with both site characterization and performance confirmation needs, and (4) postclosure sealing are among the items considered when determining if the characterization program is consistent with meeting these regulations. In particular, the length of time for which the ramps/shafts are designed to be usable is 100 years, consistent with the requirements for maintaining the option to retrieve the waste. Sections of 8.4 that describe the considerations relative to assuring consistency with meeting these parts of 10 CFR 60 are tabulated in Table 8.4.1-3.

As indicated, considerable attention has been paid to ensuring that the site characterization program is consistent with the requirements of 10 CFR 60. This attention has resulted in specific layouts of proposed characterization tests and in the adoption of appropriate construction controls.

The remainder of Section 8.4 is devoted to describing in more detail the characterization program, the planned operations, and how these operations have been evaluated to ensure that the program is consistent with meeting the regulations. Before proceeding with these discussions, however, the concepts of unsaturated zone flow and their application to Yucca Mountain will be discussed. These concepts are particularly important because an understanding of them is a prerequisite for understanding the potential impacts of testing activities on site integrity and because the unsaturated zone is the primary element that the DOE expects to rely on in demonstrating the waste-isolation capabilities of the site.

8.4.1.3 Concepts of unsaturated-zone flow and their application to Yucca Mountain

Introduction

Subsequent portions of this section present or make reference to analyses that address the impact of site characterization activities on waste isolation and containment or that evaluate the interaction among various tests or construction features. These analyses primarily consider the flow of fluids (liquid water and water vapor or other gases) in the vicinity of

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excavations (ramps, shafts, drifts, drillholes, or trenches) in the unsaturated zone at Yucca Mountain. An important requirement for understanding these analyses and the conclusions drawn from them is a review of some of the basic concepts of ground-water flow in the unsaturated zone. Of special importance for this section is an understanding of the effects of excavations including boreholes, ramps, shafts, and drifts on unsaturated rocks and the effects of fluids that might be introduced as the excavations are developed.

The evaluations of the ultimate performance of a repository at the Yucca Mountain site will be based on predictions of ground-water flow and radionuclide transport in the unsaturated zone. These predictions will consider both the hydrogeologic setting of the site, as derived from present information and from the site characterization program, and the credible disruptive classes that could extensively modify that hydrogeologic setting. In addition, these predictions consider the possible effects of both surface and subsurface site characterization activities on the performance of the repository. At this point in the program, preliminary evaluations can be made of the impacts of characterization activities by examining the specific effects of relatively small-scale excavations into the unsaturated zone. These preliminary evaluations must also consider the basic hydrogeologic setting and credible disruptive classes that apply to these excavations.

These evaluations of the impacts of site characterization excavations must address basic questions, including the following:

1. What effects on the moisture flow system are produced by the construction of an excavation or testing in the excavation in the unsaturated zone; i.e., does it introduce increased flux to the repository horizon or does it create a preferential pathway?

2. What effects are produced on the unsaturated-zone flow system by the existence of an excavation that is backfilled or sealed?

3. If fluids are introduced into these openings (by infiltration of surface water, by lateral moisture movement toward the excavation, or from construction fluids used during excavation) what is the expected effect on the flow system?

The remainder of this section will present information that supports some general hypotheses concerning moisture flow in the unsaturated zone that can be applied to the Yucca Mountain site. Supporting technical analyses are summarized in Section 8.4.3 and numerous activities that will evaluate or test these hypotheses are described in Section 8.3.1.2. The following hypotheses are extracted from the set of hypotheses presented in Section 8.3.1.2 and are listed for discussion:

1. The rocks at the proposed repository horizon and the rocks above and directly below this horizon are unsaturated.

2. The flow system is approximately steady state, or responds very slowly to hydrologic perturbations.

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3. Water tends to be held in rock-matrix pores and does not move readily into relatively large openings, such as large-aperture fractures, boreholes, and drifts; conversely, water tends to be imbibed into small openings (pores) from large openings (fractures).

4. Moisture flow in the unsaturated zone occurs both as liquid water and water vapor.

5. The hydraulic conductivity of an unsaturated rock mass is strongly affected by the degree of saturation and decreases with decreasing saturation.

These hypotheses concerning moisture flow in the unsaturated zone lead to the following preliminary conclusions about the impact of excavations in the unsaturated zone at Yucca Mountain:

1. Liquid-water flow occurs predominantly in the unsaturated rock matrix. Neither large-aperture fractures nor the excavations are expected to be conduits for water flow in the unsaturated zone under existing conditions. Fractures and excavations, however, must be examined as potential pathways for gas phase (including water vapor) and liquid water movement under conditions associated with the range of scenarios needed to assess total system performance.

2. Excavations will be backfilled during repository closure with material that has properties such that under expected conditions it will also be unsaturated. This backfill and other seal components will be designed to limit vapor flow and flow of surface water that might have access to these excavations. As a result of these designs, water entering the backfill would be expected to be imbibed into the rock matrix.

3. The limited quantities of liquids that are expected to be introduced into excavations during site characterization operations are expected to be dispersed into the available rock matrix pore space within reasonably short distances from the excavations; however, localized flow in fractures could result from injected liquid, although this flow also would be ultimately imbibed and dispersed within the rock matrix.

<u>Concepts of flow</u>

Current understanding of the hydrology of the unsaturated zone at Yucca Mountain is based on the knowledge of the physics of moisture flow in the unsaturated zone, preliminary data and analyses of Yucca Mountain properties (Chapter 3 of the SCP and Section 8.4.3.2.1), the understanding of the site geologic framework, and knowledge derived from physical analogs. This discussion focuses on the basic physics of flow and is a highly simplified introduction to a complex hydrologic system. A more detailed, technical discussion of fluid-flow conditions and processes in the unsaturated zone at Yucca Mountain is presented in Sections 3.6 and 3.9 of the SCP. Section 8.3.1.2 discusses alternative conceptual models, including hypotheses and uncertainties related to unsaturated fluid flow at Yucca Mountain.

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The unsaturated zone is defined to be the rock mass and its contained fluids between the land surface and the water table. Within the unsaturated zone, most of the rock-matrix pores are not completely filled with water, (i.e., the rocks are unsaturated). The percentage of pore space filled with water is expressed as the degree of saturation. Saturation generally varies spatially, and from unit to unit. Water within the partially saturated pores of the unsaturated zone is held under tension, which, in effect, produces a net negative "pressure," or potential. In contrast, in the saturated zone the interconnected pores are completely filled with water, the water is under hydrostatic compression, and the pressure in the water-filled pores is positive. The boundary between the two zones defines the water table, which is that surface at which the liquid-water pressure is atmospheric. The position of the water table at a point is commonly identified by the level at which standing water occurs in an uncased borehole that penetrates the saturated zone.

The potential energy of water determines the state and movement of water. Water usually flows from regions of high potential energy to regions of lower potential energy in both the saturated and unsaturated zones. This energy-driven water flow moves to establish an equilibrium state within the system. When water reaches the state of equilibrium, defined as a condition of uniform or equal potential energy, there is no flow. The state of equilibrium in a natural system can be approached but probably never attained. The system may, however, approach a steady-state condition in which the net rate of inflow to the system is approximately equal to the net rate of outflow from the system. Under these conditions, local equilibrium would be established between and within small scale parts of the system, such as a fracture and the adjacent rock matrix.

In the unsaturated zone, the total water potential at a point is approximately equal to the sum of the gravitational potential energy and the matric potential. The gravitational potential energy is directly proportional to the height of the point above a reference datum. Because of the gravitational potential, the general direction of flow in the unsaturated zone is downward. The matric potential is the energy of the water within the pores resulting from the attraction of water molecules in the partially filled pores to the matrix enclosing the pore and to each other. Matric potential includes the energy of water due to surface tension in the pores (capillarity) and the water adsorbed on the matrix surfaces. Matric potential is inversely proportional to the size of the pore space (or other opening, such as a fracture aperture) that contains water. The resultant force due to gravitational potential energy and matric potential determines the specific direction that water flows; locally, this direction may be other than downward. Matric potential is frequently expressed as a suction, or as a negative pressure.

Because the matric potential is inversely proportional to the size of the opening containing water, unsaturated small pores imbibe water preferentially to large pores. Thus, in this relatively simplistic capillary-bundle theory, water tends to move from large pores into small pores until matric potential equilibrium between the large and small pores is reached. As a result, under unsaturated conditions, water generally does not flow from the matrix into large-aperture fractures or into open boreholes or drifts. Once local saturated or nearly saturated conditions are reached in the

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matrix, then such flow can occur. In reality, the conditions under which water flows in fractures depend on many factors, such as the relative size of the pores and fractures, the internal geometries of the fractures, the degree of fracture interconnection, and whether wetting or drying conditions are occurring, as well as the degree of saturation. These effects are documented in many analyses of unsaturated flow around openings (see, for example, Beven and Germann, 1982). Water stored within an unsaturated rock mass, therefore, would not be expected to move spontaneously into boreholes, drifts, ramps, shafts, waste-emplacement holes, or other openings whose diameters exceed the sizes of the pores. Movement into large openings requires additional external energy to initiate a transient change capable of causing such movement, such as increased infiltration or local heterogeneities and geometries that result in focused flow.

Under certain circumstances, water-vapor flow may significantly contribute to total water flow in the unsaturated zone. In most instances, water-vapor flow in the unsaturated zone at depths typical of the repository is by diffusion, which is a relatively slow process and, therefore, contributes only a small amount to the total water flow. When large amounts of air (which is nearly saturated with water vapor) circulate within or flow out of the unsaturated zone, then water-vapor flow may become much more substantial. Water-vapor flow may be greater near the land surface, especially if large openings, such as fractures, faults, boreholes, ramps or shafts, occur in the unsaturated zone exposed to the surface where the effects of barometric air pressure changes are more pronounced (Weeks, 1987).

The concepts of liquid-water flow in unsaturated and fractured porous media can be illustrated with characteristic curves (Figure 8.4.1-1), which depict saturation as a function of matric potential for both a fracture and the adjacent rock matrix. When a porous material is saturated, the matric potential is zero. When the saturation decreases, water leaves the largest pores first, decreasing the corresponding value of matric potential. The smaller pores that preferentially hold the water retain water at much smaller matric potentials (more negative pressure). Water-characteristic curves can be empirically or theoretically derived; their shape is related to the distribution of different pore sizes in the matrix. In general, at a particular saturation, the matrix with smaller pores has a smaller matric potential (more negative) than a matrix with larger pores.

Under equilibrium conditions, the water potential in a fracture and the water potential in the matrix immediately adjacent to the fractures are equal. If a fracture is thought of as a large pore, then a fracture at equilibrium with a matrix that is unsaturated contains very little water if, for example, as shown in Figure 8.4.1-1, the matrix potential is -100 bars, corresponding to the saturation value of 0.3 for the matrix. In this example, measurable amounts of water do not move into the fractures until the matric potential approaches -10 bars (matrix saturation of 0.7).

The pore-size distribution and the tortuous geometry of the flow path fixes the upper limit of hydraulic conductivity (the measure of the ability to transmit fluids) in the matrix. The highest conductivity for flow through the matrix is the saturated hydraulic conductivity. The hydraulic conduc-

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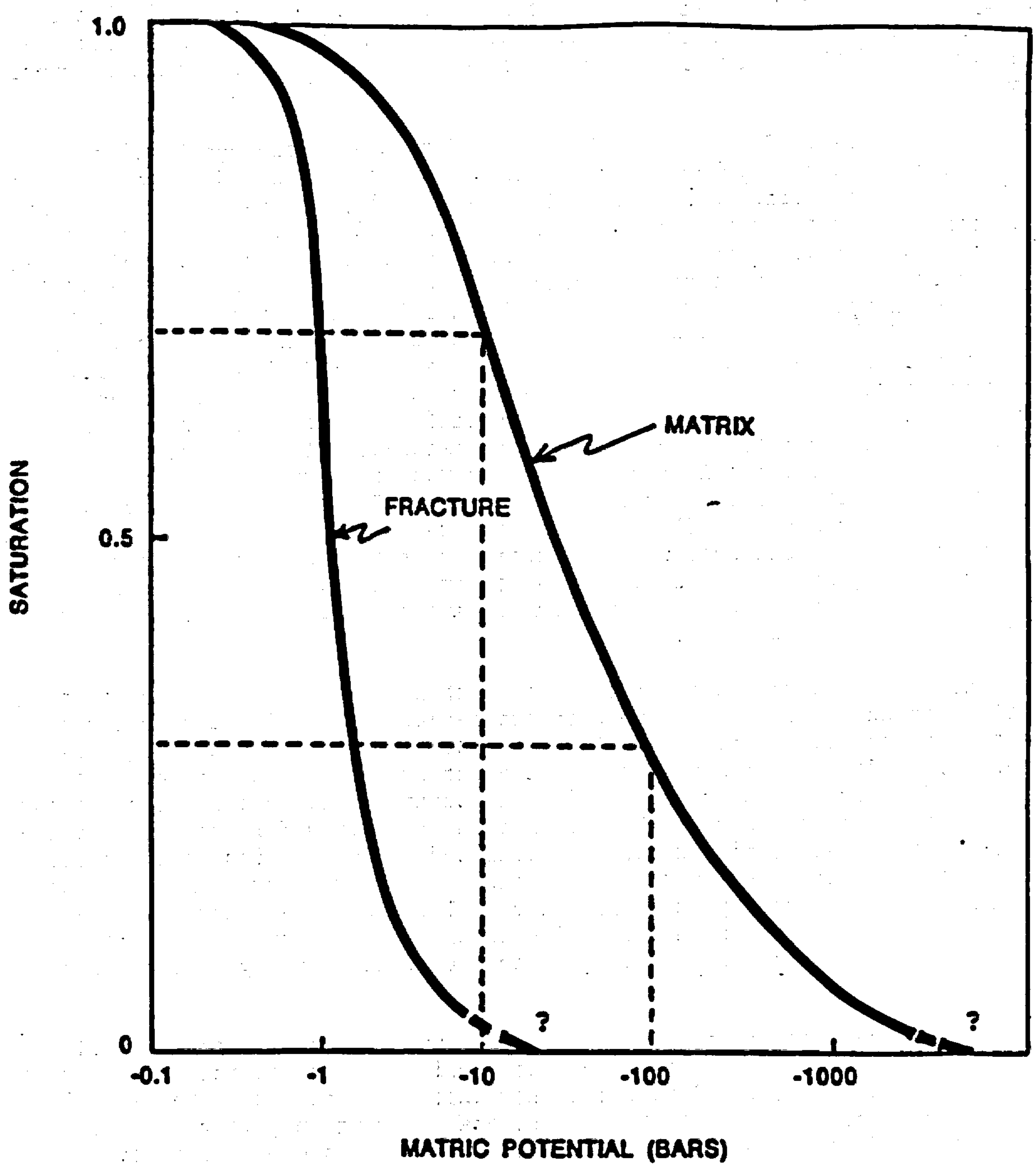

Figure 8.4.1-1. Hypothetical matric potential verus saturation for fractures and rock matrix; ? indicates uncertainty.

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tivity of the matrix is reduced if the saturation is less than 1.0 (Figure 8.4.1-2). This reduction in hydraulic conductivity with decreasing saturation is one of the major differences between saturated and unsaturated water flow.

The example in Figure 8.4.1-2 is provided to show the hypothetical relationship between hydraulic conductivity in the matrix and fractures over a wide range of matric potentials. In this example, the saturated hydraulic conductivity for the matrix is approximately 5 x 10^{-6}m/s. If the matric potential were lowered to -10 bars (saturation of 0.7, Figure 8.4.1-1), then the unsaturated hydraulic conductivity would be 1 x 10^{-6}m/s, a factor of 5 reduction in hydraulic conductivity. If, in this hypothetical case, the fracture and the matrix were at the same matric potential (-10 bars), the conductivity of the fracture would be less than 1 x 10^{-9}m/s, practically nonexistent compared with that of the matrix. Water flow in fractures would make an equivalent contribution to the overall flow rate when the water potential is approximately -0.3 bars (near saturation for the matrix), because until that point is reached, the hydraulic conductivity of the fractures is much less than that of the matrix. If water potentials in the matrix exceed this value, flow in the fractures would be expected to dominate the system because the hydraulic conductivity of the fracture would be substantially greater than that of the matrix. The hydraulic conductivity would be limited only by the saturated hydraulic conductivity of the fracture (approximately 5 x 10^{-5}m/s).

The degree of matrix saturation at which a fracture begins contributing to flow depends on the effective saturation-matric potential curves for both the matrix and fractures. Generally, the matrix must attain a high degree of saturation before water movement occurs along fractures. Water may move across a fracture at asperities, which are points of contact between the two walls of a fracture. Because heterogeneities in values for the matrix properties (e.g., characteristic curves, saturated conductivities, porosities) and the state variables (such as saturation) commonly occur in nature, water movement in fractures may occur at sporadic locations where local saturations in the matrix material are high. While this sporadic flow in fractures may occur, the predominant flow in the unsaturated zone probably is through the matrix.

At steady-state conditions, the net moisture inflow is approximately equal to the net moisture outflow. This condition does not necessarily mean that water has ceased to flow, but rather that the system's state variables (such as saturation) are not changing or are changing only very slowly. Thus, at any depth within the unsaturated zone, the rate of water movement (either liquid or vapor) into a region plus any changes in state (liquid to vapor or vapor to liquid) are balanced in such a way that there is no net change in the conditions within the region (i.e., the amount and distribution of liquid water, water vapor, and air remain constant within the pore space). Under steady-state conditions, the hydrologic conditions within the unsaturated zone are likely to change only very slowly over time. Steady-state conditions do not necessarily preclude other hypotheses, such as lateral water movement or vapor movement. Transients can occur locally, even under generally steady-state flow. Transients entail a short-time change in the

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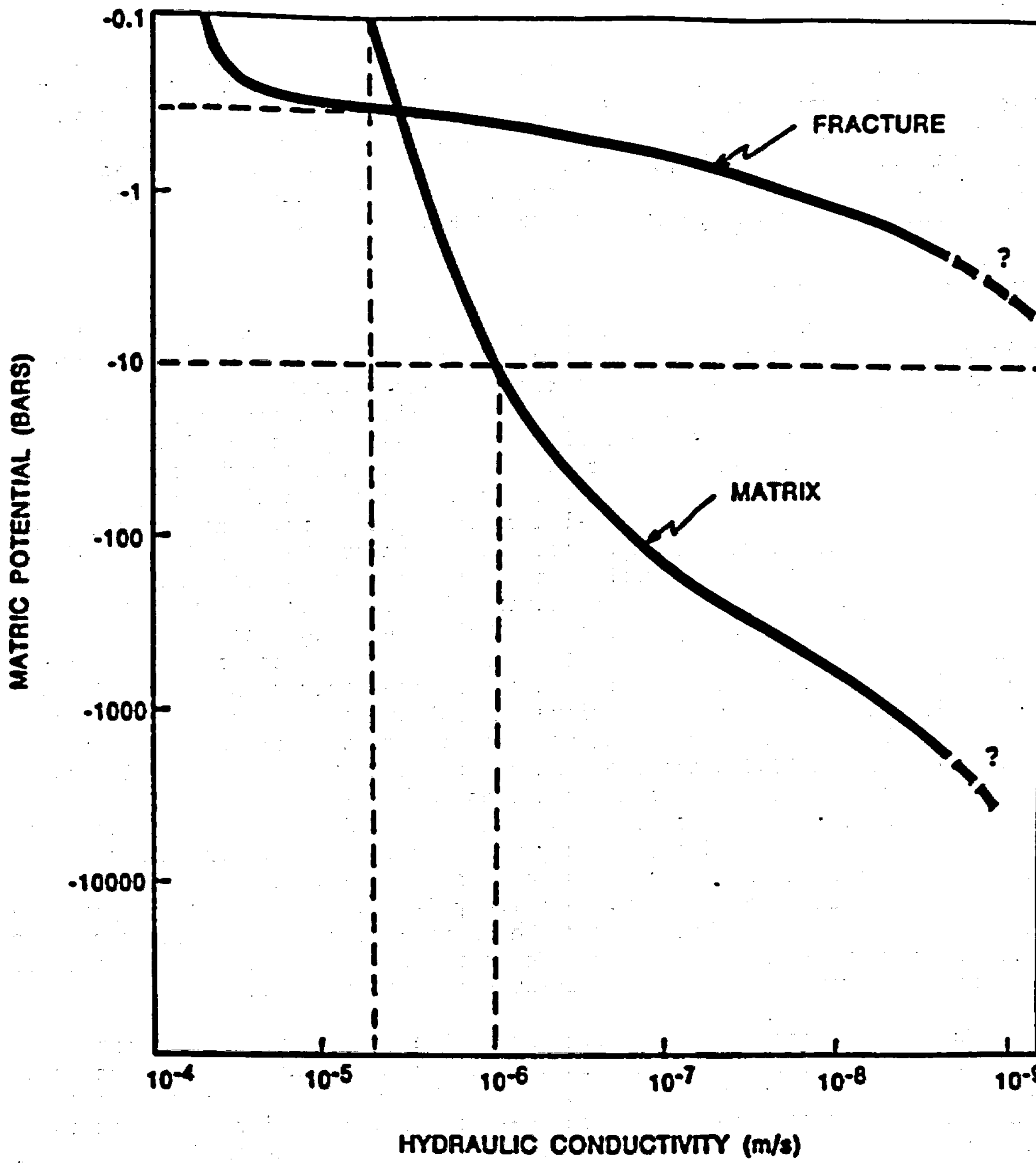

Figure 8.4.1-2. Hypothetical hydraulic conductivity versus matric potential curve for fracture and rock matrix: ? indicates uncertainty.

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state variables (i.e., saturation) within a region. After the transient flow ceases, the system will recover and steady-state flow will tend to be reestablished.

Perched water, ponding, or locally saturated conditions can occur at permeability contrasts. These include geologic contacts where water is moving from a rock with small pores (i.e., one with low saturated hydraulic conductivity) to one with large pores (i.e., one with a high saturated hydraulic conductivity), and where the geometry and structure of the rock heterogeneities and the percolation rates are appropriate.

Relation to Yucca Mountain

Geologically, Yucca Mountain is composed of a layered sequence of volcanic rocks consisting of variably indurated (or welded) volcanic ash. The hydrologic properties of these rocks depend largely on the degree of welding. In particular, the saturated hydraulic conductivity of the matrix of these rocks decreases appreciably with increasing degree of welding. Because of these variations among the properties of the rocks composing the unsaturated zone at Yucca Mountain, the rocks have been divided into a vertical sequence of five principal hydrogeologic units. The central crest of Yucca Mountain above the repository is capped by the Tiva Canyon welded unit (TCw), which has a low rock-matrix saturated hydraulic conductivity but tends to be highly fractured. Underlying the TCw is the Paintbrush nonwelded unit (PTn), which is characterized by a relatively high saturated hydraulic conductivity and few fractures. Below the PTn unit is the thick (about 300 m) Topopah Spring welded unit, which, in the discussion that follows, is subdivided into an upper unit designated TSw1 and a lower unit designated TSw2. The lower TSw2 subunit includes the repository horizon. In general both the TSw1 and TSw2 units are welded tuffs that have a relatively low saturated hydrologic conductivity but tend to be highly fractured. The Calico Hills nonwelded unit (CHnw) underlies the TSw2 unit and is situated between the TSw2 unit and the underlying water table. Within much of its areal extent beneath the repository horizon, the CHnw unit is characterized by a low hydraulic conductivity, relatively few fractures, and the presence of minerals (zeolites) that are capable of retarding radionuclide migration. Consequently, the CHnw unit is considered the principal natural barrier for radionuclide transport in the unsaturated zone at the site.

The assessments of site performance, with respect to the current understanding of the hydrologic conditions and important processes at Yucca Mountain, are based on the hypothesis that the rock mass above the water table is unsaturated, in a near-steady-state flow condition, and that the steady-state moisture flux values are low enough that matrix flow dominates the process. Additionally, it is presumed that large-scale stratigraphic features (layering and material contrasts) in conjunction with the imbibition potential of the near-surface unsaturated rocks reduce the likelihood that extremes in climatic fluctuations result in deep percolation events. Although available unsaturated-zone data are very sparse, these data and analyses based on these data are consistent with these hypotheses. More importantly, the limited data and analyses are not consistent with the presumption that the site is near saturation over the entire profile, nor with the presumption that highly transient flow conditions exist or have the potential to exist over short time periods. Current understanding of

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unsaturated-zone flow phenomena leads to the conclusion that water does not spontaneously move from the small pores of the unsaturated porous rock matrix within the unsaturated zone at Yucca Mountain into larger openings (e.g., ramps, shafts, boreholes, drifts, or fractures). Flow would be expected to be constrained primarily to the matrix except for, as noted earlier, local perturbations resulting from local conditions related to geometry and heterogeneity. On the basis of certain assumptions, hypotheses, and present understanding, the analyses lead to a prediction that ground-water travel times are very long and the system is sufficiently robust to accommodate small perturbations of ambient conditions. The appropriateness of these hypotheses will be extensively investigated during site characterization to determine if they are correct, or if alternative hypotheses are more appropriate. A direct way of determining the validity of these hypotheses will be an examination of the drifts underground within the ESF to identify the extent to which flow in fractures occurs and the degree of saturation of the matrix tuff around those fractures.

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8.4.2 DESCRIPTION AND LOCATION OF CHARACTERIZATION OPERATIONS

Section 8.4.2 addresses the adequacy of the planned surface and subsurface activities for characterizing the range of conditions and processes important to performance and design at the Yucca Mountain site. The section also evaluates whether construction or operation of facilities or the conduct of tests at the site is likely to adversely influence the results of site characterization activities.

The performance and design requirements of 10 CFR 60 Subpart E were reviewed in Section 8.4.1. The DOE has translated these requirements into an issues hierarchy, as described in Section 8.2. Performance allocation was then performed on an issue-by-issue basis to establish the testing needs for resolving each issue. Section 8.4.2.1 reviews the postclosure and preclosure data needs that were identified in Section 8.3 to satisfy performance and design issues. This section also discusses the testing methods available for obtaining these data. Based on these considerations, the planned site characterization activities are discussed, and an evaluation is made of the representativeness of the data being collected. Sections 8.4.2.2 and 8.4.2.3 assess the likelihood of test-to-test and construction-to-test interference in the surface-based and subsurface-based activities. Each of the exploratory shaft facility (ESF) tests is discussed, along with layout constraints imposed on the design, construction, or operation of the facility. The zone of influence is estimated for each test, and the potential for construction and operation interference is evaluated.

8.4.2.1 Rationale for planned testing

The purpose of this section is to present information that establishes the adequacy of the proposed site characterization program for estimating the ranges of conditions and processes that are needed to support repository design and to evaluate the performance of the Yucca Mountain site. Based on current understanding, data from surface-based testing, in conjunction with testing in the proposed ESF, is expected to be adequate for performance assessment. This section provides the rationale for this statement by discussing (1) the principal data needed for preclosure and postclosure design and performance evaluation; (2) the various methods available for obtaining these data; (3) the activities to be conducted during site characterization, and the major considerations for choosing them; and (4) the representativeness of the data to be obtained, focusing on the relation between surface-based testing and testing in the ESF, the location of the ESF, and statistical considerations.

Before site characterization begins, only a limited amount of regional and site-specific information will be available, which will limit the following planning and analysis activities:

1. Evaluation of repository and engineered barrier designs.

2. Evaluation of the representativeness of data collected in the planned characterization activities.

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3. Comparative evaluation of potential benefits of planned activities versus risks to site performance.

4. Evaluation of the potential for interferences between tests and between construction and tests that could affect data quality.

5. Evaluation of the adequacy of planned activities with respect to measurement type, range, accuracy, location, etc.

These are important constraints because they require flexible, incremental plans that can be advanced or modified as new information becomes available. As more is learned about the system through observation and testing, ongoing or planned characterization activities will be reviewed to ensure that they are appropriately focused. The bases for evaluating and adjusting the activities during site characterization are as follows:

1. The early results from site characterization activities will be used to identify what further testing may be necessary.

2. Intermediate stages of characterization will refine the descriptions of site conditions and the significant processes involved, concentrating on reducing the uncertainty in performance evaluations and obtaining information for model validation.

3. Later stages will be primarily involved in acquiring information for the performance confirmation program for completing model validation.

Changes in planned site characterization activities or the inclusion of new site characterization activities will be reported in the semiannual progress reports.

The representativeness of data from the planned site-characterization activities is evaluated in this section (1) by describing the data needed for performance and design analyses and (2) by considering the alternative methods for obtaining this information, as well as the rationale for selecting the proposed test methods. The data needs were identified in the performance-allocation process described in Section 8.1 and are associated with quantifiable performance measures and parameters for assessing the performance and design issues. Because performance measures are often described in terms that cannot be compared directly with observations, they must be evaluated using models and parameters derived from observations. In other instances, the large time scales associated with a process and the spatial variability of data preclude an approach to issue resolution based only on observation.

Another consideration in developing site characterization activities is the need to evaluate the hypotheses that constitute alternative conceptual models. These hypotheses concern physical domain, driving processes, boundary conditions, geometry, and system responses that are important to performance. By testing the validity of competing hypotheses, the site

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characterization activities reduce the uncertainty in the performance-assessment predictions. The various hypotheses and the activities planned to test alternatives are discussed in general in Section 8.3.1.1 and, specifically in various site programs in Section 8.3.1.

Sections 8.4.2.1.1 and 8.4.2.1.2 present the principal data needed to evaluate postclosure performance and preclosure design requirements. Section 8.4.2.1.3 discusses the various methods currently available for obtaining this information, which is followed by a description in Section 8.4.2.1.4 of what methods have been included in the planned testing program and the bases for these decisions. Section 8.4.2.1.5 evaluates data representativeness based on the extent and location of planned tests and other statistical considerations.

8.4.2.1.1 Principal data needed for postclosure performance evaluations

The following is a summary discussion of the principal links between the issues hierarchy and the data needs. Table 8.4.2-1 summarizes the principal postclosure data needs (including those for pre-waste-emplacement ground-water travel time), and shows the related performance measures or other criteria, information needs, and design and performance issues. This table presents only those information needs, performance measures, or other criteria that require site data; Sections 8.2 and 8.3.5 provide a more complete discussion of issue resolution. The table can be used to relate the data needs to the requirements set forth in the various regulations by reviewing the issues hierarchy discussion in Section 8.2.1.2.

In the following discussion, principal data needs are grouped by major areas of evaluation; specific data needs are shown in performance-allocation tables in Section 8.3.5. The parameters included in those tables, and the data needs discussed below, generally are those that are directly needed for performance evaluations. Those parameters generally are supported by a great variety of less-specific data that are needed to develop the performance parameters and to build confidence in the values for those parameters.

Flow and transport data needs

Because of the reliance being placed on the unsaturated zone for waste isolation performance, principal data needed for flow and transport aspects of postclosure performance evaluation are from the unsaturated zone. Included is the consideration of pre-waste-emplacement ground-water travel time. The data needs derive in part from a need to test concepts of fluid flow in the unsaturated zone. To model flow and transport in the unsaturated zone with an acceptable level of uncertainty in the predictions, additional unsaturated-zone information is needed in the following areas: (1) hydrologic conditions and processes, including those for the Calico Hills unit; (2) geochemical conditions and processes; (3) geomechanical and thermal influence on the hydrologic conditions and processes; (4) the magnitude of surface infiltration and processes controlling flux; (5) gaseous movement and the pneumatic conductivity in the repository block; (6) stability of the water table; and (7) water chemistry.

Table 8.4.2-1. Principal site data needed for postclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 1 of 4)

Issues	Information need[b]	Performance measure or other criteria[c]	Principal site data needed[d]
		PERFORMANCE ISSUES	
Issue 1.1: Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?	1.1.1--Site information needed to calculate releases to the accessible environment	Scenario evaluations; need probability distributions for events constituting scenarios Linked to virtually every other performance issue Reliance on ground-water travel time (GWTT) in the UZ Geochemical retardation in the UZ as backup Saturated zone processes as backup	Data for unsaturated zone (UZ) flow and transport models[e] Data on the scale dependence of rock mass under experimental conditions Data on the waste package environment Site data for geologic, hydrological, and geochemical/geophysical models[f] Data for thermal/mechanical/hydrologic and physical-properties models[f] Data to evaluate alternative conceptual models of postclosure performance
Issue 1.2: Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15?	1.2.1--Determination of doses to the public in the accessible environment through liquid pathways 1.2.2--Determination of doses to the public in the accessible environment through gaseous pathway	For ground-water transport of nuclides, rely on GWTT in 1,000 yr For gaseous transport, rely on low inventory, gaseous diffusion, and (possibly) chemical immobilization of carbon-14 in the UZ	Data for UZ flow and transport model[e]
Issue 1.3: Will the mined geologic disposal system meet the requirements for the protection of special sources of ground water as required by 40 CFR 191.16?	1.3.1--Determination whether any Class 1 or special sources of ground water exist at Yucca Mountain, within the controlled area, or within 5 km of the controlled area boundary 1.3.2--Determine for all special sources whether concentrations of waste products in the ground water during the first 1,000 yr after disposal could exceed the limits established in 40 CFR 191.16.	Show three aquifers (valley fill, tuff, lower carbonate) are not "special sources" as defined (survey local population distribution and ground-water use) If necessary, evaluate contamination within 1,000 yr of waste emplacement using an approach similar to Issue 1.1, and relying on GWTT in the UZ	Data for UZ flow and transport models[e]
Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?	1.4.3--Scenarios and models need to predict the rate of degradation of the container material 1.4.4--Estimates of the rates and mechanisms of container degradation in the repository environment for anticipated and unanticipated processes and events, and calculation of the failure rate of the container as a function of time	Substantially complete containment; need additional data for site specific definition Current definition calls for analysis of breaching scenarios for 1,000 yr, data on quantity and quality of water to contact container during containment period	Bounding conditions for UZ flow and transport model[e] Data on the waste package environment

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Table 8.4.2-1. Principal site data needed for postclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 2 of 4)

Issues	Information need[b]	Performance measure or other criteria[c]	Principal site data needed[d]
PERFORMANCE ISSUES (continued)			
Issue 1.5: Will the waste package repository engineered barrier system meet the performance objective for limiting radionuclide release rates as required by 10 CFR 60.113?	1.5.3--Scenarios and models needed to predict the rate of radionuclide release from the waste package and engineered barrier system 1.5.4--Determination of the release rates of radionuclides from the waste package and engineered barrier system for anticipated and unanticipated events 1.5.5--Determination of the amount of radionuclides leaving the near-field environment of the waste package	Engineered barrier system (EBS) requires definition; EBS boundary currently taken at surface of underground openings; EBS may control how ground water contacts waste; dependence on design	Data for UZ flow and transport model[e] Data on waste package environment for times between 1,000 and 10,000 years
Issue 1.6: Will the site meet the performance objective for pre-waste-emplacement GWTT as required by 10 CFR 60.113?	1.6.1--Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the GWTT along the path 1.6.5--Boundary of the disturbed zone	Definition of disturbed zone; evaluate appropriate calculational model(s) for flow system relying on site data from surface boreholes and the exploratory shaft facility (ESF) Identify fastest path from calculational models	Data for UZ flow and transport model[e]; GWTT under nominal conditions Data on in situ hydrologic responses of the rock mass under experimental conditions Data on the scale dependence of rock mass characteristics
Issue 1.7: Will the performance-confirmation program meet the requirements of 10 CFR 60.137?	To be determined	Details of program depend on content of license application, and therefore on information obtained during site characterization Candidate tests have been identified that begin during site characterization; See Table 8.3.5.16-1	Area within ESF reserved as preliminary accommodation
Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?	None identified	Resolution similar to Issue 1.1, but may rely more on expert judgment Results should match Issue 1.1, and bounds on site studies (i.e., identification of major performance parameters) from Issue 1.1 should apply Favorable and potentially adverse conditions; investigate favorable conditions only to the extent such conditions could lend confidence to demonstration of compliance, and compensate, if necessary, for potentially adverse conditions	Data for UZ flow and transport model[e] Data on the waste package environment Data to evaluate alternative models of postclosure performance

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Table 8.4.2-1. Principal site data needed for postclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 3 of 4)

Issues	Information need[b]	Performance measure or other criteria[c]	Principal site data needed[d]
		PERFORMANCE ISSUES (continued)	
Issue 1.9: (a) Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the postclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for geohydrology, geochemistry, rock characteristics, climate changes, erosion, dissolution, tectonics, and human interference; and (b) can the comparative evaluation required by 10 CFR 960.3-1-5 be made?[e]	None identified	Depends on resolution of Issues 1.1 through 1.6, and 1.8 (since the Department of Energy guidelines reference Nuclear Regulatory Commission performance objectives) Also requires erosion data from site studies	Data for UZ flow and transport model[e] Data on the scale dependence of rock mass characteristics Site data for geologic, hydrologic, and geochemical/physical models[f]
		DESIGN ISSUES	
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 for the resolution of the performance issues?	1.10.4--Postemplacement near-field environment	Rock load on waste container; temperature vs. time for container environment quantity and quality of water in contact; information on tectonic processes (breaching, igneous intrusion, or eruption) Depends on repository design and EBS design and performance	Data needed to model the waste package environment
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?	1.11.1--Site characterization information needed for design	Data on stress, fracturing, etc., affecting repository layout, orientation Location and characterization of faults, water inflow conditions, ground conditions Data to support controls on water use chemical changes with respect to postclosure performance Data needed to define and control excavation-induced permeability changes Data to support thermal loading consistent with performance	Data on geomechanical rock mass characteristics Data for thermal/mechanical/hydrologic and physical properties models[f]

Table 8.4.2-1. Principal site data needed for postclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 4 of 4)

Issues	Information need[b]	Performance measure or other criteria[c]	Principal site data needed[d]
		DESIGN ISSUES (continued)	
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?	1.12.1--Site, waste package, and underground facility information needed for design of seals and their placement methods 1.12.2--Materials and characteristics of seals for shafts, drifts, and boreholes 1.12.3--Placement method for seals for shafts, drifts, and boreholes 1.12.4--Reference design of seals for shafts, drifts, and boreholes	Data on hydrology of sealing environment Data on nominal expected stress and temepratura conditions Data on geochemical, hydrochemical, and seismic conditions with respect to seals performance Hydrologic characterization of faults and fault zones	Data on the scale dependence of rock mass characteristics Data on the in situ hydrologic responses of the rock mass under experimental condition Site data for geologic, hydrologic, and geochemical/geophysical models

[a]Issues 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.9, 1.10, 1.11, and 1.12 and their respective information needs are given in Sections 8.3.5.13, 8.3.5.14, 8.3.5.15, 8.3.5.9, 8.3.5.10, 8.3.5.12, 8.3.5.18, 8.3.4.2, 8.3.2.2, and 8.3.3.2, respectively.

[b]Extracted from Table 8.2-2.

[c]From performance allocation discussed in Section 8.2.2.1.

[d]This column presents generalized descriptions of principal site data needed, for purposes of discussion in Section 8.4.2.1.

[e]UZ flow and transport model used to refer to predictive model of gaseous and liquid movement, and the resulting movement of radionuclides, under nominal and disturbed conditions, in the rock mass between the surface and the water table; emphasis is on liquid movement between the repository and water table, gaseous efflux from the repository, and natural infiltration along pathways such as fault zones.

[f]The models referred to are descriptive models described in the issue resolution strategies for hydrology (8.3.1.2, 8.3.1.2.2.8, and 8.3.1.2.2.9) geochemistry (8.3.1.3 and 8.3.1.3.7) and rock characteristics (8.3.1.4, 8.3.1.4.2.3.1, and 8.3.1.4.3.2.1).

[g]Given the passage of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987), such comparisons are no longer required, although the evaluation will still be performed.

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Because the saturated zone has been assigned a role of backup barrier for flow and transport, less emphasis is being placed on data needs for this component of the flow system. Nonetheless, to assess flow and transport characteristics of this system, data needs include hydrologic and geochemical conditions and processes, and hydrochemistry. Furthermore, saturated-zone conditions influence flow paths and rates in the unsaturated zone, principally by the position of the water table. As a result, data are needed on factors that affect the position of the water table, including the influences of geologic structure and lithology, climate, and tectonics. Thus, data are needed on rock characteristics, present and paleoclimates, paleohydrology, and current tectonic processes and stress conditions as they affect hydrology. The location and condition of faults within the repository site are also important data needs related to flow and transport, because they represent potential pathways to the accessible environment.

Waste package environment data needs

Information on temperature, stress state, moisture, and chemistry in the near-field environment of the waste package are needed to model the postclosure performance of the waste package and engineered barrier system, and to address the criteria of 10 CFR Part 60.135. Specific areas where data are needed include (1) ambient temperature and stress state in the repository horizon; (2) the hydrologic and geochemical conditions of the rock mass in the near-field; and (3) the heat-transfer processes and the influence of temperature variations on moisture migration, geochemistry, hydrochemistry, and thermomechanical processes.

Postclosure tectonics data needs

Data on the nature and condition of faults in and around the repository block are important for evaluating several of the scenarios for performance assessment related to radionuclide transport. Needed information includes (1) the geometry and condition (hydrologic, mechanical, and geochemical) of local faults; (2) the regional stress state; (3) nature and past history of faulting in the vicinity of the site; (4) the history of volcanism, potential eruptive and intrusive processes, and inferred future activity; and (5) the relation between tectonic processes and hydrology. These data are required for assessing various disruptive scenarios and their impact on the long-term performance of the site and the engineered barriers.

Resource evaluation data needs

The location, extent, value, and probability of occurrence of mineral resources at the site are needed to evaluate the likelihood of human intrusion. Similar information for natural gas resources is needed, particularly in the deeper rock formations of Paleozoic age.

Spatial variability of properties and conditions

Because rock is seldom homogeneous, the variability of the geologic, hydrologic, geochemical, mechanical, and thermal properties and conditions within the repository block needs to be characterized. Spatial variability within the site is a major source of modeling uncertainty, and the confidence

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in the performance predictions will be improved by accounting for the variability of those parameters that significantly affect the output from an analysis.

Summary of postclosure information needs

The data needs for site characterization important for postclosure performance assessment were identified in the performance allocation process. In general, the data needs are related to the hydrologic, geologic, geochemical, mechanical, and thermal properties and processes relevant to the flow of water and the transport of radionuclides; waste package environment; tectonic activities; resource evaluation; and the spatial variability of the data.

8.4.2.1.2 Principal data needed for preclosure performance evaluations and design

Site characterization data are needed to support analyses related to meeting the two preclosure performance objectives (radiological safety and retrievability), to meeting 10 CFR 60.111(a) and (b), and to supporting and evaluating the repository design, including nonradiological health and safety concerns. The data needed by each of the preclosure performance and design issues (Section 8.2.2) are detailed in the performance allocation tables in Sections 8.3.2, 8.3.4, and 8.3.5. The principal types of site data needed for these issues are identified in Table 8.4.2-2. These data are grouped below relative to the support for surface and underground facilities design.

Surface facilities design data needs

The site information needed to design the repository surface facilities can be summarized into four categories: geologic information, meteorological and surface hydrologic information, site geometry, and surface soil properties. Many of these needs are specific to proposed locations of the surface facilities, as summarized in the following:

1. Geologic information needed includes location and characteristics of features, such as faults, and other data necessary to determine the probability, magnitude, and effects of seismic and volcanic events.

2. Meteorological and surface hydrologic information is needed to estimate flood potential and magnitude for design of area drainage; to set the values for tornado and wind loads on structures; to provide design values for heating, air conditioning, and ventilation systems; and to provide input to analyses of dispersion of potential radioactive releases for the assessment of worker and public radiological safety.

3. The geometry of the surface of the site is needed in conjunction with the meteorological information to estimate areas of potential flood inundation and to select favorable locations for surface facilities, including roads, buildings, and portals for underground access.

Table 8.4.2-2. Principal site data needed for preclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 1 of 4)

Issues	Information need[b]	Performance measure or other criteria[c]	Principal site data needed[d]
		PERFORMANCE ISSUES	
Issue 2.1: During repository operation, closure, and decommissioning (a) will the expected average radiation dose received by members of the public within any highly populated area be less than a small fraction of the allowable limits and (b) will the expected radiation dose received by any member of the public in an unrestricted area be less than the allowable limits as required by 10 CFR 60.111, 40 CFR 191 Subpart A, and 10 CFR Part 20?	2.1.1--Site and design information needed to assess preclosure radiological safety	Characterization of dilution, transportation bioaccumulation of radionuclides in rivers, streams, foodstuffs Characterization of atmospheric transport by wind and other convection mechanisms, including dispersion and diffusion	Meteorological and radiological monitoring Surface hydrology information (runoff, streamflow)
Issue 2.2: Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological safety of workers under normal operations as required by 10 CFR 60.111 and 10 CFR Part 20?	2.2.1--Determination of radiation environment in surface and subsurface facilities due to natural and man-made radioactivity	Characterization of atmospheric transport dispersion and diffusion within the site boundaries Characterization of radiation attenuation by the host rock Characterization of naturally occurring radionuclide radiation levels from miscellaneous sources, e.g., testing	Data on meteorological and radiological conditions Compositional data including radon emanation rates and radiation shielding characteristics of the host rock
Issue 2.3: Can the repository be designed, constructed, operated, closed, and decommissioned in such a way that credible accidents do not result in projected radiological exposures of the general public at the nearest boundary of the unrestricted area, or workers in the restricted area, in excess of applicable limiting values?	2.3.1--Determination of credible accident sequences and their respective frequencies applicable to the repository 2.3.2--Determination of the predicted releases of radioactive material, and projected public and worker exposures, and exposure conditions under accident conditions, and that these meet applicable requirements	Frequency and consequences of initiating events caused by natural or site-related phenomena Characterization of atmospheric transport characteristics at the site, including long-term environmental dispersion, dilution, diffusion, and bioaccumulation processes	Data on tectonic, volcanic, and meteorologic, or other hazards
Issue 2.4: Can the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111?	2.4.1--Site and design data required to support retrieval	Shielding characteristics of the host rock (see Issue 4.1) Data on rockfall, emplacement borehole liner curvature, and liner lifetime in retrieval period	See data required by Issue 4.4

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Table 8.4.2-2. Principal site data needed for preclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 2 of 4)

Issues	Information need[b]	Performance measure or other criteria[c]	Principal site data needed[d]
	PERFORMANCE ISSUES (continued)		
Issue 2.5: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for population density and distribution, site ownership and control, meteorology, and offsite installations and operations?	Needed information taken from other preclosure issues		Uses information from Issues 2.1 and 2.2
Issue 4.1: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for surface characteristics, rock characteristics, hydrology, and tectonics	Needed information taken from other preclosure issues		Uses information from Issues 4.2, 4.3, and 4.4
	DESIGN ISSUES		
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?	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 2.6.2--Design information needed to comply with preclosure criteria from 10 CFR 60.135(c) for waste forms	Strategy combined with Issue 1.10 No site characterization data have been identified	
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?	2.7.1--Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate 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 additional appropriate design and protection of structures, systems, and components important to safety have been met	Identification of design-basis accidents, and site characterization data that can be used in support of design features in enhancing radiological safety	Data on spatial distribution of site characteristics, for geologic/geophysical, and hydrologic models[e] Data on tectonic, volcanic, and meteorologic hazards Data on geomechanical rock mass characteristics

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Table 8.4.2-2. Principal site data needed for preclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 3 of 4)

Issues	Information need[b]	Performance measure or other criteria[c]	Principal site data needed[d]
	DESIGN ISSUES (continued)		
Issue 2.7 (continued)	2.7.3--Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objectives pertaining to criticality control have been met		
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?	4.2.1--Site and performance assessment information needed for design	Characterization of the properties and geometry of host rock, which control overbreak, blast-induced fracture, opening closure (supported), rock movement, rock fall, ramp grades, opening size, ventilation leakage, ventilation pressure drop, dust suppression, air quality, host rock temperature during retrieval, air quality, air cooling capacity, seismic activity	Principal needs taken from issue 4.4 below
Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues?	Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package	Related to site data only through waste package performance issues	
Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?	Site and performance assessment information needed for design	Location of surface facilities important to safety with respect to active geologic structures; characterization of potential for ground motion, and potential for volcanic eruption and ash fall Location of surface facilities with respect to foundations (especially facilities important to safety), retaining walls, slopes, hydraulic conditions, soil stability Location of underground facilities with respect to faults, potential faulting, potential volcanic activity, ground motion Characterization of host rock area and thickness with adequate overburden, and physical properties, for repository construction Characterization of host rock properties for evaluations of nonradiological health and safety	Geological and meteorological information, site geometry, and subsurface soil properties in vicinity of surface facilities Site geological information, site geometry, mechanical and physical properties of candidate horizon, rock shielding and radon emanation characteristics, site hydrological data, and site meteorological data

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Table 8.4.2-2. Principal site data needed for preclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 4 of 4)

Issues	Information need[b]	Performance measure or other criteria[c]	Principal site data needed[d]
	DESIGN ISSUES (continued)		
Issue 4.5: Are the costs of the waste packages and the repository adequately established for the resolution of the performance issues?[f]	4.5.1--Estimate the costs of the reference and alternative waste packages 4.5.2--Estimate the costs of the reference and alternative repository designs 4.5.3--Estimate the life cycle costs of the reference and alternative total system design	Related to site data only insofar as information obtained during characterization may impact total cost estimate, through analyses performed for other issues	

[a]Issues 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 4.1, 4.2, 4.3, and 4.4 and their respective information needs are given in Sections 8.3.5.3, 8.3.5.4, 8.3.5.5, 8.3.5.2, 8.3.5.6, 8.3.4.3, 8.3.2.3, 8.3.5.7, 8.3.2.4, 8.3.4.4, and 8.3.2.5.

[b]Extracted from Table 8.2-2.

[c]From performance allocation discussed in Section 8.3.5.

[d]This column presents generalized descriptions of principal site data needed, for purposes of discussion in Section 8.4.2.1.

[e]The models referred to are descriptive models described in the issue resolution strategies for hydrology (8.3.1.2, 8.3.1.2.2.9, and 8.3.1.2.2.10), geochemistry (8.3.1.3 and 8.3.1.3.7), and rock characteristics (8.3.1.4 and 8.3.1.4.2.3.1).

[f]Resolution of Issue 4.5 is not required as the Yucca Mountain site is the only site under consideration for development as a repository as designated by the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987).

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4. Soil properties, including both physical and mechanical properties, are needed to ensure that soil is not subject to excessive alteration as a result of wetting or to unacceptable rates of erosion. Mechanical properties of the surface soils are needed for foundation design and to predict the mitigation of seismic inputs to facilities important to safety.

Data needed for underground facility design

The site information needed to design the underground facilities (Tables 8.3.2.5-2 through 8.3.2.5-12) can be summarized into five basic categories: site geology, site geometry (surface topography, and the location, orientation, and extent of the candidate horizon), mechanical and physical properties of the host rock, site hydrology, and site meteorology. The information needed for these categories is described by the following:

1. Site geologic information, such as location and characteristics of physical structures such as faults, is needed to locate the subsurface facilities and to assess the magnitude and potential for occurrence of loading produced by seismic events.

2. Site geometry, including topography and the location, orientation, and extent of the candidate horizon, is needed to ensure that sufficient area is available for the required quantity of waste, to locate the repository in compliance with requirements for overburden and location relative to the water table, to establish roadway and drainage grades in the access ramps and underground openings, to set the elevation of the repository within a host-rock interval where physical and mechanical properties of the host rock are adequate, and to ensure that access ways to the underground facility are not located in areas subject to flooding inundation.

3. Mechanical and physical properties of the candidate horizon are needed to ensure that underground openings (shafts, ramps, drifts, and boreholes) can be designed and constructed to require only minor maintenance for the operational life of the repository. This determination must consider the nature of both the rock mass (fractures, voids, moisture content, etc.) and the intact rock properties as they are affected by elevated temperature. Thermal properties are needed to design the emplacement configuration for the waste packages so that temperature constraints will be within design limits. Additional needed site data includes the radiation shielding characteristics and radon emission rates for the host rock.

4. Site hydrologic data (related to the potential existence and quantitative description of perched water) are needed to choose appropriate sizes for pumps for water removal and to evaluate sources for the water needed to support repository operation.

5. Site meteorological data are required to design the underground ventilation system.

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Preclosure tectonics data needs

Data are needed on the subsurface geometry of local faults (within about 25 km of the site), on the amount of total slip along such faults, and on the extent to which faulting events involve slip on more than one fault. This information can affect the evaluation of the design basis for ground motion, including time histories and the corresponding response spectra for facilities. In addition, the estimated combined potential for ground motion from all faults and the probability for fault displacement greater than 5 cm in the repository and at the location of facilities important to safety may be affected. The rate of total slip along various faults may affect the estimated probabilities of various size faulting events. The relative importance of contemporaneous slip on associated faults may affect estimates of magnitude, probability of faulting, and the characterization of single-event displacements.

Summary of preclosure data needs

Information is needed for radiological safety and waste retrievability performance evaluations, for design of surface and underground repository facilities, and for nonradiological safety and worker safety evaluation. Geologic information is needed to locate repository facilities, and to evaluate potential tectonic and volcanic hazards. Information on the spatial distribution of host rock characteristics and site geometry is needed to locate and design the underground facility. Data on surface characteristics are needed for seismic design. Meteorological information is needed for safety evaluations. Fault detection and characterization for the Yucca Mountain region is needed for seismic design and performance evaluation. Detailed information on potential faulting in the repository block during the preclosure period is needed primarily for retrievability evaluation.

8.4.2.1.3 Methods for obtaining needed site data

This section briefly reviews the methods available for obtaining needed data. The methods are broadly grouped into categories for obtaining surface and subsurface data, and the methods for subsurface characterization are emphasized. These methods have been further categorized according to whether testing is based at a surface or subsurface location. The scale of the data, or volume of rock influenced, is also discussed. Scale and representativeness of data from the various methods are discussed in greater detail in Section 8.4.2.1.4.

8.4.2.1.3.1 Characterization methods for obtaining surface data

The postclosure and preclosure data needs were discussed previously in Sections 8.4.2.1.1 and 8.4.2.1.2. The surface data needs are summarized as

1. Magnitude of surface infiltration and the processes that control influx.

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2. Surface expressions of local faulting and information concerning the nature of faulting and other structural features within the repository block.

3. Surface evidence related to the regional volcanic history and eruptive and intrusive processes.

4. Surface topography for locating surface facilities and shafts beyond potential flood zones.

5. Soil properties for designing surface facilities and evaluating erosion processes.

6. Meteorological data for radiological release analysis and ventilation system design for surface and subsurface facilities.

The surface data needs can generally be met by measurements at the ground surface, such as meteorological monitoring, radiometric monitoring, geodesy, seismic monitoring, evapotranspiration studies, geologic and surficial deposits mapping, and geophysical methods. Standard methods are proposed in Section 8.3.1 for these measurements. Several of the data needs will require shallow borings and the construction of berms, trenches, flumes, scour chains, and pits. Test methods will include the instrumentation to monitor changes in conditions within the test areas, as well as visual observations.

8.4.2.1.3.2 Characterization methods for obtaining subsurface data

The characterization methods for obtaining subsurface data are discussed by the location at which the methods are applied (surface and subsurface).

Surface-based methods

Two general methods are available for characterizing subsurface conditions remotely from the surface: geophysical methods and borehole methods. Geophysical methods include seismic, electromagnetic, and resistivity methods used for detecting geologic anomalies, estimating the thickness and extent of stratigraphic units, and correlating various parameters from other site characterization methods. Interpreting data from these methods can be difficult if strongly contrasting properties are absent or if other information for correlation is unavailable. Detection of anomalies usually requires significant contrast in density, magnetic susceptibility, or electrical conductivity. Geophysical methods are desirable because they generally are not invasive and provide information on relatively large volumes of rock. These methods are most useful when the data can be correlated with information from boreholes or underground investigations.

Borehole methods include the use of core or rock samples recovered from drilling and downhole testing methods. Samples provide data on hydrologic, geologic, mechanical, and thermal properties. Limitations on borehole observations include the small scale of samples and of certain measurements, and the inherent directional bias of the borehole. Such limitations can be

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addressed (at least along the borehole axis) by sampling and testing the rock matrix and fracture intersections over the length of a borehole. Also, directional variability of the data can be analyzed from borehole inclinations. Boreholes can also be used for collecting water and gas samples for chemical analysis and interpretation.

Borehole test methods are available for characterizing some of the hydrologic and mechanical properties and conditions in the subsurface and for geologic studies using many of the geophysical methods just discussed. Hydrologic methods such as pumping tests and tracer tests provide medium-scale to large-scale data, but they typically require simplifying assumptions on site conditions or processes to interpret the test data. This is also true for mechanical tests, such as stress measurements, where relatively small volumes of rock are influenced by the test. In general borehole geophysical methods, such as cross-hole seismic methods, test a smaller volume of rock than the surface-based methods, but they offer improved resolution and capability to correlate the data with information obtained from the core and other borehole methods.

Subsurface-based methods

Subsurface-based methods are considered to include all test methods applied in underground excavations, including shafts, ramps, tunnels, drifts, and adits. Samples are readily acquired from excavated rock or from exposed underground surfaces during excavation. Information on fractures and faults collected from underground excavations is likely to be more representative than what can be obtained from borehole methods. Compared with boreholes, the scale of the rock exposed for testing and observation is several orders of magnitude greater, and the directional bias is substantially reduced. Large-scale features such as faults and fracture zones can be accessed and studied in detail, at scales that are unattainable from boreholes.

Large-scale hydrologic, thermal, and mechanical tests can be performed in underground openings, but the in situ or ambient conditions of the rock mass may be locally altered by the excavation process and exposure of the rock to atmospheric conditions. Excavation effects can be minimized by using careful blasting or mechanical excavation techniques, but some localized disturbance of the ambient conditions is unavoidable.

The borehole methods can be used for remote access to the rock mass from the underground openings. The combination of approaches serves several purposes: (1) rock outside the zone around the opening disturbed during excavation can be accessed; (2) multiple boreholes can be drilled at depth to evaluate the variability of properties and conditions at several nearby locations in order to evaluate the magnitude of any bias; and (3) small-scale data can be used to interpret the large-scale tests and for correlation with the geophysical data.

Indirect methods

Various indirect methods are available for characterizing subsurface conditions. Outcrops are convenient for many test methods mentioned earlier, as well as observational methods (e.g., fracture mapping). However, outcrop methods have a greater uncertainty associated with the results because of

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biased exposure, differences in physical and state conditions (weathering, stress state, moisture conditions, etc.), and possible spatial variability of structural characteristics between the outcrop and the subsurface location of interest. Despite these limitations, outcrop data are potentially useful if they can be demonstrated to support data from subsurface and borehole methods, thereby increasing overall confidence in site characterization.

8.4.2.1.4 Relationship of planned testing to data needs

This section explains how the sample and data needs identified in Sections 8.4.2.1.1 and 8.4.2.1.2 are addressed by the planned testing, thereby establishing the need for the various types of characterization activities. Those subsurface methods that could potentially impact site performance or influence other tests are emphasized. The planned tests are described more completely in Section 8.4.2.2. The particular test plan described in this document was developed in part based on the professional judgment of Project scientists and engineers from a knowledge of site conditions and processes and data needs. The types, numbers, and locations of tests that were selected collectively represent only one of various alternative strategies and approaches that could be taken that may be equally suitable to obtain the data needed to characterize the site.

8.4.2.1.4.1 Addressing principal postclosure information needs

As suggested by Table 8.4.2-1, data needs for postclosure performance evaluation are dominated by the need to reduce uncertainty in the alternative conceptual models of unsaturated-zone flow and transport. Such uncertainties may be broadly categorized as model, parameter, and calibration. All three need to be investigated for model validation. Model uncertainties exist because the characteristics of the physical system are simplified for tractability, and so a particular model is not unique for a given physical problem. An appropriate way to address model uncertainty is to develop different models in parallel, and conduct field tests to evaluate which model is appropriate. Uncertainties on the parameters that are used as model inputs generally are treated as mathematical distributions based on property measurements. Properties data and state measurements that are areally distributed are needed to provide parameter distributions and initial conditions throughout the site area.

Information on hydrologic conditions and processes in the unsaturated zone will be provided by a combination of exploratory shaft facility (ESF) testing and surface-based testing. To evaluate model uncertainties in situ hydrologic tests in the ESF are planned to investigate moisture distribution and flow processes. The effects of fractures and other discontinuities and the effects of ESF construction on the rock mass will be emphasized. Fracture and matrix flow processes will be investigated at different scales by the planned percolation test and bulk permeability test. The Ghost Dance fault and other structural features will be observed and tested from long, intercepting drifts at the repository horizon. Geomechanical and hydrologic effects of construction will be investigated by the multiple purpose borehole

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activity, the radial boreholes test, and the excavation-effects test in the ramps or shaft. The ESF tests are discussed further in Section 8.4.2.1.5.1 (relationship between surface-based testing and testing in the ESF).

Sampling and testing associated with the systematic drilling program and the site vertical boreholes study will provide information on the distribution of hydrologic parameters and state variables across the site area. These surface-based programs will provide similar types of samples and data on in situ hydrologic conditions. They comprise nearly all of the borehole penetrations of the unsaturated zone within the conceptual perimeter drift boundary (CPDB) or in the immediate vicinity. (The CPDB is the projection to the surface directly above the perimeter drift as defined in the conceptual design perimeter presented in Chapter 6 of the SCP. Both the CPDB and perimeter drift are discussed more thoroughly in Section 8.4.2.2.) The access and samples provided by these activities will also address the need for information on geochemical characteristics and gaseous-phase conditions and processes. The strategy for locating the holes is developed in Section 8.4.2.1.5 and in the description for Activity 8.3.1.4.3.1.1.

Information on the waste package environment and geomechanical rock mass will be acquired from planned ESF construction and testing at the repository horizon. Rock-mass mechanical, hydrologic, and chemical responses will be investigated under experimental conditions of stress and temperature. The effects of ESF construction on the geomechanical and hydrologic characteristics of the surrounding rock mass will be investigated. Information on the spatial variability of properties and conditions (obtained from the surface-based drilling program) will be the basis for applying the results from ESF testing to the overall repository area.

Alternative conceptual models (ACMs) for site conditions and processes affecting postclosure performance generally are addressed by the activities described for other data needs. Evaluation of postclosure tectonic processes is an example of where alternative conceptual models have distinct data requirements. Scenarios for tectonic effects on waste isolation will be evaluated using information on the configuration of local faults, regional stress state, faulting history, and the history and style of recent volcanism, collected by a comprehensive program of site activities. These activities include geophysical exploration, remote sensing, trenching of faulted surface deposits, investigation of vein deposits, seismic and geodetic monitoring, and exploration of magnetic anomalies to determine the nature of volcanic origins. Other information needs for ACM evaluation will be addressed by (1) acquiring representative geochemical, unsaturated-zone hydrochemical, and saturated-zone hydrochemical data from surface-based boreholes for evaluating the temporal stability of the water table; (2) investigating scale-dependent rock-mass hydrologic and geomechanical characteristics in the ESF for evaluating modeling approaches, such as the effective continuum approximation; and (3) using surface-based boreholes and the subsurface access provided for borehole geophysical methods to investigate the geometry of fault blocks.

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Information needs for natural-resource evaluation will be addressed by geophysical surveys, geochemical evaluations, and surface and subsurface sampling. Planned geophysical methods include high-resolution surface gravity and aeromagnetic surveys of the site area, seismic exploration for deep structure, and remote sensing for constitutive properties of surface materials. Geophysical requirements for mineral-resource evaluation will be integrated with related needs for the tectonics and rock-characteristics investigations. Planned subsurface sampling, in the absence of indications of significant mineral occurrences in the site area, will be based on drilling planned for other activities, including the systematic drilling program and the more remote geologic coreholes and volcanic holes.

Information on the spatial variability of properties and conditions will be obtained primarily by means of surface-based drilling. Vertical boreholes are a principal means for providing needed information on vertical and lateral variability at locations distributed across the site. Lateral variability is coupled to structural conditions that can readily be characterized from vertical boreholes, such as lithostratigraphy, lateral facies changes, or laterally heterogeneous conditions at the surface. Samples, logs, testing, and monitoring data from the systematic drilling program, the site vertical boreholes study, and other drilling will be used to infer the geologic history and structure of the site. Matrix properties data for thermal, mechanical, hydrologic, and physical properties models will be provided by spatially distributed boreholes. Models of variability for these properties will be considered in the evaluation of results from the systematic drilling program (Activity 8.3.1.4.3.1.1).

Sampling in the ESF excavations, in boreholes drilled from the ESF, and from surface outcrops is also planned to provide information on small-scale lateral variability. Boreholes will provide subsurface access for geophysical exploration by such means as borehole gravity and vertical seismic profiling. Geochemical and hydrochemical information and samples for analysis of natural tracers will also be obtained from surface-based boreholes. In addition, various surface-related activities, such as mapping, remote sensing, and geophysical surveys, will be used to characterize surface conditions and processes, interpolate subsurface conditions between boreholes, provide information for depths beyond the range of planned drilling, and explore for anomalies indicative of unexplored subsurface structures or mineral occurrences.

8.4.2.1.4.2 Addressing principal preclosure information needs

Geologic information needed for surface facilities design will be provided by drilling and trenching activities, for evaluation of the recurrence of seismicity and volcanism in the Yucca Mountain region. Ongoing meteorological monitoring will support the evaluation of wind loads, flooding potential, and radiological safety for the surface facilities. Drilling and testing activities at proposed locations for the repository surface facilities will provide information on surficial materials, foundation-bearing characteristics, seismic response, and erosion history.

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Information on host-rock geometry over the site area will be provided for underground design by planned surface-based boreholes. Samples from these boreholes will also be used for the thermal/mechanical/hydrologic and physical properties models, which will be used to infer ground support and maintenance requirements, temperature constraints for the host rock, and radiation shielding properties over the site area. The exploratory drifts in the ESF will intercept major structures, such as the Ghost Dance fault, from which needed hydrologic and geomechanical information will be obtained. Responses of lithophysal tuff to repository-sized excavation and geomechanical testing are planned to be investigated in the upper demonstration breakout room in the ramp or optional shaft. These responses will be used to evaluate the sensitivity of lithologic constraints on the geometry of the repository.

Special trenching procedures will be used to investigate strike-slip displacement along major faults in the vicinity of the site. Extensive trenching will be done across Midway Valley, near the proposed location of the repository surface facilities.

8.4.2.1.4.3 Summary of how information needs are addressed

Information needs for both postclosure and preclosure design and performance evaluations will generally be met through a combination of surface-based and ESF activities. Samples, data, and other information from the surface-based drilling program will be used to address a variety of information needs. The areal coverage strategy of the systematic drilling program is simple and, on the basis of current understanding of site conditions and alternative conceptual models, appropriate for the various applications. A method for allocating samples to multiple uses is presented in Activity 8.3.1.4.3.1.1 (systematic drilling program). The relationship of testing in the ESF to surface-based testing is discussed further in Section 8.4.2.1.5.1. The activities described to this point do not involve excavation in the Calico Hills unit beneath the conceptual perimeter drift boundary or immediate vicinity. Section 8.4.2.1.6 further describes characterization plans for the Calico Hills unit.

8.4.2.1.5 Representativeness of planned testing

The planned characterization program is expected to yield data that are representative of site conditions and processes, and to support the use of multiple approaches for demonstrating representativeness. A systematic approach to program planning, involving performance allocation as introduced in Section 8.1, was used to identify characterization activities that effectively respond to information needs specified in the issues hierarchy. The major field activities planned for site characterization are associated with the principal information needs discussed in the preceding section. The rationales for the locations and for the methods for conducting many of these activities are presented in Section 8.4.2.2.

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The investigations detailed in Section 8.3.1 will be extensive, with intensive surface and subsurface coverage of the immediate site area. Results from surface-based and excavation-based activities such as geologic mapping, geophysical surveys, exploratory drilling, underground construction, and in situ testing will be used in multiple approaches to developing an understanding of variability in site conditions and processes. In one approach, predictive, quantitative descriptions of variability will be based on statistical analyses, and used to infer locations from which additional data would be collected to improve representation of site conditions. In another approach, descriptions of geologic, hydrologic, or geochemical characteristics will be based on observations and scientific inference, and will include the history of the natural processes that produced present conditions.

The planned characterization program is based on general technical criteria, statistical concepts, and site-specific information to the extent practicable. There is abundant information from Yucca Mountain and similar locations concerning geologic, hydrologic, geochemical, or other conditions and processes that affect site performance. This general and site-specific information constrains the conceptual understanding of site conditions and processes used in planning the characterization program. It also supports the expectation that representative data will be collected. A general discussion of the sources of variability in volcanic deposits is presented in this section to show that variability in tuff units at Yucca Mountain has nonrandom characteristics that can be appropriately investigated by spatially distributed, surface-based boreholes.

Requirements for achieving representative data from planned testing vary with the individual tests. The strategies for siting and design of different tests, especially surface-based tests relative to testing in the ESF, reflect different requirements for representativeness. A site-screening process used for siting the ESF is discussed in this section, in terms of how the location selected supports data representativeness. Tests planned for the ESF are discussed in general terms in this section, for the purpose of relating ESF testing results to the spatially distributed data from surface-based testing. This section also discusses how the surface-based program can be functionally separated into systematic and feature-sampling approaches, as a means for detecting bias in data collected, and as a mechanism for responding to new site information as it becomes available.

This section discusses the representativeness of planned testing using several approaches, which are summarized as follows:

1. Both surface-based testing and testing in the ESF will be used to detect and characterize the variability in site conditions and processes and to address information needs identified in the performance assessment process and described in the preceding portion of 8.4.2.1.

2. ESF investigations will be used to provide representative results for the site because the current understanding of overall site conditions and processes supports this approach.

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3. Systematic sampling and feature sampling will be used to evaluate sampling bias, and geostatistical methods will be used to quantify spatial variability and to estimate confidence in the understanding of spatial variability.

4. The geostatistical approach will be used to characterize the variability in key rock properties because information available about characteristics of tuff units at Yucca Mountain and a general understanding of volcanic deposits support this approach.

The following subsections explain these approaches in more detail, and conclude that they represent reasonable approaches to ensuring data representativeness. This outcome is also supported through the planned iterative reevaluation of information from the site, for example, as discussed for the geologic model in Investigation 8.3.1.4.2 and the statistical modeling of Study 8.3.1.4.3.2.

8.4.2.1.5.1 Relation between surface-based testing and testing in the exploratory shaft facility

The planned testing program in the ESF consists of several (more or less exclusive) categories of tests: (1) tests intended to investigate the processes and phenomena contributing to waste-isolation performance of the host rock, (2) tests to directly investigate the effects of ESF construction, and (3) tests to investigate undisturbed in situ conditions at the ESF location. Many of the tests fall into the first and second categories, for which the primary objective is to first investigate site processes important to waste isolation and then correlate these processes with the conditions present (natural or artificially controlled), through the use of models. Whether the test conditions and the observed responses are representative of the site area will be evaluated using data on site conditions from surface-based boreholes, and from observations of the range of conditions and processes evident from the ESF. Spatial variability of site conditions will be evaluated statistically, using both classical and geostatistical approaches. The resulting statistical descriptions of parameter variability, and the models relating conditions and processes, will form the basis for extending the results from these ESF tests to the overall site area. The remaining category of tests (to characterize undisturbed conditions) may be regarded as similar to surface-based borehole tests, although enhanced by the subsurface access and information from other testing, facilitated by the ESF. For most such tests, the extension of results from the ESF to the site area will be possible through the use of parameters or conditions that can be characterized from surface-based boreholes.

The set of parameters that will be used to extend information from testing in the ESF to the overall site area depends on the individual tests and can be fully specified when additional site-specific information is available. A basic set of parameters will be collected intensively from each planned borehole within the conceptual perimeter drift boundary or immediate vicinity, as described for the systematic drilling program (Activity 8.3.1.4.3.1.1). Other such parameters will be characterized by additional measurements either in open boreholes or on core samples. Alternatively, an

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approach will be used whereby parameters that are difficult to measure are correlated with the basic, index parameters in a scheme such as the conceptual strategy outlined in Section 8.3.1.4.3.1.1. Chapter 2 of the SCP describes how geomechanical properties such as intact rock compressive strength are correlated with matrix porosity, adjusted for clay content. Similar relationships are expected to be developed for other parameters, as additional information becomes available during site characterization.

Many of the parameters that affect ESF test results can be measured or sampled in boreholes, with a few exceptions. In particular, borehole characterization of fractures or other discontinuities is limited by detection bias and scale effects. To the extent that generalizations about smooth variability of rock characteristics (discussed in Section 8.4.2.1.5.4) hold for tuff units at Yucca Mountain, the strongest local rock-mass variability is probably associated with the distribution and characteristics of fractures, especially tectonic fractures. The limitations of borehole methods principally affect characterization of hydrologic and large-scale geomechanical conditions. Accordingly, the in situ hydrologic and geomechanical tests planned for the ESF will incorporate an assessment of sensitivity to fracture parameters and a comparative evaluation of test conditions relative to fracture conditions encountered throughout the ESF. Extensive drifting in the test facility and the drifts planned to intercept known or inferred structures at the repository horizon will provide ample opportunities to observe the range of fracture characteristics.

In summary, the representativeness of data from many ESF tests is based on the capability to identify and investigate the variability of processes that control site performance, and the relationship of these processes to variability of site conditions. Many of the relevant site conditions can be effectively explored by surface-based drilling and testing. For fracture-related characteristics, the extent of exploratory excavation at the main test level of the ESF is expected to provide abundant data for evaluating the range of variability for such characteristics across the overall site area.

8.4.2.1.5.2 Representativeness of the exploratory shaft facility (ESF) location

As described in the previous section, tests planned for the ESF generally are intended to investigate (1) processes and phenomena that contribute to performance of the host rock (see discussion of model uncertainties in Section 8.4.2.1.4.1); (2) rock-mass response to ESF construction; or (3) undisturbed in situ conditions at the ESF location. In accordance with the discussion in the previous section, the principal representativeness constraints on the ESF location are (1) whether the rock characteristics are such that the processes extant throughout the site can be adequately investigated and whether ESF test results can be readily extended to the overall site area, and (2) that the local rock characteristics are such that difficult ramp/shaft construction conditions, which would be nonrepresentative of conditions encountered in repository excavations, are avoided. This section

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presents the results of the original ESF location screening and more recent syntheses of site data, and discusses the assessment of new information during site characterization to show how these constraints are addressed by the planned ESF location.

The ESF location screening analysis (Bertram, 1984) considered five alternative sites distributed in the central part of the conceptual perimeter drift boundary and to the north. The sites differed markedly with respect to terrain, geologic aspects, and proximity to features of geologic or hydrologic interest. A broad range of screening criteria was used, including shaft-construction feasibility, cost, environmental concerns, expected data representativeness, and general repository design considerations. About 46 percent of the weighting in the screening process was given to criteria related to data representativeness, including extent of site area explored, proximity to potentially adverse structures, thickness of target units, and repository design compatibility. For the ESF location indicated in the SCP, the Coyote Wash location was selected for several reasons, including (1) subsurface exploration within about 1,000 to 2,000 ft of the location would result in sampling of a significant portion of the area within the conceptual perimeter drift boundary; (2) conditions appear favorable for shaft construction; and (3) geologic structures potentially adverse to repository performance such as the Ghost Dance fault, Drill Hole Wash, and the imbricate fault zone east of the conceptual perimeter drift boundary are readily accessible.

Geologic conditions in the vicinity of the planned ESF location have already been sampled by several boreholes, including USW G-4. Data from this borehole are considered representative of the ESF location in the SCP in the analysis of Nimick et al. (1988) discussed later. Geologic conditions and saturated-zone hydrologic conditions for this borehole are reported in Spengler and Chornack (1984) and Bentley (1984), respectively. USW G-4 was sited with the intention of evaluating conditions at the ESF location in the SCP, and the results were consistent with expected lithostratigraphic and structural conditions, which comprised part of the basis for the selection decision (Bertram, 1984).

The functional stratigraphy proposed by Ortiz et al. (1985) distinguishes different units on the basis of (1) degree of welding inferred from matrix porosity, (2) geologic classification based on lithostratigraphy and eruptive origin, and (3) degree of zeolitization. Quantitative mineralogical information from 14 drillholes in the vicinity of Yucca Mountain was evaluated by Campbell (1987), with the objectives of (1) evaluating the unit divisions of Ortiz et al. (1985) with respect to data not used in its formulation and (2) evaluating lateral variation in the distribution of zeolites and other sorptive minerals. Data from a large proportion of core and cutting samples were found consistent with the stratigraphic model. This is essentially the same model used for defining the host rock unit in the repository conceptual design and for performance allocation. As expected, information from boreholes located at some distance from the site area, such as wells J-12 and J-13 near Fortymile Wash to the east, varied somewhat from conditions at the site. This variability suggests that the methodology used was sufficiently sensitive to support the finding of relatively homologous mineralogical conditions, and conformance with the functional stratigraphy, within the site area.

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Another analysis by Nimick et al. (1988) uses various published descriptions of rock characteristics based on existing boreholes distributed throughout the site area and other information about the Yucca Mountain site to evaluate the representativeness of the ESF location in the SCP. Statistical comparisons are used for mineralogic, hydrologic, and thermal/mechanical properties data from USW G-4 and other boreholes throughout the site area. This analysis confirms that the ESF location in the SCP is representative of the site area for the following characteristics: unit thickness, lithophysal abundance and certain other lithologic characteristics, overburden thickness and vertical in situ stress, grain density, matrix porosity, geomechanical intact rock properties, ground-support requirements, and certain design requirements. For fault zone and fracture characteristics, the available borehole information is inherently unsuited to statistical evaluation for the reasons discussed in Section 8.4.2.1.3. For these characteristics, however, there are special measures planned within the current reference ESF design concept, particularly the long exploratory drifts at the repository horizon, which will provide representative information on the range of site conditions (Section 8.4.2.1.5.1). The current reference ESF design concept has the dedicated test area and the optional exploratory shaft in approximately the same location as the ESF location in the SCP. Therefore, the analyses discussed above are applicable to the representativeness of this reference concept. In addition, the extensive drifting that is planned, both at the Topopah Spring and Calico Hills levels, between the north and south ramps will extend the length of the potential repository block. This drifting is planned to intersect various fault zones of interest at more than one location.

In summary, rock characteristics that can be investigated from boreholes, and for which data are available, indicate that the planned ESF will provide underground test locations that support test results that will be representative of site conditions and processes. For other parameters affecting test results, such as fracture and fault zone characteristics, the planned ESF includes extensive excavation to intercept and characterize features representing the range of conditions and processes in the host rock.

8.4.2.1.5.3 Statistical representativeness

This section describes differences between the systematic drilling program and the balance of surface-based drilling, explains how the planned characterization program provides for detection of bias in collected data, and discusses the importance of the geostatistical approach and how it will be evaluated using information from an integrated drilling program.

<u>Differences between feature sampling and systematic sampling</u>

The systematic drilling program (Activity 8.3.1.4.3.1.1) is different from previous drilling, and the other drilling planned for site characterization. This systematic program is associated with a deductive, probabilistic approach, and the balance of drilling with a more deterministic, feature-sampling approach to site characterization.

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In the feature-sampling approach, the location of a single borehole or set of several boreholes is chosen for testing a specific hypothesis at that location. For example, an exploratory borehole could be located where there are anomalous surface geophysical indications to test the related hypothesis of a buried structure, possibly of a particular type. If the structure is not observed as a result of the drilling, another hypothesis for the sources of the anomaly would be proposed and tested to reduce uncertainty in the conceptual geologic model. If the predicted structure was observed as a result of drilling, confidence in the predictive nature of the conceptual model is improved.

The principal objectives of the systematic program are to characterize spatial variability, and to provide areal coverage of the site for investigation of geologic, hydrologic, and geochemical parameters. The use of existing boreholes and planned boreholes of the feature-sampling program, in conjunction with the systematic program, will significantly increase the data available for evaluation of spatial variability. This, in turn, will reduce the cost of site characterization, and the extent of surface and subsurface disturbance.

The feature-sampling approach supports the systematic drilling program in another way. Systematic sampling as proposed (Activity 8.3.1.4.3.1.1) does not necessarily sample extreme values of structural or state variables that may be expected from foreknowledge of the site, and the feature-sampling approach is needed to ensure that statistical descriptions of variability appropriately treat the possible range of site conditions in the alternative conceptual models.

Representative sampling approach

The feature-sampling and systematic-sampling approaches differ with respect to the information used to site boreholes. Many of the proposed boreholes of the feature-sampling program are planned to investigate structures of interest, such as the Solitario Canyon fault, Ghost Dance fault, or conditions underlying the crest of Yucca Mountain. Because the conceptual perimeter drift boundary (CPDB) is essentially bounded by fault structures and because site performance may be affected by faults, the feature-sampling program may be intrinsically biased particularly for evaluation of state variables. Accordingly, seven of the twelve planned holes of the systematic drilling program are sited to provide approximately uniform areal coverage of the CPDB, in conjunction with planned boreholes of the feature-sampling program (including USW holes UZ-2, UZ-3, UZ-7, and UZ-8; Section 8.4.2.2.1). These seven boreholes are similar in number to the planned feature-sampling program within or near the CPDB, which is appropriate if statistical comparisons are to be used to evaluate bias. Samples from these holes, in conjunction with the planned feature-sampling program, will address needs of all planned test programs, including thermal and mechanical properties (Investigation 8.3.1.15.1) and mineralogy/petrology/geochemistry studies (Investigation 8.3.1.3.2), which do not call directly for boreholes as described in Section 8.3.1, but require "representative" samples from distributed locations to detect variability and to evaluate trends.

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Geostatistical approach

Geostatistics, proposed for Study 8.3.1.4.3.1, is directly related to the probabilistic analyses needed to address such performance objectives as the ground-water travel-time requirement of 10 CFR 60.113 and the radionuclide release limits of 40 CFR Part 191, Subpart B. Regulatory objectives generally are stated in terms of limiting values, with an overriding requirement to provide reasonable assurance, with allowance for the time periods and uncertainties involved. For certain objectives, an allowable probability for exceeding the limiting value (or some function thereof) is also specified (e.g., 40 CFR 191.13). In either instance, demonstration of compliance will be probabilistic, whether to provide quantitative support to the assertion of reasonable assurance or to directly address prescribed probability levels. Geostatistical methodology provides estimates of confidence in understanding of spatial variability, in probabilistic form.

Geostatistics (or spatial statistics) is the part of applied statistics that helps provide an analysis and a mathematical description of spatially related geologic data. Sample values in geologic deposits usually are not independently random variables but are spatially related. Classical statistical methods typically assume that observations are independent, which may be inappropriate for geologic deposits. Geostatistical methods quantify spatial variability as a function of distance between sample locations and are therefore well suited for modeling and interpolating the three-dimensional variability of the measured properties in a geologic deposit (Buckley et al., 1986).

The basic data for geostatistical evaluation are observations of key properties, separated by distances that range from a few inches to the largest dimension of the CPDB. Outcrop studies and studies in the ESF will provide the data for small separation distances (less than 500 ft). Existing boreholes, planned boreholes of the feature-sampling program, and the seven boreholes of the systematic drilling program that are distributed for areal coverage will provide the data for large spacings (greater than 3,000 ft). The other five boreholes of the systematic drilling program are intended to provide sufficient data at intermediate spacings of about 1,000 feet. The five boreholes are clustered near several planned boreholes of the site vertical boreholes study (i.e., USW holes UZ-7 and UZ-8 and UE-25 holes UZ#9, UZ#9a, and UZ#9b), in order to maximize the number of borehole pairs at small spacings. The five-borehole array described in Section 8.3.1.4.3.1.1 is flexible and could be modified without detriment to geostatistical objectives. But as planned, this array lies outside the CPDB and thus avoids direct effects on the repository in accordance with 10 CFR Part 60.15(c).

8.4.2.1.5.4 Volcanic stratigraphy

The variability of the rock characteristics of tuff units at Yucca Mountain was produced by variability of the volcanic sources, eruptive processes such as sorting and turbulence, local conditions at the Yucca Mountain location during the eruptions, posteruptive alteration, and tectonic deformation since the Miocene time. Although complex, these are known geologic processes that produced systematic variations in the ash deposits. Moreover,

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the volume and extent of ash flows such as that which formed the Topopah Spring host rock were so enormous that heterogeneities at the scale of the Yucca Mountain site are likely to be minor relative to overall, large-scale variability. Tectonic deformation may have had more local effects, as described later. The discussion in this section supports the proposition that variability of key rock properties has a significant, nonrandom, systematic component that can be effectively characterized using the planned geostatistical approach.

Each geologic unit in the tuff sequence may be characterized as consisting of one or more of the following: (1) multiple ash flows consolidated into a cooling unit with characteristic mineralogic and petrologic differentiation; (2) clastic material; (3) ash fall deposits; or (4) a zone of secondary alteration (e.g., zeolitization), which may transect lithostratigraphic units. Whereas vertical variability can be associated with the sequence, thicknesses, and variation within these layers, lateral variability is associated with their continuity.

Lithostratigraphic continuity within the site area is important for statistical modeling of spatial variability. Geostatistical methods will be used to analyze unit thickness and depth-averaged properties for thicker units at Yucca Mountain, without much emphasis on lithostratigraphic continuity. However, for thinner units (e.g., PTn or TSw3 functional units of Ortiz et al. [1985]), there is evidence of lateral termination (especially of subunits) over distances smaller than the separation between existing boreholes (Scott and Castellanos, 1984). The lateral continuity of a property of interest in a volcanic tuff unit is strongly related to processes occurring during the eruption and emplacement of the unit.

Trends in the physical properties and composition of pyroclastic-flow and pyroclastic-fall units are inherited from magmatic sources, imposed by emplacement mechanisms, or imposed by postdepositional modification and alteration. The eruption of a Miocene tuff unit in the vicinity of Yucca Mountain, like many tuff sequences, is likely to have been from a magma chamber that was chemically stratified with more silicic products evolved early in the eruption, and more mafic products erupted later (Smith, 1979). Such chemical stratification is typically associated with an increase in the proportion of crystalline to glassy pyroclasts in the more mafic deposits.

Eruption can impart another type of variability based on emplacement processes. Ash-fall units are subject to sorting by size; heavier pyroclasts fall closer to the vent than lighter ones, resulting in progressive decrease of median grain size with distance from the eruptive source. Vertical variations within ash-fall units can be expected if the intensity of eruption changes with time (Fisher and Schminke, 1984). Also, the total volume of an erupted ash-fall unit tends to control the areal distribution. In general, the larger the volume, the more area blanketed by the tephra and the thicker the deposit at a given distance from the source (Fisher and Schminke, 1984).

For pyroclastic flow deposits, changes in grain size, fabric, sorting and composition are more complex relative to the hydrodynamically simpler ash-fall units. In general, pyroclastic flow units can be expected to vary with distance from the source vent as a result of pre-eruptive topography, and according to the energy of the eruption. An idealized sequence of

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deposits and textures within a pyroclastic flow event has been proposed by Sparks et al. (1973), and most such flows conform in some way to the idealized scheme (for example, see Fisher and Schminke, 1984). The deviation of actual sequences from the idealized scheme may appear random, but in many instances can be associated with variation in the energy of eruption or the topography onto which the flow was erupted.

Postemplacement modification processes are of several general types: welding/compaction of the deposit, chemical changes such as zeolitization and vapor-phase alteration, and fracturing due to thermoelastic cooling stress or subsequent tectonic effects. The degree of welding and compaction of an ash-flow unit is primarily a function of the volume and thickness, temperature of emplacement, and to a lesser extent composition. The main factor in welding is the time the deposit remains above a minimum temperature, thus in general, the thicker a deposit, the more likely it is to weld. Likewise, hotter deposits are more likely to undergo welding. The factors involved with welding have been explored by many investigators (for example, Sheridan and Ragan, 1976; Peterson, 1979). In addition to gradual lateral trends in welding, abrupt changes can be caused by topographic effects or the amount of water vapor present locally in the pyroclastic flow (caused, for example, by water present on the pre-eruptive surface).

Vapor-phase alteration tends to be confined to the upper part (about half) of the thickness of welded ash-flow deposits. The distribution of alteration is, in general, related to the composition and quantity of volatile phases in the deposit after it comes to rest. Zeolitization is partly related to vapor-phase alteration. Further production of zeolites can be caused by hydrologic processes that may be essentially unrelated to deposition and immediate postemplacement alteration.

Cooling fractures tend to form perpendicular to the free surface of a flow, in response to stress caused by differential contraction. Cooling fractures, therefore, tend to be vertical, and spatial variation in the frequency or distribution is related to variations in characteristics that control welding, fabric, and cooling (i.e., thickness, temperature, composition, topography, etc.). The scale of variability in the distribution of cooling fractures may be larger than that for tectonic fractures, based on the frequency of faults at Yucca Mountain and the association of fracture frequency with proximity to fault structures.

The scale of each of these effects is variable; Table 8.4.2-3 relates the different effects to gross differences in scale of variability. It is likely, based on studies of various tuff sequences, that the variability observed in characterization of the Yucca Mountain site will conform to these types of variability, and associated trends in scale. However, no ash-flow sequence has been explored by means of systematically located boreholes in the manner planned for Yucca Mountain, therefore the observed variability may appear to be random at early stages of exploration.

In summary, characteristics of volcanic units exhibit systematic variation at different scales, because of the nature of the formative processes. It is expected that during site characterization, parameters affecting site performance (e.g., hydraulic conductivity, compressive strength, alteration) will be found to also vary systematically because they depend on the basic

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Table 8.4.2-3. Scale of variation of geologic-unit properties

Property	Principal scale of variation
Chemical composition	Whole deposit, both vertically and laterally
Grain size	Centimeter to meter
Sorting	Whole deposit, both laterally and vertically
Fabric	Vertically, meter scale; laterally, whole deposit
Welding	In general, tens of meters vertically, and whole-deposit laterally; abrupt changes in deposition conditions (pre-eruptive surface water or topography) can bring about tens of meters-scale lateral changes

unit characteristics and formative processes. The planned integrated surface-based exploration program is appropriate for detecting and characterizing systematic variability and will support the performance allocation goals for repository design and performance.

8.4.2.1.5.5 Drifting to the southern part of the repository block

The southeastern margin of the proposed repository block has a higher density of faulting than other areas within the CPDB, as mapped or inferred from surface geologic indications (Scott and Bonk, 1984). The SCP contains plans to drill several surface-based vertical boreholes in this general area, including drilling of boreholes SD-7 through SD-12 of the systematic drilling program (Activity 8.3.1.4.3.1.1), and deepening of unsaturated-zone boreholes USW UZ-7 and USW UZ-8 (Activity 8.3.1.2.2.3.2). The extent to which borehole information is sufficient to establish the range of geomechanical and hydrologic site conditions in this region has been the subject of documented comments to the DOE (e.g., Linehan, 1987). As a result, questions have been raised regarding the need to drift from the ESF location in the SCP to the southern part of the block.

The ESF Alternatives Study (SNL, 1990) recently undertaken by the DOE considered, among other factors, the extent to which drifting to the southern part of the potential repository block would be desirable. As a result of that study, as well as other recommendations, the current reference ESF design concept includes both a north and a south ramp with extensive drifting that extends the length of the potential repository block. Extensive drifting is also planned for the Calico Hills level.

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8.4.2.1.6 Characterization of the Calico Hills nonwelded unit

As a result of the performance-allocation process, the Calico Hills nonwelded unit has been designated the primary barrier to ground-water flow and radionuclide transport. As such, the flow processes and conditions in that unit must be sufficiently understood to have a high degree of confidence in the effectiveness and limitations of that barrier.

The Calico Hills nonwelded unit is composed of both vitric and devitrified facies. The devitrified facies is pervasively zeolitic and is, therefore, generally referred to as the zeolitic facies. The zeolites are potentially important to long-term isolation because of their capability to significantly retard transport of radionuclides (Daniels et al., 1982; DOE, 1986b). Thickness of the zeolitic facies generally increases from the southwest to northeast beneath Yucca Mountain. Beneath the northern and northeastern parts of the central block (including the proposed locations for the exploratory shafts), the Calico Hills nonwelded unit is almost entirely zeolitic (Nimick et al., 1988). The saturated matrix permeability of the zeolitic tuff is comparable to that of the overlying Topopah Spring welded unit, and generally is several orders of magnitude less than that of the vitric facies of the Calico Hills unit (Peters et al., 1986; Montazer and Wilson, 1984). The porosity of the nonwelded Calico Hills tuff matrix is about 30 percent. The thickness of the unsaturated portion of the unit ranges from about 100 m to about 250 m across the central block (Montazer and Wilson, 1984).

Data needed for characterization of the Calico Hills unit are closely aligned with data needs for postclosure performance evaluation described in Section 8.4.2.1.1. Data needed that are specific to understanding the contribution of the Calico Hills unit to postclosure performance are

1. Knowledge of hydrologic properties of matrix, fractures, and faults (including statistical distributions) over a range of scales to evaluate alternative conceptual models of conditions and processes in the Calico Hills unit; and information on whether flow is occurring in fractures or faults, on matrix and fracture saturation conditions, and on other characteristics indicating the nature of flow, including conditions under which fracture flow might occur.

2. Information on the heterogeneity of the unit with respect to flow and transport properties, and on the hydrochemistry and isotopic age of in situ water, to evaluate the occurrence of and potential for moisture flow in fractures in the Calico Hills unit, and to compare with conditions and processes in the overlying welded units.

3. Data on bulk rock permeability in the Calico Hills unit, at a range of scales and under controlled conditions and information on the nature of flow phenomena at the contact between the Topopah Spring welded unit and the Calico Hills nonwelded unit that will support evaluations of the influence of geohydrologic structures on two-dimensional flow.

This information is needed to assess the flow paths and flux of moisture through the Calico Hills unit under conditions associated with expected and

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disruptive scenarios that will be evaluated as part of total system performance. The available methods for obtaining this information and their advantages and limitations are now briefly discussed below.

Characteristics of the Calico Hills nonwelded unit could be estimated from information obtained from other unsaturated tuff units. This approach would present little significant risk to site performance. In a second option, hydrologic properties, system geometry, extant processes, and initial boundary conditions for modeling could be estimated using data from the nonwelded and welded units above the Calico Hills unit. The usefulness of this approach is difficult to estimate because it is not currently known to what extent and how information from the other units could be correlated to the characterization of the Calico Hills unit. Although some constraints probably could be placed on flux and flow paths under present conditions, not directly observing the Calico Hills unit may result in an unacceptable degree of uncertainty about the characteristics of this unit and how they would affect flow under conditions associated with the full range of scenarios needed to assess total system performance.

Another option is to acquire data from outcrops of the Calico Hills unit. Although this approach would allow direct observation of the same hydrogeologic unit as that occurring in the subsurface beneath the site, certain limitations would apply. The nearest substantial outcrop is approximately one mile north of the CPDB in Yucca Wash. The degree of zeolitization of this outcrop is different from the zeolitization in the Calico Hills unit that has been penetrated by existing boreholes within or in the immediate vicinity of the CPDB. This difference in zeolitization would affect hydrologic and transport properties of the unit. The physical properties and in situ hydrologic state of the outcrop, including fracture characteristics, matrix saturation, and in situ matrix moisture potential, probably would not be representative of the unit beneath the site. This is because the outcrop is weathered, has smaller overburden pressure, and is closer to the volcanic source area than the subsurface component of the unit.

Planned boreholes of the feature-sampling program and the systematic drilling program (Section 8.4.2.1.5.3) will penetrate the Calico Hills unit and provide information and samples from it. Boreholes could also be drilled from the main test level of the ESF to the Calico Hills unit. Testing of the samples obtained from boreholes will provide information on heterogeneity of matrix parameters on a site scale. Boreholes within the CPDB are preferred because (1) planned boreholes will provide heretofore unavailable information on matrix properties and in situ saturation within the repository block, and (2) a current understanding of site conditions and processes would allow an evaluation of the representativeness of information from outside the CPDB. Samples from boreholes have some limitations, because they provide little information about the distributions and flow characteristics of fractures and faults.

Currently, five boreholes penetrate the Calico Hills unit within the CPDB (USW H-4, USW H-5, USW WT-2, USW UZ-6, and USW G-4). The drilling methods used for these penetrations did not permit acquisition of saturation profiles because of sampling limitations or the use of drilling fluid. For this and other similar reasons, a comprehensive set of hydrologic information was not obtained from any of the existing boreholes. Further discussion of

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the nature and amount of fluid lost during drilling at the site is provided in Section 8.4.2.2. These boreholes did provide mineralogic, petrologic, lithostratigraphic, and some hydrologic data that will be used as corroborative information to develop the geologic, hydrologic, and geochemical models of the site during site characterization. Existing and planned borehole penetrations through the repository horizon into the Calico Hills unit will be accommodated in pillars in the Topopah Spring unit within the conceptual repository design. Risks associated with penetrating the Calico Hills unit by boreholes are considered minimal because of the expected ability to seal boreholes, as supported by analysis (Section 8.3.3.2) and by testing and modeling reported in the literature (also reported in Section 8.3.3.2). Impacts of the existing and planned borehole penetrations of the repository horizon and the Calico Hills unit on postclosure site performance are evaluated in Section 8.4.3.

Penetration of the Calico Hills unit by underground excavation would allow for scale effects to be readily investigated. Macroscopic behavior of the rock mass could be monitored for validation of concepts of flow in unsaturated, fractured nonwelded tuff. Specific questions regarding flow paths (by lateral movement at unit contacts and through a fault) could be investigated, and bulk rock-property values could be measured.

When the SCP was issued, the DOE had deferred the decision on whether to excavate into the Calico Hills Unit pending an analysis of the risks vs. benefits. For whatever testing is done, assurance must be given that the gathering of data would not jeopardize the effectiveness of the unit as a barrier. The Calico Hills Risk/Benefit Analysis has been conducted by the DOE, taking into consideration the factors discussed above. The results of this analysis were incorporated into the ESF Alternatives Study, the outcome of which was a recommendation that an extensive drifting program be undertaken to directly characterize the Calico Hills unit.

As is further discussed in Section 8.4.2.3, the current reference ESF design concept includes a north and a south ramp leading down to the Calico Hills level, which would be connected by a long drift. The testing to be done to characterize the Calico Hills unit is currently being defined.

8.4.2.1.7 <u>Conditionally planned activities</u>

A practical drilling method for dry, continuous coring to depths of up to 2,600 ft in fractured tuff is needed for site characterization, but has not yet been demonstrated. The ODEX method used previously at Yucca Mountain did not penetrate, and the reverse vacuum method did not provide sufficient samples for analysis of in situ matrix saturation and flow properties. An alternative method will be evaluated by means of one or more prototype holes to be drilled outside the CPDB near the UE-25 UZ#9 complex of holes, early in the characterization program. A general preferred method based on existing technology has been identified (Spaeth, 1988), but the engineering of a prototype test is still ongoing. The method selected may be used in the site vertical boreholes study, systematic drilling program, and saturated zone programs or wherever samples from the unsaturated zone are needed.

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A series of saturated zone well tests is planned for the existing UE-25 c#1, UE-25c#2, and UE-25c#3 complex of boreholes, using conservative and reactive chemical tracers in single- and multi-well testing schemes. On the basis of the results, single-well saturated zone testing will be extended to existing boreholes distributed across the site area, or a new cluster of saturated zone boreholes (southern tracer complex) may be drilled to the south-southeast of the CPDB at a site to be determined.

Detection and characterization of natural perched water is an important requirement for all surface-based drilling in the vicinity of the site. If perched water is detected during drilling of the multipurpose boreholes, the site vertical boreholes, the systematic drilling program, or saturated zone boreholes in Solitario Canyon, penetration will be suspended so the perched zone can be sampled, tested if appropriate, and isolated from any detrimental effects of continued drilling.

The systematic drilling program is planned in two phases. The first phase is a definite program of 12 boreholes, designed from general statistical principles to obtain areal coverage of the site and to sample small-scale lateral variability. An additional phase of drilling may be appropriate to refine statistical descriptions obtained from the first phase. The attributes of a second phase would depend on the data collected from the first phase and associated activities of the feature-sampling program.

An activity to investigate in situ stress in the Yucca Mountain region calls for hydraulic fracturing stress measurements in several existing boreholes, plus drilling of one or two additional shallow boreholes specifically for stress measurements. The location of such boreholes and the scope of the activity to test existing boreholes have not yet been determined. Also, many of the methods that will be used for geophysical exploration of the site have not been determined. Various methods are proposed for testing and evaluation in Investigation 8.3.1.4.2 (geologic framework of the Yucca Mountain site), and in Study 8.3.1.17.4.7 (subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain).

8.4.2.2 Surface-based activities

Surface-based tests consist of geologic, geophysical, hydrologic, geochemical, and other tests and surveys that will be performed both at the land surface and in exploratory boreholes drilled from the surface. Section 8.3.1 describes theses activities in detail. Construction and testing activities are grouped in the following sections according to whether they lie within the conceptual perimeter drift boundary (CPDB), or the conceptual boundary of the controlled area. Rautman et al. (1987) state that the perimeter drift "defines the outer limit of mined openings at waste emplacement depths." The CPDB is thus taken as an outline on the surface directly above the perimeter drift (Figure 8.4.2-1a). The definition of the controlled area used is also that of Rautman et al. (1987), which includes an area of 100 square kilometers and the subsurface region underlying this area, consistent with 40 CFR Part 191.12(g). The controlled ar definition is used in this section only to reference the locations of planned activities, because it is widely

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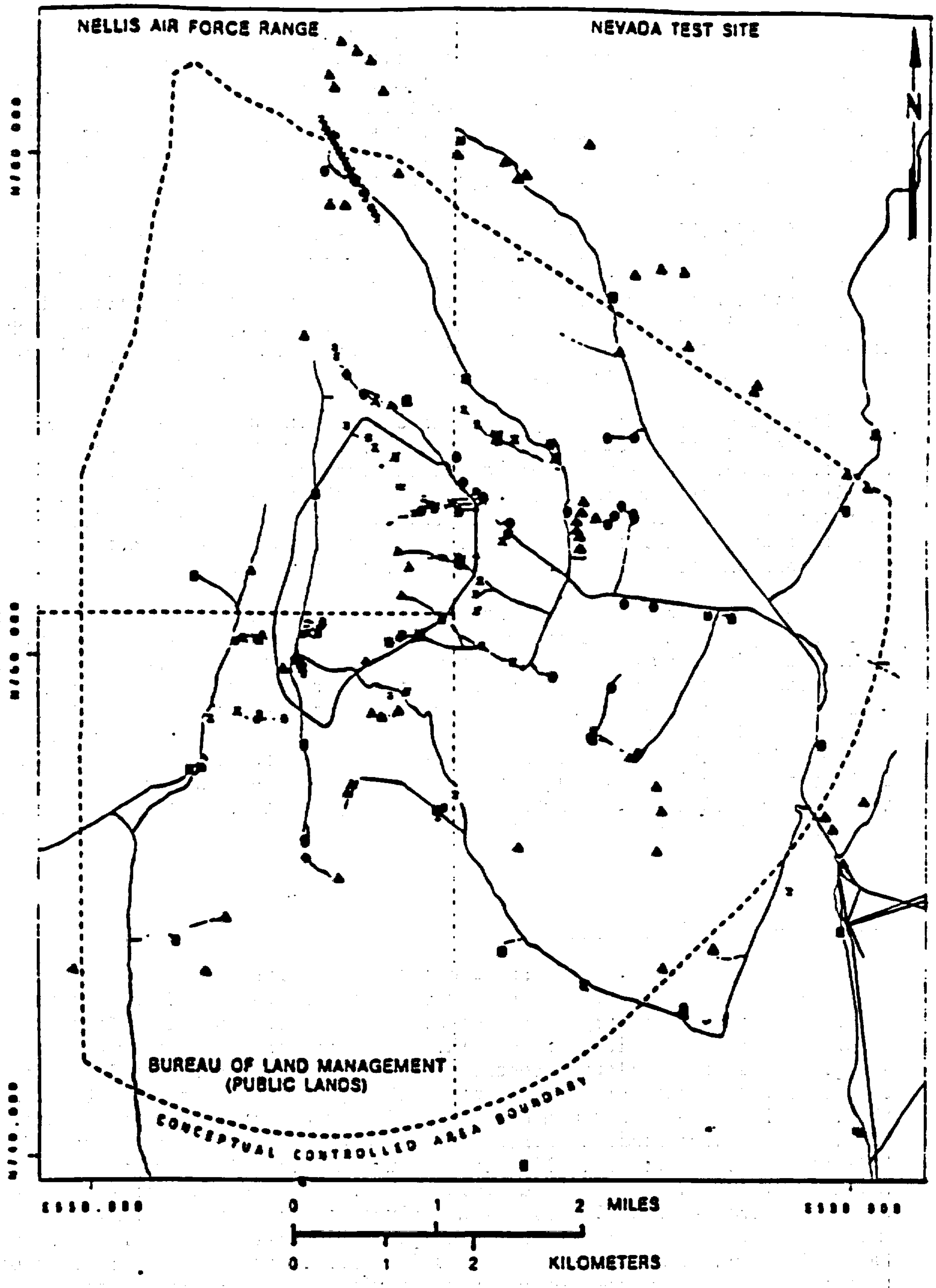

Figure 8.4.2-1a. Existing surfaced-based activities. See Figure 8 4 2-1b for legend.

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LEGEND

- ⁑ SHALLOW BORINGS <100FT
- ◆ DRY DRILLHOLES—UNSATURATED ZONE BOREHOLES
- ● COREHOLES
- ■ SATURATED ZONE AND WATER TABLE BOREHOLES
- ▲ TRENCHES
- × PAVEMENTS

- LIGHT DUTY ROADS
- UNIMPROVED ROADS
- TRAILS

- CONCEPTUAL PERIMETER DRIFT BOUNDARY

SOURCES

1956 1:24,000 USGS TOPOGRAPHIC MAPS
1976 1:24,000 USGS ORTHOPHOTO MAPS
1983 1:100,000 USGS TOPOGRAPHIC MAPS
7/1986 AND 8/1987 1:24,000 AERIAL PHOTOGRAPHY
GRID TICKS BASED ON NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE
CONCEPTUAL PDB - SNL DRAWING R07083A
MAP COMPILED IN SEPTEMBER 1988

Figure 8.4.2-1b. Legend for Figure 8.4.2-1a.

published and describes a minimum 2 km distance from the CPDB. Construction controls described in this section are not contingent on the definition of the controlled area.

This section provides site characterization construction and testing activities. Potential environmental effects of surface-based testing have been addressed in Chapter 4 of the final environmental assessment for Yucca Mountain (DOE, 1986b). Site characterization activities are affected by permitting requirements and constraints. The Environmental Regulatory Compliance Plan (DOE, 1987b) describes the plan for complying with applicable regulations and statutes. Applicable permit requirements and constraints are incorporated into surface-based activities (i.e., dust control). If additional permitting requirements are identified, they may modify the design and operation of certain site characterization activities.

All planned field activities exclusive of those associated with the ESF are included in the Project Surface-Based Investigations Plan (SBIP) (DOE, 1988d). The SBIP is a compilation of information on each field activity planned in the SCP, with emphasis on factors affecting environmental and site performance impacts. The SBIP including the following information for each planned activity: references to the SCP and other planning documents; responsible Yucca Mountain Project participants; basic activity information, including type, location, and purpose of the planned activity; relevant technical information (for example, equipment to be used, borehole depths, and survey area descriptions); and anticipated schedule information. The SBIP also includes a summary of planned activities, a general discussion of technical rationale for various activities, and a portfolio of detailed maps showing the locations of planned surface-based testing and construction activities.

The Project Site Atlas is a companion document to the SBIP and contains historical summaries of field studies that have already been performed. The Site Atlas briefly describes each activity and where it was performed. It also contains detailed maps and location information for completed and ongoing activities. Ongoing surface-based testing activities include seismic monitoring, potentiometric-level monitoring, unsaturated-zone hydrologic monitoring, meteorological monitoring, runoff monitoring, and geodetic surveys.

Standard USGS topographic maps were used as the base maps for these two documents. Location data for existing activities were obtained from as-built construction surveys or were provided by the organization responsible for the activity. Locations of planned activities are approximate and were obtained from descriptions in Section 8.3.1, drillhole layout surveys, or from draft study plans. Information sources for each activity are indicated in both documents.

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

Figures 8.4.2-1a and 8.4.2-2a depict the locations of existing and proposed surface-based field activities. These have been organized by type of

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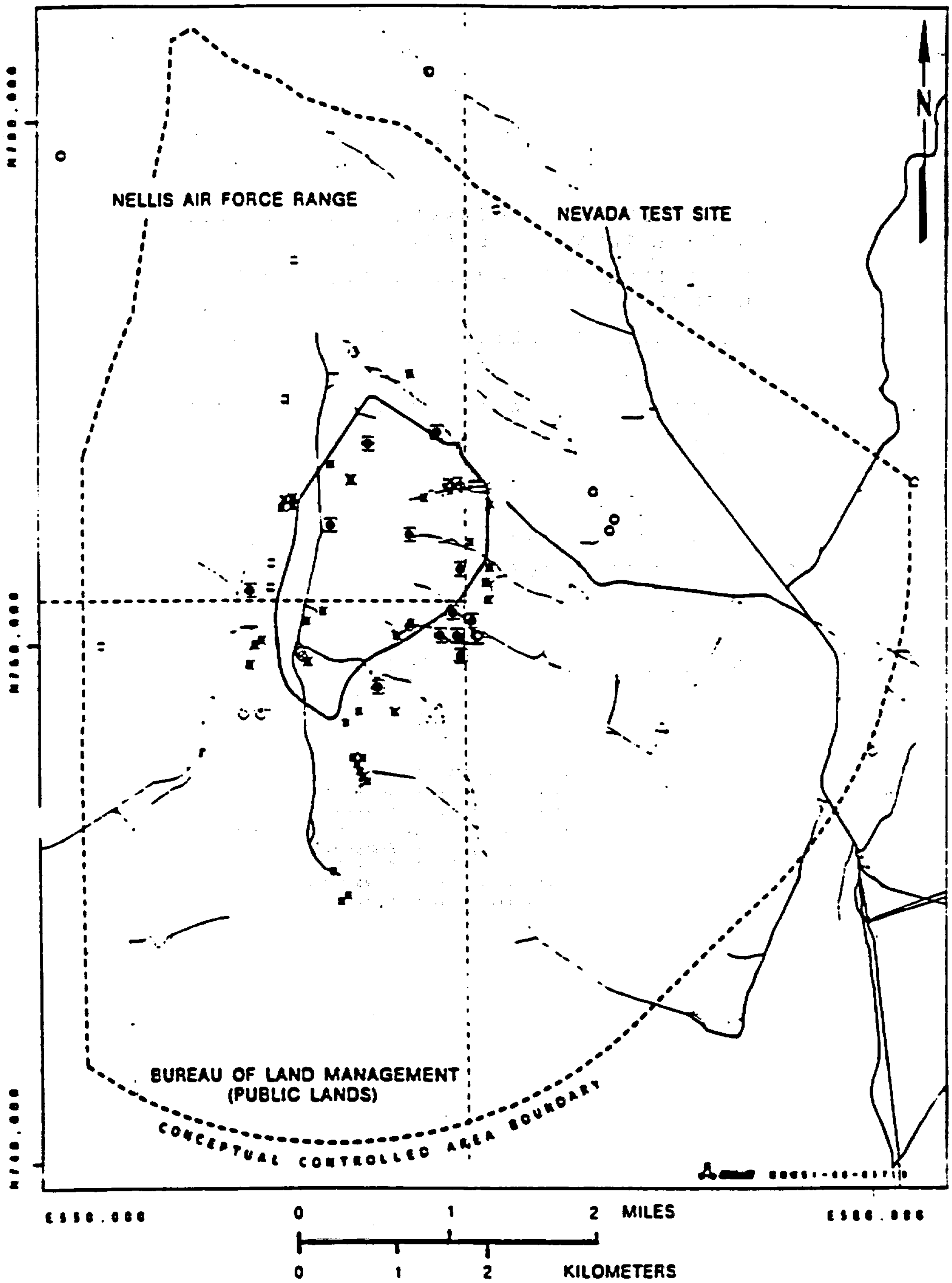

Figure 8.4.2-2a. Proposed surface-based field activities See Figure 8 4 2-2b for legend

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LEGEND

- DRY DRILLHOLES——SHALLOW UNSATURATED ZONE NEUTRON HOLES (<100FT.)
- DRY DRILLHOLES——UNSATURATED ZONE BOREHOLES
- SYSTEMATIC DRILLING PROGRAM HOLES
- COREHOLES
- SATURATED ZONE AND WATER TABLE BOREHOLES
- TRENCHES

- LIGHT DUTY ROADS
- UNIMPROVED ROADS
- TRAILS

- CONCEPTUAL PERIMETER DRIFT BOUNDARY

SOURCES:

1956 1:24,000 USGS TOPOGRAPHIC MAPS
1976 1:24,000 USGS ORTHOPHOTO MAPS
1983 1:100,000 USGS TOPOGRAPHIC MAPS
7/1986 AND 9/1987 1:24,000 AERIAL PHOTOGRAPHY
GRID TICKS BASED ON NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE
CONCEPTUAL PDB - SNL DRAWING R07003A
MAP COMPILED IN SEPTEMBER 1988

Figure 8.4.2-2b. Legend for Figure 8.4.2-2a.

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surface penetration; drilling-related activities are further organized by drilling methodology and relative depth. Planned trenches are not shown on the figures, because field reconnaissance is needed to locate them accurately. Investigations 8.3.1.5.2 and 8.3.1.17.4 include descriptions of the channel areas and fault zones where this additional trenching is planned. As stated previously, the Project Site Atlas and Surface-Based Investigation Plan contain more detailed maps and location coordinates for existing and proposed activities.

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

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

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

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

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

Plans for surface-based testing do not include the use of high-level radioactive materials or the introduction of radioactive artificial tracers. Radioactive sensors and sources will be used in planned testing, such as borehole geophysical logging, but are designed to be fully contained and

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Footnotes

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

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

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

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

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

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

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

Footnotes

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

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

[c]Estimate based on extent of existing disturbance.

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

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

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retrievable. Any plans to use high-level radioactive materials or to introduce radioactive artificial tracers at the site will be included in SCP progress reports and will be subject to NRC review as specified by 10 CFR 60.18(e).

8.4.2.2.2.1 Site preparation and surface-related activities

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

Activities involving minimal or no disturbance

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

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

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

3. Geophysical use of noninvasive seismic or electrical sources.

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

5. Infrequent off-road vehicular travel.

Surface-related characterization activities producing minimal or no disturbance, as summarized in Table 8.4.2-7, include surface stratigraphic studies, the Southern Great Basin Seismic Network, planned surface geophysical surveys, airborne geophysical surveys, surface stratigraphic studies, soil studies, surface sampling, and meteorological monitoring. Many of these activities are also remote from Yucca Mountain, including debris-flow monitoring, erosion monitoring, surficial-deposits mapping, geomorphic mapping, portable seismic monitoring, and radiological monitoring.

Off-road travel will be required for shallow seismic-reflection studies; for shallow seismic-refraction studies; for other geophysical surveys, such as gravity surveys (Activity 8.3.1.4.2.1.2); and for geologic, geomorphic and surficial-deposits mapping and surface stratigraphic studies (Activities 8.3.1.4.2.2.1, 8.3.1.5.1.4.3, 8.3.1.6.1.1.1, 8.3.1.8.5.1.3, and 8.3.1.16.1.1.1). All these planned activities will use existing roads where possible; no new roads will be constructed for these activities. Off-road vehicular travel will be coordinated among these activities to the extent practicable. For geophysical methods that may be introduced in the future,

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

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

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

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

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

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

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

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or for which analysis is required before application, the extent of surface disturbance and the potential impacts to site performance will be evaluated before implementation. For example, the surface disturbance and potential impacts from intermediate depth (2 to 3 km) seismic reflection and refraction will be evaluated when the objectives and methods for these surveys are determined.

Activities involving potentially significant disturbance

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

Roads

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

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

Water will probably be sprayed on unpaved access roads to control dust. This is the most commonly used method of dust control at construction and

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

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

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

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

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

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

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

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

[a]SBIP = Surface-Based Investigations Plan (DOE, 1988d).
[b]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design presented in Chapter 6. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).
[c]Controlled is the actual area chosen according to the 40 CFR 191.12(g) definition.

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

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

Drill pads

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

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Trenches

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

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

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

Pavements

In this context, the term "pavement" refers to a bedrock surface that has little or no regolith covering; pavements are uneven natural surfaces and are commonly located on slopes. Pavement studies involve mapping and measurement of fracture patterns in bedrock. The objective of these studies is to provide fracture information for evaluating the geomechanical response of stratigraphic units at the site and for hydrologic modeling, as described

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in Activity 8.3.1.4.2.2.2. Planned pavement studies will be undertaken only where bedrock is relatively close to the surface. In some instances, clearing of thin layers of surficial material may be required to expose a sufficient amount of bedrock (up to 800 m^2 of cleared area is needed per pavement, depending on the geologic aspects of each pavement location). Where necessary, bedrock will be cleared by spraying water under moderate pressure on the surface. Water for this purpose will be hauled to the site by truck. Displaced surface material will collect adjacent to the cleared area. Water is expected to puddle on the uneven bedrock surface, run into fractures, and possibly run off into nearby drainages. Currently, four pavements exist within the CPDB and two pavements within the controlled area. A comparable number of additional pavements in similar locations is planned.

Seismic shotholes

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

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

Natural infiltration studies

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

The neutron-access boreholes (for use of neutron moisture probes and crosshole gamma probes) are a principal aspect of infiltration studies at the site. Currently, 74 neutron-access boreholes exist in the vicinity of Yucca Mountain, in which moisture logging has been conducted since July 1984. The boreholes were drilled dry and cased using the ODEX system with air

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

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

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

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

Artificial infiltration experiments

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

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

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

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

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8.4.2.2.2.2 Drilling-related activities

Drilling-related activities are summarized in Table 8.4.2-9. These include testing and sampling activities, and many activities that are relatively remote from the site. The following descriptions emphasize activities located in the site vicinity.

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

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

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

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

Site vertical borehole studies (Activity 8.3.1.2.2.3.2)

The drilling program under this activity involves dry drilling and coring of 17 vertical boreholes, within and in the immediate vicinity of the conceptual perimeter drift boundary. At present, seven of these boreholes have been at least partially drilled. This includes a series of relatively shallow unsaturated zone boreholes designed to penetrate only to the top of the Topopah Spring welded unit, and several deeper boreholes that penetrate the repository horizon and most of the unsaturated portion of the Calico

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 1 of 8)

Activity category	SBIP[a] designation	SCP activity	Description
Site vertical bore-holes; drilling	USW UZ-2 USW US-3 USW UZ-9 USW UZ-9a USW UZ-9b USW UZ-10 USW UZ-11 USW UZ-12 USW UZ-14	8.3.1.2.2.3.2	For site vertical borehole studies. Drill dry to the water table; sampling plans integrated with with drilling program.
	UE-25 UZ#4 UE-25 UZ#5 USW UZ-7 USW UZ-8 USW UZ-13	8.3.1.2.2.7.1	For site vertical borehole studies. Deepen to water table using dry drilling methods; sampling plans integrated with systematic drilling program.
Vertical seismic profile support and unsaturated zone (UZ) proto-type	UE-25 VSP#1	8.3.1.4.2.2.5	Investigate the potential for vertical seismic profiling techniques as a means for broadly detecting and characterizing the subsurface fracture network. Provide a prototype hole to test dry drilling and coring.
Multipurpose boreholes, drilling[b]	TBD	8.3.1.2.2.4.9	If feasible, to sample baseline condition before ramp/shaft construction, and monitor disturbance during construction. Drilled dry.
Saturated zone recharge studies; drilling	UE-25 FM #1 - #3	8.3.1.2.1.3.3	Infiltration measurements for Fortymile Wash recharge study. Near conceptual boundary of controlled area.[c]

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 2 of 8)

Activity category	SBIP[a] designation	SCP activity	Description
Water table studies; drilling	USW WT-8	8.3.1.2.3.1.2	Study of saturated zone in vicinity of Solitario Canyon fault. Drilled dry through the UZ.
	UE-25 WT#19 UE-25 WT#20 USW WT-21 USW WT-22	8.3.1.2.3.1.2	Investigate potentiometric levels east of repository site. Located >1 km from conceptual perimeter drift boundary.[d]
	USW WT-9	8.3.1.2.3.1.1 8.3.1.2.3.1.2	Study of saturated zone in vicinity of Solitario Canyon fault. Drilled dry through UZ.
	USW WT-23 USW WT-24	8.3.1.2.3.1.2 8.3.1.2.1.3.2	Investigate the nature of potentiometric gradient to the north of the site.
Solitario Canyon fault study in the saturated zone; drilling	USW H-7	8.3.1.2.2.1.2	Study of hydrologic character of Solitario Canyon fault zone. Drilled dry through the unsaturated zone.
Multiwell tracer tests; drilling	STC #1 STC #2 STC #3 STC #4	8.3.1.2.3.1.8	Multiple well tests with conservative tracers; may be drilled if single well tracer tests at the C-well complex are unsuccessful.
Geologic coreholes; drilling	USW G-5 USW G-6 USW G-7	8.3.1.4.2.1.1 8.3.1.17.4.8.2 8.3.1.2.3.2.2	Correlate lithology changes with changes in potentiometric surface (G-5); provide subsurface stratigraphic control for water table gradient north of Yucca Mountain in

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Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 3 of 8)

Activity category	SBIP[a] designation	SCP activity	Description
Geologic coreholes; drilling (continued)			vicinity of Windy Wash (G-6); and check on lapping of Topopah Spring tuff onto paleo-high in Crater Flat tuff and correlate to regional ground-water flow, possibly intercepting Paleozoic-Tertiary contact (USW G-7). The three holes are located outside conceptual boundary of controlled area.
Vein deposits study; drilling	UE-25 PH #1A1 UE-25 PH #1A2 UE-25 PH #1A3 UE-25 PH #1A4 UE-25 PH #1A5	8.3.1.5.2.1.5	Investigate depth extent, configuration of calcite/silica vein deposits, in the vicinity of Trench 14.
Systematic drilling program	USW SD-1 USW SD-2 USW SD-3 USW SD-4 USW SD-5 USW SD-6 USW SD-7 USW SD-8 UE-25 SD-9 USW SD-10 USW SD-11 USW SD-12	8.3.1.4.3.1.1	Characterize matrix saturation and flow properties, fracture properties, geochemistry, and geochemical properties.
Conceptual repository surface facilities site; exploratory drilling	UE-25 RF#1 UE-25 RF#2	8.3.1.14.2.1.3	Geophysical measurements of dynamic soil properties to support engineering design/environmental hazard assessment.

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Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 4 of 8)

Activity category	SBIP[a] designation	SCP activity	Description
Solitario Canyon horizontal borehole	(e)	8.3.1.2.2.3.3	Conceptual plan for dry drilled penetration into Topopah Spring Member, from scarp. Depends on feasibility of drilling, sealing.
Site vertical bore-holes; testing	USW UZ-1 USW UZ-2 USW UZ-3 UE-25 UZ#4 UE-25 UZ#5 USW UZ-7 USW UZ-8 USW UZ-9 USW UZ-9a USW UZ-9b USW UZ-10 USW UZ-11 USW UZ-12 USW UZ-13 USW UZ-14	8.3.1.2.2.3.2	Pneumatic testing, logging, instrumentation, stemming, and monitoring of dry-drilled holes that penetrate to the water table.
	USW UZ-1 USW UZ-2 USW UZ-3 UE-25 UZ#4 USW UZ-7 USW UZ-8 USW UZ-9 USW UZ-10 USW UZ-14	8.3.1.2.2.7.1	Measure gas composition in unsaturated zone.

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Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 5 of 8)

Activity category	SBIP[a] designation	SCP activity	Description
Site vertical boreholes; testing (continued)	UE-25 UZ#5 USW UZ-6 USW UZ-6a USW UZ-13	8.3.1.2.2.6.1, 8.3.1.2.2.6.1	Measure gas circulation and gas composition in unsaturated zone.
Vertical seismic profile support and unsaturated zone prototype	UE-25 VSP#1	8.3.1.4.2.2.5	Investigate the potential for vertical seismic profiling techniques as a means for broadly detecting and characterizing the subsurface fracture network. Provide a prototype hole to test dry drilliing and coring.
Multipurpose boreholes;[b] testing	USW UZ-11 USW UZ-12	8.3.1.2.2.6.1	Measure gas circulation in unsaturated zone.
	TBD	8.3.1.2.2.4.9	Periodic logging and pneumatic packer testing during ramp/shaft construction.
Saturated zone single-well tracer testing	UE-25 C#1 UE-25 C#2 UE-25 C#3	8.3.1.2.3.1.4 8.3.1.2.3.1.5 8.3.1.2.3.1.7	Flow testing of C-hole complex using conservative and reactive tracers. Chemical tracers only.
	STC #1 STC #2 STC #3 STC #4	8.3.1.2.3.1.6 8.3.1.2.3.1.8	Multiple well tests with conservative and reactive tracers; conducted if single well tracer tests at C-well complex prove unsuccessful.
	UE-25 A#1 UE-25 B#1 USW G-4	8.3.1.2.3.1.6 8.3.1.2.3.2.2	Well testing with conservative tracers, to be conducted if single-well tests at the C-well complex prove successful.

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 6 of 8)

Activity category	SBIP[a] designation	SCP activity	Description
Saturated zone single-well tracer testing (continued)	USW H-1 USW H-3 USW H-4 USW H-5 USW H-6	8.3.1.2.3.2.2 8.3.1.2.3.1.8	Well testing with conservative tracers, to be conducted if single-well tests at the C-well complex prove successful.
Solitario Canyon fault Study in the saturated zone	USW H-6 USW H-7 USW WT-8 USW WT-9	8.3.1.2.2.1.2	Cross-hole testing between USW H-6 and USW H-7; other holes to be used as observation wells.
Water supply testing	J-12 J-13	8.3.1.16.2.1.1	Assess feasibility and adequacy of wells J-12 and J-13 for use in construction and operation of Yucca Mountain repository. Located just outside conceptual boundary of controlled area.
Saturated zone recharge studies, testing	UE-25 FM#1 UE-25 FM#2 UE-25 FM#3	8.3.1.2.1.3.3	Infiltration measurements as part of Fortymile Wash recharge study. Dry drilled to the water table.
Water table studies testing	USW WT-8 UE-25 WT#19 UE-25 WT#20 USW WT-23 USW WT-24	8.3.1.2.3.1.2	Site potentiometric level study; water level monitoring, and water pumping/sampling.
	USW WT-21 USW WT-22	8.3.1.2.1.3.2	Regional potentiometric level study; water level study; water level monitoring, and water pumping/sampling. WT-22 is located >5 km from conceptual perimeter drift boundary.

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Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 7 of 8)

Activity category	SBIP[a] designation	SCP activity	Description	Remarks
Water table studies testing (continued)	USW WT-1 USW WT-2 UE-25 WT#2 UE-25 WT#4 UE-25 WT#6 USW WT-7 USW WT-10 USW WT-11 UE-25 WT#12 UE-25 WT#13 UE-25 WT#14 UE-25 WT#15 UE-25 WT#16 UE-25 WT#17	8.3.1.2.3.1.2 8.3.1.2.3.2.2	Site potentiometric level study; water level monitoring, and water pumping/ sampling.	
	USW G-5 USW G-6 USW G-7	8.3.1.4.2.1.1 8.3.1.17.4.8.2 8.3.1.2.3.2.2	Correlate lithologic changes with appropriate structural and hydrologic information; sample water from saturated zone; possibly perform hydrofract stress measurements.	
In situ stress studies	USW ISS-1	8.3.1.17.4.8.2	Measure in situ stress.	Shallow hole >250 m.
Conceptual repository surface facilities site; borehole testing	RSF #1 RSF #2	8.3.1.14.2.1.3	Geophysical measurements of dynamic soil properties to support engineering design/ environmental hazard assessment.	

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Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 8 of 8)

Footnotes

[a]Surface-Based Investigations Plan (DOE, 1988d).
[b]Multipurpose borehole testing is described in Section 8.3.1.2.2.4.9.
[c]Controlled area is the actual area chosen according to the 40 CFR 191.12(g) definition.
[d]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design presented in Chapter 6 of the SCP. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).
[e]Borehole designation is to be determined. This is a conceptual activity and plans are not presently included in the Surface-Based Investigations Plan.

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Hills nonwelded unit. The shallow boreholes were drilled dry using the ODEX 115 system with continuous wireline coring to depths up to 430 ft (F&S, 1987b). Plans call for deepening of UE-25 UZ#4, UE-25 UZ#5, USW UZ-7, USW UZ-8, and USW UZ-13 to the water table.

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

At least two candidate drilling schemes have been considered for planned dry drilling to the water table, with continuous sampling suitable for hydrologic data needs: (1) dual-tube reverse circulation (DTRC) rotary or down-the-hole hammer technology, and (2) a telescoping ODEX concept similar to the shallow UZ program, with provision for stepdown tool sizes to attain required depth penetration. Feasibility testing of one or more alternative drilling methods will be conducted at the location of the planned UE-25 UZ#9 complex of boreholes, about 0.5 km southeast of the CPDB. The selection of the drilling method for the unsaturated-zone boreholes, the multipurpose boreholes, and the systematic drilling program will be based on this feasibility test.

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

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

After the conclusion of monitoring at some future time yet to be determined, water-injection testing is planned. The sampling apparatus and stemming configuration from monitoring will be used for injecting moderate quantities of water. These tests are tentative and have, therefore, not been included in the test interference discussion of Section 8.4.2.2.3. The

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potential test interference and site performance impacts of this type of water injection will be evaluated before its implementation, on the basis of information acquired from the preceding parts of the study.

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

Multipurpose borehole activity (Activity 8.3.1.2.2.4.9)

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

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

Each of the proposed MPBH activity boreholes would be drilled to the maximum depth of the respective shaft. The specific location of each hole would be determined to meet the requirement for long-term surface access for monitoring, the requirement to locate the boreholes at least two drift diameters away from any underground openings, and the requirement to not penetrate the mechanical zone of influence expected to occur around each

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shaft. Dry drilling and coring are necessary. The drilling method for this application has not been selected; the selection would be based on feasibility testing conducted in conjunction with the unsaturated-zone drilling program. At the conclusion of drilling, a surface casing would be cemented in place, and geophysical logging and pneumatic packer testing will commence. Short-term logging and packer testing would be repeated throughout the process of ESF surface facilities construction, shaft construction, and testing in the shafts. Long-term monitoring would monitor the behavior of the rock mass between the MPBH and the shaft. The boreholes would be uncased throughout the monitoring period; the surface casing would be capped when testing is not in progress to inhibit moisture efflux. The option of instrumenting the boreholes would be maintained.

Systematic drilling program (Activity 8.3.1.4.3.1.1)

The systematic drilling program consists of drilling twelve boreholes within the CPDB or in its immediate vicinity, to collect samples and data on lithostratigraphy, basic physical properties, fracture characteristics, mineralogy, in situ moisture conditions, and other characteristics, as discussed in Section 8.4.2.1.4. This information will address various information needs, particularly for the model for unsaturated-zone flow and transport. The systematic drilling program is also an important source of samples for geomechanical, geochemical, and geophysical studies. Seven of these boreholes are distributed across the site area, and in conjunction with other planned drilling will provide areal coverage of the site with about 3,000-ft spacing between boreholes. The other five boreholes of the systematic drilling program are clustered immediately to the southeast of the CPDB to provide information on small-scale lateral variability of matrix hydrologic properties and other parameters. Each borehole will be drilled to approximately 200 ft below the water table. Nonwelded and partially welded intervals will be continuously cored, and welded intervals will be continuously cored if feasible; otherwise, they will be spot cored on a regular basis. The boreholes will be drilled dry to reduce disturbance to the hydrologic and hydrochemical properties of the samples acquired. The drilling method has not been determined, and the selection will be based on results from the feasibility testing described above.

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

Solitario canyon horizontal borehole study (Activity 8.3.1.2.2.3.3). This borehole will be drilled laterally into the Topopah Spring welded unit, at the Solitario Canyon scarp where the upper part of this unit is exposed at the site (Activity 8.3.1.2.2.3.3). The location of this borehole has been tentatively identified as about 2,000 ft north-northwest of the CPDB. The borehole will be drilled dry to provide representative information on in situ moisture conditions. The length of the borehole will be sufficient to

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penetrate the zone of fracturing or alteration associated with the fault; this could require a borehole up to 1,000 ft long. Important uncertainties pertaining to this planned borehole are (1) the engineering feasibility of drilling, testing, and stemming a long horizontal hole through relatively highly fractured conditions, and (2) the method of plugging a horizontal borehole, should this be required. These questions will be evaluated before drilling of the borehole.

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

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

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

Saturated-zone exploration, sampling, and testing

Eight boreholes are planned specifically for exploration and sampling of the saturated-zone in the vicinity of the site, in addition to the 16 such boreholes that already exist (Activity 8.3.1.2.3.1.2). Also, a new borehole (USW H-7) is planned just within the CPDB to address multiple objectives. A

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program of sampling will be conducted in the water-table boreholes (existing and proposed), and a series of pumping tests will be performed in USW H-7 and in other boreholes in the site vicinity (USW H-6 and USW WT-8).

Water-table boreholes

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

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

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

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Water-table borehole sampling

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

Saturated-zone hydrologic borehole USW H-7

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

Other saturated zone testing

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

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

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

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

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

Regional potentiometric-level drillholes

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

Other boreholes

In addition to those just described, several other boreholes are planned, as indicated in Table 8.4.2-9. These holes are generally remote from the site but are described here for completeness. A series of five or more shallow holes (approximately 200 ft deep) will be drilled in the vicinity of Exile Hill, just east of the site, to explore subsurface expression of the Trench 14 vein deposits. Two shallow exploratory holes (RF-series boreholes) are planned for Midway Valley east of Exile Hill for further testing

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of the proposed location for the repository surface facilities. Three or more boreholes to the water table and several shallow neutron-access holes are planned for recharge studies in Fortymile Wash, a few miles east of the site (FM-series boreholes). A series of four holes to about 1,000 ft depth are planned in Crater Flat to investigate the buried volcanic deposits that are the cause of aeromagnetic anomalies (V-series boreholes). One or two additional holes in the Yucca Mountain region are planned to measure in situ stress by hydraulic fracturing; the number and locations of these boreholes is yet to be determined.

8.4.2.2.2.3 Basis for surface-based testing construction controls

<u>Water use during site characterization</u>

An estimated 4.5 million gallons of water will be used for surface-based drilling (based on current SCP planning) during site characterization. An additional estimated 1.1 million gallons will be used during surface-based testing, and an estimated 35 million gallons (for five years of surface-based site characterization activity) will be used for maintenance, including dust control for access roads. The amount of water to be used during construction and testing associated with the ESF is presently being determined.

The DOE has applied to the State of Nevada for a water appropriations permit for well J-13 water (Application for Permit No. 52338). The appropriation applied for was 131 million gallons or 402 acre feet to be used for site characterization at Yucca Mountain. The difference between the water use estimates described previously and the appropriation applied for is the result of revisions of test plans and construction controls, specifically, (1) dry drilling is now specified for the systematic drilling program, and for other drilling within the CPDB and immediate vicinity; (2) the systematic drilling program and in situ stress measurement activities have been revised; (3) the amended water application considered more than 6 years of use versus 5 years as described previously in this section; (4) water use for surface dust control at the ESF has been overestimated, and (5) a 10 percent contingency has been applied to water needs for ESF construction, in the amended application.

The use of larger figures in the water application is necessary because of uncertainties regarding estimates of water use. For example, the largest expected use of water is for surface dust control on roads. Most of the road mileage associated with site characterization is situated outside the CPDB, and effective dust control on such roads may require additional water in excess of the estimates. Water needs for dust control are particularly difficult to estimate and will vary with environmental and operating conditions. Despite the intention of the Project to minimize water use during site characterization, it is important to have sufficient appropriation to meet unanticipated needs, especially those related to safety, such as dust and fire control.

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Water-use estimates for planned surface-based testing are given for drilling, testing, and maintenance (primarily for dust suppression on roads as described earlier) in Tables 8.4.2-10 and 11. These estimates should be considered maximum amounts that will be used under anticipated conditions. None of the water estimated for use in surface-based drilling will be used for boreholes located within the CPDB, given planned construction controls. Approximately 400,000 gallons of water will be used in surface-based tests that may be located within the CPDB. Well J-13 is the planned source of all the water used for site characterization.

Dry drilling

A key aspect of construction control for surface-based testing, including infiltration testing, unsaturated-zone hydrology testing, and the systematic drilling program, is the selection of dry drilling or coring methods. The determination to use air circulation in drilling-related operations associated with these activities is based on three criteria: (1) core or cuttings samples should be reasonably free of hydrologic invasion or hydrochemical contamination by drilling fluid; (2) for studies where monitoring of in situ hydrologic conditions is planned, the environment in the immediate vicinity of monitoring boreholes should be reasonably free of artificially introduced moisture, or other perturbation caused by drilling (e.g., contamination); and (3) for activities located within or close to the CPDB, drilling operations should not result in the loss of fluid into the unsaturated-zone, which could have a deleterious effect on the representativeness of site characterization data, or on the waste-isolation performance of the site.

Unsaturated-zone hydrologic data and sample requirements

Core samples from the unsaturated zone are needed for such tests as measurement of unsaturated matrix conductivity and extraction of pore fluid. Various dry sampling methods were used in the neutron-access borehole drilling program with different results, depending on the materials being sampled; these methods included cuttings, drive sampling, and air rotary coring (Hammermeister et al., 1985). Although of limited applicability, these results show that a dry sampling method in addition to cuttings is needed, that drive sampling produces bias in sample water-content data due to mechanical effects but is adequate for sampling unconsolidated materials, and that air rotary coring probably is adequate for sampling nonwelded and welded material.

In principle, samples should be drilled dry to preserve in situ conditions, but the value of dry drilling has not actually been demonstrated. This will be addressed in a prototype test program for evaluating the effects of wet and dry drilling fluids on the in situ hydrologic properties of tuffaceous rocks. This test will involve coring, testing, and monitoring of closely spaced parallel boreholes in the G-tunnel Rock Mechanics Facility located at the Nevada Test Site. Both dry and conventionally (water) drilled coreholes will be investigated in both welded and nonwelded units. This

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Table 8.4.2-10. Water-use estimates (in gallons) for planned surface-based activities--drilling and testing[a] (page 1 of 3)

Activity category	Borehole designation	Within conceptual perimeter drift boundary[b]	Within controlled area boundary[c]	Outside the controlled area boundary
		DRILLING		
Shallow boreholes (<100 ft deep)		0	0	0
Site vertical boreholes	USW UZ-2	0		
	USW UZ-3	0		
	UE-25 UZ#4[d]		0	
	UE-25 UZ#5[d]		0	
	USW UZ-7[d]	0		
	USW UZ-8[d]	0		
	UE-25 UZ#9		0	
	UE-25 UZ#9a		0	
	UE-25 UZ#9b		0	
	USW UZ-10		0	
	USW UZ-11		0	
	USW UZ-12		0	
	USW UZ-13[d]		0	
	USW UZ-14		0	
Vertical seismic profile support/unsaturated-zone prototype	UE-25 VSP#1		0	
Solitario Canyon horizontal hole	To be determined		0	
Multipurpose boreholes[e]	USW MP-1	0		
	USW MP-2	0		
Saturated-zone borehole	USW H-7 (below water table only)		151,200	
Water-table boreholes	USW WT-8		0	
	USW WT-9		0	
	UE-25 WT#19			100,800
	UE-25 WT#20			100,800
	USW WT-21		100,800	
	USW WT-22			100,800
	USW WT-23		100,800	
	USW WT-24		100,800	

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Table 8.4.2-10. Water-use estimates (in gallons) for planned surface-based activities--drilling and testing[a] (page 2 of 3)

Activity category	Borehole designation	Within conceptual perimeter drift boundary[b]	Within controlled area boundary[c]	Outside the controlled area boundary
		DRILLING (continued)		
Geologic coreholes	USW G-5			630,000
	USW G-6			630,000
	USW G-7			630,000
Volcanic boreholes	.SW V-1, V-2, V-3 and V-4			268,000
Calcite silica vein deposit coreholes	UE-25 PH#1 (5 slant holes)		84,000	
	UE-25 PH#2 (if needed)		16,800	
Systematic Drilling Program (12 holes total, 5 within the conceptual perimeter drift boundary and 7 within the controlled area boundary)		0	0	
Southern tracer complex (if needed)	STC-1		302,400	
	STC-2		302,400	
	STC-3		302,400	
	STC-4		302,400	
Conceptual repository surface facilities coreholes	UE-25 RF#12		100,800	
	UE-25 RF#13		100,800	
In situ stress borehole	UE-25 ISS#1			67,200
Drilling totals		0	1,965,600	2,528,400

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Table 8.4.2-10. Water-use estimates (in gallons) for planned surface-based activities--drilling and testing[a] (page 3 of 3)

Activity category	Borehole designation	Within conceptual perimeter drift boundary[b]	Within controlled area boundary[c]	Outside the controlled area boundary
		PLANNED SURFACE-BASED TESTING		
Artificial infiltration	Small plot rainfall simulation (23 sites)	960	1,800	
	Large plot rainfall simulation (14 sites)	9,000	33,000	
	Ponding studies	340,000	660,000	
In situ stress tests	UE-25 ISS#1			5,000
	(at an existing hole near the site)		5,000	
Tracer tests	UE-25 C-hole complex (up to 10 tests)		10,000	
Testing Totals		349,960	709,800	5,000

[a]Water use figures are given only for areas where drilling or testing will occur.

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

[c]Controlled area is the actual area chosen according to the 10 CFR 60.2 definition.

[d]These are existing shallow unsaturated-zone boreholes (<500 ft in depth). They will be reentered and drilled to depths necessary to penetrate the saturated zone.

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

Table 8.4.2-11. Water-use estimates for planned surface-based pumping tests[a]

Activity category	Borehole designation	Approximate discharge rates (gpm)	Test duration (days)	Approximate gallons withdrawn
Solitario Canyon fault pump test	USW H-7	350-500	30	21,600,000
	USW H-6	350-500	30	
Drawdown pumping tests	UE-25C-hole complex	50-400	3-5 & one 30-day test	34,560,000
	J-13 (primary water supply well)	50-400	7	4,000,000
Drift-pumpback tracer tests	UE-25C-hole complex	50-150	3	1,944,000
Two-well convergent tracer tests	UE-25C-hole complex	100-300	24	24,192,000
Two-well recirculating tracer tests	UE-25C-hole complex	(minimal discharge for sampling only)		
Drawdown pumping tests before the drift-pumpback tests[b]	UE-25a #1	50-200	3-5	1,440,000
	UE-25b #1	50-200	3-5	1,440,000
	USW G-4	50-200	3-5	1,440,000
	USW H-1	50-200	3-5	1,440,000
	USW H-3	50-200	3-5	1,440,000
	USW H-4	50-200	3-5	1,440,000
	USW H-6	50-200	3-5	1,440,000
Drift-pumpback tracer tests throughout the site[b]	Same as above	50-150	3	4,536,000
Drawdown pumping tests for recirculating tracer tests[b]	4 southern tracer-complex boreholes	100-300	28	24,192,000

[a]Discharge amounts were estimated using the maximum pumping rate and the maximum number of days tentatively planned for each test.

[b]Either the drift-pumpback tests or the recirculating pumping tests will be conducted. The type of additional tracer tests depends on results of the previous tests conducted at the C-hole complex.

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program will provide hydrologic measurements under closely controlled conditions, for use in preliminary application of unsaturated flow models to provide a theoretical basis for understanding the hydrologic effects of different drilling and excavation methods.

Formation invasion by fluid

Controlled field experiments have shown that water injected into the unsaturated zone during conventional drilling or flow testing under saturated conditions may mobilize over unanticipated distances by apparent channel flow, and that once in the formation this water can change the measured pneumatic conductivity. Because most of the studies in the unsaturated-zone hydrology program, including those in the ESF, will measure the rock-mass hydraulic conductivity, the choice of drilling method could significantly impact the results from unsaturated-zone hydrologic testing in the ESF and from surface-based programs. Dry drilling and coring methods provide the highest assurance that such impacts are minimized. Field testing of the effects of different drilling methods and drillhole inundation on measurable in situ hydrologic characteristics of the unsaturated zone will be incorporated in the wet versus dry prototype test in G-tunnel.

Slightly more than 500,000 gallons of water-based drilling fluid were lost to the unsaturated zone during drilling of USW G-1, of which traces were detected about two years later during drilling of borehole USW UZ-1, about 1,025 ft away. A significant effort (i.e., borehole USW UZ-14, Activity 8.3.1.2.2.3.2) is planned to resolve the specific origin of this fluid and the structural conditions that contributed to its movement.

All the existing boreholes within the CPDB or immediate vicinity were drilled dry (USW UZ-6, USW UZ-6S, USW UZ-7, and USW UZ-8) or with air foam (USW G-4, USW H-4, USW H-5, and USW WT-2). The use of air foam has resulted in the loss of approximately 100,000 to 200,000 gallons per hole. Total recorded fluid use for these boreholes was about 2 million gallons. The amount actually lost to the unsaturated zone was approximately 850,000 gallons; the balance was recovered and dispersed or evaporated in pits at the surface. Borehole television logs made during drilling operations show water inflow from the fractures and lithophysae intersected by the borehole. While reduction in overall fluid loss was gained by the use of air foam instead of water or mud (with the application of lost-circulation materials), losses in the unsaturated-zone were comparable in the boreholes for which data are available. Based on prior drilling history at Yucca Mountain, dry drilling is the only demonstrated means of controlling formation invasion by fluid.

The need to reduce uncertainty concerning the hydrologic conditions and processes operating at the site suggests that further fluid losses should be avoided until uncertainty is reduced. Fluid already lost during pre-site characterization activities can be considered to have altered the state of moisture of the unsaturated zone, for which characterization is planned. However, if construction controls were to permit significant additional losses to the subsurface during site characterization, characterization data might not be representative of altered conditions. Dry drilling methods are therefore specified for planned drilling in the unsaturated-zone within the CPDB and immediate vicinity.

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Most of the fluid that has been lost to the formation contains a conservative tracer, primarily lithium chloride, but lithium bromide has also been used. These salts were mixed with drilling water to produce a solution of approximately 20 ppm. The majority of boreholes drilled at or near Yucca Mountain (including all boreholes within the CPDB or in the immediate vicinity) used lithium chloride as a tracer. Several of the water-table drillholes used lithium bromide and a few boreholes drilled early in the site-selection process and located away from the CPDB (e.g., USW G-1) were drilled without the use of a tracer.

8.4.2.2.3 Surface-based test interference

Interference with surface-based testing is limited, principally because these activities are widely separated. Many surface-based testing activities such as mapping, trenching, and geophysical surveys are concerned with durable characteristics of the site that generally are unaffected by interference. Hydrologic monitoring activities in the unsaturated zone, such as the site vertical boreholes study (Activity 8.3.1.2.2.3.2) or the gas-phase circulation study (Activity 8.3.1.2.2.6.1), may detect the influence of hydrologic stress tests such as pneumatic packer testing from neighboring boreholes, but this would be unexpected because the various test locations are far apart. Similarly, potentiometric-level interference caused by pumping tests in the saturated zone is possible and will be investigated. The events that could lead to this type of interference in the unsaturated or the saturated zone are under experimental control and can be knowingly evaluated if interference effects are suspected. The types of activities that have the most potential to produce interference effects are, therefore, (1) artificial introduction of water or gas wherever planned tests are located close together, thereby facilitating possible communication, and (2) disturbance to the structural characteristics of the site such that natural hydrologic processes are disturbed, producing interference with the measurements of those processes.

Possible interference from water use

The planned use of water in testing could potentially produce test-to-test interference if different activities are located close enough together, which is most likely in the immediate site area. The only significant testing-related use of water planned within the CPDB or the immediate vicinity is for the artificial infiltration tests, for which a total of up to 400,000 gallons of tagged water will be used within the CPDB. These tests are planned in conjunction with the natural infiltration monitoring program and are widely separated from infiltration monitoring installations that could be adversely impacted. The other possibility is that water used in artificial infiltration testing could percolate deep into the unsaturated zone, thereby affecting measurements of the natural moisture state there, specifically in the site vertical boreholes study (Activity 8.3.1.2.2.3.2). Significant vertical and lateral movement of introduced water would be required, because the potentially interfering activities are widely separated. The evaluation reported in Section 8.4.3.2 indicates that moisture pulses from such sources may travel slowly. Furthermore, the chemically tagged water used in artificial infiltration testing could be identified

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during drilling of any borehole where such water is intercepted in sufficient quantity to significantly interfere with characterization of in situ matrix moisture conditions. This type of tracer detection strategy is relied upon in the multipurpose borehole activity (Activity 8.3.1.2.2.4.9) and the radial boreholes test in the ESF (Activity 8.3.1.2.2.4.4). In summary, the use of tagged water for artificial infiltration studies appears unlikely to interfere with planned natural infiltration monitoring or testing and monitoring in the deep unsaturated zone. However, the available information is inconclusive, so the potential for interference will be reevaluated as new information on lateral fluid mobility becomes available.

The other significant planned use of water within the CPDB or immediate vicinity is for dust suppression on roads. As discussed in Section 8.4.2.2.2, the dust control methods used previously at the site call for application of 1 to 2 mm of chemically tagged water, typically twice per day, under meteorologic conditions conducive to evaporation. This amount of water is not sufficient to produce significant runoff. Successive applications of water, however, could possibly produce saturation buildup in the road bed and underlying strata, which could conceivably interfere with natural infiltration monitoring, or with testing and monitoring in the deep unsaturated zone. Because road and pad surfaces are highly compacted and because of relatively large evaporative losses, dust suppression is unlikely to cause test interference. Natural infiltration study locations for monitoring undisturbed conditions are separated from roads and drill pads. For studies in the deep unsaturated zone, test interference depends on the mobility of moisture through the overlying drill pad and near-surface rock or alluvial material. This flow probably is restricted to the matrix of these materials and is, therefore, unlikely to penetrate to monitoring locations in the deep unsaturated zone in the time frame of site characterization. Further analysis of test interference, including the effects of watering for dust suppression, will be part of the study plans for the activities that may be affected.

Possible interference from disturbance to hydrologic processes

Construction of roads and drill pads alters the surface infiltration, runoff, and evapotranspiration characteristics of the site. For existing and planned roads at Yucca Mountain, this effect is associated primarily with devegetation and compaction of natural materials used for the road bed. Runoff from roads and pads is significantly increased for precipitation events that range from light events that cause runoff only from sloping road surfaces to heavy events that cause runoff from undisturbed surfaces. This type of runoff generally flows onto and infiltrates alluvium-filled, shallow gradient areas at lower elevations. Increased runoff associated with surface disturbance probably tends to increase the saturation of near-surface materials in these infiltration areas. As this occurs, the capacity for infiltration into those materials decreases, thus extending the distance traveled by runoff. This effect is unlikely to interfere with infiltration measurements in upland areas, but may affect measurements in the canyons and washes of Yucca Mountain. Because of the distribution of natural-infiltration monitoring installations, some will probably register increased infiltration and the remainder will be unaffected. The impact of using affected information in site performance assessment is not currently understood, but the hydrologic characteristics of the areas disturbed by roads and pads are likely to return to pre-disturbance conditions relatively quickly, as a result of natural

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processes and eventual reclamation activities. This is a complex issue for which current understanding of site conditions and processes does not permit immediate resolution. Controls will be applied in the construction and maintenance of the features involving significant disturbance as discussed in Section 8.4.2.2.2, to reduce the magnitude of the interference effect to the extent practicable during site characterization. Knowledge that the effect probably exists will be applied throughout site characterization in the interpretation of infiltration data.

The other type of potential hydrologic interference involves the effect of borehole penetrations through the unsaturated zone on the natural movement of gas and vapor. Air has been observed to flow into and out of deep, open boreholes on the crest of Yucca Mountain (e.g., USW UZ-6), various neutron-access holes, and several of the WT-series boreholes. This flow is driven by seasonal and diurnal fluctuations in air density and local barometric pressure, and probably occurred in some form before construction of the boreholes. The flow generally involves inhalation of dry air and exhalation of moist air. All the existing boreholes at the site have surface casing and have been shut in except for intermittent observation periods. The significance of these observations to this discussion is that in situ hydrologic conditions will support appreciable flow (e.g., 10 ft/s in a 20-in. diameter hole) in response to potential gradients produced by atmospheric effects. No information is yet available on internal gas or vapor flow in shut-in boreholes.

Currently, five penetrations through the unsaturated zone exist within the CPDB at Yucca Mountain; of these, one is uncased and the remainder have tubing or casing installed throughout the unsaturated zone without cement (other than what was used to "tack" the lower end). A comparable number of existing holes stand uncased or uncemented through the unsaturated zone, in the immediate vicinity of the site. The casing is not fully cemented in boreholes in the vicinity of Yucca Mountain so that it can be readily removed for borehole sealing. Planned drilling for site characterization will produce at least 10 additional penetrations through the entire unsaturated-zone section within the CPDB, of which only three will be completed in such a way as to occlude flow in the open bore or the casing annulus. About 20 similar penetrations are planned for the surrounding vicinity (the exact number depends on the area considered). The same controls on casing cementation will apply to the planned program. The result will be boreholes spaced approximately 3,000 ft apart over the site area, and clusters of more closely spaced holes at the ESF location, near the USW UZ-6 location, and southeast of the CPDB near planned borehole USW UZ-9. The interference concern is that once the site vertical boreholes (Activity 8.3.1.2.2.3.2) are instrumented and stemmed for long-term monitoring, internal circulation in the unsaturated-zone penetrations will affect the data collected.

Planned investigations are expected to provide the information needed to evaluate the extent of interference. Several studies are planned to evaluate the effects of air circulation through Yucca Mountain, and in open boreholes, to characterize test interference and the effect on repository performance, if any. One of the objectives for Study 8.3.1.2.2.6 (characterization of gaseous-phase movement in the unsaturated zone) is to describe the pre-waste-emplacement gas-flow field and identify the structural controls on fluid flow. Activity 8.3.1.2.2.6.1 plans to reconstruct the history of artificial

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effects on air circulation in the repository block and to relate flow rates to barometric pressure and air temperature changes. Flow-rate measurements will be made with a hot-wire anemometer under both open-hole and shut-in conditions. This information will be used with numerical simulation techniques to determine the volume of rock affected and the time required for the rock mass to return to pre-disturbance conditions. Gas flux and gaseous transport will also be investigated in Study 8.3.1.2.2.7 (hydrochemical characterization of the unsaturated zone).

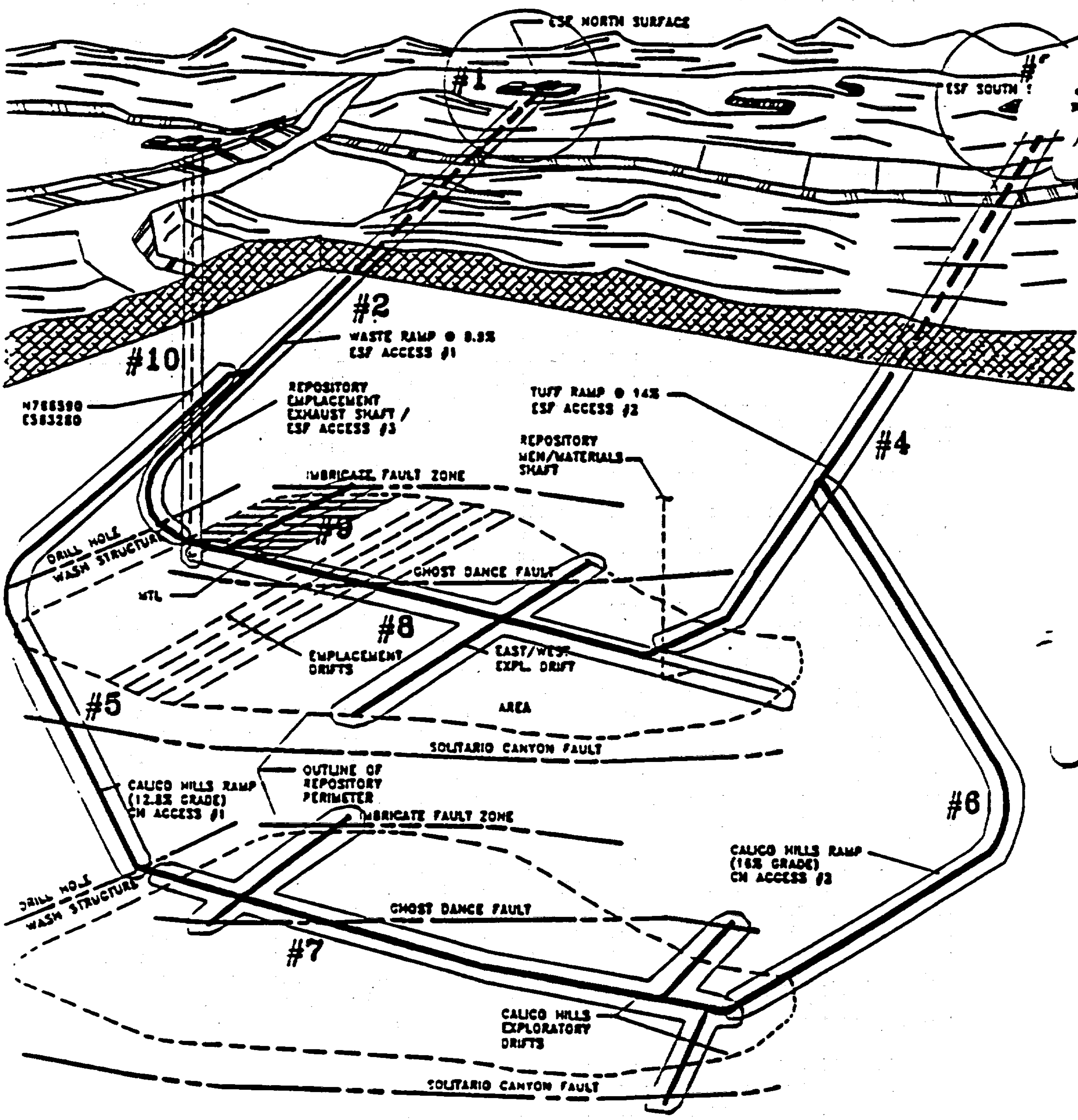
8.4.2.3 Subsurface-based activities

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

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

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

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



NOTE: THIS IS PICTORIAL ONLY AND NOT DRAWN TO SCALE

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

Figure 8.4.2-3. Reference Design Concept for Commencing Study.

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

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

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

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

1. Multi-purpose Borehole (MPBH) (may be replaced by engineering investigation boreholes for ramp accesses)

2. Geologic Mapping

3. Short Radial Boreholes

4. Hydrochemistry

5. Mineralogy/Petrology (sampling)

6. Matrix Hydrologic Properties (sampling)

7. Chlorine-36 (sampling)

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

9. Perched Water (if encountered).

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

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1. Upper Demonstration Breakout Room

2. Heater Experiment in TSw1

3. Overcore Stress

4. Vertical Seismic Profiling

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

6. Intact Fractures

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

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

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

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

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

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

1. Vertical Seismic Profiling

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

3. Intact Fractures

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

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

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

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

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

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

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

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

1. Lower Demonstration Breakout Room
2. Geologic Mapping
3. Mineralogy/Petrology (sampling)
4. Sequential Drift Mining
5. Canister Scale Heater
6. Heated Block
7. Thermal Stress
8. Heated Room
9. Equipment/Development
10. Plate Loading
11. Rock Mass Strength
12. Evaluation of Mining Methods
13. Ground Support Monitoring
14. Monitoring of Drift Stability
15. Air Quality/Ventilation
16. Engineered Barrier
17. Seals
18. Overcore Stress
19. Matrix Hydrologic Properties (sampling)
20. Percolation
21. Bulk Permeability
22. Perched Water (if encountered)
23. Diffusion
24. Chlorine-36 (sampling)

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

In the next section, each of the 34 ESF test activities, including possible testing in the multipurpose borehole, is briefly described, as are the layout-related constraints imposed on the ESF design, construction, or operations. The estimated zones of influence that must be accounted for in locating and conducting the tests are also described. The integrated data system, the ESF design, the construction operations, and the underground support systems planned for use in supporting the testing are described in Sections 8.4.2.3.2 through 8.4.2.3.5, respectively. Finally, the ESF layout and operations is evaluated in Section 8.4.2.3.6 relative to (1) the potential for interference between tests, (2) the potential for construction and operations interference with testing, (3) the integration of the ESF and the repository designs, (4) the design flexibility, and (5) the impact of safety concerns on the design and planned operations.

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8.4.2.3.1 Exploratory shaft facility testing operations, layout constraints, and zones of influence

Each of the presently planned ESF testing studies or activities listed in Table 8.4.2-12 is briefly described in the following sections from an operational and design perspective. These operational descriptions are followed by a discussion of potential interferences (constraints and zones of influence) that have been considered in locating each test. The interference evaluations were used to establish minimum requirements for separating the ESF tests from each other and from other mining operations.

The various tests planned for the exploratory shaft facility (ESF) are designed to acquire data on geologic, hydrologic, geomechanics, geochemical, and waste package environment characteristics. Table 8.4.2-12 identifies in which ESF development phase these tests are planned to be conducted, and whether the test is a deferred test. Section 8.3 provides the rationale for each test and information about how the resulting data will be used.

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

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

Table 8.4.2-12. Exploratory shaft facility tests (page 1 of 3)

Test title	ESF Phase[a]	SCP section
Geologic mapping of the exploratory shaft facility	2,4,5,6,7,8,9	8.3.1.4.2.2.4
Fracture mineralogy studies	2,5,7,8,9	8.3.1.3.2.1.3
Seismic tomography and vertical seismic profiling	2D,5D,7,8	8.3.1.4.2.2.5
Shaft convergence	2D,10	8.3.1.15.1.5.1
Demonstration breakout rooms	2D,9	8.3.1.15.1.5.2
Sequential drift mining	9	8.3.1.15.1.5.3
Heater experiment in unit TSw1	2D	8.3.1.15.1.6.1
Canister-scale heater experiment	9	8.3.1.15.1.6.2
Yucca Mountain heated block	9	8.3.1.15.1.6.3
Thermal stress measurements	9	8.3.1.15.1.6.4
Heated room experiment	9	8.3.1.15.1.6.5
Development and demonstration of required equipment	9	8.3.2.5.6
Plate loading tests	8,9	8.3.1.15.1.7.1
Rock-mass strength experiment	8,9	8.3.1.15.1.7.2
Evaluation of mining methods	8,9	8.3.1.15.1.8.1

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Table 8.4.2-12. Exploratory shaft facility tests (page 2 of 3)

Test title	ESF Phase[a]	SCP section
Evaluation of ground support systems	8,9	8.3.1.15.1.8.2
Monitoring drift stability	8,9	8.3.1.15.1.8.3
Air quality and ventilation	8,9	8.3.1.15.1.8.4
Shaft and borehole seals components testing	9	8.3.3.2.2.3
Overcore stress experiments in the exploratory shaft facility	2D,7,9	8.3.1.15.2.1.2
Matrix hydrologic properties testing	2,5,7,8,9	8.3.1.2.2.3.1
Intact-fracture test in the exploratory shaft facility	2D,5D,7,8	8.3.1.2.2.4.1
Percolation tests in the exploratory shaft facility[c]	9	8.3.1.2.2.4.2
Bulk-permeability test in the exploratory shaft facility	7,8,9	8.3.1.2.2.4.3
Radial borehole tests in the exploratory shaft facility	2,2D,5,5D	8.3.1.2.2.4.4
Excavation effects in the exploratory shaft facility	2D,5D,10	8.3.1.2.2.4.5
Perched water test in the exploratory shaft facility (contingency test)	2,4,5,6,7,8,9	8.3.1.2.2.4.7

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Table 8.4.2-12. Exploratory shaft facility tests (page 3 of 3)

Test title	ESF Phase[a]	SCP section
Hydrochemistry tests in the exploratory shaft facility	2,5,7	8.3.1.2.2.4.8
Diffusion tests in the exploratory shaft facility	7,9	8.3.1.2.2.5
Chloride and chlorine-36 measurements of percolation at Yucca Mountain	2,5,7,8,9	8.3.1.2.2.2.1
Engineered barrier system field tests	9	8.3.4.2.4.4
Laboratory tests (thermal and mechanical) using samples obtained from the exploratory shaft facility	--[b]	8.3.1.15.1
Hydrologic properties of major faults encountered in the main test level of the exploratory shaft facility	2,4,5,6,7,8	8.3.1.2.2.4.10
Multipurpose borehole testing[d]	2	8.3.1.2.2.4.9

[a]D = deferred test in phase indicated

[b]Samples and information used for laboratory tests will be obtained from other tests conducted throughout the ESF.

[c]This test used to be called the infiltration test.

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

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

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

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

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

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

Table 8.4.2-14 lists the principal factors (mechanism(s) considered in establishing a zone of influence for each test. Only the dominant driving mechanism(s) are given in this table even though some secondary or coupled mechanisms for altering the natural state were also considered in analyzing each test. For example, heating the rock mass also affects the local hydrological and stress conditions. Many of the tests planned for the ESF are designed to address coupled phenomena. For the purposes of establishing zones of influence for each test, however, the mechanism(s) that led to the establishment of the most pervasive zone was considered the principal mechanism, with the influence of secondary mechanisms falling within or coincident

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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with the zones established by the principal mechanism. These principal mechanisms are given in Table 8.4.2-13. In some instances, no physical mechanism was identified that would cause additional perturbation to the natural conditions (stress, temperature, moisture, etc.) from conducting the test. In these cases the principal mechanism in Table 8.4.2-13 is listed as none. The table also lists tests, such as the proposed seal components testing, where the zone of influence is to be determined (TBD). Even though concepts exist for these tests, they are not sufficiently developed at this time to establish a zone of influence. As the designs of these tests progress, interferences related to them will be analyzed and zones of influence established. These will be documented in the semiannual progress reports.

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

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

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

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

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

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

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

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

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Activity: Geologic mapping of the exploratory shaft facility (Section 8.3.1.4.2.2.4)

Purpose and operations

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

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

Constraints and zones of influence

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

Activity: Fracture mineralogy studies (Section 8.3.1.3.2.1.3)

Purpose and operations

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

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

Constraints and zones of influence

Stratigraphy and variability of the rock matrix. This activity involves sample collection and subsequent laboratory examination of rock from the

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underground excavations where a variety of geologic conditions are expected to be encountered. Because only sample collection is involved, no special constraints are required to conduct this activity in the ESF, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity. No significant zone of influence results from this activity.

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

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

Purpose and operations

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

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

Constraints and zones of influence

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

Activity: Shaft convergence (Section 8.3.1.15.1.5.1)

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

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Purpose and operations

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

Using standard overcore techniques (Section 8.3.1.15.2.1.2), horizontal stress measurements will be made at each of three test locations as the shaft is being sunk.

Rock-mass deformation around the shaft will be monitored at three measurement stations consisting of two levels separated by several meters, using multiple-point borehole extensometers (MPBXs) placed at 120° intervals around the shaft circumference (Figure 8.4.2-4). The MPBXs will be installed as soon as practicable after excavation of the relevant level in the shaft. Deformations will be measured across the shaft diameter and as a function of distance from the shaft at multiple locations in the walls. The MPBX heads will not be covered by the shaft liner, so that the deformations can be monitored as a function of time. In addition to MPBX measurements, deformations will be measured with rod extensometers at each of the three measurement stations. Extensometer measurements will be made along diameters in the same plane as the MPBXs at 60° from the MPBX heads.

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

Constraints and zones of influence

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

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

Activity: Demonstration breakout rooms (Section 8.3.1.15.1.5.2)

Purpose and operations

These tests will be used to demonstrate constructability and stability of drift openings in the upper lithophysal zone of the Topopah Spring member (PTn) in the upper demonstration breakout room (UDBR) and in welded fractured tuff on the main test level.

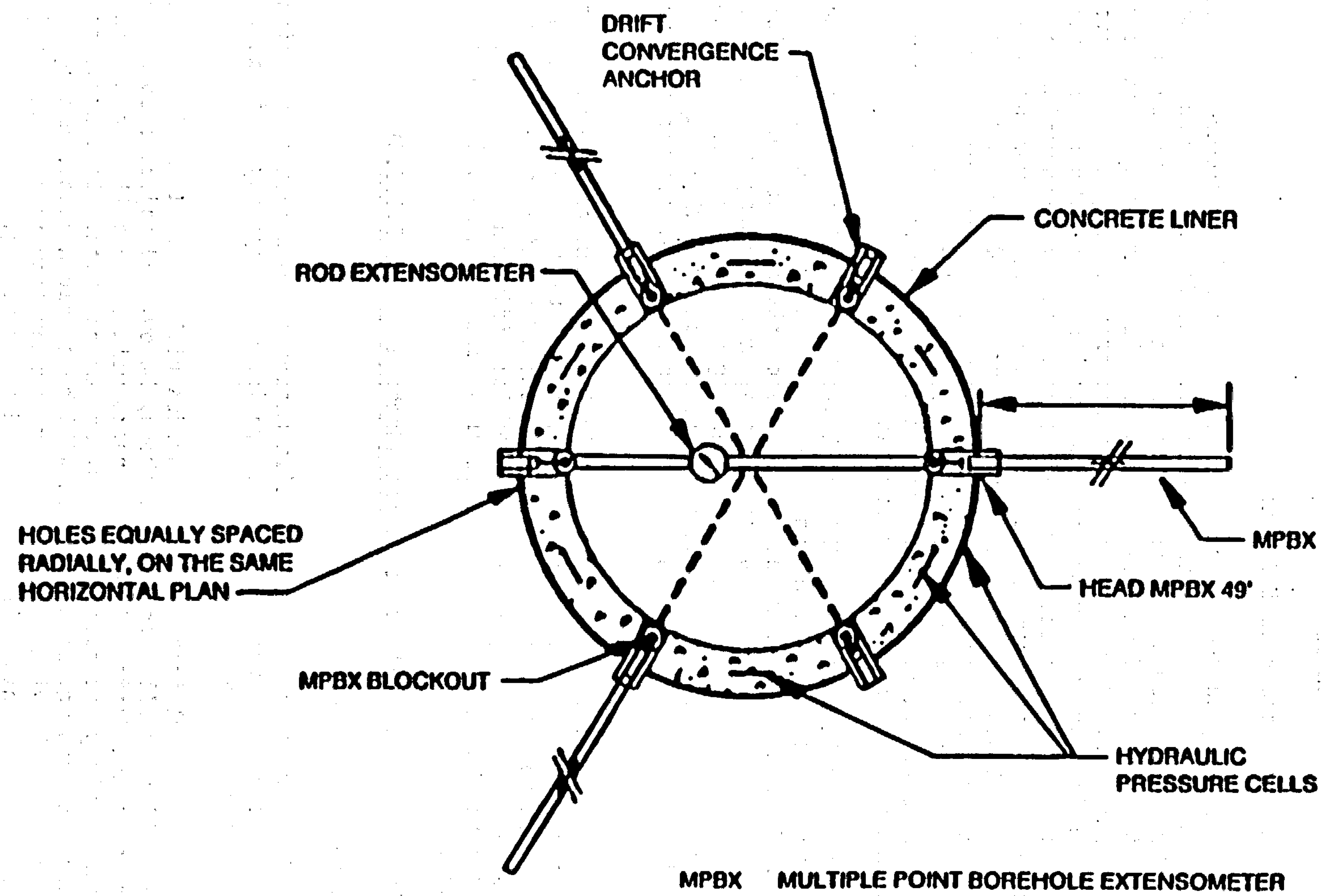

Figure 8.4.2-4. Measurement details of the sh[illegible] [illegible]rgence te[illegible]

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

Constraints and zones of influence

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

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

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

Activity: Sequential drift mining (Section 8.3.1.15.1.5.3)

Purpose and operations

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

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

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Constraints and zones of influence

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

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

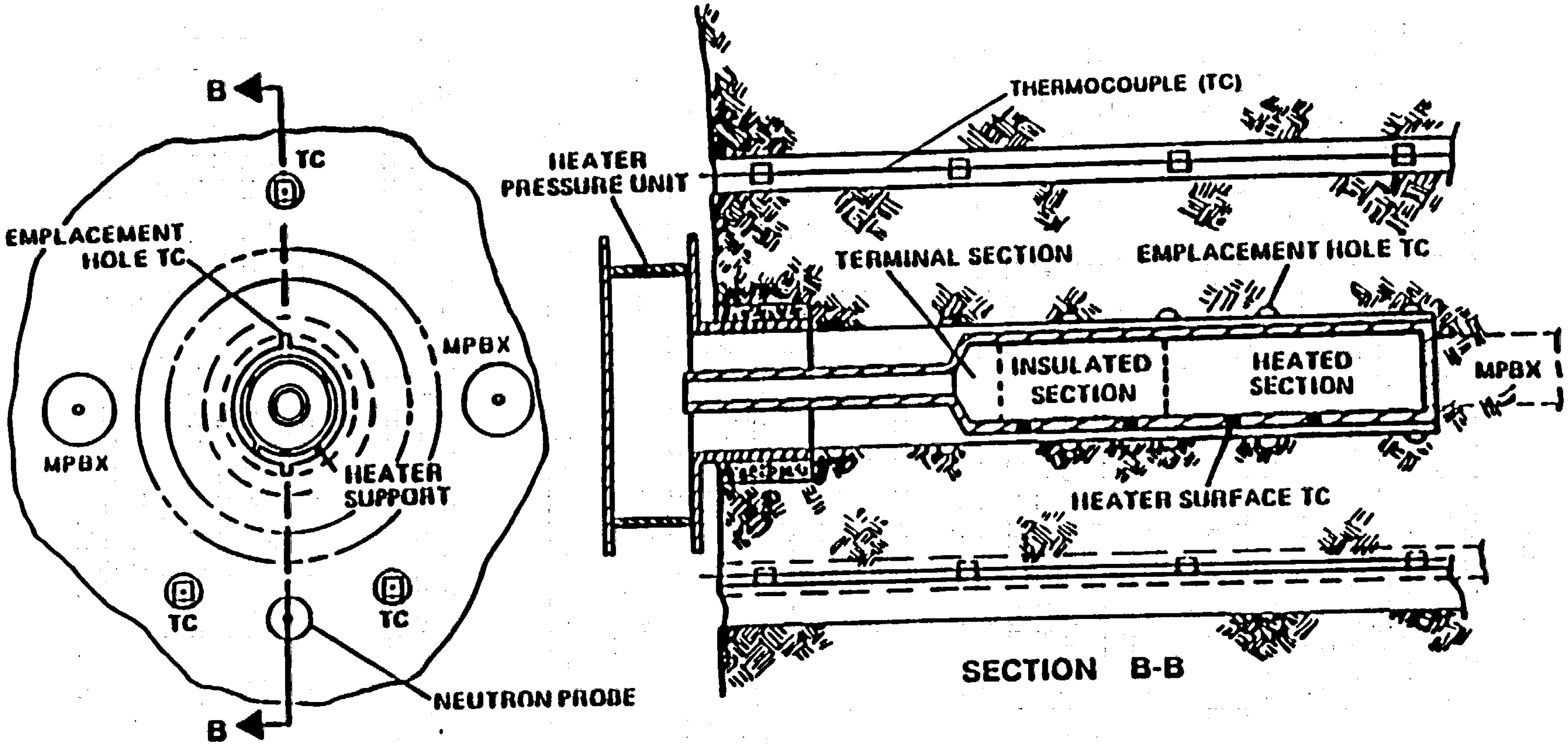
Within the area between adjacent drifts, a zone of flexibility is defined such that the stress altered zone due to mining will not affect other drifts that may be mined later. Drifts may be oriented within a 60 degree shaped fan (±30 degrees from the proposed centerline orientation) or the entire configuration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

<u>Activity: Heater experiment in unit TSw1 (Section 8.3.1.15.1.6.1)</u>

Purpose and operations

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

In the upper demonstration breakout room (UDBR), a heater-emplacement hole will be drilled approximately 8 ft (2.4 m) into the drift wall as shown conceptually in Figure 8.4.2-5. Several instrumentation holes parallel to the heater hole will be drilled and then heater and instruments (multiple point borehole extensometers (MPBX) and thermocouples) will be installed. In a borehole near the heater, neutron logs will be run before, during, and after the heating cycle to monitor moisture content changes. After the heater is started, the rock response to thermal loading, heat flow, and moisture changes will be monitored.



MPBX - MULTIPOINT BOREHOLE EXTENSOMETER
TC - THERMOCOUPLE

NOT TO SCALE

Figure 8.4.2-5. Conceptualized elevation view of heater experiment in TSw1 (lithophysal Topopah Spring unit) Modified from Title I design package (DOE, 1988)

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Constraints and zones of influence

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

Activity: Canister-scale heater experiment (Section 8.3.1.15.1.6.2)

Purpose and operations

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

At a location within the dedicated area, a 13 in. (0.37 m) diameter hole will be drilled 20 ft (6.1 m) into a drift wall. Parallel small-diameter instrumentation holes (Figure 8.4.2-6) will be drilled. Baseline moisture data in neutron probe holes will be recorded. A heater and instrumentation (thermocouples, MPBXs, borehole deformation gages, and radon monitors) will be installed. Finally, heating steps will be initiated, and thermal, thermomechanical, and hydrothermal phenomena, and radon release rates, will be monitored at increasing heat loads.

Constraints and zones of influence

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

At 30 months, the 100°C isotherm will be approximately 5 m radially from the center of the canister (Bauer et al., 1988). Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending to a maximum of 10 m beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region extending up to 14 m radially from the heater may be created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 14 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). The 35°C isotherm (4°C above expected ambient temperature) will attain a maximum distance of 15 m radially from the heater and 20 m from the emplacement drift wall along the axis of

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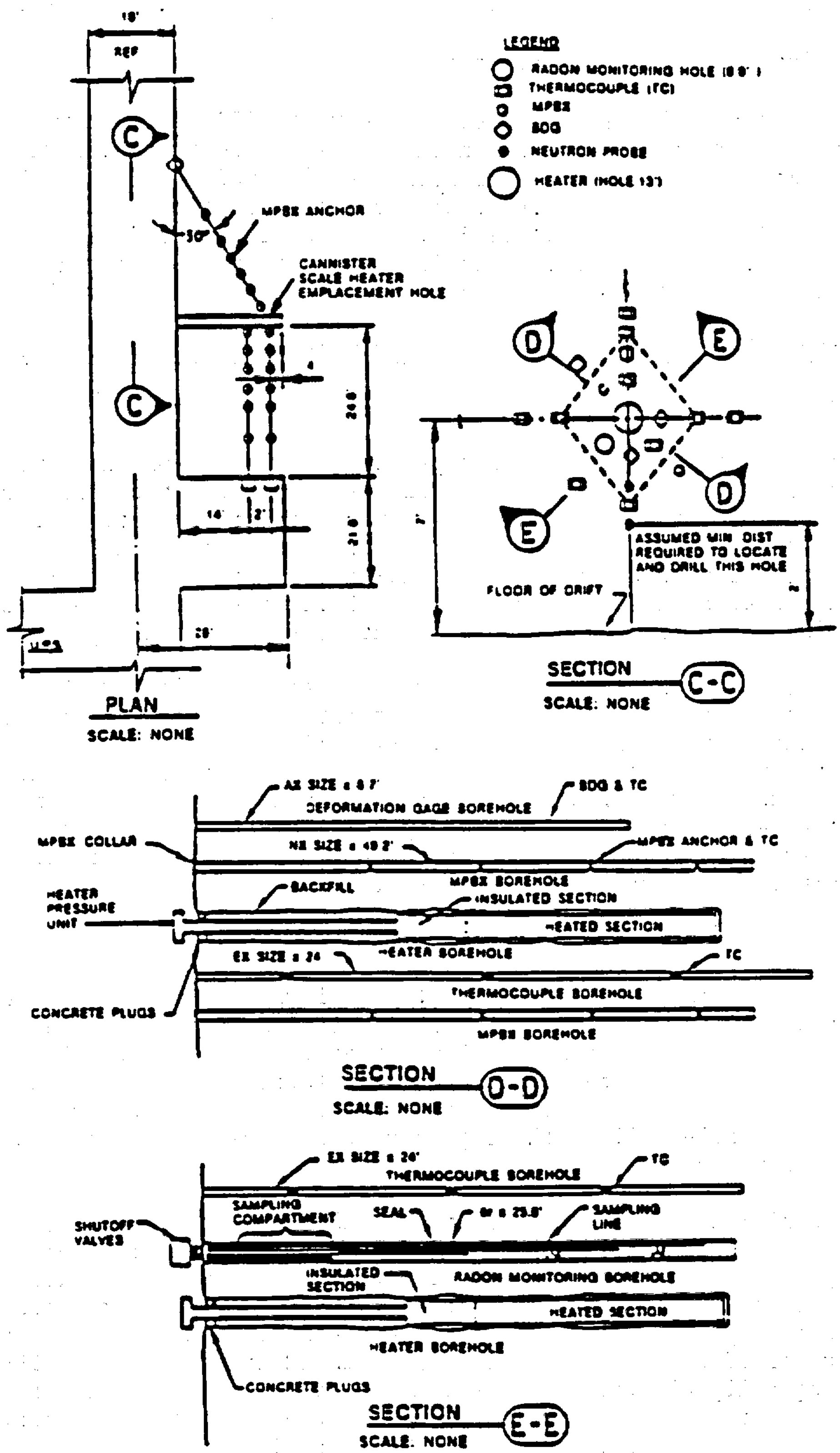

Figure 8.4.2-6. Canister scale heater test. Modified from Title I design package (DOE, 1988).

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the heater (Bauer et al., 1988), resulting in a thermal zone of influence of approximately 30 m by 20 m. Therefore, both the zones of potential chemical and hydrological alteration are expected to be contained within the zone of thermal alteration. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stress should not be more than 10 percent above the initial in situ stress (Bauer et al., 1988).

Activity: Yucca Mountain heated block (Section 8.3.1.15.1.6.3)

Purpose and operations

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

At a selected location in the dedicated test area, an alcove will be mined and a 6 ft by 6 ft (2 m by 2 m) area of rock will be defined within the alcove. Baseline fracture permeabilities will be measured, reference survey pins will be established, and crosshole ultrasonic measurements will be made. Next, slots will be cut on each side of the block approximately 6 ft (2 m) deep and flatjacks will be inserted. An array of heaters will be installed in holes on opposite sides of the block as shown in Figure 8.4.2-7. Other instrumentation holes will be drilled and instrumented with thermocouples, MPBXs, and deformation gages. Finally, cyclic tests will be conducted at various mechanical loads (imposed using flatjacks) and thermal loads (imposed using heaters). The rock responses and permeability changes under induced conditions will be monitored.

Constraints and zones of influence

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

The thermal zone (within 5°C isotherm above ambient temperature) resulting from two thermal cycles lasting a total of 100 days is calculated to extend to approximately 32.5 ft (10 m) from the center of the block (Costin and Chen, 1988). Thus, the thermal zone will extend approximately 20 ft (6 m) beyond the test alcove in a direction normal to the lines of heaters. Within the thermal zone, the 100°C isotherm will attain a maximum distance of approximately 3 ft (1 m) radially from the centerline of the heaters. Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending up to a maximum of approximately 33 ft (10 m) beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region that may extend to a maximum of approximately 36 ft (11 m)

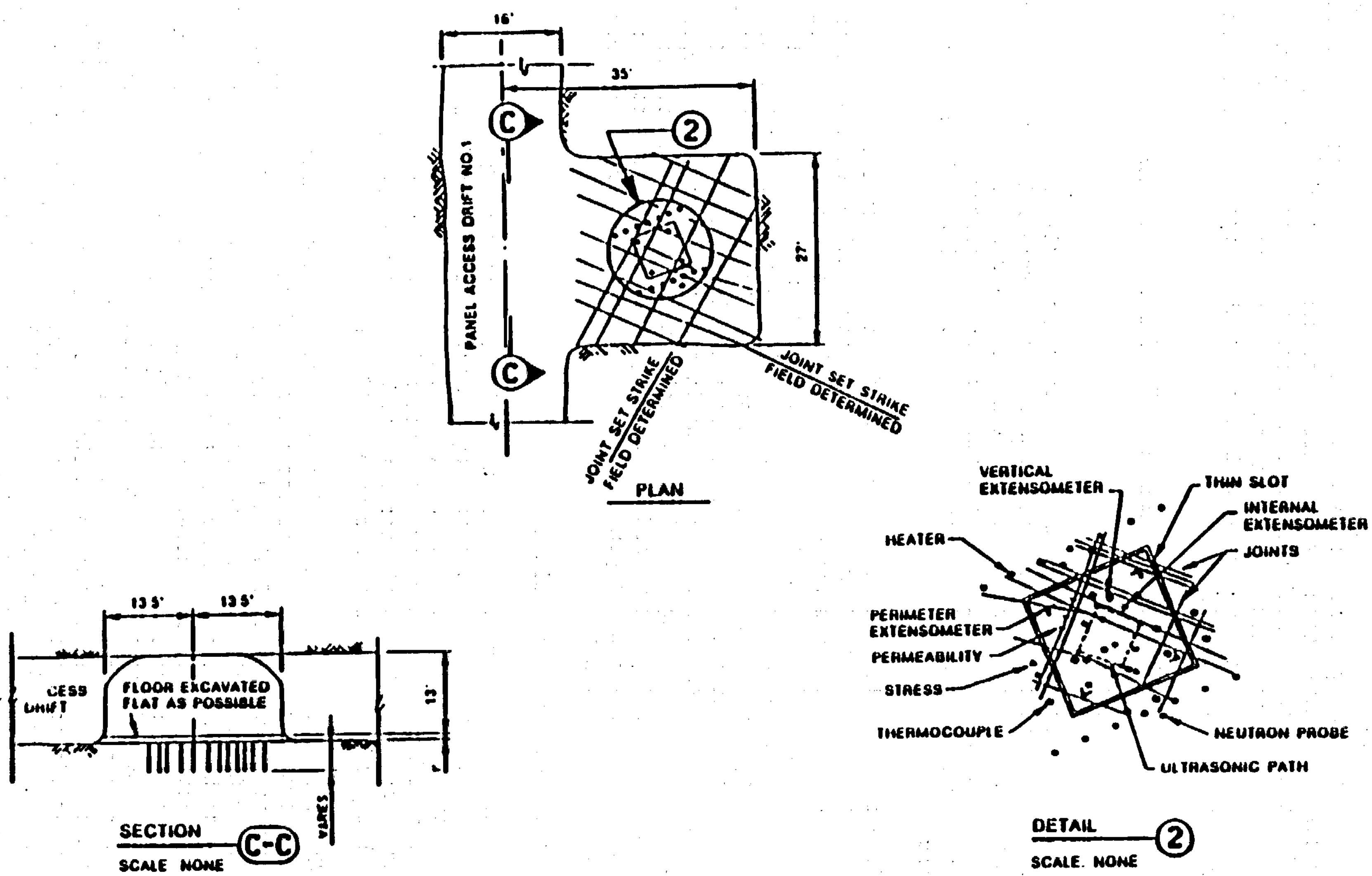

Figure 8.4.2-7. Design of the Yucca Mountain heated block experiment. Modified from Tit design package (DOE, 1988).

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from the lines of the heaters is created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 11 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, the zones of potential chemical and hydrological alteration are approximately coincident to the zone of thermal alteration. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress. Construction of the small alcove will produce a stress-altered zone of approximately one alcove diameter, 27 ft (8.2 m) around the experiment.

Activity: Thermal stress measurements (Section 8.3.1.15.1.6.4)

Purpose and operations

These tests will measure thermal stresses in a relatively large volume of jointed rock and relate the stress changes to thermomechanical displacement for numerical modeling. The specific number and location of these experiments has not yet been defined. At each experiment location, single slots will be cut in both the back (roof) and rib (wall) 6 ft (2 m) long and 6 ft (2 m) deep after reference pins are established on either side. Flatjacks will be installed in the slots, and heaters will be installed in the holes drilled on either side of the slots (Figure 8.4.2-8). An insulating blanket will be installed over the test area of the drift to reduce heat loss. Heaters will be started and stress changes in the near-field volume will be monitored as thermal loading increases.

Constraints and zones of influence

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

At 90 days, for the test being conducted in the roof, the +5°C isotherm (above the expected ambient temperature) will be approximately 5 m horizontally from the drift wall and approximately 7 m vertically from the roof. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress (Bauer et al., 1988). Within the 5°C isotherm, it is predicted that the 100°C isotherm will be approximately 1 m radially from the centerline of the heaters (approximately 3 m horizontally from the drift centerline). Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence a zone of saturation is likely to occur in this region. The water contained in this region is anticipated to be imbibed into the matrix in a zone that may extend to approximately 10 m beyond the 100°C isotherm (Martinez, 1988).

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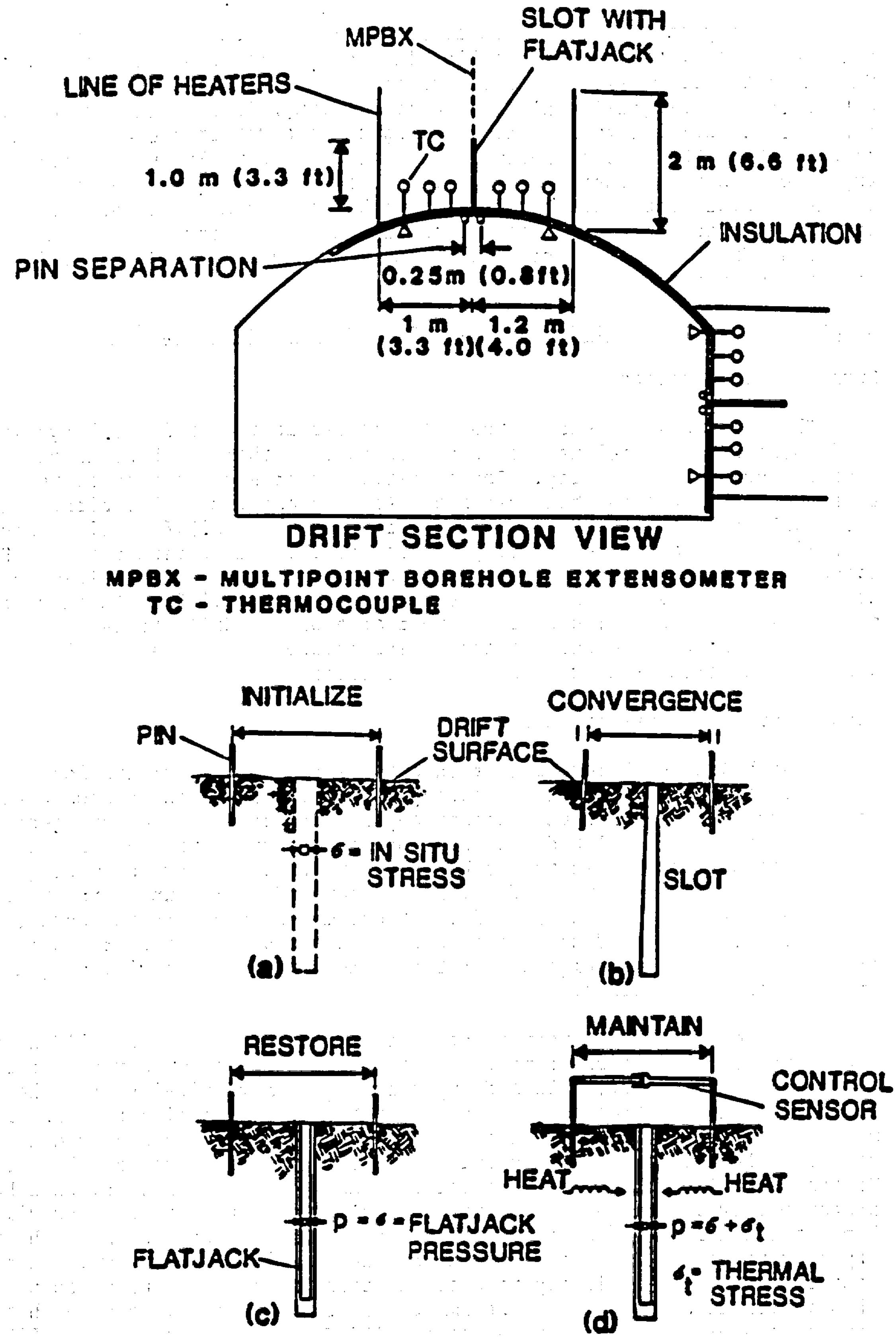

Figure 8.4.2-8. Conceptual design for thermal stress measurements.

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Because of the small volume of rock dehydrated, the hydrologically altered region is likely to be less than the 10 m estimated maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Stress alteration due to mining extends two drift diameters (50 ft) laterally, which is greater than any alteration expected due to the local heat load (Bauer et al., 1988).

<u>Activity: Heated room experiment (Section 8.3.1.15.1.6.5)</u>

Purpose and operations

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

In the dedicated test area at a location to be determined, a drift representative of repository-size drifts is planned to be excavated and the rock around it heated. Either a preexisting drift will be used, or more likely, a new drift, as shown conceptually in Figure 8.4.2-9, may be constructed in the performance confirmation area specifically for this experiment. The drift will be instrumented to provide data on rock mass deformation, rib stress change, thermal conductivity, heat capacity and thermal expansion coefficient, and ground-support loading and deformation, as well as to estimate the region in which the stress state is changed by heating. The experiment may involve more than one drift opening so that temperatures around and between drifts more nearly represent those expected in the repository.

Constraints and zones of influence

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

Estimates of the potential zone of influence of the experiment were taken from preliminary design calculations (Bauer et al., 1988) that assumed the drifts were separated by 65 ft (20 m) center to center with the test drift being 20 ft (6.1 m) wide and the access drifts being 13 ft (4 m) wide. For a 50 kW heat load and a 3-yr test duration, the thermal zone resulting from this experiment will extend approximately 90 ft (28 m) laterally from the central drift. Although the thermal zone extends slightly above and over the access drifts, the extent of the thermal zone is effectively limited by the presence of the two access drifts. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses are predicted to be less than 10 percent above the initial in situ stress (Bauer et al., 1988). The 100°C isotherm will attain a maximum distance of approximately 7 m horizontally and 10 m vertically from the center of the line of heaters on each side of the central drift (Bauer et al., 1988). Water within this isotherm is expected to be

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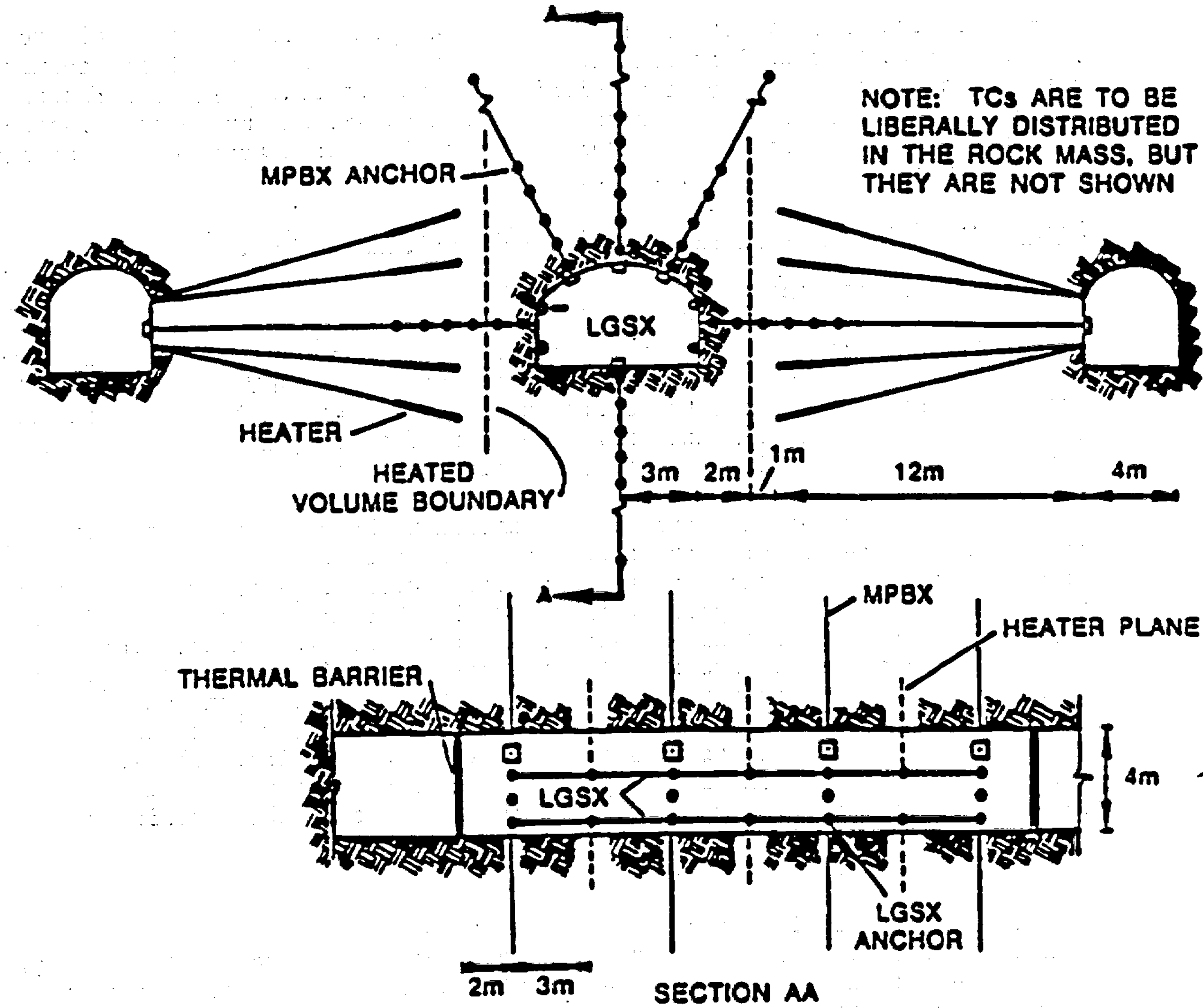

LGSX	LONG GAGE SURFACE EXTENSOMETER
MPBX	MULTIPLE-POINT BOREHOLE EXTENSOMETER
TC	THERMOCOUPLE

Figure 8.4.2-9. Conceptual layout for heated room experiment.

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vaporized and to condense near the 100°C isotherm boundary. Hence, a zone of saturation is likely to occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending a maximum of approximately 33 ft (10 m) beyond the 100° C isotherm (Martinez, 1988). The heated region, however, is bounded by the two access drifts, which are ventilated. Thus, the region of potential hydrologic alteration will likely not extend beyond the access drifts. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, both the zones of potential chemical and hydrological alteration are expected to be contained within the zone of thermal alteration. The stress-altered region resulting from the mining of the drifts will extend laterally approximately 100 ft (31 m) from the centerline of the central experiment drift (i.e., out to two drift diameters from the outside access drifts) and 20 ft (6.1 m) (one drift diameter) from the end of the central drift. Possible changes in orientation were not considered. If the experiment continues longer than 40 months, additional standoff distance may be required. The layout should provide standoff distances of 150 ft (45 m) laterally from the centerline of the central drift and 50 ft (15 m) longitudinally from the end of the central drift.

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

Purpose and operations

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

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

Constraints and zones of influence

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

Activity: Plate loading tests (Section 8.3.1.15.1.7.1)

Purpose and operations

Plate-loading experiments, as illustrated in Figure 8.4.2-10, will be performed at selected locations in the upper DBR, MTL DBR, and in other locations on the main test level to measure the rock-mass deformation modulus and evaluate the fracture zone adjacent to the mined openings. Rock deformations will be measured with a multipoint borehole extensometer oriented parallel to the load axis in the center of the plate area. Deformation of the loading column will be monitored with rod extensometers. Values of the rock deformation moduli will be calculated by using the rock-deformation and the applied stresses. Moduli from different stations will be compared to evaluate spatial variability within unit TSw2 (low lithophysal Topopah Spring). These data primarily will be applicable to the material around an opening that has been affected by the presence of the opening and by the excavation process. As such, the moduli will represent lower bounds on the modulus of the undistributed rock mass.

Constraints and zones of influence

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

Activity: Rock-mass strength experiment (Section 8.3.1.15.1.7.2)

Purpose and operations

The objective of this activity is to evaluate the mechanical behavior of the rock mass or its components. Experiments will be performed to obtain information with regards to the mechanical response of single joints and multiply jointed volumes of rock. It is envisaged that this experiment will be conducted in several areas that are representative of the range of conditions encountered in the 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.

Experiments will be conducted in several areas on the main test level chosen to be representative of the geologic conditions expected in most of the repository. The experiments will be conducted in stages. The joint shear-strength stage will be performed on samples of field-scale size, where field-scale is considered the expected in situ joint length (up to a few meters is possible). If random jointing is encountered, then the compressive

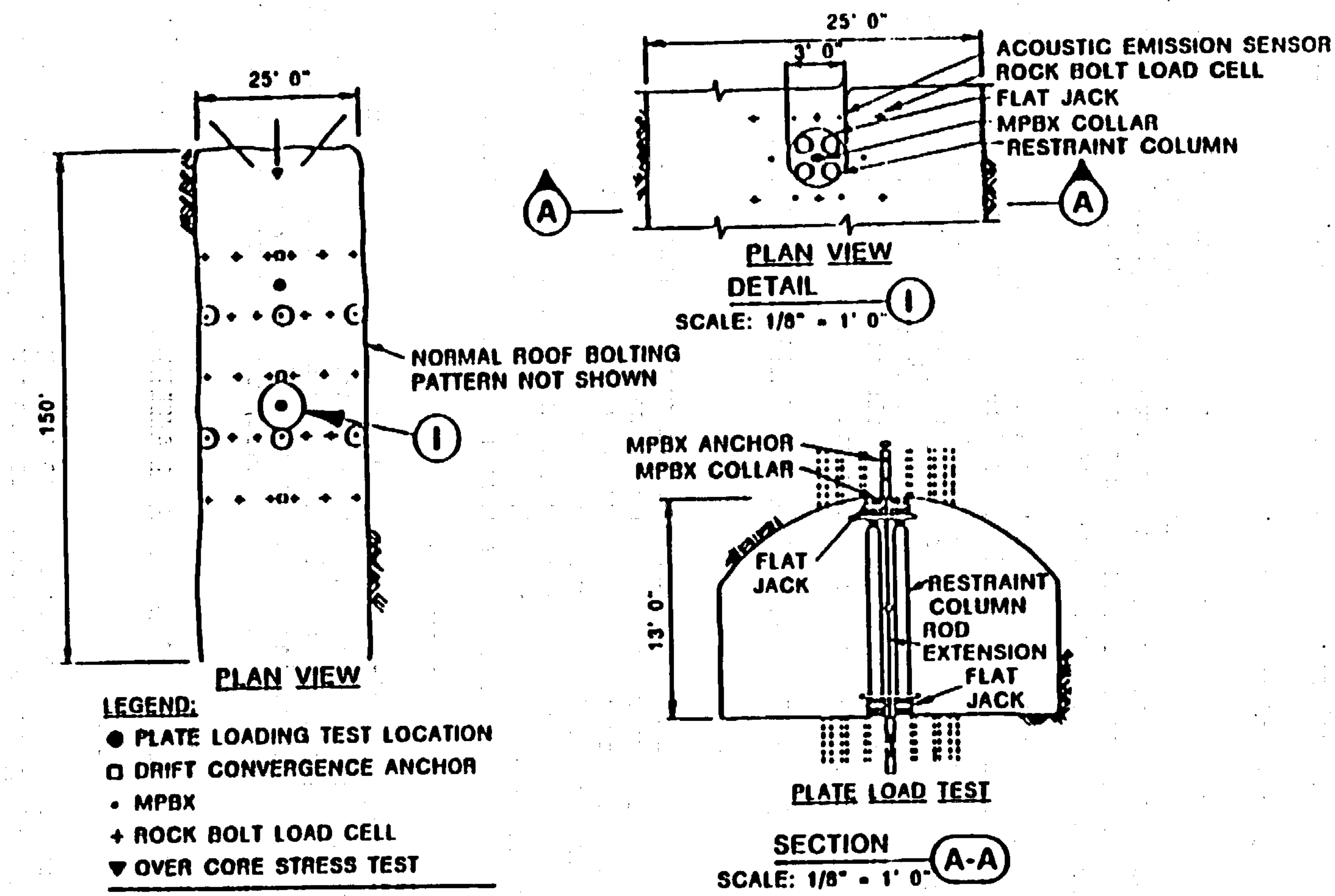

PLATE LOADING TEST LOCATIONS IN DEMONSTRATION BREAKOUT ROOM

SCALE: NONE

Figure 8.4.2-10. Design of the plate loading test.

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strength stage of the experiment will be performed in which a volume of randomly jointed rock will be loaded to a point beyond its maximum support capacity. The final stage of this experiment will require a block of jointed rock (1 to 3 m^3) to be carefully characterized as to joint spacing, aperture, properties, etc., and then loaded to predetermined stress levels. This stage of the experiment will provide information on joint loading and closure characteristics for evaluating and validating a jointed-rock model.

Constraints and zones of influence

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

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

<u>Activity: Evaluation of mining methods (Section 8.3.1.15.1.8.1)</u>

Purpose and operations

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

Constraints and zones of influence

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

<u>Activity: Evaluation of ground-support systems (SCP Section 8.3.1.15.1.8.2)</u>

Purpose and operations

The purpose of this activity is to develop recommendations for a ground-support methodology to be used in drifts in the repository, based on evaluations of the ground-support techniques used in the underground excavations,

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and on experimentation with other ground-support configurations. This activity will be carried out on the main test level. The selection, installation, and performance of the support systems used will be monitored. Experimentation with ground supports will include pull tests on rock bolts, observation of unsupported rock, strength measurements on shotcrete cores, and trials of alternate ground-support configurations from those prescribed for the ESF. The effects of heat on ground support will be considered in the heated room experiment.

Constraints and zones of influence

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

Activity: Monitoring drift stability (Section 8.3.1.15.1.8.3)

Purpose and operations

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

Constraints and zones of influence

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

Activity: Air quality and ventilation experiment (Section 8.3.1.15.1.8.4)

Purpose and operations

The purpose of these tests is to assess the impact of site characteristics on ventilation requirements to ensure a safe working environment. This activity consists of (1) measurements of radon emanation; (2) surveys of airflow and pressure, temperature, and humidity; (3) determinations of air

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resistance factors; and (4) dust characterization. The radon emanation measurements will be made in a dead-end drift that has been sealed with a bulkhead at equilibrium conditions and at various rates of airflow. Radon concentrations might also be measured in a borehole. Activities 8.3.1.15.1.8.1 through 8.3.1.15.1.8.3 (discussed earlier) will be performed with portable instruments over periods of a few days each. They are not expected to interfere significantly with other underground activities.

Constraints and zones of influence

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

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

Purpose and operations

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

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

1. Verification of emplacement techniques.

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

3. Seal behavior under in situ hydrogeological conditions.

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

Constraints and zones of influence

While particular experiments are not defined yet, the three general categories of field-test operations are expected to provide some constraints on the test location. For example, if testing is performed to verify emplacement techniques, this operation may involve a significant amount of

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equipment, as well as construction operations that may require physical separation from other more sensitive tests.

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

Activity: Overcore stress experiments in the exploratory shaft facility (Section 8.3.1.15.2.1.2)

Purpose and operations

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

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

Constraints and zones of influence

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

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Activity: Matrix hydrologic properties testing (Section 8.3.1.2.2.3.1)

Purpose and operations

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

Constraints and zones of influence

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

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

Purpose and operations

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

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

Constraints and zones of influence

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

Activity: Percolation tests in the exploratory shaft facility (Section 8.3.1.2.2.4.2)

Purpose and operations

This test will be used to observe and measure fluid flow through a network of fractures under controlled in situ conditions in order to characterize and quantify important flow processes in fractured welded tuff. The percolation test design is not completely finalized. The test is planned to

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use a large, isolated block of rock 6 ft (2 m) on a side. The block will be instrumented to detect fluid flow under physical conditions that can be mechanically controlled and systematically varied. Tracer-tagged water will be introduced from a trickle system/sand bed on the surface of the block.

Constraints and zones of influence

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

<u>Activity: Bulk-permeability test in the exploratory shaft facility (Section 8.3.1.2.2.4.3)</u>

Purpose and operations

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

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

Constraints and zones of influence

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

Test holes for each test will be dry-drilled deep enough (approximately 150 ft (46 m)) into the rock mass so that the cross-hole permeabilities will be measured in undisturbed rock (outside the stress-altered zone of the excavations). Gas-phase pressure pulses may occur as much as 100 ft (30 m) away from centerline of the cross-hole frustum configuration. Test holes may penetrate the rock mass to 150 ft (46 m). Thus, a zone of influence extends along the frustum out to 150 ft (46 m) longitudinally and radially to approximately 100 ft. The air injected for this test will contain a

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tracer to allow discrimination between the natural gas in pore spaces and the injected air. Hence, no interference caused by air injection between this test and any other test is expected. No significant mechanical, hydrological, thermal, or chemical alteration to the rock mass is expected to result from this activity, that is, there is no zone of influence.

Activity: Radial borehole tests in the exploratory shaft facility (Section 8.3.1.2.2.4.4)

Purpose and operations

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

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

Constraints and zones of influence

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

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the radial borehole test, the use of an air tracer will control the potential interference between these tests. No thermal or mechanical alterations to the rock mass will result from this test.

Activity: Excavation effects test in the exploratory shaft facility (Section 8.3.1.2.2.4.5)

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

Purpose and operations

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

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

Constraints and zones of influence

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

Activity: Perched-water test in the exploratory shaft facility (Section 8.3.1.2.2.4.7) (Contingency test)

Purpose and operations

The purpose of the perched-water test is to detect the occurrence, and delineate the lateral and vertical extent, of perched-water zones (if encountered) during ramp construction, drifting, and testing to identify perching mechanism(s), and to sample the water for chemical analyses.

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Because there is significant uncertainty regarding the likelihood of encountering perched water, the perched-water test is categorized as a "contingency test."

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

Constraints and zones of influence

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

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

<u>Activity: Hydrochemistry tests in the exploratory shaft facility (Section 8.3.1.3.3.4.8)</u>

Purpose and operations

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

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

Constraints and zones of influence

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

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analysis proposed for this test. One of the results of this effort will be to define the construction controls to be used in the ESF needed to successfully complete this test.

Study: Diffusion tests in the exploratory shaft facility (Section 8.3.1.2.2.5)

Purpose and operations

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

Constraints and zones of influence

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

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

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

Purpose and operations

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

Constraints and zones of influence

Because rock samples will be collected from rubble at several depths for laboratory analysis under this activity, no special constraints on the layout

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or operation of the ESF are imposed by this experiment. The methods developed to control both the influences of construction and use of water (including tracer tagging) are expected to be sufficient to ensure that the geochemical analysis conducted under this activity will not be adversely affected by construction operations. Studies are in progress to assess the effect of explosion by-products and the tracer-tagged water on the type of geochemical analysis proposed for this test. One of the results of this effort will be to define the construction controls to be used in the ESF that will allow these tests to be successfully completed.

Study: Engineered barrier system field tests (Section 8.3.4.2.4.4)

Purpose and operations

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

Constraints and zones of influence

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

At 24 months, the zone of thermally disturbed rock around either vertical or horizontal heater holes is calculated to extend approximately 10 m (33 ft) radially from the heater centerline (based on the expectation of 6 months of heating at maximum power, 6 months of rampdown from the maximum power level to zero, and 12 months with no heat (Buscheck and Nitao, 1988)). Within the thermally altered zone, the 100°C isotherm will be a maximum of approximately 2 m radially from the centerline of the heater. Water within this isotherm is expected to be vaporized and to condense near the 100°C iso-

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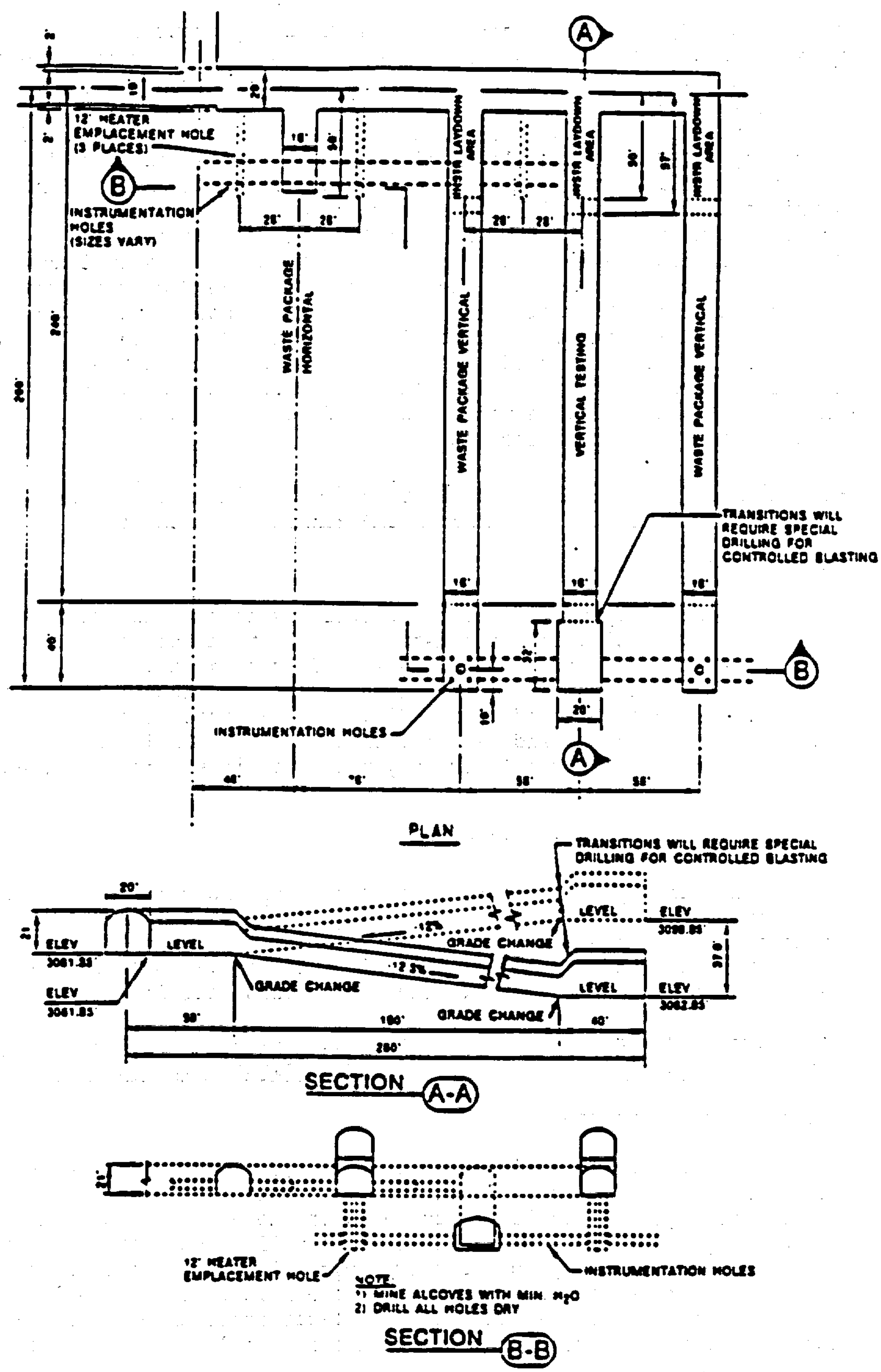

Figure 8.4.2-11. Repository horizon near-field hydrologic properties (waste package environment) typical test arrangement. Modified from Title I design package (DOE, 1988).

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therm boundary. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone that may extend to a maximum of about 10 m beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region that may extend to a maximum of 12 m from the heater is created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 12 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, the zones of potential chemical and hydrological alteration are approximately coincident with the zone of thermal alteration. Thermally induced stresses are also expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress (Butkovich and Yow, 1986). The stressaltered region, due to mining of the test rooms, will extend two drift diameters from the outer drifts. The thermal, chemical, and hydrologic zones of influence are anticipated to be contained well within the mechanical zone resulting from drift construction.

Activity: Laboratory tests (thermal and mechanical) using samples obtained from the exploratory shaft facility (Activity 8.3.1.15.1)

Purpose and operations

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

Constraints and zones of influence

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

Activity: Hydrologic properties of major faults encountered in the main test level of the exploratory shaft facility (Activity 8.3.1.2.2.4.10)

Purpose and operations

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

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

Constraints and zones of influence

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

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

<u>Activity: Multipurpose borehole testing (Activity 8.3.1.2.2.4.9)</u>

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

The MPBH test plans are being evaluated to determine if it is feasible to conduct such tests within the reference ESF design configuration. The current plans for the MPBH test are tied to the original ESF design configuration with two shafts in close proximity. The test would include two

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

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

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

Constraints and zones of influence

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

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

Summary

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

It is recognized that 10 CFR 60.140(b) requires that a performance confirmation program shall have been started during site characterization. However, Section .3.5.16 (performance confirmation) describes the DOE's current approach to performance confirmation and explains that certain tests will likely continue after the submittal of the license application. Therefore, performance confirmation must be considered now in ESF design, test planning, and repository design. Specifically, allowance for continued access to the dedicated test area during repository operations and operational flexibility necessary to support follow-on performance-confirmation testing have been considered. These aspects are discussed in Section 8.4.2.3.6.

8.4.2.3.2 Exploratory shaft facility integrated data system

The following section briefly describes the ESF integrated data system (IDS). Approximately 20 experiments in the ESF testing program will generate electronic data that must be collected, stored, and distributed. A computer-based central data-collection utility, the IDS, will support the data acquisition and recording needs of these tests. The system will automatically acquire, record, and provide copies of certified site characterization data to each participating organization for data management and analysis. At the ESF, the IDS will allow the principal investigators to control and monitor their tests. The primary purpose of the IDS is to provide the principal investigators with a uniform, controlled, and verifiable data acquisition and recording system that will function reliably and efficiently.

8.4.2.3.2.1 Purpose and Scope of the integrated data system

The data acquisition system will collect measurements from tests distributed throughout the ESF. IDS facilities will be located underground, at the surface, and remotely in the administration and engineering (A&E) building at Area 25 on the Nevada Test Site. Measurement and control capabilities will be provided at the surface, in the declines, along the exploratory drifts, and in the experiment drifts of the main test level (MTL) as required for testing. Primary data recording and system control and monitoring will be performed in a dedicated IDS surface facility near the north surface entrance to the ESF. User workstations, off-site communications equipment, system repair and calibration facilities, and data-record duplicating equipment will be located in the IDS surface facility and other buildings located at the north portal.

The IDS provides all experiment and common data with accurate time references, protects records for long-term storage, and distributes experiment and common data to the organizations of the principal investigators in a uniform format at required intervals. The IDS will also provide workstations and portable terminals to users for data quick-look and calibration purposes. Any classical data management and analyses performed by principal investigators on their own computers are not within the scope of the IDS.

8.4.2.3.2.2 Integrated Data System Description

The IDS will be a distributed data acquisition system with nodes as required at each experiment site within the ESF. These nodes or Data Acquisition Stations (DAS) will be connected via a data network to a surface computer system. The surface computer system will receive regular data transfers from the DAS units. This data will include DAS unit status, instrument status, and raw site characterization data. The DAS units and the surface computer system will be acquired in a phased manner to meet the varying testing needs during the construction and operation of the ESF.

Data accuracy, integrity, and reliability will be primary concerns in the design of the IDS. The distributed nature of the system allows increased reliability by providing layers of redundancy. The DAS units will be capable of a minimum of 24 hours of data storage thereby allowing manual retrieval of the acquired data during data network or surface computer failure. Frequent regular transfer of data from the DAS units to the surface computer system via the network helps to minimize data loss due to a failure of a DAS unit. Fault tolerant or redundant techniques will be implemented for the surface computer system to further ensure data integrity and reliability. Additionally, modular construction, common design, and adequate spares in conjunction with on site technicians, will facilitate a rapid repair of any failed IDS component.

The data network that interconnects the DAS units and the surface computers will facilitate connection of additional DAS units at new areas for testing without significant extra wiring. Data terminals can also be connected to the IDS in any location that the network reaches. The network also allows a surfaced based operator to be informed immediately of any IDS alarm condition from anywhere in the ESF. Technicians can then be dispatched to the alarming component for further diagnosis and repair.

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In summary, the IDS will provide the users with reliable, accurate, and permanent records of their test data that may be used for site characterization of Yucca Mountain in the license application process to obtain NRC licensing for the high-level waste repository. The system is designed to be flexible and expandable to meet the changing requirements of the users. Accuracy and traceability of the data is the primary objective of the system.

8.4.2.3.3 Description of exploratory shaft facility

8.4.2.3.3.1 Introduction

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

Control of the design for the exploratory shaft facility

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

The requirements that pertain to the design of the ESF are contained in a set of requirements documents. That portion of the Yucca Mountain Project document hierarchy that relates to the design of the ESF is depicted in Figure 8.4.2-12. The requirements flow down in a systematic manner from the OCRWM Waste Management System Requirements through a series of intermediate, more detailed documents, down to the ESF Design Requirements (ESFDR). While 10 CFR 60 provides the primary requirements for the design, DOE orders, policies, other applicable federal regulations and mining laws, codes, and safety regulations from the States of Nevada and California are also considered.

The ESFDR guides the design activities as they proceed. Typically, the design consists of two major elements: (1) the development of the facility configuration and associated studies to define that configuration and (2) supporting analyses to evaluate the design with respect to the requirements. Specific examples of these analyses are presented in Sections 8.4.2.3.6 and 8.4.3 to evaluate test interferences and impact on the 10 CFR Part 60

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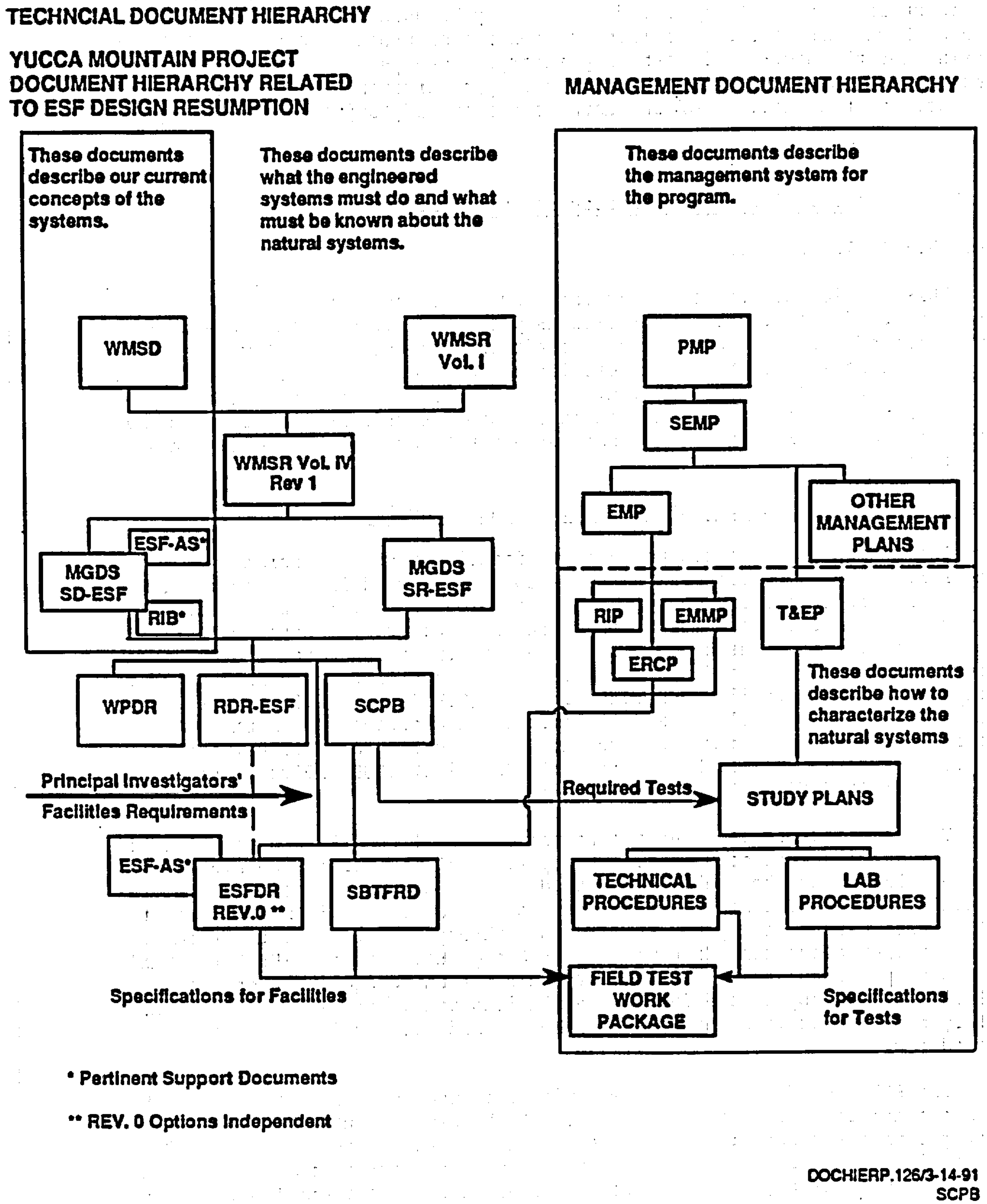

Figure 8.4.2-12. [illegible] of the Yucca Mountain Project Hierarchy.

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requirements to meet the postclosure performance objectives. The design is developed using data, principally parameters defining rock characteristics, design conditions, and other site-related information. These data are contained in a controlled data base designated the reference information base (RIB). The contents are maintained by a change control process to reflect the current status of knowledge from site characterization activities.

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

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

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

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

<u>Activities leading to the selection of the location and configuration of the exploratory shaft facility</u>

The location of the exploratory shafts described in the SCP and the method used to construct them were selected on the basis of formal screening evaluations conducted in 1982 and 1983 (Bertram, 1984). During that same time, two other screening evaluations were underway or completed that are relevant to the exploratory shaft location and construction method selection: the selection of the Yucca Mountain site and the selection of the Candidate Repository Horizon. In 1982, Northern Yucca Mountain was selected from other locations at the Nevada Test Site as a possible repository location, and the decision subsequently verified on the basis of a site-screening evaluation

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(Sinnock and Fernandez, 1982). These site-screening evaluations considered criteria based upon containment, isolation, construction, and environmental concerns.

The second evaluation examined four distinct formations or stratigraphic horizons of Yucca Mountain that at that time were considered to be potentially acceptable host rocks for a repository. An evaluation was performed to select a single stratigraphic horizon upon which to focus site characterization activities and evaluations of suitability for a repository (Johnstone, et al., 1984). That study ranked each of the four horizons on radionuclide isolation time, allowable gross thermal load, excavation stability, and relative economics. This evaluation was performed simultaneously with the evaluations of the construction method and location of the shaft.

In the formal screening evaluations for the exploratory shaft locations, an Ad Hoc Committee used a Figure of Merit technique to analyze and support two distinct decisions. The first decision was to select a construction method for the shaft from several alternatives available at the Nevada Test Site; the second was to select a location for the exploratory shaft from several candidate sites at Yucca Mountain. The Ad Hoc Committee evaluated the two decisions individually and then combined the results. Screening criteria were developed and their relative importance evaluated. The Figure of Merit technique was then used to evaluate the ability of each alternative to satisfy the criteria. These criteria are tabulated in a summary report (Bertram, 1984).

The objectives of the construction method to be selected were to provide access to the rock unit targeted for repository development so that strata would be characterized in situ and to demonstrate constructability of a large diameter shaft at Yucca Mountain. The selection process considered twelve alternatives (seven of which were unique) developed from combinations of the following: drill the shaft, conventionally mine the shaft, or conventionally mine a decline in the unsaturated or saturated zones. The evaluation criteria for the decision addressed the ability to conduct site characterization, including shaft wall characterization, constructability, cost and schedule, environment and health and safety. In making the decision about the shaft construction method, the Ad Hoc Committee specifically considered the potential for rock damage from blasting but concluded that mining would allow better control of water losses than would drilling. On the basis of the criteria rankings developed by the committee (Bertram, 1984) the DOE concluded that the exploratory shaft should be mined by conventional methods.

The objective of the exploratory shaft location screening evaluation was to select an exploratory shaft site from which to explore target units within the exploration block. The evaluation emphasized the unsaturated zone but retained the capability to access both unsaturated and saturated target units to both confirm expected favorable conditions and to assess potentially adverse conditions. Furthermore, the objectives included the desire to avoid known areas of potentially adverse subsurface conditions for shaft siting, but to retain the capability to access these areas for testing from the shaft. Another objective was to avoid surface areas where constructing the shaft would result in environmental impacts that could not be mitigated. The site screening evaluation criteria addressed scientific, engineering, envi-

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ronmental, and nontechnical concerns. The scientific criteria addressed offset from structural features (so that the exploratory shaft would not be constructed in areas of fractures associated with the structural features), thickness of rock units and homogeneous physical properties, distance to potentially adverse structures (to enable their exploration), and exploration of as large a volume of rock as possible. The engineering criteria addressed constructability, terrain (including flooding), and compatibility with potential future development of a repository. The evaluation also considered repository compatibility concerns using a preliminary repository design configuration.

The actual screening for exploratory shaft location was applied in two steps: first, a subset of the set of screening criteria was applied to determine preferred areas at Yucca Mountain. Four specific criteria were then used to screen preferred areas: offset from structure, distance to potentially adverse structures, constructibility, and adverse topography and slopes. Overlay maps of exclusionary areas based on these criteria were prepared, and five preferred areas were identified for further screening using the remaining criteria. The site with the highest Figure of Merit is located in Coyote Wash and is approximately 600 ft by 800 ft. The DOE accepted the committee's recommendation to locate the exploratory shaft at that site.

Subsequent to the formal selection of Coyote Wash as the location for the exploratory shaft, two events occurred that have a bearing on the discussions in this section. The first was a decision to enhance worker and user safety in the exploratory shaft facility by providing a secondary means of egress. This decision was made at the time that the environmental assessments were in preparation. Thus, the exploratory shaft facility described in the environmental assessment actually contains two shafts. One is the 12 ft diameter conventionally mined shaft originally considered; the second was to be a 6-ft diameter raise-bored shaft for emergency egress.

The second event related to the shaft location decision arose as a result of Project review of characterization activities in the exploratory shaft facility. The 12-ft diameter of ES-1 was initially established in 1983 on the basis of the understanding of scientific measurements to be made in the shaft and at each of the horizons (520, 1,200 and 1,400 ft), size of equipment, material handling, and ventilation requirements. The initial concepts for the facility configuration and testing program were developed between 1980 and 1983 to provide access to geologic formations to characterize the subsurface environment, and to provide services to build and operate a small underground facility. The DOE and its contractors raised questions as the environmental assessment was being finalized and the SCP being prepared of whether adequate characterization or representativeness were likely and whether sufficient expansion capability existed with the facility as designed. Specifically, the DOE was concerned about potential safety problems associated with an expanded mining program, the proposed ventilation system design, larger equipment for mining exploratory drifts requiring larger shafts, hoisting capacity, the compatibility of underground configuration for scientific tests with operational requirements (without interference), size of drifts, and compatibility with the repository conceptual design. On the basis of analyses on these concerns and a meeting with the NRC and State to discuss potential changes, the DOE, in June 1987, adopted five recommended

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changes to the exploratory shaft facility. These were (1) to relocate the shaft collars out of the alluvium and in rock (yet remain within the area in Coyote Wash described in Bertram, (1984)); (2) to relocate the main test level to the 1,055-ft level; (3) to construct approximately 5,600 ft of drifts (rather than drilling) to investigate geologic structures; (4) to expand the main test level complex by approximately 2,500 ft of drifts; and (5) to change ES-2 to a 12 ft-diameter conventionally mined shaft. These changes incorporated concerns raised by the NRC about the location of the exploratory shaft collars with respect to the runoff patterns in Coyote Wash. The location and elevation of the collars were changed to provide further separation from the limits of the probable maximum flood.

This briefly summarizes the activities that led to the ESF configuration contained in the SCP. A more detailed summary of the activities, leading to selection and approval of that ESF location and an integrated discussion of events relevant to evolution of the ESF concepts, designs, and location are provided in Gnirk et al. (1988).

As a result of comments and recommendations on the SCP made by the Nuclear Waste Technical Review Board (NWTRB), the NRC, and the State of Nevada, the DOE undertook a study of alternative ESF/repository configurations. In the initial part of this study, called the ESF Alternatives Study (ESF-AS), all previous ESF and repository conceptual configurations were reviewed and new ESF/repository configurations were generated. New configurations were developed to address regulatory and other requirements, as well as to address the comments and concerns expressed by the NWTRB and NRC. In addition, a number of major design features were addressed in various ways within the new options so that a direct comparative evaluation of features, as they are embedded in a number of different ESF/repository systems, could be made. The screening of these configurations was conducted by a panel of experts using multi-attribute utility analysis as the primary decision-aiding tool.

The analysis resulted in the relative ranking of 34 ESF/repository configurations. Each of these configurations incorporated the recommendation of the Calico Hills Risk/Benefit Analysis group (DOE, 1991d), which resulted in the inclusion of approximately 19,000 ft. of exploratory drifting in the Calico Hills unit. The testing strategy for configurations 1-17 consisted of the systematic progression of construction and site characterization testing from the surface down the accesses to the Topopah Spring and then on down to the Calico Hills. In contrast, the testing strategy for configurations 18-34 was to proceed to the Calico Hills as rapidly as possible to make an early determination of suitability (or unsuitability) of the principal natural barrier, while conducting only those tests in the accesses necessary to acquire site data that would be irrecoverable if not acquired during initial construction.

Figure 8.4.2-3 illustrates the configuration that contains the majority of the favorable features of the highest ranked configurations identified by the ESF-AS. It also incorporates additional modifications recommended by DOE management. This configuration will be used as the reference design concept for the design studies leading to Title II design. It should be noted that the main test level dedicated testing area in this reference concept is approximately in the same location as the ESF configuration included in the

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SCP. Subsequent sections describe the facility. The adequacy of the configuration is presented in Section 8.4.2.3.6, while the potential impact of the construction and operation of the facility is assessed in Section 8.4.3.

8.4.2.3.3.2 General arrangement of surface facilities

At this time, existing surface facilities consist of an access road to the ESF site that is paved on the Nevada Test Site except in washed-out areas and a water line and 69 kV overhead power line extending to the NTS boundary. The water is from well J-13 and the power is from the Canyon Substation; both are located in Area 25. In addition, there is a transformer to change the 69 kV power to 4160 V, which is underbuilt on the same power poles. Figure 8.4.2-13 graphically illustrates the arrangement as it exists today. Surface facilities are intended to provide full and independent service to the underground test work.

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

<u>Pads and roads</u>

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

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

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

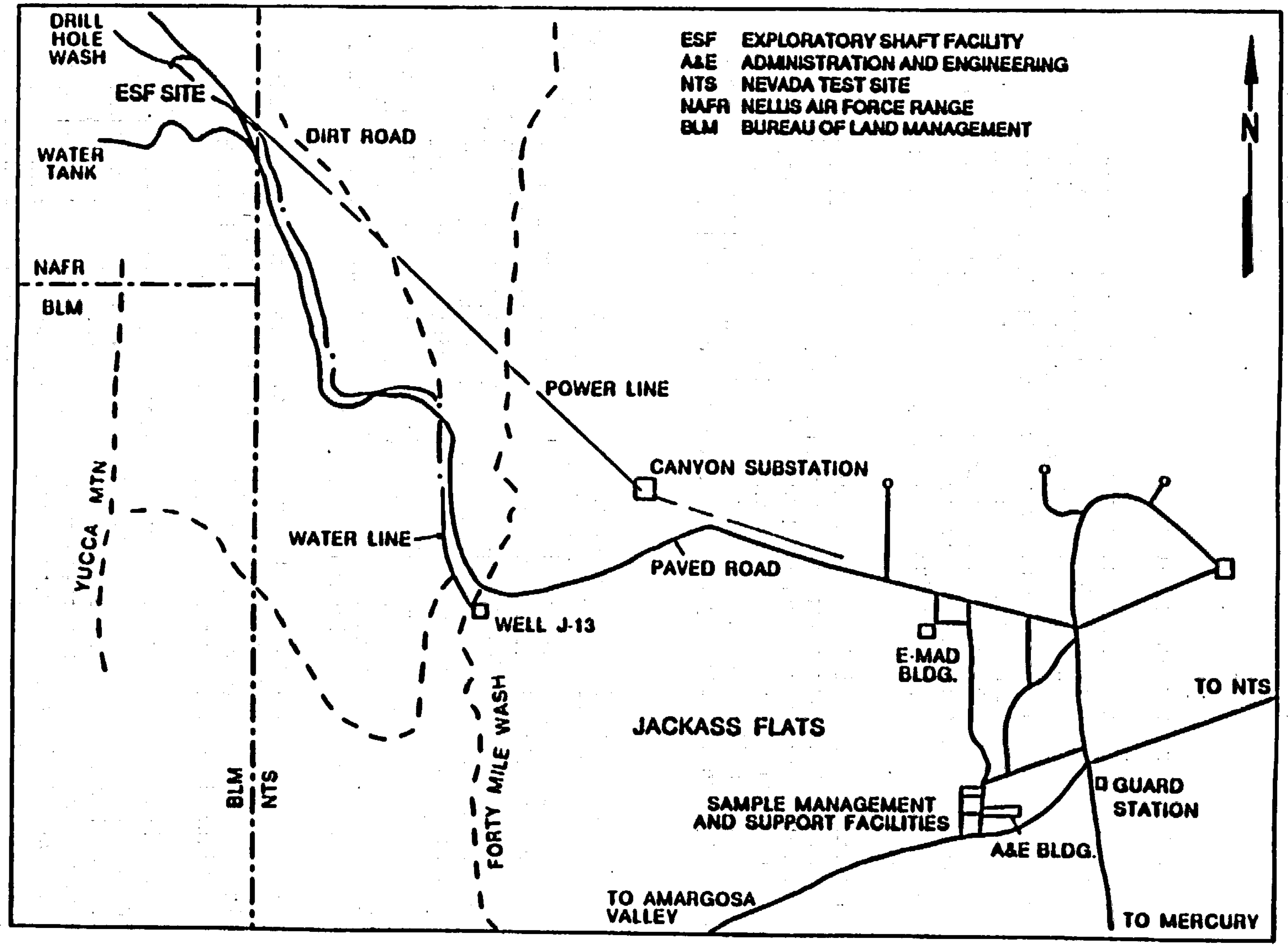

Figure 8.4.2-13. General arrangement of surface facilities.

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Buildings

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

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

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

Temporary buildings will be assembled or moved onto the ESF site as they are needed during the construction and operations phases. The pads will accommodate only a limited number of buildings, and, as one construction phase is complete, buildings may be converted for different use or removed from the site. Trailers will be located on the ESF pads and used for office and sample preparation space, and a first aid station. Most functions not directly supporting construction will be conducted from offices and laboratories in the A&E building, the sample management facility, or laboratories in other existing buildings located in Jackass Flats (Figure 8.4.2-22). The A&E building will also serve as a visitors' center.

Electrical facilities

A surface substation to be constructed at the ESF site will provide the aboveground electrical supply and power for the underground distribution system. The substation will be supplied from an existing 69-kV overhead powerline that extends from the Canyon Substation in Jackass Flats to the Nevada Test Site boundary (Figure 8.4.2-22). The substation will be equipped with transformers to supply power to the tunnel boring machines (TBMs) hoists (optional), air compressors, ventilation fans, surface buildings, and the underground facilities.

A powerline will be added to the existing power poles to provide power to the water supply booster pump station located southeast of the ESF site. Night lighting will be provided by pole-mounted area floodlights. Standby electrical power will be provided by diesel generators.

The diesel generators will cover interruptions to electrical systems critical to life safety and data collections. The generators will be sized to the use and be on a demand start. Further backup to critical systems will be provided with uninterruptable power supplies. These will be put on the

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lines supplying the data collection equipment as determined by the experimenters. New powerlines will be installed to accommodate the facility as required. The 4,160 V feed will be transformed locally to provide power at the levels required at each use point.

Load studies may indicate a need for additional utility powerlines to the site and increased voltage from off-site sources.

Water

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

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

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

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

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

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

Waste water

The disposal of the waste water is divided into two systems. Sanitary waste from about an expected 200 persons will be disposed of in a septic tank leach field system. The disposal point will be offsite and downhill from the ESF, well away from the water supply and all personnel activity. The other system is the mine waste water, which it will be processed through a separator to remove oils and disposed of in a settling pond. This system will

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handle the capacities of both mining water and naturally occurring water expected from the ramp/shaft. Permits will be required for both systems and the disposal systems will be built to code.

The settling and evaporation pond for mine waste water will be used to contain all the waste fluids pumped from the underground facility. The unlined mine waste-water settling pond will be located east of the ESF 2,000 ft beyond the repository block boundary. Drilling fluids that will be used underground, including air-water mist, bentonitic mud with water control agents, and polymer foam, and any other no-sewage water used for construction, will be pumped from the underground facility to this pond. The mine waste water will be tagged with a tracer, and treated before being discharged into the tail end of Coyote Wash. To support this design, an analysis will be performed to ensure all concerned parties that this system will not impact site characterization. The design life for the pond will be a minimum of 25 years, and it will be able to hold approximately 375,000 gal (1.4×10^6 L) of waste water. Top soil removed during construction of the pond will be placed in a topsoil storage area and saved for eventual reclamation of the area once the pond is no longer used.

Communications and data management system

The ESF communications system provides telephone communications to the outside world, a life-safety warning system, an underground paging system, intercoms, and a hoist operators communication system. The system is designed as a unified system to provide the maximum flexibility to the operation. The life safety system will be centered around the supervisor's office, which will house the annunciators and response controls. Both audio and visual warning will be provided. If the optional shaft is constructed, the hoist operator will have verbal communication, the traditional bell system, and a closed circuit TV system to provide visual indication of the landing areas. The system is being designed as state of the art in all respects using proven equipment built to the most stringent of the applicable codes. The data produced by various tests described in Section 8.3.1 will be collected by an integrated data system (IDS) as described in the Section 8.4.2.3.2.

Shaft collar

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

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Exploratory shaft facility plant and support facilities

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

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

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

Hoists and headframes

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

Ramp Portals

The ESF will contain two ramps, one in the north and one in the south. The ramp portal is a structure that provides a stable foundation for entry into the ramp. The portal would consist of concrete wing-walls on the sides of the entry to support the compacted fill that serves as the road surface. The portal would also have some type of roof support (e.g., corrugated iron).

Muck storage

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

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8.4.2.3.3.3 General arrangement of ramps and shaft

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

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

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

Both the north and south ramps are oriented to enter the ESF main test level from the east. These ramps are expected to be approximately 25 ft. (7.6 m) in diameter, with the north ramp extending approximately 6,500 ft. (1,981 m) in length to the Topopah Spring level and the south ramp being approximately 3,600 ft. (1,097 m). The north ramp leading down to the Calico Hills level is expected to be approximately 18 ft. (5.5 m) in diameter and 6,300 ft. (1,920 m) long. The south ramp to Calico Hills is expected to be the same diameter as the north ramp and approximately 5,000 ft. (1,524 m) long. The general arrangements for these ramps are presently being developed, so, therefore, these dimensions are preliminary.

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

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

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

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

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

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

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

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

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

The excavations at the Topopah Spring and Calico Hills levels consist of long drifts that connect the north and south ramps. From these drifts, lateral drifts would be constructed to features of special interest (e.g., Imbricate Fault Zone, Ghost Dance Fault, Solitario Canyon Fault). The drifts in the Topopah Spring level also include the MTL dedicated testing area, in the north. These drifts are illustrated in Figure 8.4.2-3.

The drifts within the Topopah Spring level are expected to be approximately 25 ft. (7.6 m) in diameter. Approximately 20,000 ft. (6,096 m) of drifting is planned for this level of the ESF (not including the MTL dedicated testing area). The drifts within the Calico Hills level are expected to be approximately 18 ft. (5.5 m) in diameter and a total of approximately 19,000 ft. (5,791 m) long.

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

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

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

2. Flexibility for experiments.

    a. Required areas for expansion for future testing.

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

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

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

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

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

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

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

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

8.4.2.3.4 <u>Description of exploratory shaft facility construction operations</u>

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

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

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8.4.2.3.4.1 Site pads

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

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

8.4.2.3.4.2 Exploratory shaft facility surface facilities and utilities

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

8.4.2.3.4.3 Ramp portal and shaft collar construction

The ramp portals will be constructed first by excavating the area around where the portal will be located. The concrete wing-walls will be constructed, followed by placement of compacted fill for the road surface. Some form of roof support (e.g., corrugated iron) will be installed to a specified distance down the ramp.

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

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8.4.2.3.4.4 Exploratory shaft facility underground construction and operations

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

The underground portion of the ESF will be constructed using mechanical mining equipment. Tunnel boring machines (TBMs) will be used to construct the north and south ramps from the surface to the Topopah Spring level. TBMs will also be used to construct the two ramps from the north and south ramp turnouts to the Calico Hills level. The two ramps at the Calico Hills level will be connected by a long exploratory drift, also constructed with a TBM. The lateral drifts to the Imbricate Fault Zone, Ghost Dance Fault, and Solitario Canyon Fault will then be constructed. These drifts may be constructed with a TBM, but most likely with a mobile miner or road header.

As in the Calico Hills level, the two ramps leading to the Topopah Spring level will be connected by a long drift, constructed with a TBM. The lateral drifts to the Ghost Dance Fault and Imbricate Fault Zone will most likely be constructed with a mobile miner or road header. This is also true for the individual excavations to be constructed in the dedicated test area in the MTL.

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

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

8.4.2.3.5 General description of underground support systems

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

Mine ventilation

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

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

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

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

Rock support

Rock support needs are determined using several available methods. These methods include both analytical and empirical approaches, which are supported by historical experience with underground construction. Results of these analyses serve as a basis for developing the flexible systems for reinforcement capable of accommodating various rock conditions anticipated underground.

Ground support requirements for each segment of a drift may vary over relatively short distances, depending on the local geologic conditions. Based on the visual inspection by a qualified professional, the local ground conditions are classified in terms of rock-mass categories. In turn, the rock-mass category is assigned a specific rock-support system, including the procedures and the hardware necessary for its proper implementation. Thus, the rock-support system is adaptable to local conditions.

Depending on the rock-mass class, the rock-support system may include rock bolts, wire mesh, shotcrete, or the combination of those as specified for each system.

Analytical methods

Analytical methods use the analyses of stresses and deformations around openings and include numerical modeling techniques, such as the finite-element method. These methods are very useful in strata control because they enable comparisons of various underground excavation systems and serve as a design process. They are also very useful in forecasting the possible performance of underground openings over extended periods of time, where such aspects as the influence of temperature and/or time-dependent properties of rock (e.g., creep) are to be assessed.

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Finite-element codes, such as VISCOT, will be used to evaluate the stability of underground openings. Several studies in which this code was used have been reported in the literature, and the code certification process is currently well under way. Once the certification process is completed, the code will serve as one of the design tools acceptable from the quality assurance point of view.

There are a number of other codes currently available, each appropriate for analysis of certain types of problems. Other code(s) may be used to analyze the stability of underground openings.

Empirical methods

Sophisticated computer analyses inherently incorporate a number of assumptions related to the properties of the rock mass, the state of stress anticipated in a particular underground situation, the geometry of the opening(s), etc. As pointed out by Hoek and Brown (1980), the combined effect of all the factors and processes contributing to the stability of underground openings can seldom be determined. Invariably, the designer is faced with the need to arrive at a number of design decisions in which his engineering judgment and practical experience must play an important part.

To provide a link between the results of analytical studies as well as to incorporate practical experience gained from operations performed under similar underground conditions at other sites, some form of classification system is needed. Such a system allows the results obtained from analytical studies and experience to be translated into a series of engineering drawings, specifications, and procedures leading to a successful implementation of the design concepts.

Hoek and Brown (1980) recommend two common classification methods for use in the preliminary design of underground excavations, namely, the classification of joint rock masses (South African Council for Scientific and Industrial Research) proposed by Bieniawski (1974), and the tunneling quality index (Norwegian Geotechnical Institute) proposed by Barton et al. (1974a).

These two methods will serve as a point of departure for the development of a site-specific rock-mass classification appropriate for the tuff formations at Yucca Mountain. As a result, a set of procedures, along with detailed drawings showing various rock-support systems, will be developed. These will be simple enough to use under field conditions and will contain specific information to help select a suitable rock support system for particular rock conditions encountered underground.

Life safety

The function of the life safety system is to provide systems to alert on-site personnel of danger, ensure a timely response to emergency conditions, provide safe shutdown and evacuation if necessary and limit interruption to the site characterization program.

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Life Safety is a broad concept that includes other major system components. Some of these components are

1. Fire protection.
2. Alarm warning system.
3. Emergency communication systems.
4. Evacuation plans.
5. Atmospheric monitoring and control systems.

Each of these systems is engineered separately to maintain its individual integrity. In addition, all systems are designed to function in a coordinated capacity by interfacing shared responsibilities for overall program effectiveness.

Fire protection

The fire protection system is a part of the life safety system. Its development is based on the anticipated fire hazards, and the use and occupancy of each area. The fire protection system will include

1. Automatic extinguishing systems using water sprinklers, halon, and foam.

2. Manual extinguishing systems such as portable dry chemical units, factory-equipped rolling extinguisher systems, fire doors, fire dampers, and ventilation controls.

3. Automatic detection system for smoke and heat (flame).

Each component of the fire protection system is designed considering credible accident scenarios that may be attributed to various ESF functions. Fire protection for these events is part of the total consideration given to safety, and the system interfaces with other life safety systems involved.

Health and safety

The DOE has an established health and safety program. The following policies are followed by the project management:

1. Accident prevention.

2. Safety promotion and training.

3. Supervisors' health and safety inspections and reports.

4. Resolving safety and health complaints.

5. Accident and injury reporting system.

6. Safety awards for outstanding injury and illness prevention achievement.

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7. Job safety analysis program.

8. Construction and occupational safety standards.

Evacuation and rescue

The ESF organization has emergency evacuation and rescue procedures developed to respond to fire, flood, and other catastrophic events. These procedures detail the proper response and sequence of action to be taken by subsurface personnel to various emergency calls.

A well-planned and well-rehearsed program of evacuation and rescue for ESF personnel will be followed. Adequate training and drilling of personnel and management in this program will be provided, including these topics:

1. Early warning and alarm systems.
2. Use of self rescuers.
3. Basic ventilation circuitry.
4. Direction to emergency exits.
5. Use of emergency hoist (if optional shaft is constructed).
6. Use of refuge chambers.
7. Survival techniques.
8. Barricading.

Equipment that is important to life safety is designed with redundancy so that back-up systems are available during an emergency.

A designated person in each shift will be responsible for initially coordinating the emergency response until relieved by the head of the Emergency Coordinating Committee. Initial rescue response such as mobilization of mine rescue team, planning to establish underground fresh air base, and actual rescue and recovery work will be started as soon as possible after an emergency occurs. The head of the Emergency Coordinating Committee may solicit the help from various organizations to carry on the rescue and recovery work.

8.4.2.3.6 Evaluation of exploratory shaft facility layout and operations

This section evaluates the ESF layout and operations with respect to interferences that could affect the experimental program, coordination with the geologic repository operations area design as required in 10 CFR 60.15(c), design flexibility as required in 10 CFR 60.133(b), and operational safety. This section is divided into five subsections. The first three subsections discuss various aspects of the interference concerns regarding construction and operation of the ESF, the experimental program, and the repository. The fourth subsection examines the flexibility of the ESF design and layout in handling variable geologic conditions, in incorporating additional testing within the dedicated test area, in exploring other areas, and in reorienting or relocating certain experiments. The final section deals with operational safety concerns addressed in the design and their consistency with the governing regulations.

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[NOTE: The interference evaluations contained in Sections 8.4.2.3.6.1 and 8.4.2.3.6.2 were conducted for the ESF configuration, construction method, and testing layout described in the SCP. This evaluation still needs to be conducted for the reference ESF design concept shown in Figure 8.4.2-3. These sections will be revised when that evaluation is available. These sections are being included unchanged because, while the details of the evaluation will be different for the new design concept, the overall methodology and considerations for conducting the evaluation will be similar.]

Three categories of potential interference concerns affecting the underground design and testing are discussed in the first three sections. In Section 8.4.2.3.6.1, the approach used to analyze the potential for test-to-test interference is described and applied to the current design layout. In the following section (8.4.2.3.6.2), test and construction/operations interferences are discussed, along with the means used to mitigate those concerns. The approach used to plan and coordinate the ESF layout and construction with that of the repository is discussed in Section 8.4.2.3.6.3. Within each of these sections, several mechanisms of potential interference were considered, principally those due to hydrologic, thermal, mechanical, and geochemical activity associated with the experiments (Table 8.4.2-14). Other potential sources of interference among tests or between the tests and the ESF construction and operations, such as ventilation, blast vibration, instrumentation, and traffic (including vibration), were also considered. The means used to limit interferences are discussed and analyzed relative to the current design. In general, potential interference problems can be limited through the use of physical separation (including orientation of tests), but other means are also used and their applications discussed. These include the sequencing of operations and testing to limit interference, control of operations such as blasting and fluid usage to limit the extent of changes induced in the rock mass, and monitoring and observation before accepting the location for testing. The application of these methods to the interference problem are discussed in the appropriate sections.

8.4.2.3.6.1 Potential for interference between tests

Purpose and background

This section describes the general approach used to evaluate the potential for test-to-test interference among the experiments planned for the ESF and the use of this methodology in evaluating the current design layout of the ESF with respect to test-to-test interference. Each test proposed for the ESF is briefly described in Section 8.4.2.3.1. This section also discusses the constraints imposed on the underground layout by each experiment and the estimated zone of influence of each experiment. The design requirements generally arise from the requirement that the in situ conditions, such as stress state, degree of saturation, and temperature in the region where the experiment is to be conducted, not be altered by other activities in the ESF. Flexibility in choosing the final location and orientation of an experiment may also be an important constraint because of local variations in geology and fracture orientation. The zone of influence is intended to describe the extent to which each experiment alters or influences the sur-

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rounding region. In the conduct of each test, it is vital to ensure that the data derived from the test is not corrupted by the influence of other experiments that may be underway at the same time. The combination of experiment descriptions, design constraints, and zones of influence for each test, given in Sections 8.3.1 and 8.4.2.3.1, provides sufficient information to evaluate the current ESF layout with regard to addressing concerns regarding test-to-test interference.

Approach

The approach taken to assess the potential for interference among the ESF experiments consisted of three basic steps. First, each experiment was evaluated with regard to potential interferences and zones of influence (Section 8.4.2.3.1). Several mechanisms for zones of influence and other potential interference sources were considered. For example, regions of material potentially affected or altered by an experiment due to heating, hydrologic alteration, geochemical reactions, and mechanical changes (excavation of drifts or thermally induced stress changes) were determined. Next, these four interference considerations and zones of influence for each test were combined and the one that gave the maximum zone of influence was translated into a physical area (standoff) requirement that represents the maximum extent of the rock zone affected by the test given the expected rock properties. These regions were then superimposed onto the design layout of the ESF test area. Finally, the overlay of zones of influence on the test locations was examined for potential interferences among the experiments.

The criteria for determining if a potential interference existed was to determine if the zone of influence of one experiment impinged on another experimental area to such a degree that the results of the experiment could be affected. To ensure conservatism in this approach, the potential for interference was considered high if the zones of influence of two experiments overlapped. Where the zones of interference for two or more experiments overlapped, the timing of the experiments and the type of interference (i.e., effect) resulting from the individual experiments were reviewed. If the tests were separated sufficiently in time to preclude an interference problem (i.e., one test may have been completed, with no unacceptable alteration of the rock, before the second was begun), the tests were considered to be independent of interference effects. If potential interference effects were found during the analysis, then adjustments to the timing or the layout of the experiments were considered.

The test-to-test interference concerns were completely evaluated using this methodology only for the experiments proposed for the main test level. Experiments and observational activities planned for the underground excavations were evaluated with regard to potential zones of influence (Section 8.4.2.3.1). Further evaluation was not, however, considered necessary because the tests involved primarily observational and sample collection, affected a limited amount of rock (see Section 8.4.2.3.1), or had large physical separations between them and other tests.

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The principal mechanisms for creating zones of influence were considered to be thermal (for experiments using heat sources), mechanical (for experiments requiring extensive excavation), hydrologic (for experiments that introduced fluids to the environment) and geochemical (for experiments that altered the local in situ geochemistry). Other potential sources of interference, such as the location and extent of instrumentation (included in the mechanical category in Table 8.4.2-14), were also considered on a test-by-test basis. In general, most tests will have several zones of influence summarized in Table 8.4.2-14 resulting from different mechanisms. The effect of some coupling of mechanisms was also considered. For example, heating the rock mass also affects the local hydrological and stress conditions. Analyses of these coupling effects are quite complex but generally depend on the gradient of the principal driving force. That is, hydrological and stress changes are a function of the thermal gradient. Therefore, the approach taken to account for these effects was to extend the zone of influence of the principal mechanism far enough so that gradients were low and secondary coupling effects would likely be contained within the zone defined by the principal mechanism. Thus, thermal zones of influence were extended to include all material surrounding an experiment whose temperature changed by more than 5°C.

The coupling of thermal and hydrologic zones of influence is also considered by Nitao (1988). In this investigation of thermal and hydrological behavior in the vicinity of the waste package, the region of condensed water vapor extends to approximately the same location (within 4 m) as the 80°C isotherm (approximately 50°C above ambient). As this water condenses, it is rapidly imbibed into the matrix (Martinez, 1988) where it remains relatively immobile (Peters, 1988). Since the 80°C isotherm is contained within the 5°C above ambient isotherm, the assignment of the 5°C isotherm as the boundary for the experimental zone of influence provides a conservative zone that addresses coupled thermal and hydrologic effects.

Geochemical and hydrological zones of influence were conservatively assumed to be identical where elevated temperatures are not encountered. At elevated temperatures (approximately 100°C), some geochemical alteration of tuff may occur (Smyth and Caporuscio, 1981; Smyth, 1982). However, beyond the boundary of the thermal zones of influence the temperature is assumed to be less than 5°C above ambient. This distinction between geochemical and hydrologic zones of influence need not be made.

Thermal zones of influence were estimated from preliminary thermal analyses performed in support of the experiment designs (for example, Bauer et al., 1988). The thermal zone of influence was taken to be the maximum extent of the isotherm that was 5°C above ambient temperature because temperature changes of less than 5°C are unlikely to have any measurable thermomechanical effect on the host rock. Thus, material outside the zone of influence was subjected to less than a 5°C temperature change. Figure 8.4.2-14 gives an example of such a thermal analysis for the canister-scale heater experiment. The view shown is looking along the axis of the heater with the instrument access drift shown 8 m to the left. After 30 months of operation, the 35°C isotherm (31°C is ambient) has extended approximately 12 m from the heater. The effect of the ventilated drift on

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heat conduction away from the heater is also evident. The effects of nearby drifts were factored into the estimation of thermal zones of influence where necessary.

Hydrologic zones of influence were estimated from pretest analyses, if available, or from generic studies such as those reviewed by West (1988) and are summarized in Section 8.4.3.2. The rock surrounding an experiment was considered to have been hydrologically altered if the in situ saturation change was more than 0.01. Changes in saturation of less than 0.01 are not considered appreciable and are difficult to measure with standard instrumentation.

Mechanical interferences from stress-altered regions around drifts and alcoves were estimated from preliminary structural analyses of the experiments (summarized in Section 8.4.3.2) such as those in Costin and Bauer (1988). Figure 8.4.2-15 gives an example of the expected alteration in stresses around the demonstration breakout drift (Costin and Bauer, 1988). In the figure, lines of constant vertical stress are shown as a percentage of the initial in situ stress. The figure shows that stresses differ by less than 10 percent from the in situ stress in the region beyond approximately one drift diameter from the wall of the drift. For tests where such analyses were not available, the results of generic analyses of repository size drifts were used. In general, structural analyses of underground openings using linear elastic (Hill, 1985; Johnson and Bauer, 1987; St. John, 1987 a,b,c) or nonlinear jointed rock mass models (Thomas, 1987) show that beyond one drift diameter (in a horizontal direction) from the wall of a long drift, the stresses are within 10 percent of the initial in situ stresses. Thus, a two-drift-diameter standoff around openings was maintained to account for the stress-altered zone around the opening.

Most of the structural analysis calculations performed to support the design of the ESF underground excavations and the thermomechanical testing used a linear elastic material model to simulate the rock mass. In many of these calculations, the elastic moduli are reduced from the measured values taken from intact rock samples in an attempt to account for the effect of joints and other discontinuities on the stiffness of the rock mass. But even when such efforts to account for the discontinuous nature of jointed rock are included in the analyses, the results from linear elastic calculations may not completely represent the behavior of the rock mass, especially in regions very close to the excavations. Very near the opening (usually within 1 to 3 meters), rock is loosened by the excavation process and stresses are reduced so that joints previously held intact by high normal forces may open or shear, resulting in displacements larger than predicted from elastic theory. The severity of this nonlinear rock response near mined openings depends on the nature of the rock mass. For example, Cording (1974) found that for openings where extensive rock loosening did not take place, the tunnel closure displacements predicted from elastic calculations were within a factor of two of the measured values. Where rock movement and loosening along joints was evident, measured displacements ranged from 3 to 10 times the predicted elastic displacements. Farther away from the opening, where stress gradients resulting from the excavation are low, the elastic analysis is generally accurate in predicting both the trend and magnitude of displacements.

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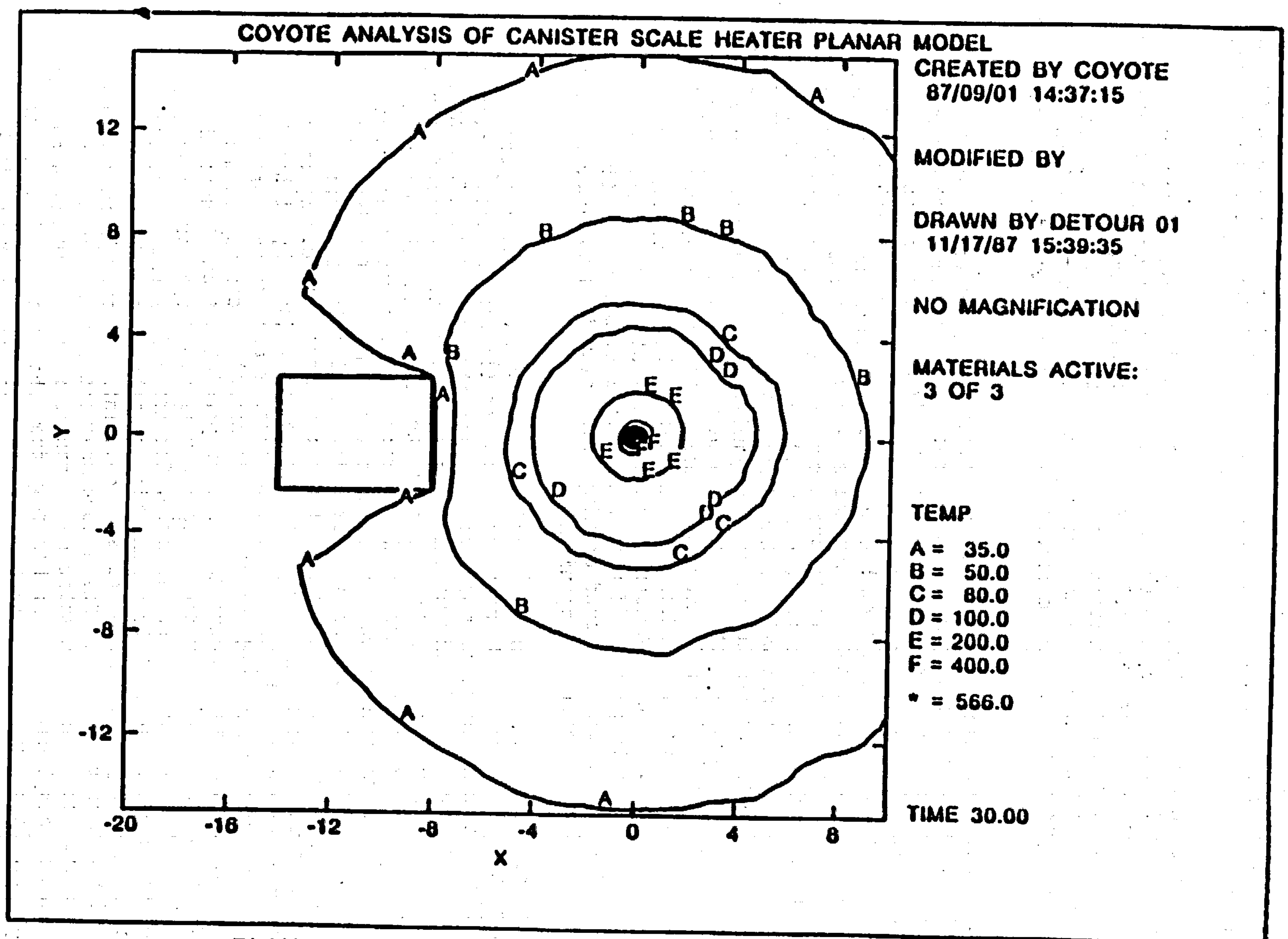

PLANAR MODEL TEMPERATURE CONTOURS AT 30 MONTHS

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

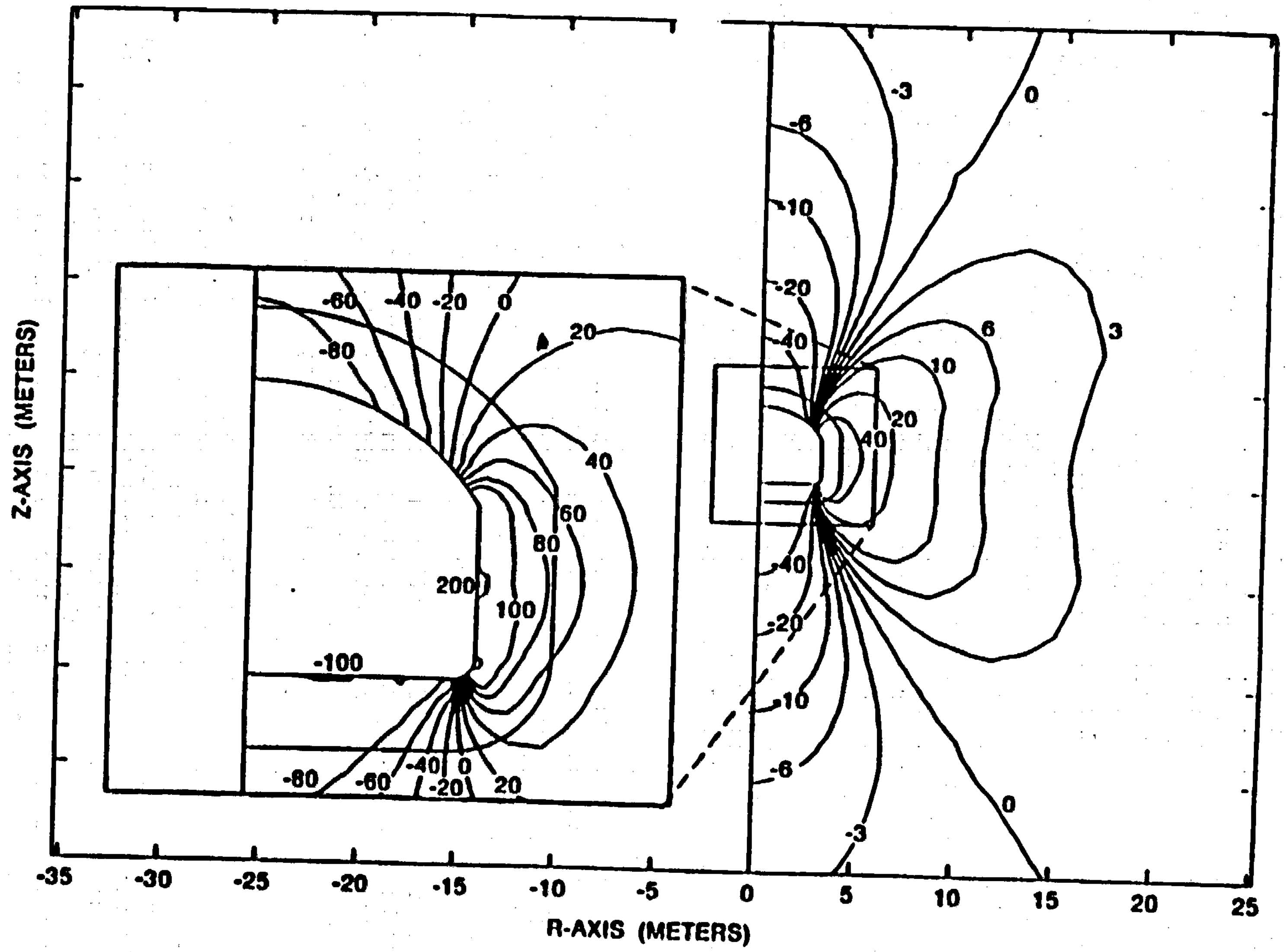

Figure 8.4.2-15. Analysis of demonstration breakout room--percentage change from in situ vertical stress.

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Based on preliminary testing, the rock is expected to be relatively competent at the repository level. Although the rock is known to be fractured, elastic analyses will provide good estimates of rock behavior near excavations. However, before and during site characterization, several actions are being taken to ensure that the standoff requirements and drift stability estimates (based on elastic analyses) are conservative and to substantiate that the results of previous analyses of the underground excavations and experiments are reasonable. One ongoing effort is to look carefully at the existing mining experience in welded tuff. Prototype testing of excavation methods and instrumentation has been conducted in G-Tunnel on the Nevada Test Site. Zimmerman et al. (1988) reported the results of a mining experiment conducted in welded tuff. Careful measurements of rock motion and permeability were made before mining the drift, during mining, and after an experimental drift (6.1 m wide by 4.0 m high, with an arched roof) was mined. Measurements of rock motion around the drift using MPBX gages that extended 15 m into the rock around the drift indicated that the measurable disturbance to the rock extended approximately 6 m laterally from the drift. As would be expected, the disturbance into the floor and ceiling were somewhat greater. Injection tests were also conducted to measure the hydraulic quotient of the rock in several boreholes. The hydraulic quotient is a measure of the apertures of fractures that are connected with the borehole in the region tested. From this testing, the fractures were found to be tighter after excavation than before, in most places near the excavation. Near a large fault through which the drift was mined, some rock loosening was noted. However, the measured hydraulic quotient only increased from the pre-mining value for 2 to 3 m into the drift wall. In addition, displacements predicted from an elastic analysis were generally found to be within a factor of 2 of the measured displacements, except near the fault, which was not taken into account in the calculations.

This preliminary evidence suggests that the results of the elastic analyses conducted so far should reasonably predict the structural response of the ESF underground excavations. An assumption of the acceptability of a two-drift-diameter standoff for precluding significant interference between test drifts and other mined areas seems conservative. Both analyses and preliminary measurements indicate that the stress-altered region around a drift will extend only approximately one drift diameter into the rocks.

With the exception of the diffusion test, geochemical alteration was not found to be sufficiently extensive as a primary mechanism to require a standoff region. The zone of influence due to diffusion of tracers in the diffusion test was estimated to be 0.3 m at the bottom of the borehole. This estimation was taken from previous field work using a similar technique (Birgersson and Neretnieks, 1982).

Other possible interference mechanisms were considered on a test-by-test basis. The extent of instrumentation for excavation deformation analyses was the most common reason for other mechanical zones of influence. Deformation gauges, such as multiple point borehole extensometers (MPBXs), extend 15 m into the rock surrounding an instrumented drift. For proper interpretation of the displacement measurements made from such gages, the bottom anchor should remain fixed, or move only as a result of displacements induced by the instrumented drift. If other drifts are constructed close to the bottom anchor during the period when measurements are being made, the bottom anchor

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may move and make interpretation of the displacement data more difficult. To preclude this, interference standoff zones for such instrumentation were included in the design so that no drifts would be constructed closer than two drift diameters from the bottom of the gages.

In defining the constraint and estimating the zones of influence for each test it was assumed that strict controls over water usage and blasting methods would be applied during construction of the test area. Therefore, the zone of hydrologically or chemically disturbed material created by these construction activities was not included in the zone of influence estimation for each test but rather is included in a general way in Section 8.4.2.3.6.2. Hydrological or chemical zones of influence were determined only on the basis of the fluids and chemicals used in the test itself.

The zones of influence estimated for each experiment are based primarily on results of numerical analyses, results of prototype tests, and assumptions regarding the physical nature of the rock mass. One purpose of the early testing in ES-1 and on the main test level is to provide some data that may be used to confirm or adjust the estimated zone of influence resulting from the mechanisms described above. Specifically, the multipurpose boreholes and radial boreholes experiments will provide data on water transport near the shaft and allow for monitoring of a hydrologic zone of influence. Similarly, the demonstration breakout rooms and the heater test in TSw1 will provide thermal and mechanical data for comparison with current analyses. If estimated disturbed zones are found to be inadequate on the basis of early test results, needed adjustments and redesign can be completed before the experiments are set in place on the main test level.

Current assessment

An overlay of the zones of influence from the main test level experiments on the current (Title I design) dedicated test area layout is shown in Figure 8.4.2-16. Several of the 33 activities shown in Table 8.4.2-9 are not shown on the figure because those tests are to be conducted in ES-1 during construction, or involve only sampling or observations and, thus, have no specific location to be illustrated. The figure shows that the current layout provides sufficient separation between tests to preclude interference resulting from the mechanisms analyzed.

The drifts for demonstration breakout room (DBR) and the sequential drift mining tests are enclosed in fan-shaped regions representing the possible area affected by stress alteration resulting from construction of the drifts. The regions are fan-shaped because flexibility of orientation of the drifts was taken into account in developing the layout. The flexibility requirement results in having to set aside an area larger than would be required if the orientation of the drifts could be fixed at the present time. In addition to the orientation flexibility shown by the fan region, there is sufficient area available for the DBR and the sequential drift mining experiments that the layout could be completely rearranged within the area set aside for these tests (i.e., the experiment drifts could be reconfigured to be in a direction perpendicular to that shown in the layout). For other experiments, the flexibility requirement is satisfied by providing additional

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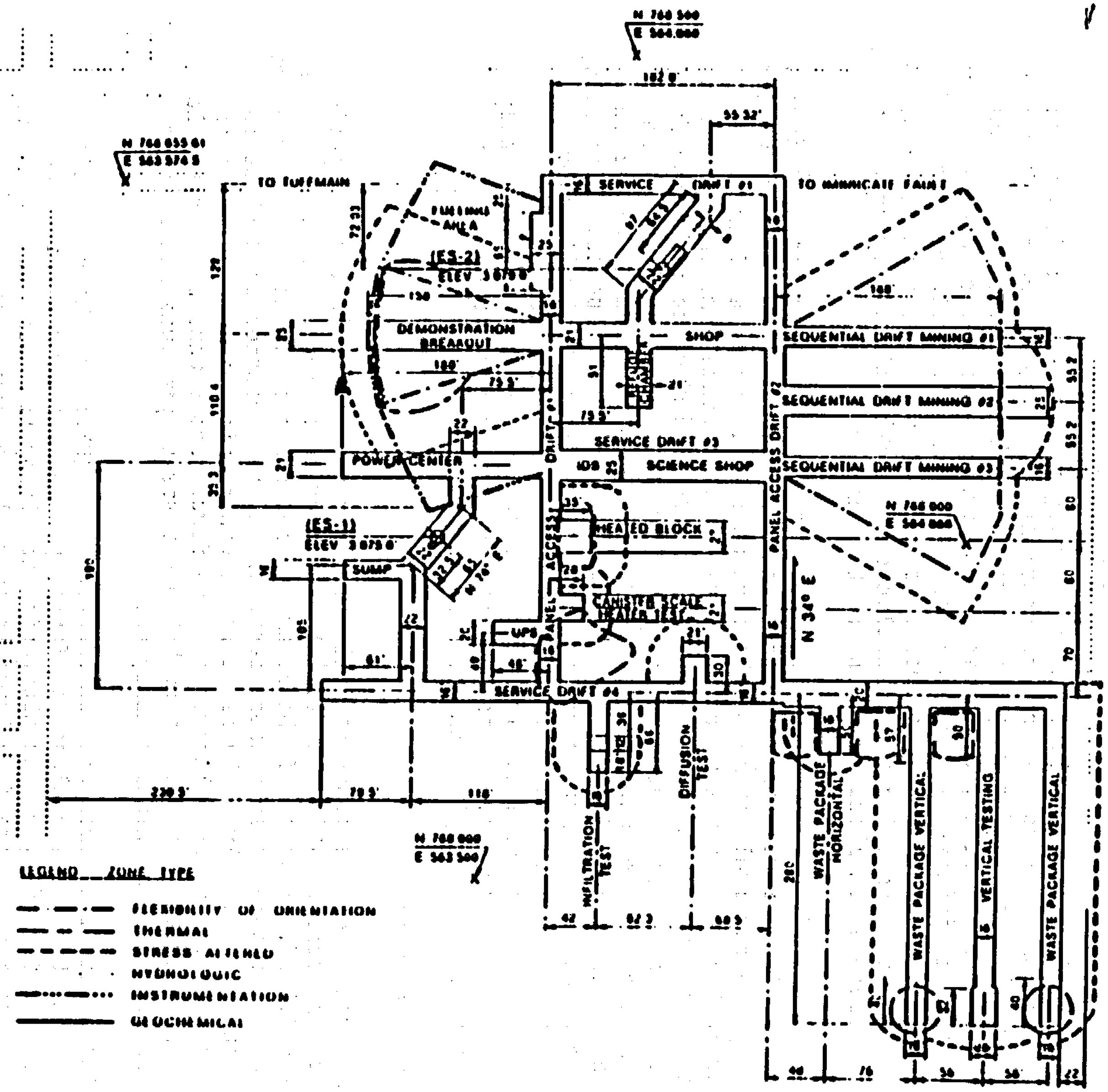

Figure 8.4.2-16. Zones of influence from main test level experiments on dedicated test area layout.

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areas where the experiment could be conducted if the location shown in Figure 8.4.2-16 proves to be unsatisfactory. This is discussed further in Section 8.4.2.3.6.4.

For the DBR drift, Figure 8.4.2-16 shows both the early-time zone of mechanical influence and the additional standoff area that would be required if the displacement gages in the room are to be monitored for an extensive period of time. Note that developing the access drift to the northwest, which will connect to the long exploratory drifts in that area, may affect DBR instrumentation. The DBR experiment, however, is intended to provide early data on rock response that will be used in the development of later experiments. Therefore, measurements in the DBR should be completed before any further construction takes place, and no interference with construction or other testing is expected. Additional area for instrumentation is not required for other excavation experiments such as the sequential drift mining experiment because the instrumentation is confined between the two outer access drifts. Also shown in the DBR is the thermal zone expected to result from the thermal stress test, if it is conducted in that area.

The principal thermal experiments shown on the layout include the canister-scale heater, the heated block, the thermal stress test, and the waste package environment tests. These tests are sufficiently separated that thermal effects will not pose a problem to other test areas. The canister-scale heater test provides the most severe thermal loading. The heater is located in the pillar formed by the intersection of two drifts, which not only provides instrumentation access from two directions, but also helps contain the region of elevated temperatures to near the intersection. The drift ventilation helps block the thermal load from conducting across the drifts. This produces the nonsymmetric shape of the thermal front shown in Figure 8.4.2-39. However, in the near field of the heater, where the principal thermal and mechanical measurements are to be made, the thermal field is axisymmetric about the canister (Bauer et al., 1988). The waste package tests are quite isolated in the southern end of the test area and have small zones of influence so test-to-test interference should not be a problem. Not shown on the current layout is the heated room test, which is intended to be located within the dedicated test area. Preliminary thermal and structural analyses have been completed for this experiment (Bauer et al., 1988), and zones of influence have been estimated for the proposed design. With this information, designers can locate the experiment (during Title II design) with due consideration for interference concerns.

The zone of influence for the infiltration test is small relative to the alcove where it is to be conducted. Thus, this test should not affect other nearby experiments or potential experiments that may be fielded in the dedicated test area. Similarly, the diffusion test affects only a narrow region near the borehole drilled from the diffusion test alcove. The central portion of the pillar containing the test should not be affected by the thermal experiments located in the northwest section of the pillar. Since the bulk permeability test areas have not been agreed upon yet, they are not shown. Because this test potentially could affect large areas with gas-phase pressure pulses, location relative to the longer-term, more sensitive tests located in the southern portion of the dedicated test area is of concern and will be addressed.

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Like the heated room test the seal-component tests are not shown on the layout. Both tests are still in the early stages of design definition and will be added to the layout when the tests are approved.

This discussion indicates that the layout design is a dynamic and evolving process of refining and modifying the design. Thus, the information shown in Figure 8.4.2-39 represents a snapshot of the current state in this evolutionary process. New tests may be added and perhaps some of the currently defined tests may be changed, all of which will have some effect on the layout. These changes will be documented in the semiannual progress reports. Also, as the layout changes, the interference analysis (described earlier) will be updated as needed and used to ensure that changes will not produce unacceptable interference problems.

8.4.2.3.6.2 Potential for construction and operations interference with testing

Introduction and background

This section discusses the potential effect of construction and operation of the underground excavations on the conduct of the experimental program. In particular, the process used to evaluate the current layout and planned operations for potential interference with the testing program is described. Using this process, a current assessment of the construction and operations interference potential is then presented. Such assessments are an ongoing process and subject to frequent review as the design evolves and more data become available. The assessments are expected to be refined during the final preconstruction phase, during shaft construction when site-specific data become available, and during mining of the main test level when data for test locations and orientations become more specific. For the present, descriptions of the testing program, the ESF layout and the construction operations are given in Sections 8.4.2.3.1 through 8.4.2.3.5, which contain sufficient information to perform the evaluations described in this section.

Approach

The approach taken to evaluate the potential impact of construction and operations on the testing program consisted of both a forward and a backward evaluation method. The forward evaluation looked in detail at the description of planned operations. It specifically looked at the controls placed on those operations to reduce the effect of construction and operations on the testing environment and to determine whether those controls are sufficient to satisfy the constraints to the design imposed by the experiment plans (discussed in Section 8.4.2.3.1). Operational controls include such things as plans for blast control to limit damage to surrounding rock; control of fluids introduced in the shafts and main test level from mining or other sources; control of dust, vibration, and traffic near sensitive experimental areas; use of phased construction and testing; and inclusion of sufficient separation distances between experiments to reduce the potential for interference.

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The backward evaluation consisted of looking at each constraint placed on the design by the experiment plans (Section 8.4.2.3.1) and determining whether ESF operations would satisfy that constraint. This part of the assessment included an evaluation of the sensitivity of each experiment to changes in the environment that may occur due to ESF operations. The experiments were evaluated with regard to their sensitivity to such operational considerations as ventilation changes; traffic; potential of excess water from surface flooding; and vibration, overpressure, and dust from nearby mining.

Current assessment

The earliest testing will be conducted during construction of the shafts. ES-1 will be used for scientific investigation, requiring that construction in that shaft cease while measurements are being made or instrumentation is being installed. ES-2 will be constructed in parallel with ES-1, using identical methods. One concern for the testing in ES-1 was the simultaneous development of ES-2 and the effect it might have on hydrologic or structural measurements made in ES-1. The principal means for reducing the interference between the shafts are separation distance, construction methods, and control of fluids. Operational, safety, and testing interference concerns were all factors in evaluating the location of and the distance separating the shafts. Shafts need to be spaced close enough to allow reasonable distances for power instrument cabling and for water piping, and to provide for redundancy in mine water discharge. In addition, both shafts need to be located so that collars can be anchored in bedrock and be sufficiently above the drainage channel to preclude inundation by the probable maximum flood (PMF) (Section 8.4.3.2). It was also desirable to locate ES-2 close to a panel access drift but still provide for an adequate shaft pillar. This location provides for isolating operations such as dumping, haulage, and shops from the testing in the dedicated test area. The orientation of the hoisting operation is determined by the strike of Dead Yucca ridge. Thus, ES-2 is located as far away from ES-1 as practical to still have the desirable orientation and a suitable location relative to the ESF boundary. Safety considerations used to evaluate the ESF design are discussed in detail in Section 8.4.2.3.6.5.

For testing, the shafts must be sufficiently separated so that general hydrologic or structural interference between the shafts is unlikely. The 300 ft separation was analyzed for potential hydrologic interference by first identifying the fluid quantities likely to be used in ESF construction and then assessing the impacts of using those fluids. This impact of construction fluids was analyzed by West (1988) (Section 8.4.3.2.1.3, topic 2). Several calculations were performed to estimate the effects of construction water. First, the extent of matrix flow of water from the shaft was estimated (Section 8.4.3.2.1.3, topic 3) by estimating that 10 percent of the construction water (see Section 8.4.3.2.1.3, topic 2 for specific amounts) used in the shaft goes into the formation and is retained in a modified permeability zone, estimated to be one-shaft radius thick. In this instance, analysis shows that the water will slowly migrate outward from the opening so that, after 10 years, a zone 10 m in radius from the shaft centerline will have been affected by a change in saturation of approximately 0.08. The effect of hydrologic interaction due to water flow in fractures under pres-

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sure was also estimated (Section 8.4.3.2.1.2, topic 9). For small aperture fracture flow (24 to 100 µm opening), the results indicate that water moved 10 to 15 m vertically with a 20 m pressure head. For larger aperture fractures (250 µm), the water in the fracture may extend to 50 to 60 m from the shaft.

Because of the small amounts of water contained in the fractures, however, the water is predicted to be imbibed into the matrix, reaching an equilibrium state within a few days. The matrix adjacent to the fracture is predicted to return to nominal saturation state within a few weeks. These analysis and results indicate that, during construction, water would be expected to move short distances in the matrix or small aperture fractures and that changes in the rock mass saturation due to construction water are likely to be small. It was also noted that relatively large fractures are required to move water long distances. Occurrences of fluid transport were encountered in USW UZ-1 as a result of drilling of USW G-1 where it was evident that drilling fluid moved a great distance along possible geologic structures in Drill Hole Wash. However, Drill Hole Wash may be along geologic structures, while the orientation of ES-1 and ES-2 is oblique to the apparent structural trends at Yucca Mountain. Further drilling operations planned for ESF construction will not result in the relatively high pressures that existed in drilling USW G-1 since there will be no large, standing columns of water. Therefore, substantially increasing (i.e., doubling or tripling) the shaft separation distance is not expected to significantly reduce the likelihood of some effect of one shaft on the other. In conclusion, then, the most likely source of water that could influence testing in ES-1 is the construction water used in ES-1.

Mechanical interference between the shafts was also considered. The zone of stress-altered rock surrounding the shaft was estimated from linear elastic calculations (summarized in Section 8.4.3.2) of a shaft with a 1.0-ft thick concrete liner subjected to horizontal and vertical in situ stresses (Costin and Bauer, 1988). The stress-altered region is assumed to be that region where the stresses vary by more than 10 percent from the in situ stresses. According to the calculations, this region extends approximately 5.5 m (1.5 shaft diameters) radially from the centerline of the shaft, and the region where the stresses vary by more than 1 percent from the in situ values extends approximately 16 m (4.5 shaft diameters). ES-1 and ES-2 are located approximately 20 shaft diameters apart. Therefore, mechanical interference between shafts is unlikely. Since both shafts will be constructed by drill and blast methods, blasting in ES-2 is not expected to affect experiments being conducted in ES-1 any more than blasting in ES-1 itself. Preliminary testing in G-Tunnel has demonstrated survivability of geomechanical instrumentation placed within 1.0 m of a full face blast (Zimmerman et al., 1988). Test results also indicate that the accuracy and calibration of the instrumentation are not affected by nearby blasting activities. Figure 8.4.2-17 shows the estimated hydrologic and mechanical zones of influence of ES-1 and ES-2 projected on the plan view of the ESF main test level.

On the basis of these analyses, the location and separation distance of ES-1 and ES-2 are considered to be acceptable because (1) general hydrologic interference is not likely to be observed; (2) significant reductions in the probability of such an event are not likely to be gained by reasonable

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increases in shaft separation or by changes in the sequence of construction of ES-1 and ES-2, although the possibility of flow in large aperture fractures reaching the adjacent shaft cannot be precluded; (3) no mechanical interference or unacceptable vibratory interference is expected; and (4) the location and separation of the shafts is consistent with operational and industrial safety considerations.

The forward evaluation of the main test level layout considered whether the construction and operations considerations used in the design were compatible with the constraints placed on the layout by the experimental program (Table 8.4.2-12). A discussion of the principal operational considerations used in planning the layout and how they were satisfied follows.

First, the need to develop separate experiment areas and shop and training areas was included in the layout by placing the shop area close to ES-2 where most of the construction activities associated with development of the long lateral drifts are centered. This also allows such scheduling requirements as the need to develop service areas and facilities before experiment drifts are developed to be met. Safety considerations require that only limited mining be done before the two shafts are connected. The placement of the shop area drift also helps isolate more sensitive experiments located in the southern part of the dedicated test area from mine traffic. The nearby demonstration breakout room and sequential drift mining experiments are not affected by nearby construction or the additional traffic of mining equipment in the shop area.

Next, flexibility for experiments was included in the design by allowing additional area for experiments where orientation was critical and by including easy development into additional areas for future testing. Flexibility concerns are discussed in more detail in Section 8.4.2.3.6.4. The principal dedicated test area requirement was to adequately separate the tests from each other and from the potential repository area and to provide access for continued mining and construction activities while early tests were in progress. In addition, considerations, such as those for hoisting and ventilation, affect the room layout and main drift locations. Test-to-test separation considerations were used to determine spacing between experiments; more recently, detailed evaluations have been provided through analyses of zones of influence such as those discussed in Section 8.4.2.3.6.1. Other requirements, such as schedule and the degree of isolation from mining necessary to conduct each experiment are used in determining a specific area for the experiment. The orientation of the shaft stations was determined by hoisting and mucking requirements, but were consistent with the experimental program objective to limit mine traffic in the dedicated test area. The muck pocket for ES-2 is to the north side, allowing mine traffic to be limited to one service drift while developing the dedicated test area and allowing subsequent mining of the long exploratory drifts to proceed without having to disturb the dedicated test area.

The backward analysis of the layout was done to ensure that the experiment locations were consistent with the specific requirements of each experiment. Zones of influence and test-to-test interference were discussed in Section 8.4.2.3.6.1, demonstrating that the layout was consistent with those experimental considerations. Operational interference considerations included ensuring that (1) experiments to be done early in the ESF test plan

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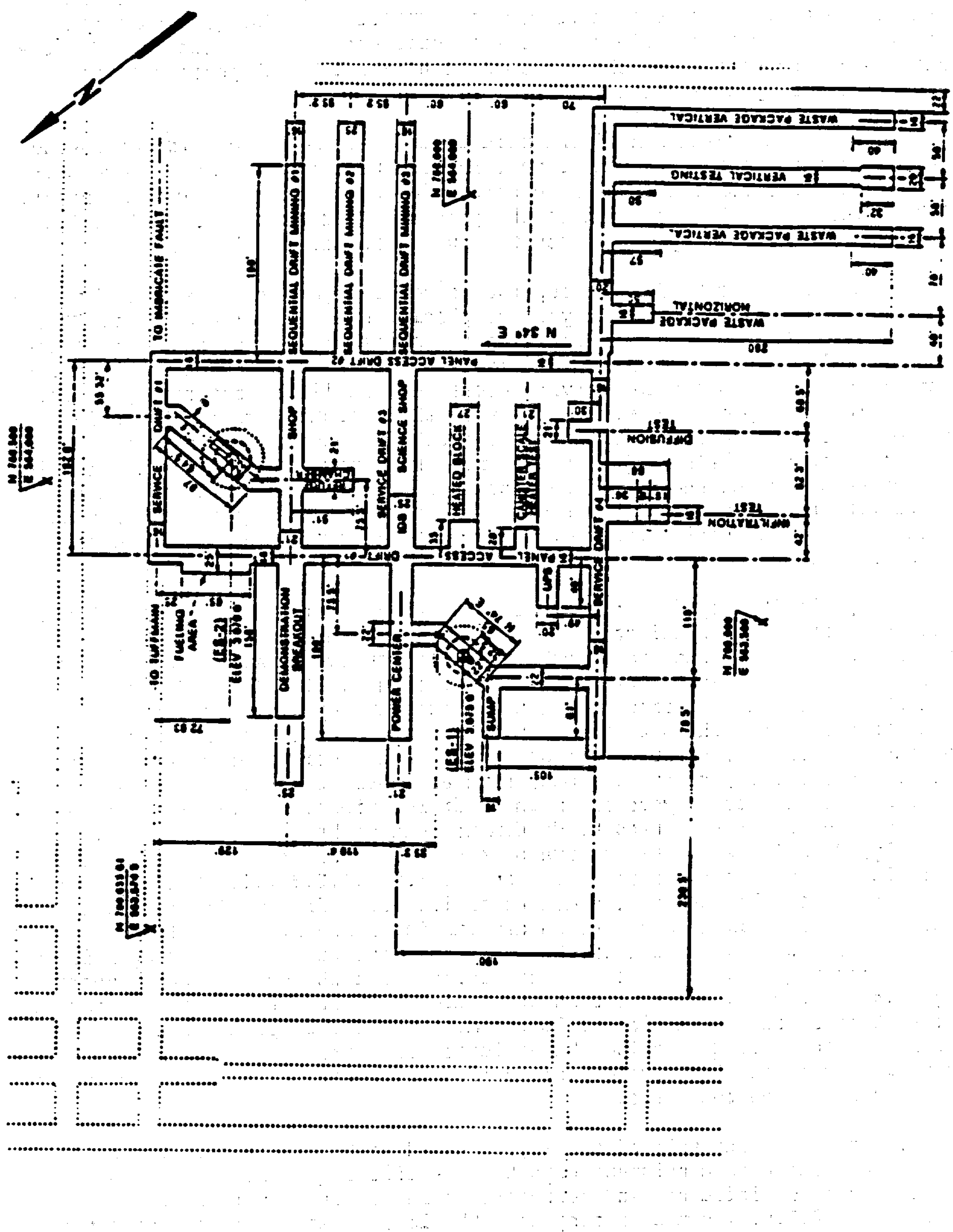

Figure 8.4.2-17. Hydrologic and mechanical zones of influence of exploratory shafts 1 and 2.

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were located close to the shafts or in drifts that would be mined early in the development; (2) experiments requiring isolation from the mining environment, such as the waste package experiment, were located farthest away from the shafts or in isolated drifts or alcoves; and (3) fluids in the underground area were adequately controlled to prevent contamination of sensitive experimental areas. Points 1 and 2 and the control of mining water in the shaft construction have already been discussed. The main test level layout was also evaluated for consistency with experimental requirements for fluid control. Infiltration of surface water due to an unusual influx of water down the shafts, such as from a flood at the surface, is considered unlikely to significantly impact testing activities because (1) the shaft collars are located above the PMF so that the probability of a large influx of water is very low; (2) the surface pad is designed to preclude water flow into the shafts; (3) diversion of water from the shaft into the test levels would be unlikely; and (4) the drifts are graded to drain toward the sumps located at the shafts so that any unusual influx of water will flow away from experiments where control of fluids is important (such as the diffusion test, the waste package test, the infiltration test, the canister-scale heater test, and the heated block test.) In addition, the analysis presented for estimating the hydrologic disturbance from construction water used in the shafts was also used as a basis for estimating the hydrological zone of influence around mined drifts due to construction fluids. A 10-m hydrologic zone of influence around drifts was assumed. This estimate will be reevaluated when data from hydrologic experiments in ES-1, principally neutron probe measurements in radial boreholes test, become available. In most instances, the two-drift-diameter standoff region around the drifts was sufficient to preclude interference from mining fluids, as well as from the altered stress state. The sensitive hydrologic experiments are conducted from boreholes that penetrate beyond the estimated mechanical and hydrological zones.

The conclusions of analyses of the layout with regard to the potential for construction or operational interference are that the shaft locations, spacing, and underground layout are consistent with the constraints imposed on the design by the experimental program. In addition, no experimental constraints or requirements were found that were not addressed directly or indirectly by the design.

8.4.2.3.6.3 Integration of the exploratory shaft facility with the repository design

This section describes the general objectives and specific actions taken to plan and coordinate the ESF design and layout with the repository design in a manner consistent with the governing regulations (10 CFR 60.15(c)(3) and (4)). The specific intent of this effort is to ensure compatibility between the ESF and the repository designs and to limit potential interference between the ESF and the repository. The repository conceptual design was described in detail in Chapter 6 of the SCP and supported by detailed evaluations presented in the Site Characterization Plan Conceptual Design Report (SNL, 1987). The ESF testing, layout and operations are described in Sections 8.4.2.3.1 through 8.4.2.3.5.

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The ESF Alternatives Study recently completed by the DOE evaluated 34 different ESF/repository configurations. In that study, a configuration was defined as the combination of an ESF configuration and associated construction methods integrated with a repository configuration so as to provide compatible interfaces between the ESF and potential repository. That is, for each configuration the accesses and other ESF interfaces with a potential repository were defined in the context of a total ESF/repository system so that ESF accesses were compatible with and had integral functions in the repository.

In the initial part of the study, all previous ESF and potential repository conceptual configurations (including the one described in Chapter 6 of the SCP) were reviewed and new ESF/repository configurations were generated. The resulting reference ESF design concept, shown in Figure 8.4.2-3, is different from the configuration discussed in the SCP. However, the potential repository underground layout is quite similar to the layout shown in Chapter 6 of the SCP.

The general approach taken to limit ESF and repository interference focused on two compatibility concerns. First, the ESF was designed to maintain compatibility with the repository layout and operations. Particular attention was paid to ensuring that repository preclosure performance objectives (10 CFR 60.111), retrievability, and radiological health and safety were not compromised by any component of the ESF design. Second, steps were taken to ensure that the ESF design was compatible with postclosure considerations, particularly with the repository sealing objectives. Specific steps taken in the design to meet these two compatibility objectives are discussed below.

Compatibility with the preclosure performance objectives was addressed primarily by establishing the experiment drifts within the dedicated testing area at the repository level. Because it is a dedicated area, no waste is planned to be stored in the test area. A minimum of a two-drift-diameter standoff from repository drifts (resulting in an even greater standoff from waste emplacement areas) is also maintained to isolate the dedicated test area and reduce the probability that testing activities would interfere with or alter any part of the repository area. The dedicated test area was planned to support both site characterization and performance confirmation testing and to locate both close to support facilities. In addition, requirements were set to incorporate the test area within the repository block but near the boundary. This was so the test area would have a limited impact on the usable repository area and still retain the flexibility to expand without affecting the planned repository mains or panel access drifts (Section 8.4.2.3.3). Also, to limit the disturbance to the repository area, the long exploratory drifts were planned to be coincident with repository drifts (and at repository grade). These drifts will also be mined using methods and controls similar to those planned for the repository. Indeed, experience gained in mining these drifts will provide important input to the mining procedures used in the repository.

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Consistent with the design criteria in 10 CFR 60.134(b)(2) that require that seals not become pathways that compromise meeting the postclosure objectives, compatibility with repository sealing requirements was addressed in several ways. First, only a limited number of interconnections of the dedicated test area with the repository were allowed. These interconnections include long exploratory drifts, which will be used as repository drifts, and other drifts needed for ventilation. The standoff area between the dedicated test area and the repository area also provides a degree of isolation between the dedicated test area and the repository so that postclosure sealing questions are limited to the few interconnections. Additionally, any boreholes penetrating the repository horizon will be located in pillars to the extent practicable. Finally, a drainage plan was established that was compatible with repository operations and postclosure sealing concerns. Specifically, excess water entering the dedicated test area either through ramp/shaft flooding or encountering perched water zones will be expected to remain in the area and drain into the formation. The long exploratory drifts are graded to repository grades so that if repository construction proceeds they will be consistent with the repository drainage plan (drifts will slope away from the rooms in which waste is emplaced). The drainage features of the ESF layout and standoff between the testing and waste emplacement areas are consistent with meeting the additional design criteria of 10 CFR 60.133, particularly criteria (a)(1), (a)(2), (d), and (h).

8.4.2.3.6.4 Design flexibility

One of the design criteria in 10 CFR 60.133 is the requirement for flexibility of design (10 CFR 60.133(b)). That criterion requires the underground facility to have sufficient design flexibility to allow for necessary adjustments to accommodate specific site conditions. And since the ESF construction is exploratory, significant flexibility is necessary. A major aspect in the ESF design is to include sufficient flexibility (1) to provide alternative locations and orientations for the various experimental areas to ensure that geologic, hydrologic, and other constraint conditions or acceptance criteria on the location of the test can be met; (2) to incorporate additional tests within the dedicated test area; (3) to open additional areas to exploration and testing without significant impact on the repository; (4) to accommodate uncertainties or unusual site-specific conditions that may be encountered; and (5) to incorporate schedule changes allowing the more rapid development of some areas or the suspension of some activities while tests are performed. This section discusses the features of the design and layout of the ESF that address these flexibility concerns. The design and operations of the ESF are described in Sections 8.4.2.3.2 through 8.4.2.3.5, and test constraints and flexibility requirements are presented in Section 8.4.2.3.1.

Tests to be conducted in the ramps have flexibility in location. Specific depths at which each test will be performed will not be determined until construction of the ramp reaches the depths where testing is planned. Because experiments, such as the perched-water test, will be conducted only if specific conditions (such as perched-water zones) are encountered in the ramp, flexibility in scheduling of activities is necessary.

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The design also provides ample space for additional testing within the boundary of the dedicated test area. While the specific location of tests have not yet been determined, the space available within the dedicated test area is much larger than the space provided in the ESF configuration described in the SCP. If necessary, areas proposed for shops and training could be converted to provide additional space for the experimental program. The shops and storage areas could then be relocated, possibly by developing the planned repository shops area that is nearby. Larger scale experiments can be incorporated by additional drifting within the dedicated test area. This is an option for incorporating the heated room experiment into the test plans.

Sufficient flexibility in the construction and operations plans to extend the scope of many of the planned activities and open additional regions for exploration or testing was included in the design. If deemed necessary, shaft sinking and mining operations could continue into the Calico Hills horizon or additional areas in the Topopah Spring Member could be explored by mining along planned repository drifts (at repository grade) as far as the planned repository boundary. Ventilation, utilities, and other support facilities are designed to support additional mining capability (drilling jumbos, muck haulers, etc.) so that additional mining could be done without greatly compromising the schedule.

Uncertainties in ground conditions and water flow are always part of any mining operation. The underground design for the ESF, therefore, provides for flexibility in ground support to ensure stable drifts for all areas. The ground support design is based on rock quality determinations and, thus, is tailored to the specific ground conditions encountered. Additional ground support may be required in experimental areas where severe environmental conditions may be imposed on the rock mass. In addition, poor rock conditions or excessive water may be encountered in planned test areas requiring the relocation of some tests. As discussed previously, additional area is provided for this contingency.

In conclusion, evaluations indicate that the current design layout has a great deal of inherent flexibility for arranging test activities. In addition, flexibility relative to changes in design, construction schedule, and experiment requirements have been considered. Finally, provisions or contingencies for handling changes that may be necessary during construction and experiment fielding have been considered.

8.4.2.3.6.5 Design and operational safety

Introduction and background

This section discusses the impact of safety considerations on the design and operation of the surface facility and the underground excavations of the ESF. Safety concerns and regulations are a critical factor in the design process. All applicable codes and regulations regarding health and safety, as defined in DOE Order 5480.4, were followed in the design of the ESF. These include (1) the Mine Safety and Health Administration (MSHA) code 30 CFR 57, (2) the State of Nevada Revised Statutes (NRS) Title 46, (3) the

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California Administrative Code Tunnel Safety Order (CTSO) Title 8, (4) the California Administrative Code Mine Safety Order (CMSO) Title 8, and (5) the Occupational Safety and Health Administration code 29 CFR 1926. The surface facilities, the underground layout, and the ESF operations are reviewed in Sections 8.4.2.3.2 through 8.4.2.3.5. This section reviews those features of the ESF design most relevant to safety.

Discussion

The design of the surface plan includes sufficient pad size and a general arrangement of features to ensure compliance with the applicable regulations. Surface noise regulations are considered in the design of the ventilation fan systems. Finally, the road system was limited to 6 percent grades for heavy truck traffic and 10 percent grades for other traffic to limit safety hazards associated with the grades.

The underground excavation was designed so that adequate ground-support control could be maintained. This is accomplished by limiting the size and shapes of the drifts and the intersections to ensure that ground support can be designed to limit rock fall. Two independent means of egress are required to be available at all times while personnel are underground, except during the limited period before the ramps are connected. For safe equipment operation, drifts and rooms are generally limited to less than 10 percent grade.

Consideration of safety concerns is evident in the design of the support and operations systems. Support systems include ground support, ventilation, utilities (water, electrical, and compressed air), communications, and emergency escape systems. These are discussed in the following paragraphs.

The ground support system is based on a rock quality rating method and rock mechanics analyses. The requirements for support vary with the observed rock quality to ensure that all drifts will have the support necessary to maintain stability and limit the probability of rock fall in the area.

The ventilation system is designed with an overcapacity, primarily to allow for flexibility in the underground design. This overcapacity, however, also includes a margin of safety for controlling dust and maintaining air quality in the ESF. The ventilation fans are reversible and ventilation control is provided so that in the event of a fire underground, the spread of the fire and the resulting smoke and fumes can be controlled with the ventilation system.

The utility substations for electrical distribution are isolated in separate alcoves to keep them out of the main traffic patterns and to limit exposure of personnel to high voltage equipment. In addition, an uninterruptable power supply is used, with backup generators to ensure that in the event of loss of power to the site, critical facilities and equipment will have backup power.

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Besides the ramps and optional shaft for emergency egress, the underground design also includes a refuge chamber. This chamber is centrally located to the operations on the main test level so personnel will have a safe, controlled area to wait for evacuation if needed. As the long lateral drifts are extended away from the dedicated test area, additional refuge areas may be included for personnel working in areas remote from the ramps. The refuge chambers are equipped with emergency utilities and communications and are airlocked to provide a controlled atmosphere.

Operational aspects of the ESF related to safety include (1) the control of the traffic patterns to limit areas where personnel and heavy equipment must work at the same time, (2) the control and isolation of potentially hazardous areas such as the shops and equipment handling areas, and (3) the isolation of the shaft stations where dumping and mucking operations are concentrated.

As just discussed, the design process for both the surface and underground operations has considered safety as a paramount issue both through enforcement of codes and regulations in the design and through additional design constraints imposed to enhance safety of the project.

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8.4.3 POTENTIAL IMPACTS OF SITE CHARACTERIZATION ACTIVITIES ON POSTCLOSURE PERFORMANCE OBJECTIVES

This section evaluates the potential impacts of the site characterization activities (as summarized in Section 8.4.2.2 and 8.4.2.3) on postclosure performance objectives and determines whether any of the activities might preclude the site from meeting those performance objectives. Both the Nuclear Waste Policy Act and 10 CFR Part 60 request an analysis of characterization activities that could affect the waste-isolation capabilities of the site. Because the unsaturated zone at Yucca Mountain is the primary repository system element the DOE expects to rely on in demonstrating the waste-isolation capabilities of the site, considerable attention is given to the potential for impacts on the performance of this natural barrier.

Section 8.4.3.1 presents the postclosure objectives that will be addressed and discusses the approach to assessing potential performance impacts from site characterization activities. Section 8.4.3.2 presents information that is pertinent to evaluating the impacts of site characterization activities on site conditions and, subsequently, on the long-term performance of the site. The potential impacts of activities that could affect the postclosure performance objectives are evaluated in Section 8.4.3.3.

[NOTE: The evaluations of potential impacts contained in the sections that follow were conducted for the ESF configuration, construction method, and testing layout described in the SCP. These evaluations need to be conducted for the reference ESF design concept shown in Figure 8.4.2-3. These sections will be revised when the evaluations are available. These sections are being included unchanged because, while the details of the evaluations will be different for the new design concept, the overall methodology and considerations for conducting the evaluations will be similar.]

8.4.3.1 <u>Introduction to postclosure performance objectives and approach to performance assessment</u>

Subpart E of 10 CFR 60 describes the total system performance objective and three subsystem performance objectives for the postclosure period. The subsystem performance objectives are

> 10 CFR 60.113(a)(2): The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other time as may be approved or specified by the Commission.
>
> 10 CFR 60.113(a)(1)(ii): ...the engineered barrier system shall be designed, assuming anticipated processes and events, so that:
>
> (A) containment of HLW [high-level waste] within the waste packages will be substantially complete for a period to be determined by the Commission taking into account factors specified in

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60.113(b) provided, that such period shall not be less than 300 years nor more than 1,000 years after permanent closure of the geologic repository;

(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.

The total system performance objective is

> 10 CFR 60.112: 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...standards...established by the Environmental Protection Agency.

The standards referred to in 10 CFR 60.112 are given in 40 CFR Part 191 and are now being revised by the Environmental Protection Agency. These standards require that the design of disposal systems provide a reasonable expectation that, for 10,000 years following permanent closure, cumulative releases of radionuclides to the accessible environment from all significant processes and events that may affect the geologic repository shall (1) have a likelihood of less than one chance in 10 of exceeding quantities calculated according to Table 1 of Appendix A to 40 CFR 191, and (2) have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated in accordance with that table.

Hereafter, for convenience, these four performance objectives will be referred to, respectively, as the ground-water travel time (GWTT) performance objective, the EBS release rate performance objective, the waste package containment performance objective, and the total system release performance objective.

In addition to addressing the four postclosure performance objectives, the evaluations in this section address or consider other regulations that are relevant to performing site characterization activities. For example, 10 CFR 60.15 lists requirements that address site characterization activities; and parts 60.133, 60.134, and 60.135 of title 10 list additional postclosure design criteria for the underground facility that may be relevant, with respect to construction, testing, and operation of the ESF, in evaluating potential impacts to postclosure performance objectives. In particular, Section 8.4.3.2.4 describes design features that address regulations listed in 10 CFR 60.133, 60.134, and 60.135 and that may

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contribute to the postclosure performance of the site. The evaluations in this section do not explicitly address the siting criteria of 10 CFR 60.122. Postclosure performance Issue 1.8, Section 8.3.5.17, addresses the NRC siting criteria. The strategy for resolving this issue ensures that the overall system performance assessment considers the site characteristics that are the basis for the NRC's siting criteria.

The regulations specify multiple performance objectives to stimulate a defense-in-depth, or multiple-barrier, philosophy. Using this approach, the performance of the repository system will be obtained from both natural and engineered barriers. The GWTT performance objective is specified to ensure that the natural geologic formations of a site, with its current hydrologic conditions (i.e., before waste emplacement or construction), will have long ground-water travel times to the accessible environment and that the travel time along any likely potential radionuclide path will not be less than 1,000 years. The performance objectives for container lifetime and EBS release rate were formulated to ensure that the engineered components of the system (associated with the waste form) will contribute some performance to the overall system, providing an additional barrier to radionuclide release. The total-system-release performance objective is the overall performance objective; it designates the limit on the probability of release of radioactivity to the accessible environment over a 10,000-year period. The total-system-release performance objective must consider all significant processes and events that could occur over the 10,000-year period.

To identify and quantify the potential impacts of site characterization activities on postclosure performance of the site, the elements of the system that are important to evaluating the performance objectives must first be identified. The issue-resolution strategies of each postclosure performance issue define the components of the repository system that will be relied upon to contribute to performance in assessing the degree of compliance with the four performance objectives. The issue-resolution strategies for the four postclosure performance objectives are summarized in Sections 8.4.3.3.1 through 8.4.3.3.4 before potential impacts to the objectives are evaluated. For more discussion on the issue-resolution strategies for the performance objectives for total-system-release, container lifetime, EBS release rate, and GWTT, see Sections 8.3.5.13, 8.3.5.9, 8.3.5.10, and 8.3.5.12, respectively.

The unsaturated zone (as discussed in Section 8.4.1.3) at Yucca Mountain is the primary repository-system element that the DOE expects to rely on in demonstrating the waste-isolation capabilities of the site. Both the GWTT and the total-system performance objectives rely on the unsaturated Calico Hills nonwelded unit as the primary barrier. The container-lifetime objective based on the postemplacement environment of the waste package (the unsaturated Topopah Spring welded unit), as well as the waste container and the waste form. The EBS-release performance objective relies on both the engineered environment to control water contact with the waste and the waste form itself. In general, the primary manner by which site characterization activities could affect postclosure performance would be by altering the hydrologic or geochemical environment at Yucca Mountain. The evaluations made in Section 8.4.3.3 focus on changes to the hydrologic environment and how performance might be affected by those changes. Changes to the geochemical, geological, thermal, and mechanical environment are also considered as appropriate; the significance of most of these changes, however, lies primarily in their potential effects on the hydrologic environment.

8.4.3.1.1 General approach to performance assessment

Conceptual and mathematical models will be developed by the site characterization programs and will be the bases for the analytic techniques used to make performance assessments of the Yucca Mountain site. Preliminary work has been performed to develop the alternative models of the site, the conditions currently considered in expected and unexpected scenarios, and the evaluations to date of how this system is predicted to behave with respect to the performance objectives in 10 CFR Part 60. This information has been documented in Chapters 1 through 7, and in Sections 8.3.1 through 8.3.5. Chapters 1 through 7 provide information on the natural and engineered components of the repository system. Section 8.3.1 discusses planned site characterization activities and the alternative hypotheses, or models, that the site activities will address. Sections 8.3.2 through 8.3.5 discuss the issues and proposed issue-resolution strategies to address the pertinent regulations.

An ongoing process of performance allocation has been initiated to identify the specific information considered necessary by preclosure and postclosure performance assessment to address the issues described in Sections 8.3.2 through 8.3.5. The site characterization program, described in Section 8.3.1, will provide the descriptions of the natural and engineered systems, physical processes, material properties, and boundary and initial conditions that are required to assess the performance of the Yucca Mountain repository system. Uncertainties in the provided information will be identified and quantified when possible. Performance assessments of the repository system will use the information to determine whether specific issues, related to regulatory requirements, can be resolved.

Because performance assessments will always be made to address specific issues, the models and information provided by the site characterization programs may be broader in scope than is required to resolve the issues. The process of performance assessment will often entail the simplification of models provided by the site characterization programs through the use of sensitivity analyses, bounding analyses, and uncertainty analyses. The simplified models will comprise the significant elements of the more general models to assess the performance of the repository system. For example, the hydrologic model for the unsaturated zone developed in the site characterization program will include descriptions of both liquid and vapor movement. If sensitivity and bounding analyses indicate that vapor movement does not significantly affect liquid water movement, it may be possible to use a simplified performance-assessment model that only includes phenomena of liquid water movement to evaluate the pre-waste-emplacement ground-water travel time performance objective. The more general site characterization models will be important for testing hypotheses, investigating coupled processes, and ensuring that no significant processes or conditions are being overlooked.

The performance-assessment models developed will be used to determine values for the performance and design measures identified within the specific issues in Sections 8.3.2 through 8.3.5. The analyses may be deterministic or probabilistic; probabilistic analyses will be needed to assess the uncertainties in the measures used to resolve the issues. Professional judgment, based on both site-specific and nonsite-specific information, will be used to evaluate the performance and design measures.

The models considered in assessing the performance of the site and developing issue-resolution strategies have been described in Chapters 1 through 7, in Section 8.3.1, and under the various issues addressing the performance objectives. Because of the importance of the hydrologic conditions to assessing postclosure performance, the important hydrologic conditions and processes in the unsaturated zone at Yucca Mountain were described earlier in Section 8.4.1.3. A number of site characterization activities involve excavations in the unsaturated zone, and the considerations, discussed in Section 8.4.1.3, related to the possible effects of such excavations are summarized here.

1. Liquid-water flow occurs predominantly in the unsaturated rock matrix. Neither large-aperture fractures nor the excavations are expected to be conduits for water flow in the unsaturated zone under existing conditions. Fractures and excavations, however, must be examined as potential pathways for gas-phase, including water-vapor, movement.

2. Excavations will be backfilled with crushed tuff. The properties of this backfill will be such that, under expected conditions, it will also be unsaturated. This backfill will inhibit gas-phase flow and flow of surface water that might have access to these excavations. Water entering the backfill would be expected to be imbibed into the rock matrix.

3. If fluids are introduced into excavations during site characterization operations, these fluids are expected to be dispersed into the available rock matrix pore space within relatively short distances from the excavations. Furthermore, although localized flow in fractures could result from injected fluid, this flow would be ultimately imbibed and dispersed within the rock matrix.

4. Data from site characterization activities are required to determine the validity of the descriptions of conditions and processes at the site given in items one through three. The large uncertainties in the preliminary assessments of site performance cannot be quantified without data from site characterization activities.

These interpretations of current data are based primarily on physical concepts of unsaturated flow in a porous, fractured rock such as the rock at the repository horizon at the Yucca Mountain site. Continuous reevaluation of these interpretations will occur during site characterization as alternative models for unsaturated flow at Yucca Mountain are refined (Section

8.3.1.2.2). Furthermore, many aspects of alternative models of hydrologic behavior have already been considered in the evaluations of the potential impacts for both the nominal and disruptive scenario classes discussed in Section 8.4.3.3.1.2.

8.4.3.1.2 Approach to assess the potential impacts of site characterization activities on the performance of the repository system

The approach taken to evaluate potential impacts of site characterization activities on performance is first to determine how each category of activity in both the surface-based testing and ESF testing programs could affect the thermal, mechanical, geochemical, and hydrological conditions at the site. Second, the potential impacts on the postclosure performance objectives from these modified conditions are determined. Only those activities that will be performed within the repository conceptual perimeter-drift boundary will be considered. The effects on performance of the site from activities outside the site boundaries are expected to be much smaller than effects from similar activities occurring within the site boundaries.

The credibility of these and all other performance assessments of the repository system relies heavily on the degree of knowledge of the behavior of its important components. For the postclosure performance objectives, the major component, or barrier, important for assessing compliance with the regulations is the unsaturated zone. Little data is available that provides site-specific information on the hydrologic conditions and processes for the unsaturated zone at Yucca Mountain. Thus, a unique or completely defined model for the unsaturated zone cannot be constructed at this time. Eventually, the evaluation of potential impacts of site characterization activities on site performance will entail the application of well-developed fluid-flow and solute transport models. Specific models will differ with respect to the underlying conceptual model, the hydrologic-property data used, the boundary and initial conditions imposed, the system geometry assumed, and the hydrologic and other physical processes on which the models are based. The models will be designed to provide the most reliable estimates of site characterization impacts on specific performance measures that can be obtained from the quantity and quality of the available input data and parameters. Stochastic modeling techniques, coupled with the techniques of classical statistics or of geostatistics, can be used to estimate the uncertainties associated with the model calculations. In addition, sensitivity analyses will be performed for selected model parameters to estimate bounding or asymptotic limits. Such analyses are intended to provide conservative estimates of the uncertainty introduced by site characterization disturbances of the system in addition to the total uncertainty associated with the assessment of both postclosure and preclosure site performance. Without carrying out site characterization activities, the uncertainty in current estimates of the performance of the site generally cannot be quantified. For this reason, many of the analyses reported in Section 8.4.3.2 attempt to bound these uncertainties.

In addition to the conservative analyses used to assess possible effects of site-characterization activities, the DOE is taking a conservative approach to conducting site characterization itself. Because changes to the

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unsaturated hydrologic characteristics of site may potentially have the most significant impact of the long-term performance of the site, fluid and material usage will be strictly controlled. Fluid amounts will be limited to the extent practicable, and all water used will be tagged with a tracer so that possible changes to the site hydrologic conditions can be detected and monitored. The location of the exploratory shafts has been selected to preclude any significant impact on waste isolation, and construction methods will be used that will limit changes to the mechanical and hydrological properties of the site. These physical actions to be taken during site characterization are believed to limit, to the extent practicable, the potential deleterious impacts to the ability of the site to isolate waste.

Chapters 2, 3, and 4 contain the basic data describing the thermo-mechanical, hydrological, and geochemical conditions of the site. Section 8.4.3.2 draws on this information and on other analyses to describe how these conditions might be altered by the site characterization activities. This information is then used in Section 8.4.3.3 to evaluate the potential impacts of each category of site characterization activity on each postclosure performance objective. Potentially the most significant effects on site post-closure performance would occur because preferential pathways were created or the saturation distribution was altered by adding or removing water from the site. Therefore, the information presented in Section 8.4.3.2 focuses on the potential impacts on the unsaturated zone at Yucca Mountain to support evaluations in Section 8.4.3.3.

The site characterization activities are summarized in Section 8.4.2.2 (surface-based activities) and Section 8.4.2.3 (subsurface-based activities). In this section (8.4.3) the activities are grouped into five types:

1. Surface-related activities (e.g., pavements, trenches, ponding tests, road construction, dust control, drill-pad construction).

2. Drilling activities (e.g., boreholes).

3. Exploratory-shaft construction.

4. Underground construction of drifts and testing alcoves.

5. Testing activities in the exploratory shaft facility.

These categories of site characterization activities affect the chemical, hydrological, and thermomechanical conditions of the site in a similar manner because the penetrations and use of fluids and materials are similar. The significance of disturbances to the site conditions are evaluated, with respect to the four postclosure performance objectives. Disturbances are judged significant only when they are of such magnitude that they could potentially affect the capability of the site to meet the regulatory requirements of 10 CFR Part 60.

In Section 8.4.3.3, each of the four postclosure performance objectives is considered in evaluating the disturbances to the site conditions caused by the site characterization activities. The performance measures defined for the performance objectives are used in determining whether the disturbances are significant. A brief summary of the issue resolution strategy for addressing each performance objective is provided. The strategies identify the performance measures for the performance objectives. An extensive evaluation and discussion of the potential impacts of site characterization on the total system release performance objective is provided in Section 8.4.3.3.1, due to the implications of this performance objective for both natural and engineered barriers. The total-system-release performance objective must consider potential impacts from the site characterization activities on credible processes and events that could occur over the 10,000-yr period following closure. The processes and events discussed in the issue resolution strategy of the total-system-release objective (Section 8.3.5.13) are explicitly considered in evaluating the potential effects of the categories of site characterization activities on that performance objective.

8.4.3.2 Supporting technical analyses and data

Analyses and data that evaluate potential impacts of site characterization activities on postclosure performance are summarized in this section. Although this section does not include all the information that will be used in the evaluations of Section 8.4.3.3, it does provide a representation of the quantitative site-specific information used to make the evaluations. These evaluations are based on preliminary hydrologic and physical-property data and on simplified conceptualizations of the hydrologic and physical processes operating within the unsaturated zone at the site. The information is divided into sections on hydrological information, geochemical information, and thermal/mechanical information. After these summaries, the information is used in Section 8.4.3.2.5 to estimate the perturbations to site conditions from the categories of site characterization activities described in Section 8.4.2. This discussion distinguishes between short-term, transient effects (e.g., controlled water use during drill-and-blast operations) and long-term, permanent changes (e.g., the creation of preferential pathways) that may affect the ability of the site to meet the postclosure performance objectives.

8.4.3.2.1 Hydrologic analyses and data

Hydrologic analyses and data that will be used in discussions of the potential impacts of site characterization activities on postclosure performance are summarized in this section. The hydrologic information is subdivided into sections on water infiltration from the surface (8.4.3.2.1.1), ground-water flow in matrix and fractures (8.4.3.2.1.2), redistribution of water retained in the unsaturated zone (8.4.3.2.1.3), and the movement of water vapor and air (8.4.3.2.1.4). In general, the information discussed will be used to infer how far water introduced from site characterization activities might penetrate into the rock formations, what the change in hydrologic conditions might be, how long these changes take to occur, and how long the change in hydrologic conditions might persist.

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Specific topics to be examined include changes in the magnitude and areal distribution of ground-water flux, changes in the distribution of hydrologic properties, and the creation of preferential pathways for radionuclide migration.

8.4.3.2.1.1 Water infiltration from the surface

Site characterization and surface-preparation activities will cause some changes to the surface and possibly subsurface portions of Yucca Mountain. Site-specific analyses and data that are summarized indicate the potential effects on the site hydrological conditions caused by applying water to the surface of Yucca Mountain. From this information, the following discussion develops preliminary inferences on how water from the surface is likely to infiltrate into the unsaturated zone at the site, on the time required for this water to reach the repository horizon, and on the possibility that surface water might reach the repository after entering an exploratory shaft. The inferences are numbered for ease in cross-referencing.

1. Low net infiltration. Net infiltration is that flux of water entering the unsaturated zone below the surficial plant-root zone and below that soil horizon from which direct evaporation of soil moisture into the atmosphere can occur. Net infiltration at the Yucca Mountain site is expected to be low because, under present conditions, the average annual precipitation is estimated not to exceed 150 mm (Quiring, 1983). The estimated potential evapotranspiration rate is on the order of 1,500 to 1,700 mm/yr (Kohler et al., 1959). Consequently, most of the precipitation received at the surface of Yucca Mountain probably is returned to the atmosphere.

Significant infiltration into the unsaturated zone, if any, probably occurs during infrequent floodwater runoff produced by isolated major storms. Surface runoff will tend to be concentrated into alluvial channels and basins or, possibly will be diverted into fault zones and fractures that could be favorable sites for infiltration. This hypothesis is being tested by detailed mapping of surficial materials at the site, artificial rainfall and surface-ponding experiments, and neutron moisture logging in a set of 74 boreholes distributed over the site (Section 8.3.1.2.1.2). The data from these activities will permit estimates of present-day net infiltration rates, the most probable maximum infiltration rates, and the probable areal distribution of net infiltration over the surface of the site.

Moisture contents measured to date by borehole neutron logging are consistent with the high potential for evapotranspiration, the relatively low annual precipitation, and the hypothesis of low net infiltration rates into the unsaturated zone under present conditions.

2. Effects of surface ponding. To evaluate situations that could result in deep percolation under present conditions, (Peters, 1988) simulated the potential effects of surface ponding on a fault zone at Yucca Mountain. The model for this analysis was a 1-D vertical column of hydrogeologic units defined by data from drillhole USW G-4. The model used the best available data for the hydrologic properties of these units. The initial pressure-head

distribution within the column was based on a constant flux of 0.1 mm/yr through the column, with the water table at the bottom of the column. The fault was simulated as a highly transmissive zone in which the saturated hydraulic conductivity of the fracture system in each hydrogeologic unit was increased by a factor of 10,000. The pond was given an initial depth of 10 m, and the pressure head at the surface of the pond was set to zero. The saturated conductivity of the uppermost unit was high enough that 10 m of water infiltrated the surface in 2.2 days. This slug of water traveled through the Tiva Canyon welded (TCw) unit and most of the Paintbrush nonwelded (PTn) unit during this time. The flux at the surface was set at 0.1 mm/yr after 2.2 days. Because there was not enough water in the injected slug to saturate the entire PTn unit, the flow in the upper Topopah Spring welded (TSw1) unit, immediately below the PTn unit and above the repository horizon, was limited to matrix flow. The water in the PTn unit slowly drained into the rock matrix of the lower units. The ground-water flux at the repository level did not change during the first 1,000 yr, but doubled during the time period between 10,000 and 100,000 yr, and returned to the initial conditions after about 200,000 yr. This calculation illustrates that a large short-duration perturbation at the surface, such as could be created by blockage of a wash, would be attenuated before reaching the repository horizon.

3. Water accumulation in the exploratory shaft. In another study of the entry of surface water, Fernandez et al. (1988) calculated an upper-bound estimate of the water flow into an unsealed, backfilled exploratory shaft from a major flooding event. This analysis evaluated the potential for water to accumulate in the shaft up to the level of the repository. At the currently proposed locations, the shafts will be collared in bedrock. The scenario analyzed by Fernandez et al. (1988) simulates ground-water flow in fractures that originates at the surface from flooding and intercepts the shafts and associated zones of modified permeability due to fracturing around the shafts at some depth below the surface. Because the shafts are located outside the channels for the probable maximum flood (PMF) storm, water is not expected to enter the exploratory shafts directly from the surface but could enter the shaft below the surface from water flow in fractures. To be conservative, the fracture network below the surface was assumed to easily communicate within the entire drainage basin, and water was not allowed to be imbibed into the unsaturated matrix tuff. These conditions allowed a greater volume of water to penetrate an exploratory shaft. Following a PMF, the analysis assumed that all the rainfall infiltrates into the ground either uniformly or only over a more restricted area defined by the existing water courses.

For these two cases, the total amount of water entering the two exploratory shafts was calculated to be 1250 m^3 and 1320 m^3 (330,000 gallons and 350,000 gallons), respectively. This calculation assumes no runoff and no imbibition of water from the fractures into the matrix. If these effects are included, the total water volume entering the exploratory shafts would more likely be one to two orders of magnitude less, or 10 to 100 m^3 (2,600 to 26,000 gallons) of water, respectively. Including the effects of shaft seals would, of course, reduce the volume of water even further. Fernandez et al. (1988) indicate that even the conservatively estimated volume of approximately 1,300 m^3 of water is well within the drainage capability of the sump

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at the bottom of the shaft. Fernandez et al. (1988) conclude that no water is expected to enter the repository through the shafts and contact waste material.

The above discussion leads to a question of the potential for accumulation of silt in the shaft sump. Accumulation of silt in the shaft sump is not expected to significantly reduce the drainage capability of the shaft for the following reasons:

a. It is within accepted engineering practice to engineer a backfill that is capable of preventing the migration of fine-grained material, such as silt (Khilar et al., 1985). This type of fines-migration barrier works on the principle of physical exclusion of fines whose median particle size exceeds one-third of the median pore or fracture size (Abrams, 1977; Herzig et al., 1970). For the exploratory shaft sump, the average fracture aperture is not expected to be smaller than about 6 microns (Section 8.4.3.2.1.2) so that particles smaller than 2 microns will pass through these fractures without causing any plugging of the shaft sump. According to the work of Khilar et al. (1985), a material whose hydraulic conductivity is 10^{-4} cm/s will retain these fines and prevent siltation.

b. The exploratory shaft is located in a region where direct inflow of water is not expected. This is because the selected location is significantly above the level of flow that would result from a probable maximum flood and very large changes in the flow would have to occur for water to directly enter the shaft. Hence, it is expected that the interstices of the rock backfill will be dry and there is a small likelihood that a mechanism for significant fines migration will exist after initial emplacement of the backfill.

c. The response of the unsaturated zone to periodic flooding events is to remove water rapidly from fractures and backfill interstices into the rock matrix. The zone in which saturated flow exists is limited, and even for the extreme case studied by Peters (1988) (see Item b above), this zone does not propagate below the PTn unit. Hence, a significant mechanism for the movement of fines to the base of the sump is not likely to exist.

d. Near-surface water diversion from the exploratory shaft pad and an anchor-to-bedrock plug seal will further limit interstitial water movement within the exploratory shaft backfill.

e. The long distance transport of silt through the shaft seals to the base of the shaft is not expected since seals will likely block the movement of all but colloidal particles by the mechanisms mentioned in a. above.

In summary, under precipitation conditions similar to those occurring over the last four years, surficial water is not generally expected to move more than approximately 10 m downward through the porous alluvium and tuff with any measurable increase in saturation. The time required for a transient pulse of water to reach the depth of the repository horizon was esti-

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mated to exceed 1,000 yr. For flooding events, water from the surface might be expected to reach the repository horizon through a permeable feature (like a fault or unsealed shaft); however, the impact, if any, to hydrologic conditions at the horizon is expected to be localized and small. Information to support future evaluations will be obtained from Study 8.3.1.2.2.1.

8.4.3.2.1.2 Ground-water flow in matrix and fractures

As discussed in Section 8.4.1.3.1, for the current estimates of the ground-water flux through Yucca Mountain, the flow of water, if any, from land surface down to the water table will be primarily through the rock matrix. Many calculations have been performed for ground-water flow in the rock matrix; selected calculations that will be used in evaluating the potential impacts of site characterization on performance are presented in the following summary, which also discusses laboratory measurements of water flow in the matrix of Yucca Mountain tuffs. Any rapid movement of water through large distances in the rock units of Yucca Mountain would probably require flow through fractures or structures like faults. Analyses have been performed using a composite model that includes the effects of fracture flow and matrix flow (see Peters and Klavetter 1988). This model does not explicitly simulate water flow in discrete fractures. To investigate the flow of water in fractures, analyses have been performed that model a fracture explicitly. Modeling studies can be used to infer how far water from site characterization activities might penetrate into the tuff matrix and fractures, how much the saturation might change, and how much time is required before the locally changed conditions return to near-equilibrium with the rest of the site. The following summaries provide information relevant to the role of the matrix and fractures in unsaturated-zone flow. The summaries are numbered for ease in cross-referencing.

1. <u>Fracture aperture size</u>. Few data are available to describe the internal geometry and aperture distribution within fractures. Peters et al. (1984) report measurements of hydraulic fracture apertures of 6 and 67 micrometers for two fractured cored samples from the Topopah Spring welded unit and hydraulic apertures values of 6, 22, and 31 micrometers for three samples from the Calico Hills nonwelded unit. Olsson (1988) reports physical apertures of 50-70 micrometers for unstressed fractures. Zimmerman and Finley (1987) summarize measurements of hydraulic apertures in the G-Tunnel facility on the Nevada Test Site, which range from 16 to 240 micrometers with the mean value being 90 micrometers. Evans and Nicholson (1987) report fracture aperture values in the range of 10 to 50 micrometers in densely welded tuff in southern Arizona.

2. <u>Matrix hydraulic conductivity</u>. Hydraulic conductivity values for saturated tuff matrix material are reported in Section 3.9 of this document. The values for densely welded tuff matrix, like those for the tuff of the repository horizon, have been measured to be approximately 10^{-11} m/s. The values of nonwelded tuff matrix, except for the nonwelded zeolitic Calico Hills tuff matrix, have been measured to be approximately 10^{-7} m/s. The matrix hydraulic conductivity of the nonwelded zeolitic Calico Hills tuff matrix has been measured at approximately 10^{-11} m/s.

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3. Simulation of matrix response to increases in flux. Peters (1988) performed two sets of simulations of matrix flow. The simulations used a 1-D vertical column with the hydrologic stratigraphy based on data from drillhole USW G-4. The initial saturation levels were established by modeling a 0.1 mm/yr vertical ground-water flux through the column. The first simulation calculated the penetration of water into the rock matrix of the Topopah Spring welded unit at the repository horizon, here designated TSw2, when a boundary pressure head of 30 psi was applied for times between 1 and 100 minutes. These calculations were investigating the response of the matrix; therefore, fractures were not included in the model. The results indicated that the penetration was less than 5 cm into the matrix when using either saturated curves based on thermocouple psychrometer data (Klavetter and Peters, 1987) or saturation curves based on mercury-intrusion data (Rulon et al., 1986). The second set of calculations investigated the manner and rate at which changes in the percolation flux could propagate. The flux was changed from 0.1 mm/yr to 0.5 mm/yr. Steady-state conditions in the top meter of the column were reached in hundreds of years using saturation curves for the matrix based on mercury-intrusion data, and in tens of thousands of years, using saturation curves for the matrix based on thermocouple psychrometer data.

4. Experimental data on matrix response to increased flux. Peterson et al. (1988) investigated the movement of water into tuff when a short (100 minute) 0.2-MPa water pulse was applied to a tuff sample. The movement of the water into the tuff sample, both during and after the water pulse was measured. As a result of the water pulse, changes in the initial saturation level after one hour were detected to a depth of approximately 1 cm. The saturation profile was measured for 21 days after the water pulse was terminated; at 21 days, measurable changes to the matrix saturation could be detected to a depth of approximately 2 cm.

5. Effects of changes in flux on travel time. Analyses of the change in water travel times resulting from changes in flux at the repository level were performed by Peters (1988), using a one-dimensional vertical column and a composite model of the fractures and matrix (Peters and Klavetter, 1988). Two water-flux histories were used in these analyses. One analysis used a water flux of 11 mm/yr for the first 90 years, 0.0 mm/yr between 90 and 1090 years, and 0.1 mm/yr until 1 million years. A second analysis used a water flux of 11 mm/yr for the first 90 years and 0.1 mm/yr until 1 million years. These calculations investigated the effect of water leaving the repository on water-particle travel times to the water table. Water particles were released throughout the column at a number of times, and the time required to reach the water table was calculated. The results indicated that there was a decrease in travel times for particles released during the first 90 yr into the zone near the repository. Their calculated travel times, however, exceeded 300,000 yr.

6. Effects of increased flux on saturation. A set of calculations was performed to investigate the possible effects of increased flux on flow characteristics in a layered, unsaturated system (Dudley et al., 1988). These calculations modeled a 1-D vertical column with the hydrogeologic units defined by data from drillhole USW G-4 using the composite fracture-matrix model (Peters and Klavetter, 1988). Both zeolitic and vitric properties for the Calico Hills unit were used. The steady-state saturation distribution

was calculated for ground-water fluxes of 0.1, 0.5, and 4.0 mm/yr. For a flux of 0.1 mm/yr, the water percolated through the matrix over the entire length of the column. At a flux of 0.5 mm/yr, the water also percolated through the matrix over the entire length of the column. For a flux of 4.0 mm/yr, the water flowed through the fractures throughout most of the length of the column. Using the initial saturation levels calculated at fluxes of 0.1, 0.5, and 4.0 mm/yr, transient calculations were performed at twice the initial flux. These transient calculations indicated that the time required to change from the initial steady-state condition at a flux of 0.1 mm/yr to a steady-state condition of 0.2 mm/yr was hundreds of thousands of years. However, the change from a steady-state conditions at 4.0 mm/yr to a steady state at 8.0 mm/yr was calculated to require only a few years.

7. Rate of change of water table after major water-table rise. Two calculations were performed by Peters (1988) to simulate the drainage of water after a major water-table rise using the composite fracture-matrix model (Peters and Klavetter, 1988). For one calculation, the water table was modeled to rise to the bottom of the TSw1 unit, and for the second calculation, the water table was modeled to rise to the land surface. For the flooded regions, the pressure head was set equal to -1 m. Except for the flooded region, the initial saturation was established by modeling a 0.1-mm/yr percolation flux through a 1-D vertical column with the hydrogeologic units defined by data from drillhole USW G-4. Following the water-table rise, the ground-water flux at the top of the unsaturated zone was set equal to 0.1 mm/yr. These calculations investigated the time necessary for water to drain from the flooded regions. After 10,000 years, the hydrologic conditions were still far from steady state in both calculations. At 10,000 years, the flux throughout most of the column was at least a factor of 10 more than the steady-state flux. For each calculation, about 200,000 yr was required to reach steady-state conditions.

8. Flux penetration into discrete fractures. Martinez (1988) analyzed capillary-driven water flow in a single discrete vertical fracture transecting a porous-media-representative of the hydrogeologic units at Yucca Mountain. Capillary-driven immiscible displacement of air by water along the fracture was induced by an abrupt change in water saturation at the fracture inlet. A 30-minute infiltration period was simulated for a 25-micrometer fracture, and moisture penetrations of 40 cm into a fracture in the Topopah Spring unit and 80 cm into the Tiva Canyon unit were calculated. Calculations for a 100-micrometer fracture with a 30-minute infiltration period indicated penetrations of 4.9 m and 9.8 m for Topopah Spring and Tiva Canyon units, respectively. Calculations are ongoing to investigate penetrations into fractures of different-sized apertures and using different inlet conditions.

9. Effects of drilling fluid on fracture-matrix saturation. The possible impact of drilling with water on the subsequent hydraulic behavior of a fracture-matrix system in a welded tuff was simulated numerically by Kwicklis and Hoxie (1988). The model simulated a block of Topopah Spring welded tuff (TSw2) that was bounded on one side by a vertical fracture whose hydraulic aperture was set equal to 24 micrometers. The initial matrix saturation was assumed to be 0.65, which corresponds to a pressure head of -11.0 m. The fracture was simulated as an equivalent porous medium whose hydrologic properties were analogous to those of a coarse sand. Initial

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equilibrium between the matrix and fracture was assumed. Analyses were performed with an imposed upper-boundary pressure head of either 0.2 m or 20 m for 1 hour at the surface of the TSw2 block. At the end of a 1-hour simulation time, the fracture was predicted to be saturated to a depth of about 0.5 m for the 0.2-m boundary pressure head. The depth of saturation within the fracture was calculated to increase to 2.1 m when a 20-m boundary pressure head was applied to the top of the block. If the fracture aperture was increased to 250 micrometers and the boundary pressure head was set equal to 0.2 m for 30 minutes, the calculated saturated depth within the fracture was 55 m. The relatively small amount of water contained in the fracture was quickly imbibed into the matrix. About 10 hours after the water was injected into a 24-micrometer fracture at a boundary pressure head of 20 m, the fracture saturation returned to within 0.05 saturation units of the initial value. The return to the initial saturation level for the matrix took longer, in that at 0.1 mm from the fracture-matrix interface, the saturation was predicted to be 0.80 (the initial value was 0.65) after 24 hours. Several weeks were predicted to be required for the matrix to return to near-initial conditions.

10. Second analyses of effects of drilling fluid on fracture-matrix saturation. Bodvarsson et al. (1988) investigated the effects of drilling with gas and liquid water on fracture and matrix hydrologic conditions. The model used in these analyses simulated a block of Topopah Spring welded unit (TSw2) bounded on all sides by fractures. A fracture aperture of about 100 micrometers and a fracture spacing of 0.6 m were used. The initial saturation conditions were established by infiltrating a flux of 0.1 mm/yr through the model. An upper-boundary pressure head of 20 m of water head was placed on the system for 12.25 minutes to represent water drilling for most of the simulations. A water flux of 0.1 mm/yr was assumed after the boundary pressure head was removed. Water penetrated a vertical fracture to a depth of about 11.5 m. After simulated drilling stopped (12.25 minutes of the boundary pressure head), the fracture saturation returned to its initial value within in a few hours. In the matrix, the saturation returned to within 3 percent of the initial saturation within one month. These relatively short times to return to near initial conditions are because of the small change in the volume of water in the matrix and fractures in a local area. Similar results for the fracture penetration were calculated for a horizontal fracture.

11. Experimental results on matrix wetting. The isothermal imbibition of liquid water into initially dry (saturation <0.05), welded tuffaceous rock was measured by Reda (1986). The rock sample contained several microfractures transversely oriented to the direction of the wetting-front propagation. Water was forced into both ends of the sample at a pressure of 0.46 MPa, and water movement through the pore volume was monitored for 624 hours. The apparent maximum distance of detectable penetration of the liquid water after 29 hours was approximately 8 cm; after 97 hours, the distance penetrated was about 10 cm. The transverse microfractures slowed liquid water movement.

12. Field observations on drilling fluid migration. An apparent flow of drilling fluids from borehole USW G-1 to the vicinity of borehole USW UZ-1 has been observed (Whitfield, 1985). This possible occurrence of fluid movement between the two wells is indicated by the presence at USW UZ-1 of polymers that were used in the drilling of USW G-1 (Spengler et al., 1981). USW UZ-1 is located 305 m northwest of USW G-1 and was drilled approximately 3 years after USW G-1. Understanding how the water-polymer mixture moved so quickly at the site is important to understanding the processes and developing models for flow that are required to perform performance assessments of the site. Water, Waste & Land, Inc. (1986), in an unpublished report to the Nuclear Regulatory Commission, discusses some preliminary evaluations of the water flow between the two wells. Their analyses show that water flow through a single fracture under the influence of large pressure heads (2.7 MPa or 277 m of water head) can move over 300 m in 3 years. These results are similar to those presented in analyses just described. To prevent such fluid movement, future drilling operations, described in Section 8.4.2.1, will use dry-drilling techniques to the extent practical, will control water usage, and will not allow high heads of water to develop such as occurred in USW G-1.

The unpublished report, previously cited, also suggested that a perched-water zone may exist at the USW UZ-1 location or that the piezometric surface may be higher than indicated in Chapter 3 at well USW UZ-1 because of a discontinuity between the two wells. This hypotheses will be investigated by Activity 8.3.1.2.2.3.2. The evaluations also question the drainage capacity of the unsaturated Topopah Spring unit around USW UZ-1. If the piezometric surface is indeed higher than previously estimated, the bottom of the well may be within the saturated zone, and the data would not provide definitive information on the drainage of the unsaturated zone.

13. Fluid loss in borehole USW G-4. Compared with other fluid losses from existing holes, a relatively large amount of fluid was lost during the drilling of USW G-4. The borehole was drilled using an air-water-detergent mixture as drilling fluid and up to 343,000 gallons of this mixture were lost to the unsaturated zone during drilling operations. A full accounting of the fluid loss is problematical because of the presence of the detergent. The detergent would tend to reduce the surface tension of the fluid and, therefore, would inhibit imbibition of the fluid into the surrounding rock matrix. On the other hand, the detergent would enhance the physical adsorption of drilling fluid on exposed surfaces such as the borehole walls, and some of the fluid probably would be adsorbed into fractures that were intersected by the borehole. Because the drilling fluid was injected into the borehole under low head values, the depth of penetration of drilling fluid into fractures probably would be small. Following borehole completion, most of the adsorbed water would tend to drain back into the borehole as was indicated by a televiewer log that was run in the borehole two days after borehole completion. Consequently, it is reasonable to assume that most of the drilling fluid lost within the unsaturated zone would drain back into the borehole and flow downward to the water table, with only a small fraction of fluid actually being retained within the unsaturated zone.

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The information summarized in this section suggests that water introduced under low pressures for relatively short times (as during the planned drill-and-blast operations) will move only a short distance (a few centimeters) into welded tuff matrix material. Because of the small volume of water that the matrix will accept, matrix saturation is likely to return to near-initial conditions within several weeks. For nonwelded tuff matrix with higher permeability, the distance of penetration would be somewhat higher and the time to return to near-initial saturation conditions shorter. The distance that water would be expected to travel in a fracture is highly dependent upon the fracture aperture, the water pressure head, and the period of time for which the fracture is exposed to the water. For average values of fracture apertures that are considered reasonable at the repository depth and below, and for relatively low pressures, the distance of water movement through the fracture is expected to be approximately 10 m or less. Because some fractures with large apertures will probably be present, the DOE expects that water will move several tens of meters in localized areas. The volume of water moving through an individual fracture will be relatively small and the estimated time for the water to be imbibed back into the tuff matrix is short (hours to days). The overall change to the rock saturation would be generally small. Data from USW UZ-1 (see number 12 above) suggest that a large volume of water can move a large distance through the extensive fracture networks at the site if extremely large water pressure heads are imposed. If air-water-foam drilling fluid mixtures are used, however, little of the water introduced during drilling operations may be retained within the unsaturated zone. Nevertheless, water use during drilling and shaft construction will be strongly controlled (see Section 8.4.2) during site characterization activities.

The summaries also indicate that ground-water travel times are long and that the time required for transients to propagate through the system may be hundreds of thousands of years when the system is initially unsaturated. According to some analyses, increasing the steady-state ground-water flux by a factor of 2 may also mean that long times will be required for the system to reach the new steady-state condition. The Peters (1988) study (see number 5) predicts that short-term changes (90 years) in ground-water flux at the repository level will not significantly affect the long ground-water travel times that are predicted.

Section 8.3.1.2.2 describes several studies that will investigate water movement in the porous, fractured tuffs at Yucca Mountain through laboratory and in situ experiments and modeling. The effects of transients on the hydrologic system will also be investigated.

8.4.3.2.1.3 Redistribution of water retained in the unsaturated zone

This section compares the quantity of water expected to be used during site characterization with the quantity of water present at the site in the interstitial pore space and with the quantity of water that is received annually on the site from precipitation. The following paragraphs summarize predictions of the extent of the potential changes in the average saturation of the rock mass in the disturbed portion immediately around an exploratory shaft. The predictions are numbered for ease in cross-referencing.

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1. Water introduced through surface activities. The amount of water that will be used during site characterization activities is small compared with the amount of precipitation that is received annually on the site. Surface-based site characterization activities are expected to disturb approximately 10 percent of the surface area within the conceptual perimeter-drift boundary (CPDB) (Section 8.4.2.2). The Project has applied for a maximum water use of 131 million gallons over 6 years. Actual water use is expected to be somewhat lower (approximately 73.8 million gallons; Section 8.4.2.2.2). Therefore, a maximum of 131 million gallons of water could be introduced to the site during site characterization (assuming approximately 5 years of site characterization work), with approximately 68 percent (or 86.6 million gallons) of that total being used for dust control. The majority of the water used for surface activities is expected to be lost from the surface through evaporation. The impacts of water added to the surface by ESF pad construction activities on existing hydrologic conditions will be examined. If a need exists to determine the pre- and post-pad construction hydrologic conditions at the site of construction activities, then activities necessary to obtain information will be developed. Comparatively, an average of about 230 million gallons of water per year falls on the surface of the proposed site from normal precipitation (based on an annual precipitation rate of 150 mm/yr and an area of approximately 1,400 acres within the conceptual perimeter drift boundary (CPDB). Thus, an average value of approximately 23 million gallons of precipitation would be expected to fall on area within the CPDB disturbed by site characterization activities (about 10 percent of the area of the CPDB). For the surface area expected to be disturbed over a 5-year period of site characterization, over 100 million gallons of water will be applied. According to the pan evaporation rate of 1500 to 1700 mm/yr (Kohler et al., 1959), the volume of water within the CPDB introduced to the surface that could be accounted for by evaporation would be approximately 2 billion gallons per year. Because of the differences between evaporation from a free-water body and evaporation from soils, actual evaporation is expected to be less than this amount. However, the volume of water actually evaporated is expected to be a considerably larger volume than will be introduced to the surface of the site by either precipitation or site characterization.

2. Effect of water used during exploratory shaft construction. West (1988) has estimated that approximately 10 percent of the water introduced in the subsurface during shaft construction will not be recovered and is assumed to be retained within the unsaturated zone. To investigate the potential effects of the retained water on the in situ conditions, the potential distance this water could move and the effects on the initial saturation levels were analyzed. Peters (1988) calculated the potential changes in saturation that could result from the construction water retained during exploratory shaft construction. West (1988) estimated that 3.02 m^3 of water per meter of shaft depth and 1.65 m^3 of water per meter of drift length would be used during construction. Ten percent of the construction water was estimated to be retained in the rock. Calculations were performed for both shaft and drift geometries to determine the distance the retained construction water could move from the surface into the rock, assuming the water initially saturated the fractures and was not adsorbed into the matrix. The analyses assumed a uniform distribution of the retained water around the shaft and drifts. The distance the water would penetrate from the shaft wall depended on the effective porosity of the fracture. The farther the water

flowed in the fracture (as a result of decreasing fracture porosity), the smaller the change in the initial saturation level. The change in initial matrix saturation was 0.0017 at the proposed repository horizon. This occurred after equilibrium was established between the matrix and water-filled fractures. Doubling the water volume retained per unit length of shaft or drift would double the change in saturation.

3. Effects of water on the modified permeability zone. Peters (1988) analyzed the radial flow of water that may be retained around the exploratory shaft during construction. For these analyses, West (1988) estimated that 10 percent of the construction water was retained in the matrix around the shaft in the modified permeability zone (MPZ). The MPZ is the disturbed zone around the shaft and is expected to extend approximately 2.2 m into the rock mass (Case and Kelsall, 1987). The hydrogeologic units were defined by data from drillhole USW G-4, and the initial saturation values were assumed to be those corresponding to a constant 0.1-mm/yr vertically downward ground-water flux. The time-dependent, one-dimensional radial flow of the retained construction water into the rock matrix adjacent to a shaft liner was calculated by Eaton and Peterson (1988). The water was assumed to be in isothermal matrix/fracture equilibrium at all times. At the end of one year, the maximum change in saturation in the MPZ for the Topopah Spring welded tuff matrix was about 0.035 above the nominal value of 0.65. After two years, the saturation in the MPZ was 0.03 higher than nominal, with small changes in saturation (<0.005) calculated at 10 m from the shaft centerline. In all instances, the saturation increase at radial distances greater than 5 m from the shaft centerline (0.6 m from the MPZ) was less than 0.03. The largest initial increase in saturation in the MPZ from the retained construction water was 0.08 for the Tiva Canyon unit.

In summary, the volume of water to be introduced to the site during site characterization is comparable to the volume of water from annual precipitation. Global redistribution of water that will be retained in the rock from mining the shafts is not expected to significantly change the initial matrix saturation profile, either near the surface or at depth. The farther the water moves from the shaft wall, the smaller the change in the matrix saturation profile. Figure 8.4.3-1 shows the estimated change in matrix saturation as a function of distance from an exploratory shaft if the water estimated to be lost from construction is distributed uniformly around the shaft. If the construction water is initially retained in the MPZ, the radial movement into the matrix is estimated to be very slow and to produce very small changes in the initial ambient saturation distribution. As will be described in the next section, the amount of water retained in the unsaturated zone may also be significantly affected by ventilation of the underground repository or exploratory shaft openings.

8.4.3.2.1.4 Movement of water vapor and air

In addition to the possible removal of water vapor from the proposed repository environment by natural processes, water-vapor removal may be induced by human disturbances, such as boreholes and shafts. Chapter 3 indicates that barometric and topographic effects at Yucca Mountain may result in air and water-vapor exchange between the fractured tuffs in the

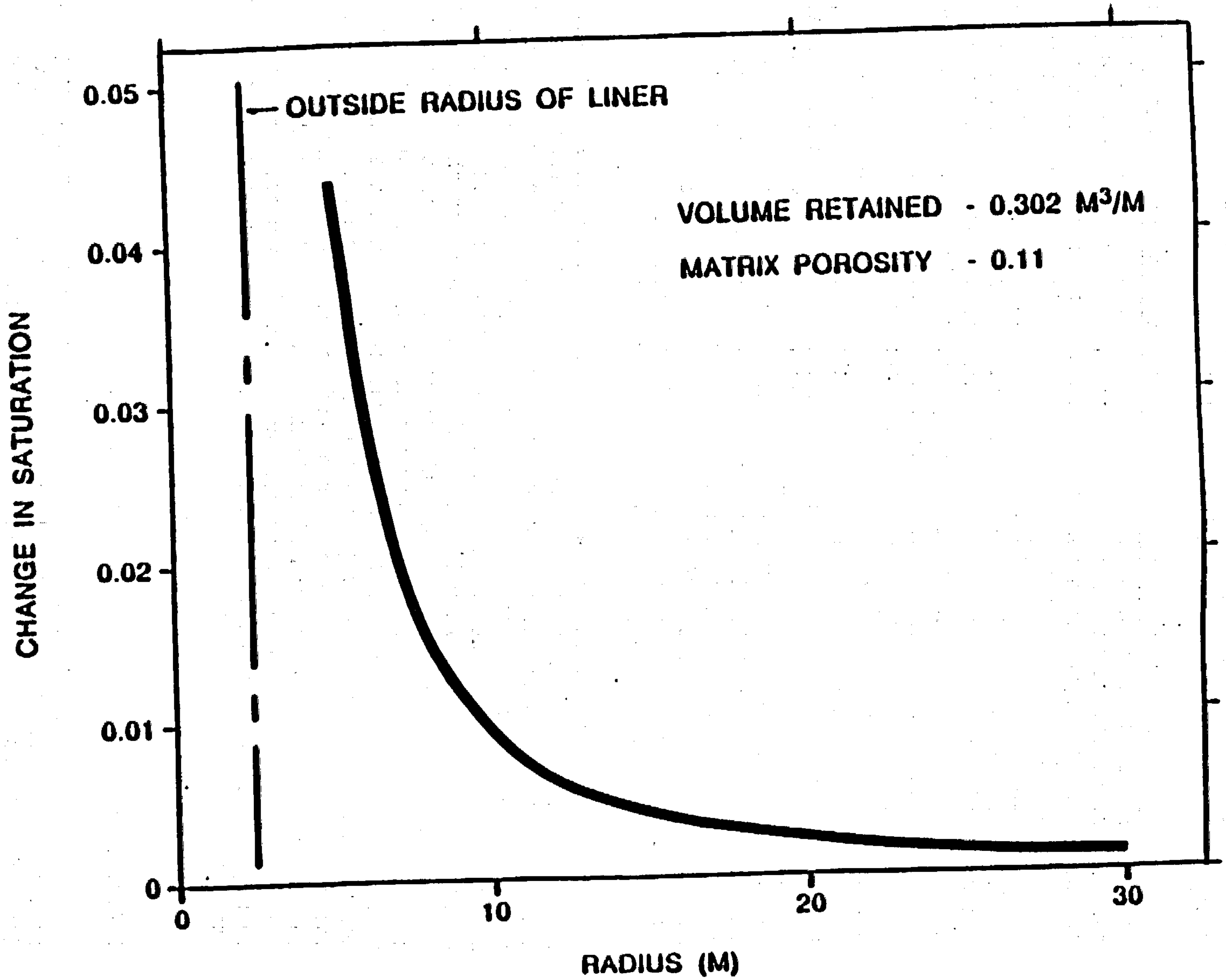

Figure 8 4 1 1 Effect of radius of area conta- tained construction water or change in saturation

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unsaturated zone and the atmosphere. Water-vapor flow from the unsaturated-zone has been observed to occur from an open borehole penetrating a fractured tuff horizon within the unsaturated zone (Weeks, 1987). Analyses have been performed to investigate the effects of this exchange, and are summarized in the following discussion. The ventilation system to be installed in the exploratory shaft facility will remove water vapor from the unsaturated zone. To investigate the potential effects of the ventilation system on the saturation level in the rock matrix, two calculations were performed. These analyses are also summarized in the following discussion. The analyses are numbered for ease of cross-referencing.

1. Water-vapor flow in an open borehole. Substantial air exchange between the atmosphere and two wells (USW UZ-6 and USW UZ-6s), located at the crest of Yucca Mountain and penetrating highly fractured welded tuffs, was observed by Weeks (1987). Well USW UZ-6 was drilled to a depth of 575 m; well USW UZ-6s was drilled to a depth of 158 m. During the winter, the wells exhausted air almost continuously at a velocity of about 3 m/s. During the summer, the wells alternately take in and exhaust air at much lower velocities than occur during the winter, and the flow directions typically reverse a few times a day. The cause of the air flow is presumably a consequence of both topographic and barometric effects. While topographic and barometric effects appear adequate to explain the air flow during summer, the magnitude of the air flow in the winter seems to exceed the flow that could be caused by these mechanisms. Naturally occurring air flow out of the unsaturated zone of the site would tend to dry the rock in the upper part of the unsaturated zone (for example, the upper 125 m of rock composed of the fractured Tiva Canyon welded unit) and could produce low liquid-water fluxes at the proposed repository horizon. No data are available, however, to indicate that air movement into or out of the unsaturated zone occurs at repository depths under natural conditions.

2. Air and water vapor flow. Kipp (1987) performed numerical analyses to investigate the effect of seasonal variations in air temperature at the surface of Yucca Mountain, coupled with topographic relief, on potential air and vapor flow in the unsaturated zone. Analyses cover the upper 150 m of the simulated mountain, and it was assumed that integrated, connected pneumatic pathways (for example, open fracture systems) existed through which air movement could occur. The calculated air-velocity fields and boundary fluxes indicated that minor atmospheric circulation can be induced through the mountain. For boundary conditions representative of summer conditions, air enters along the crest and leaves along the side of the mountain. For boundary conditions representative of winter conditions, the air flow is out at the crest and in along the side of the mountain. This analysis did not include the effect of a borehole. The calculated net water-vapor transport out of the mountain was very small, but as noted by Kipp (1987), this result may have been due to model simplification and parameter uncertainty.

3. Air flow through backfill. An analysis of the convective air flow through the rock, shafts, and ramps was performed by Fernandez et al. (1988). Air flow was calculated by assembling a "network stiffness matrix" of various resistances representing the network of underground openings and the rock mass. A pressure and temperature boundary condition was applied to this network, and the total air flow was calculated; heat effects from emplaced waste were not considered. The analysis indicated that the percentage of air

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flow through the exploratory shafts depended on the air conductivity of the backfill. The study concluded that the exploratory shafts will not become preferential pathways for gas flow if the air conductivity of the backfill is less than about 3 x 10^{-4} m/min. This conductivity value can be expected to be achieved using crushed tuff as the backfill or stemming material.

4. Barometric effects on air flow in the shaft. Fernandez et al. (1988) also evaluated the potential volume of air removed from the backfilled exploratory shafts due to barometric changes at the surface. Three weather events were modeled: a severe thunderstorm, a tornado, and seasonal barometric pressure fluctuations for one year. Comparing the calculated air volume displaced from the exploratory shaft for the weather events considered, the severe thunderstorm displaced the largest volume, followed by the seasonal barometric fluctuation and the tornado. These analyses indicated that for the weather events modeled, and a backfill with air conductivity of $\leq 3 \times 10^{-4}$ m/min, the backfill would effectively isolate the repository air from barometric-pressure fluctuations and restrict the displaced air to a small proportion of the total shaft air volume.

5. Air-drilling effects on saturation. Bodvarsson et al. (1988) investigated the effects of air-drilling on the surrounding rock, assuming an upper-boundary air pressure head of 2 bars. As in the water-drilling analyses by West (1988) discussed earlier, the air drilling was assumed to occur for 12.25 min. Only small changes (<0.005) in saturation were calculated in the rock matrix less than 1 cm from the disturbed surface. Air-pressure changes were calculated to a depth of 3 m in the interior of the matrix, while the air-pressure pulse in the fracture extended over the entire block modeled. The recovery of the air pressure was rapid with near-initial conditions reached after about one day.

6. Experimental drying of tuffaceous rock. Russo and Reda (1988) investigated the drying of an initially saturated tuff. For this investigation an initially saturated, welded tuffaceous rock was isothermally dried, and the saturation distribution monitored for a 1,400-h drying period. One end of a cylindrical saturated rock sample was exposed to flowing dry nitrogen gas. The rock sample contained several microfractures oriented transversely to the direction of the outgoing water flux. After 2 days, the average saturation of the rock was above 0.95; after 29 days the average saturation of the sample was approximately 0.70; after 58 days the average saturation was about 0.60. The microfractures appeared to dry before the smaller pores, in agreement with capillary-bundle theory.

7. Effects of ventilation on saturation of drift walls in the exploratory shaft. Peters (1988) analyzed the effects that ventilation could cause on the saturation levels in drift walls in the exploratory shaft facility. These calculations assumed that 10 percent of the construction water was retained in the walls, as indicated by West (1988). The hydrogeologic units were defined by data from borehole USW G-4, and the initial saturation was established by assuming a constant 0.1-mm/yr vertical ground-water flux. A relative humidity of 10 percent at the inside of the drift wall was used. After 4 weeks, drying from ventilation resulted in more water removed from the rock mass than lost to the rock by construction water. At one year, the effect of drying has penetrated approximately 2 m into the undisturbed rock.

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8. Ventilation effects on saturation over longer time periods. One- and two-dimensional analyses of drift ventilation effects on rock saturation were performed by Hopkins et al. (1987). The hydrologic stratigraphy used in this study was representative of the TSw2 unit. A one-dimensional calculation of constant ventilation for a period of 100 years indicated that ventilation appreciably reduced saturation levels in the drift wall. The 1-D analyses indicated that moisture removal during cycling ventilation could be reasonably represented by constant ventilation. Two-dimensional simulation of constant ventilation for 20 years resulted in changes in the initial saturation at 15 m into the drift wall. For a 2-D simulation of constant ventilation for 50 years with a subsequent recovery period, the fluid velocity field indicates that advective contaminant transport from a waste canister could be prevented for more than 250 yr. The rates of advective transport are sensitive to the assumed values of flux, which affect the initial saturation in the drift walls, and to the relative humidity. The analyses, which neglected the effects of heat from emplaced waste, indicate that, within a few years, ventilation could remove a volume of water comparable to that lost to the rock mass by construction.

In summary, although large-scale air movement within the deep unsaturated zone at Yucca Mountain has not been observed under natural conditions, the air movement observed in open boreholes penetrating the upper few hundred meters of the unsaturated zone may suggest that such processes could occur. Appreciable air flow and exchange with the atmosphere would tend to dry the rock matrix and reduce the ground-water flux at the proposed repository horizon. Drying also may result from the ventilation system that will be required during testing and operation. Water vapor will be removed by the ventilation system. This will lead to subsequent decrease of the saturation levels in the rock mass surrounding the walls of the underground facility until closure of the repository. A backfilled exploratory shaft is not expected to become a preferential pathway for gas flow if the air conductivity of the backfill is less than the value expected from using crushed tuff. Study 8.3.1.2.2.6 is intended to investigate naturally occurring and induced gas-phase movement in the unsaturated zone.

8.4.3.2.2 Geochemical analyses and data

During construction and operation of both the exploratory shaft facilities and the repository, numerous fluids besides water (such as antifreeze, hydraulic fluid, diesel fuel, and various gases) and materials (such as experimental instrumentation, concrete, and other construction materials) will be introduced into the host rock in varying quantities. The following paragraphs briefly summarize the potential impacts of these materials. The summaries are numbered for ease of cross-referencing.

1. Decision-tree analysis of potential impacts of introduced materials on repository horizon. To evaluate the effects of the fluids and materials that will be used in the ESF, a decision-tree analysis was developed that first collected and tabulated information about the type and the quantity of fluids and materials that were expected to be used (West, 1988). These data were then rearranged to obtain the total mass of a given material or fluid for a specific time of usage, location of the use, and potential for recovery

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at the conclusion of exploratory shaft site-characterization activities. The data were screened to evaluate potentially deleterious reactions among combinations of fluids and materials. This screening specifically evaluated the conditions for reaction, including such things as quantity, location (specific physical location of each material and fluid), temperature, pressure, and presence of a catalyst. The screening was performed to evaluate whether pairs of materials and fluids could actually react in the ESF environment.

The decision-tree analysis did not identify any materials or pairs of materials whose presence had a significant impact on the repository horizon, and, therefore, no materials were recommended to be prohibited from use. The results of the materials-screening study identified two major categories of materials that could have potentially significant effects: hydrocarbons and solvents. Because most of the materials fell into one of these categories, West (1988) was able to draw conclusions at the category level, thus eliminating the need to analyze the interactions between specific types of hydrocarbons, solvents, or both.

West (1988) indicates that hydrocarbons introduced into the ESF will tend to remain near the ESF, although some mechanisms can be postulated that would lead to their transport away from the ESF. From a hydrologic perspective, the quantities and effects of organics (oil, grease, etc.) lost at the surface were judged negligible by West (1988). Even if the organics are concentrated, the report indicates that the effects of any of the organics lost on the surface above the repository should not reach the repository for at least 10,000 years because of the immobility of the chemicals. The depth of penetration of the chemicals generally can be approximated by the estimated depth of water penetration (Section 8.4.3.2.1).

Compared with the millions of gallons of water that are proposed for use during site characterization, organic solvents will primarily be present in small localized quantities. The volume of rock affected by solvents will also be small, and the depth of penetration will be minimal. Though not specifically addressed in West (1988), the report suggests that solvents will evaporate, leaving an even smaller amount of solvent to penetrate the rock. West (1988) concludes that the solvents will probably not significantly affect site performance.

West (1988) points out that interactions between hydrocarbons and solvents will tend to lower the viscosity of liquid hydrocarbons, enabling them to be carried deeper into the formation. However, based on hydrologic analyses (Sections 8.4.3.2.1 and 8.4.3.2.2), West (1988) predicts that the depth of penetration will not amount to more than a few centimeters. Again, volatile solvents will gradually evaporate. From the standpoint of the decision-tree analysis, West (1988) concluded that all materials categorized as hydrocarbons or solvents were unlikely to produce any significant impacts if introduced into the ESF, but suggested that these substances be restricted to use at the surface when possible.

2. <u>Effects of biological degradation and transport</u>. The West study (1988) also investigated the potential effects of biological degradation and transport. The study concludes that organic fluids that have been or will be introduced into the repository block appear to be biodegradable and capable of supporting large numbers of microorganisms. The organic matter that may

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be introduced during ESF construction and operation are expected to biodegrade slowly. West (1988) indicates that microorganisms can exist in the Yucca Mountain environment, but no area has been identified where this constitutes a problem. Although the introduction of organic substances and the presence of suitable water chemistry, along with a source of oxygen (ventilation air), will promote biological activity, the consequences have not been identified as having a detrimental effect. Movement of significant quantities of materials due to microbial activity will probably depend on fluid transport. As discussed in West (1988), the quantities of fluids and the properties of the rock combine to limit the extent of significant effects.

3. Potential effects of the concrete shaft liner on ground-water chemistry. The potential changes in the ground-water chemistry from interactions with the concrete liner for the exploratory shafts were evaluated by Fernandez et al. (1988). They specifically evaluated the effects of leaching alkaline constituents from the concrete liner, and the pH of the pore fluid was estimated to increase to about 13.9 as a result of leached materials. Test results show that after three months of contact between well J-13 ground water and concrete, the only ion concentrations that were significantly higher than the initial composition of well J-13 water were Na^+, K^+, OH^-, and SO_4^{--}. The change in the OH^- concentration changed the pH from 6.9 to 9.9, while the concentration of Ca^{++} decreased during the test. Analysis of the effect of an increase in the OH^- concentration showed that chemical equilibrium between HCO_3^- and OH^- results in an increase in the CO_3^{--} concentration. The increase in CO_3^{--} concentration can result in the formation of a $CaCO_3$ precipitate and a decrease in the Ca^{++} concentration. Analysis also indicated that the formation of precipitates from the interaction of chemicals leached from the shaft liner with ground water would be a localized phenomenon and the precipitates would not travel far from the liner.

In summary, the construction and operation of the exploratory shaft facility are not expected to significantly affect the geochemistry of the potential repository host rock in a manner that could interfere with in situ testing or that could detrimentally impact performance of the site. Small effects may be produced locally near the ESF, but it is highly unlikely that any of the materials currently identified to be used in ESF construction or operations will move far from the site at which these materials are introduced.

8.4.3.2.3 Thermal/mechanical analyses and data

This section summarizes the results of selected thermal, structural, and other analyses, as well as the results of some preliminary and prototype experiments. Some of this material serves as background information for discussions in Section 8.4.2.3. The primary purpose of the summaries here is to support the analyses of the potential impacts of site characterization activities on performance objectives (Section 8.4.3.3). The analyses are categorized in general sections of thermal/structural analyses of shafts and drifts and pretest analyses of experiments proposed for the ESF.

8.4.3.2.3.1 Analyses of shafts and drifts

1. Excavation-induced effects on permeability. Changes in rock mass permeability due to stress redistribution and blast damage immediately surrounding a shaft being excavated in a fractured, welded tuff were evaluated by Case and Kelsall (1987). For several of the evaluated conditions, the equivalent permeability of a modified permeability zone (MPZ), averaged over an annulus whose thickness was one shaft radius around the shaft, increased by 15 to 80 times the undisturbed rock-mass permeability. At distances greater than 4 to 5 m from the shaft wall, the disturbed rock mass permeability increased by less than a factor of 2 to 3. At distances greater than 8 m, the disturbed rock mass permeability increased by less than a factor of 2.

An extensive discussion on the adequacy and the assumptions used to develop the MPZ model is given in Case and Kelsall (1987). They concluded that the models developed for the MPZ are conservative in that they overestimate the change in the hydraulic conductivity of the rock mass surrounding the shaft wall. A recent study that used the STEALTH explicit finite-difference code on the CAVS jointed rock constitutive model to evaluate the response of an orthogonal fracture system surrounding a circular shaft (Dial et al., 1988). The study concluded that, qualitatively, the excavation-induced joint response predicted by STEALTH was similar to the joint response predicted with an analytic model used by Kelsall et al., (1982). This conclusion suggests that simple analytic models are appropriate for estimating excavation-induced joint response. Because Case and Kelsall (1987) used a technique identical to the one presented by Kelsall et al., (1982), the MPZ model developed for welded tuff by Case and Kelsall (1987) is also appropriate for estimating excavation-induced joint responses.

The MPZ model implicitly includes the effects of liner removal. This model assumes no support to the shaft wall from the shaft liner, because the assumption is made that the radial stress acting at the shaft wall is zero. This assumption will tend to maximize the change in the fracture apertures, which will maximize the permeability. Further, to increase the fracture aperture, it is assumed that "onionskin" fractures normal to the radial direction will open, and are the predominant factor in the alteration of permeability. Under elastic conditions, the radial stress will decrease to zero assuming no support at the shaft wall, while the tangential or boundary stress will increase and close a system of "radial" fractures. Since permeability depends on changes in aperture for "onionskin" and "radial" fractures which will close and open respectively, it is conservative to assume that permeability is only affected by radial stress relief. Further, it is conservative to neglect the effects of support, which would reduce the degrees of stress relaxation, and the degree to which "onionskin" fractures would open. Although no analysis has been conducted to evaluate the coupled effects of fluids on the distribution and magnitudes of the circumferential and radial stresses, such effects will likely be small if the volumes of fluids are small (Rice and Cleary, 1976).

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Evidence regarding changes in permeability around a tunnel in granitic rock was obtained from the macropermeability test at Stripa, Sweden (Case and Kelsall, 1987). Radial hydraulic gradients were measured for radial flow occurring toward the room. A steep hydraulic gradient, which may be interpreted as a zone of reduced hydraulic boundary stress due to the elastic response of the rock, results in an enhanced hydraulic conductivity for a "radial" system of fractures.

From the preceding discussion, it was concluded that the effect of liner removal has adequately been addressed by the current MPZ model.

To assess the preclosure (up to 100 yr) stability of underground excavations at Yucca Mountain, Ehgartner and Kalinski (1988) have summarized 14 analyses by 10 different investigators. Although the principal purpose of these analyses was to examine various aspects of structural stability in the proposed repository, a basis is also provided for preliminary assessment of the potential for thermal and mechanical interactions between the ESF shafts, between the shafts and drifts, and between the ESF drifts and the proposed repository main drifts and access drifts. Thus, the results of these analyses are discussed briefly here.

2. Stability of unlined shaft. Hustrulid (1984a) modeled circular shaft in the Calico Hills and lower units using both elastic and plastic behavior. A 10.8 MPa horizontal in situ stress was applied to the shaft in a calculation assuming axisymmetric conditions about the shaft centerline. Under wet conditions, the concrete liner thickness necessary to maintain a factor of safety of 1.5 was determined to be 0.41 m, while no liner would be required for dry conditions with the strength reduction factor equal to 2.0. A 14-ft-diameter concrete-lined shaft in the Calico Hills formation was also analyzed by Hustrulid (1984b). In situ stress conditions of 5 MPa minimum horizontal principal stress were modeled. The maximum component of horizontal in situ stress was 5 and 10 MPa for the analyses. When the model took into account rock-mass properties, failure was predicted to occur around the shaft to a distance of 0.3 m in the rock mass in the case of equal components of horizontal in situ stress. For a ratio of 2 to 1 in the in situ horizontal stresses, fracturing was estimated to extend 0.6 m into the rock mass perpendicular to the direction of maximum horizontal stress. Thus, the study concluded that no major difficulties would be expected in constructing a shaft in the Calico Hills formation and that effects, such as fracturing, would not be expected to extend far into the wall rock. Improved conditions would be expected in the Topopah Spring tuff (TSw2) because of the larger compressive strength and the lower in situ stresses. The methods used by Hustrulid (1984a) in this analysis were shown to be conservative based on a comparison between predicted and measured liner pressures in a concrete lined shaft at Mt. Taylor (Grants, NM). Considerable differences were found between the theoretical analysis and field measurements. The theoretical analyses appear to overestimate the pressures and are therefore considered very conservative.

3. Thermal effects on stability. St. John (1987a) analyzed 6-m-diameter concrete lined repository access shafts at two different locations at repository depths. Elastic analyses were performed for a shaft located (1) centrally in the repository within a 200-m-diameter shaft pillar and (2) 100 m from the edge of a waste panel. The analyses were time dependent

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and considered the thermally induced load up to 100 yr after waste emplacement. The thermal load was based on an areal power density (APD) of 57 kW/acre. The stresses around the two shafts showed slight differences, but in neither instance was the rock mass surrounding the shaft fractured because of the in situ or thermally induced loading. The liner hoop stresses were low in comparison to the compressive strength of typical concrete. The concrete shaft liner was predicted to have approximately 4.3 MPa of tensile stress induced along its axis at the repository horizon after waste emplacement. This stress could produce horizontal cracks in the liner. However, the study concluded that there was no evidence that such cracking would be detrimental to the performance (stability) of the liner or the performance of the site.

4. Predictions of thermal stresses and displacements. Unventilated rectangular drifts in the Topopah Spring Member and Calico Hills unit were analyzed by Johnson (1981) for vertical emplacement. A ubiquitous joint model was used to determine stresses and displacements at times up to 100 yr after waste emplacement. Areal power densities (APD) of 75 and 100 kW/acre were used, with but both resulting in nearly the same stress levels near the drift. For both APDs, intact failure was predicted only at the corners of the drifts; in neither instance did it extend more than 1 m into the rock mass. Johnstone et al. (1984) also reported results of an analysis of rectangular emplacement drifts in the Topopah Spring member, Calico Hills unit, and in lower rock units to establish the maximum APD for each formation. These calculations were later documented more fully by Johnson and Bauer (1987). The results of their analysis of an unventilated vertical emplacement drift using the ubiquitous-joint model (Thomas, 1980; Johnson and Thomas, 1983) for times up to 110 years were reported assuming average and limiting properties. The limiting properties were taken as either plus or minus two standard deviations from average values; the sign was determined on a worst-case basis. No matrix fracturing was predicted around the Topopah Spring drift for the waste emplacement period for either the average or limiting property cases. Limited amounts of vertical joint slip were predicted in the sidewalls of the drift out to approximately 6 m from the wall, both at and after waste emplacement. As supported by the evidence from G-Tunnel, however, joint slippage was predicted to have no consequence on drift stability. The ubiquitous joint model predicted a slightly larger slip region for the rock surrounding a G-Tunnel (Grouse Canyon Formation) drift than for the repository drifts, but little joint displacement was evident in the mining evaluation drift or other drifts at G-Tunnel except within 1 to 2 m of the opening (Zimmerman et al., 1988). These calculations were repeated by Thomas (1987) using a different jointed rock mass model (Thomas, 1982). Two-dimensional analyses of rectangular shaped, unventilated vertical emplacement drifts in both the Topopah Spring member and Calico Hills unit were performed. Both average and limiting rock mass properties were used (as in the analysis of Johnson and Bauer, 1987) with an assumed 57 kW/acre APD. No potential for intact rock failure was noted in the drifts for either the average or limiting properties cases over the 100 yr interval analyzed. Joint slip on the order of 1 mm within 3 m of the drift walls was noted.

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5. Effects of drift shape and pillar width on stability. Hill (1985) analyzed the structural stability of the conceptual design of the ESF main test level in the Topopah Spring member. The analysis had two parts, a three-dimensional model of the ESF and a two-dimensional parametric study of two drifts separated by a pillar. Two drift shapes (rectangular and arched roof) and two pillar widths (6 and 2 m) were analyzed. The two-dimensional analyses used both elastic and inelastic joint material models (Thomas, 1982); the results from each were similar. The three-dimensional calculations were completed using a linear elastic model. For the two-dimensional analyses, the lowest safety factor against intact rock failure near a drift wall was 3.0. The wide versus narrow pillar analysis, showed that drifts had to be closer than one-half drift diameter before the stresses at a drift wall were significantly influenced by the presence of the second drift.

6. Effect of porosity on rock strength. SNL (1987; Appendix I) performed an elastic analysis of arched drifts by varying the thermal and thermal/mechanical properties of the Topopah Spring Member as a function of porosity in a thermomechanical model of the horizontal and vertical emplacement drifts 100 yr after waste emplacement. An areal power density of 57 kW/acre was used. The study concluded that, for the TSw2 formation with expected ranges in porosity of 9 to 15 percent, the drifts were stable and the drift temperatures were not excessive. Fracturing at the crown of the vertical emplacement drift was predicted to occur only if the rock porosity exceeded 21 percent. The low lithophysal layers within TSw1 have an expected porosity of 14 percent, and the high lithophysal layers within TSw1 have an expected porosity of 35 percent. For high porosity layers, no failure was predicted for a horizontal emplacement drift. However, stresses in the drift crown would slightly exceed the rock mass strength for the vertical emplacement case. These stresses imply the possibility of localized failure (fracturing) of the crown rock that could be stabilized with ground support.

7. Effects of rock bolts on stresses near emplacement drifts. The effect of rock bolting on the stresses near horizontal and vertical emplacement drifts was analyzed by St. John (1987b). Various in situ stress conditions were assumed, ranging from uniaxial to lithostatic. A damage region was modeled around the drift to simulate the effects of blasting during excavation, and rock bolts were inserted in the crown region. The calculated stresses in the rock bolts were approximately one-half the allowable strength of the rock bolts. The rock bolts had a negligible effect on drift stresses and deformation compared with the analyses of an unsupported drift.

8. Stresses developed at an unventilated drift intersection. St. John (1987c) analyzed the intersection of an emplacement drift with a panel access drift using an areal power density of 57 kW/acre. The three-dimensional elastic calculations used thermally induced stresses to examine an unventilated intersection in the Topopah Spring Member. Stresses in the crown of the intersection reached approximately 23 MPa 50 years after emplacement. Tensile stresses approaching 9 MPa were predicted in the drift wall at the intersection, and were reduced to zero at 3 m into the drift wall. The tensile stresses in the field will likely be less severe than those predicted because of the presence of low-angle (i.e., nearly horizontal) fractures.

9. Thermal stresses on arched emplacement drifts. The results of two-dimensional finite element and boundary element calculations for arched emplacement drifts under thermal loading to 100 yr after emplacement were reported by St. John (1987c). The calculations assumed a 57 kW/acre areal power density. Both vertical and horizontal emplacement drifts were analyzed assuming either continuously ventilated and unventilated drift conditions. Using average rock mass properties, the highest stresses were noted at the drift crown 100 years after waste emplacement. The magnitudes of the principal stresses in the drift crown ranged from 31 to 36 MPa for the horizontal emplacement drift, depending on the drift ventilation assumed. Higher stresses occurred for the unventilated drift condition. The vertical emplacement drift had crown stresses ranging from 13 to 54 MPa for ventilated and unventilated conditions, respectively.

10. Sensitivity study for drift failure. Ehgartner (1987) investigated specific parameter sensitivities and calculated the probability of failure of an arched roof horizontal emplacement drift using a probabilistic technique. Input parameters were varied both individually and jointly to determine the effect on the drift 50 yr after waste emplacement, assuming a 57 kW/acre areal power density. The results indicated that changes in rock strength and modulus in the Topopah Spring had a greater effect on factors of safety than did the other parameters, but in no case was failure of the rock mass predicted. The probability of encountering poor ground conditions that may need supplemental ground support for the horizontal emplacement drift was estimated to be approximately 20 percent.

11. Stability of panel access drifts. Panel access drift stability at various locations and standoff distances from the emplaced waste in the Topopah Spring Member was examined by St. John and Mitchell (1987). The elastic two-dimensional calculations considered an unventilated horizontal emplacement 50 years after emplacement using an APD of 57 kW/acre. Arched shaped drifts were analyzed at locations in the central and outer edges of the repository, assuming near lithostatic in situ stress field. No rock mass stability problems were identified at any of the potential locations.

12. Estimates of blast damage to the exploratory shaft facility pad. The ESF pad preparation will involve some blasting to remove surface rock and to produce a level pad for construction activities. The damage that these blasting operations will induce to the remaining pad can be estimated using empirical data on blast damage. Two approaches can be used: One is to examine the fracturing around a (confined) blast hole; the other is to estimate peak particle velocity levels around the blast and correlate these levels with the strength of the tuff to estimate the extent of the damage.

To estimate the damage, the explosive type and blast hole diameter must be known. Although the blasting design has not yet been chosen, blasting operations are standard and should be fairly uniform from design to design. For this estimate, 6-in.-diameter blast holes and AN-FO blasting agents will be assumed. The actual design will depend on the size and depth of the cut, but the above estimate should be representative.

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Using the first damage-estimate approach of fracturing around a blast hole, the results from four studies (Cattermole and Hanson, 1962; Olson et al., 1973; Siskind et al., 1973; Siskind and Fumanti, 1974) have shown that the radius of damage around a confined explosive charge varies from 15 to 30 charge radii. For a 6-in.-diameter blast hole, the expected damage would extend about 7.5 ft out from the blast holes. These studies were in granite, shale, and tuff and used four different explosives, including AN-FO. The study in tuff also listed a major crack-damage radius of 10 to 12 charge radii. The data for major crack damage in tuff suggest that this type of major damage may occur out to 3 ft from the blast holes. Even these limited damage ranges could probably be reduced by not confining the charges and by using standard controlled-blasting techniques.

Using the second damage-estimate approach of peak particle velocity, a study in shale showed the peak particle velocity can be estimated using only the blast-hole loading density and the range from the blast (Redpath and Ricketts, 1987). Using this and a tuff strength value of 25,000 lb/in.^{2} (170 MPa) (Chapter 2) results in a damage range of 8.5 ft for 6-in. blast holes using AN-FO. This value is fairly consistent with the previous estimate using fracturing around a blast hole. This estimate uses a well-established linear relation between stress and particle velocity (Rinehart, 1975) that has been shown to apply to very high stress levels (millions of lb/in.^{2}).

Thus, on the basis of two independent, empirical approaches, it appears that blasting damage to the ESF pad may occur 7.5 to 8.5 ft from the blast, with major cracking out to 3 ft from the blast. This situation can be even further improved (1) by using standard controlled-blasting methods, (2) by using multiple cuts with smaller blast-hole diameters (since damage is strongly related to blast-hole diameter), (3) by slanting the blast holes to reduce confinement at the bottoms of the holes, and (4) by using variable explosive columns to reduce the loading density near the critical damage areas.

8.4.3.2.3.2 Analysis of in situ experiments

The following discussion describes analyses that have been done on past in situ experiments or those prepared to predict the potential thermal and mechanical effects of some of the ESF in situ tests.

1. Analyses of effects of the shaft convergence, demonstration breakout rooms, and sequential drift mining experiments. Costin and Bauer (1988) describe analyses conducted in support of the excavation investigations planned for the ESF. Preliminary analyses of the shaft convergence, demonstration breakout rooms (DBR) and sequential drift mining experiments have been completed. In the shaft convergence analyses, the stress and displacement histories of the rock surrounding the shaft were determined as the shaft was mined through three different strata. The concrete lining was assumed to be emplaced 10 m behind the front face of the shaft. The calculated maximum convergence of the shaft is on the order of 2 mm. All the predicted displacements resulting from excavation were found to be quite small. The stress-altered region (defined as the region where the stresses differ from the initial in situ values by more than 10 percent) extended radially from

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the shaft centerline for approximately four shaft diameters (15 m). Stresses differ from the in situ values by less than 1 percent at approximately 30 m (7.5 shaft diameters) from the shaft centerline. The horizontal stresses beyond 5 m from the shaft bottom differ from the in situ stresses by less than 10 percent. Calculated stresses in the concrete liner were very low (less than 5 percent of the unconfined compressive strength of normal concrete).

The purpose of the DBR analysis was to estimate the magnitudes of the drift convergence, potential stresses in the rock bolts, and the extent of the zone of stress relaxation near the DBRs (Costin and Bauer, 1988). Only elastic analyses were performed. The analyzed drifts were assumed to have been excavated at depths of 160 and 366 m with a nominal length of 18 m. Drifts with no damage and drifts with an assumed damage zone extending 1.0 m into the rock mass around the excavation were analyzed. The damaged rock around the drifts was modeled by reducing the elastic modulus of the rock by 50 percent in the damaged zone. Similar results were predicted for drifts at the 160 m and the 366 m levels. If no damage zone was assumed, the vertical compressive stress increased 100 to 200 percent near the room wall, but was only 10 percent greater than the in situ stress at a distance of 1.2 room diameters (6.1 m). Horizontal stresses differed by less than 10 percent from the in situ values at distances greater than 1.6 room diameters from the drift. The maximum vertical displacements in the roof and floor were predicted to be approximately 3.5 mm. Horizontal displacements were much less, averaging less than 0.5 mm. The effect of including a 1.0-m-thick damage zone around the drift, either at the 160 m or 366 m level, was to transfer the high stresses around the opening to the undamaged rock region. The maximum displacements near the drift also increased from 2.5 mm in the upper DBR with no damage zone to 3.0 mm with a damage zone. In the presence of a damage zone, the results resemble the results that would be expected for a slightly larger drift.

The analysis of the sequential drift mining experiment assumed that the drifts would be mined at a depth of 320 m. Two drifts assumed to be 4.6 m by 4.6 m high and having a center to center separation of 19.2 m were modeled (Costin and Bauer, 1988). The drifts were assumed to be long enough that plane strain conditions would exist near the center, and, thus, a two-dimensional plane strain analysis would be sufficient to estimate the displacements and stresses around the drifts and to determine whether the drifts were sufficiently separated to preclude interference between the measurement drift and the instrument drift. Analyses were performed with and without a blast damaged zone that was assumed to extend 1.0 m into the rock mass surrounding the excavations. At the time of the analysis, only one access drift was planned, but the current proposal includes an access drift on both sides of the experiment drift. Even so, the analyses provide a good estimate of the stress-altered region around the drifts and the expected displacements that would be measured in the pillar between the instrumented experiment and an access drift. Following excavation of the instrumentation drift, the horizontal and vertical displacements in the region where the experiment drift was to be excavated were found to be on the order of 0.1 mm. The change in horizontal displacements near the experiment drift after excavation ranged from 0.4 mm near the drift wall to 0.1 mm at one drift diameter from the wall. The change in vertical displacement ranged from 2.4 mm in the crown of the drift to less than 0.6 mm at one drift diameter in any direction. The total maximum convergence of the experimental drift was 0.38 mm horizontally and 5.92 mm vertically for drifts with damage zones. For drifts with no damage zone assumed, the horizontal and vertical convergence was 0.07 mm and 4.55 mm, respectively. The horizontal stresses around the opening ranged from the in situ stress (1.9 MPa) to a maximum compressive stress in the crown of 2.4 MPa. Beyond one drift diameter from the opening, the horizontal stress was essentially the in situ stress except in the pillar region directly between the two drifts where the horizontal stress increased to 2.4 MPa. The maximum vertical compressive stress at the midheight of the drift wall on the pillar side was 11.8 MPa (compared with an in situ stress of 7.5 MPa). At a distance of 1/2 drift diameter from the walls and one drift diameter from the floor and roof, the vertical stresses were within 10 percent of the applied in situ stress.

2. Simulation of effects of G-Tunnel heated block experiment. A numerical simulation of the G-Tunnel heated block experiment conducted by Zimmerman et al. (1986a) was reported by Costin and Chen (1988). The analysis simulated both the mechanical and thermomechanical loading portions of the experiment using the compliant joint model (Chen, 1987). The results of the calculations were compared with those of the experiment to demonstrate a capability to model the behavior of a rock mass subjected to thermal and mechanical loads. Both the results of the calculations and the experiment indicate that the rock beyond 8 m from the edges of the block is not significantly disturbed.

3. Analyses of G-Tunnel small-diameter heater experiment. Detailed analyses of the G-Tunnel small-diameter heater experiments (Zimmerman et al., 1986b) were reported by Blanford and Osnes (1987). Three experiments were conducted in both welded and nonwelded tuffs, using small-diameter (102 mm) heaters. For two experiments, the heater was oriented vertically in fractured welded tuff and in unfractured welded tuff. The major focus of the experiments was on evaluation of numerical model applications, emphasizing thermal properties. The secondary focus was on hydrothermal measurements and evaluations. The results show good agreement with the experiment and demonstrate that heating of the rock would not extend more than 1 m below and more than 2 m radially from the heater operating at maximum power (1,200 W) for 32 days.

4. Analyses to establish thermal zone influence. Pretest analyses of the ESF canister scale heater experiment, the heated room experiment, and the thermal stress test have been conducted by Bauer et al. (1988). The analysis of the canister scale heater test was performed to determine the heater power history required to satisfy the experimental objectives of heating a large volume of rock to temperatures above 200°C so that thermomechanical models could be verified against the experimental data. Current results indicate that temperatures will be elevated above 200°C out to 1.0 m from the heater and will be above ambient out to a distance of 15 m radially from the heater and 20 m from the emplacement drift wall along the axis of the heater after 30 months of operation.

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The heated room experiment consists of a central experiment drift with two parallel access/instrumentation drifts constructed on either side of the main drift. Heaters will be emplaced in the pillars between the drifts so that the central experiment drift is heated along the central portion of its length. Preliminary analyses indicate that after 40 months of heating at 100 kW of heater power, temperatures range from 240°C near the heaters to within 5°C of ambient just beyond the access drifts. The zone of thermally disturbed rock (temperature greater than 5°C above ambient) extends approximately 30 m above and 25 m below the floor of the experimental drift. On the main test level, the presence of the access drifts which are assumed to be ventilated and remain at constant temperature, retards the thermal disturbance so that it does not reach beyond the edge of the access drifts (which are 20 m, center to center, from the experiment drift).

The thermal stress test represents an effort to examine rock mass behavior under large thermally induced stresses. It is intended that heating will be rapid and that the experiment will last only approximately 3 months. According to the proposed plan, two rows of heaters will be installed a short distance to either side of the centerline of the roof of a drift. Preliminary thermal analyses show that after 90 days of operation, the thermally disturbed zone will extend approximately 15 m vertically above and 1 m below the floor of the drift. The zone of heated rock will also extend approximately 8 m from the drift walls.

On the basis of these analyses, the planned minimum separation distance of 30 m between ESF and waste emplacement panels appear adequate. Both thermal and mechanical effects on the rock at this distance appear to be insignificant.

8.4.3.2.4 Design features that may contribute to performance

Postclosure design Issue 1.11 (configuration of underground facilities, Section 8.3.2.2) provides the mechanism for identifying repository design characteristics and configurations important to the evaluation of compliance with 10 CFR 60.133 and for incorporating postclosure performance concerns into the design. The rest of this section is an itemized discussion of some of the design features that may be important in discussing the total-system performance objective and the three subsystem performance objectives. The items discussed are design features or considerations related to site characterization activities that might contribute to performance (primarily postclosure) or aid in mitigating potential deleterious impacts to performance from site characterization activities. The items discussed do not, however, completely describe the design features that may contribute to performance. These design considerations generally address the additional design criteria of 10 CFR 60.133, 60.134, and 60.135.

1. Separation of ESF tests from potential emplacement drifts. The ESF is designed to maintain a minimum lateral separation distance from potential waste emplacement panels. The core area for testing within the ESF is separated by a minimum distance of 30 m (Section 8.4.2.2). Because unsaturated flow within the repository horizon is hypothesized to be primarily vertical,

this separation distance will help prevent the ESF from becoming a preferential pathway for radionuclide transport from waste emplacement. This separation will also prevent water used in testing activities from reaching emplaced waste containers.

2. Control of drainage direction. The ESF is designed to drain water used in ESF construction and testing toward ES-1 (Section 8.4.2.2). This design feature will inhibit water from the ESF from moving into waste emplacement panels. The locations of the exploratory shafts have been selected to significantly reduce the potential for water inflow and thereby increase confidence that sealing components can meet their performance requirements.

3. Low flood potential. The exploratory shafts have been located and collared in bedrock where flooding and erosion potential is small (Sections 8.4.3.3.4 and 8.4.2.2). This should limit the potential for shafts to serve as preferential pathways for water from the surface.

4. Location and number of boreholes. Borehole drilling will be coordinated with repository design to locate boreholes, to the extent practical, in pillars (Section 8.4.2.1). This will allow a standoff distance from waste canisters and help prevent the boreholes from becoming preferential pathways for potential radionuclide movement. In addition, statistical methods will be used in planning the boreholes in order to limit the number.

5. ESF test location. The ESF will be designed with sufficient flexibility to locate in situ tests where they will have as high a likelihood of success as possible.

6. Control of water use. The amount of water introduced to the site will be controlled. The water usage will be limited to the extent practicable and will be tagged with tracers to allow detection (Section 8.4.2). Many of the boreholes will be drilled dry to prevent water intrusion into the rock mass (see Section 8.4.2.1). Strict water controls will be used during drill-and-blast operations.

7. Limit blast damage. The openings in the ESF will incorporate excavation methods that will limit the potential for the surrounding rock mass becoming a preferential pathway. Smooth-wall blasting techniques will be used.

8. Water removal by ventilation systems. The ESF will be ventilated. As described in 8.4.3.2.1, ventilation can remove a substantial amount of water; within a few years, the volume of water removed is estimated to be comparable to the volume of water added to the rock during ESF construction testing.

9. Waste package containment. The waste canisters will be designed to have substantially complete containment for a period of at least 300 years.

10. Use of seals. Exploratory boreholes that represent potential pathways to the accessible environment and the exploratory shafts will be sealed (Section 8.3.3) to limit the potential for them to serve as preferential pathways for flooding events, increased percolation, transport of radionuclides, or gas-phase transport.

11. Avoid surface-water impoundment. Surface activities, such as the construction of spoils piles, will be conducted in a manner that will avoid the creation of surface-water impoundments that could impact postclosure performance.

12. Use of air gaps. An air gap will be maintained to the extent practical between the waste canisters and the emplacement-hole wall to inhibit water movement into the opening and thus inhibit corrosion.

13. Use of controlled blasting. Controlled blasting will be used in the construction of the exploratory shafts to limit the amount of blast-induced changes in permeability to the surrounding rock (Section 8.4.2.3.4.4 and Section 8.4.3.2.3, Item 1). The design of seals to be used in the exploratory shaft and underground facility inherently incorporates both the effects of blast damage and stress redistribution accompanying excavation. The model of Case and Kelsall (1987) provides a conservative estimate of the change in the permeability of the modified permeability zone (MPZ) surrounding the exploratory shafts. These permeability modifications are considered in Fernandez et al. (1988), where it is concluded that the MPZ does not significantly enhance radionuclide release for several extreme disruptive scenarios. The use of controlled blasting is expected to result in permeability changes that are consistent with shaft sealing concepts and performance allocation; reduce uncertainties in predicting seal performance; and reduce limitations in emplacing sealing components.

14. Removable shaft liner. The shaft liner is designed to be removable. Techniques to remove the liner are discussed in Fernandez et al. (1988). Maintaining the capability to remove the liner reduces limitations associated with emplacing seal components. Liner removal could enhance seal component performance by improving drainage from the base of the shaft.

8.4.3.2.5 Potential impacts to current site conditions from site characterization activities

This section uses the information presented in Sections 8.4.3.2.1 through 8.4.3.2.4 to determine which hydrological, geochemical, and thermal/mechanical disturbances from site characterization activities are transient and which disturbances will be long-lasting or permanent. The transient effects are those effects that will no longer be significant after permanent closure and for that reason would not be expected to affect postclosure performance. The long-lasting or permanent disturbances could potentially affect postclosure performance and will be evaluated (1) with respect to the total-system-release performance objective in Section 8.4.3.3.1 and (2) with respect to the three subsystem performance objectives addressing container lifetime, EBS release rate, and ground-water travel time in Sections 8.4.3.3.2, 8.4.3.3.3, and 8.4.3.3.4, respectively. This section evaluates the potential impacts to current site conditions; Section 8.4.3.3.1 addresses whether the permanent changes resulting from site characterization activities discussed in this section could preclude the site from meeting the performance objectives, given the occurrence of future events and processes.

The types of penetrations or disturbances to the site have been categorized in Section 8.4.2 for both surface-based and ESF-related activities. For the surface-based testing and construction activities, the categories are (1) drilling (shallow and deep dry holes, coreholes, and saturated-zone boreholes); (2) surface site characterization activities (e.g., pavements, trenches, and ponding tests); and (3) construction or site-preparation activities (e.g., roads, drillpads, dust control, installation of utility lines). For the ESF-related activities the categories are construction of the shafts, construction of drifts and testing alcoves, and testing (within the shaft, breakout areas,and the main underground facility). Many of these penetrations or disturbances will affect the hydrologic, geochemical, and thermal/mechanical conditions of the site in a similar manner because they disturb the site in similar ways (e.g., similar construction methods and similar conditions under which fluids and materials are introduced). In this summary, the categories of site characterization activities are grouped according to the type of disturbance as follows:

1. Surface-related activities (pavements, trenches, ponding tests, road construction and use, dust control, drillpad construction, and seismic surveys).
2. Drilling activities (shallow and deep dry holes, coreholes, saturated-zone boreholes, and underground boreholes).
3. Exploratory shaft construction.
4. Underground construction of exploratory shaft facility drifts and testing alcoves.
5. Exploratory shaft facility testing activities.

8.4.3.2.5.1 Potential impacts to the site from surface-related activities

The potential impacts to the site from surface-related activities are evaluated in this section. The hydrologic, geochemical, and thermal/mechanical analyses and data that provide the basis for evaluating the potential impacts resulting from surface-related activities are summarized in the previous sections. The surface-related activities are discussed in Section 8.4.2 and include pavements, trenches, ponding tests, road construction and use, dust control, drillpad construction, and seismic surveys. Evaluations of potential impacts resulting from hydrological, geochemical, and thermal/ mechanical disturbances occurring as a part of site characterization activities will be presented in the following paragraphs.

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Potential impacts from hydrologic disturbances

Hydrologic disturbances can potentially affect the site in a number of important ways; for example, the site can be affected by altering the amount and distribution of flux at the repository horizon and by changing the hydrologic characteristics of the unsaturated zone. Section 8.4.3.2.1 presents analyses and data that address the potential impacts of altering hydrologic conditions and properties in the unsaturated zone at Yucca Mountain.

Section 8.4.2.1 describes the surface-related activities that will add water to the surface at Yucca Mountain. The water pressures will be low (generally centimeters of head), and the contact times will generally be short. The data and analyses presented in Section 8.4.3.2.1.1 indicate that water introduced to the surface of the site at low pressures for short times (similar to precipitation events) will not generally produce measurable changes to the moisture content below a depth of approximately 10 m. Additionally, the analyses in Section 8.4.3.2.1.2 (e.g., items 10 and 12 in that section) indicate that any water added to the site will equilibrate within a few weeks to months. Changes to net infiltration, and subsequent percolation flux at the repository level, are thus expected to be insignificant. Most of the water introduced to the site will be for dust control and will be introduced to the surface at low heads for short contact times. Other surface-related site activities introducing water will also use low heads and short contact times. Therefore, adding water to the site from surface-related activities is not expected to result in permanent changes to the flux at the repository horizon.

Permanent changes to the physical topography of the site from surface-related activities were also considered in evaluating the potential to alter the percolation flux. Also investigated were potential impacts to percolation flux at the repository horizon if water was ponded at the surface, as for example, might occur if the spoils pile were inappropriately located where it might cause water ponding. To be conservative, the analysis in Section 8.4.3.2.1.1 assumed that the water would be ponded over a highly permeable zone at Yucca Mountain (e.g., a permeable fault zone). A column of water 10 m high was used as the pressure head and was allowed to stand for over two days. The results indicate no change to the water velocities or percolation flux at the repository level for at least 1,000 years and only a factor of 2 change in the water velocities at the repository level between 10,000 and 100,000 years. Given current site conditions, therefore, surface-related activities are not expected to provide the potential to significantly alter the flux at the repository level.

Hydrologic disturbances could potentially result in changes to the site by altering the moisture content (which changes the value of the unsaturated hydraulic conductivity). As discussed previously, changes to the moisture content caused by performing surface-related site characterization activities are expected to be transient and are not likely to permanently affect the unsaturated hydraulic conductivity of the near-surface material.

Surface-related activities are not expected to lead to new preferential pathways because the activities are limited to the surface or to within a few meters of the surface.

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Potential impacts from geochemical disturbances

Fluids and materials similar to those introduced to the ESF (West, 1988) will be introduced to the surface, as described in Section 8.4.2.1. West (1988) estimates that the depth of penetration of materials that are not soluble in water will generally not penetrate more than approximately the penetration depth of the water introduced, which is approximately 10 m. The analyses presented in Section 8.4.3.2.1.2 indicate that water takes tens to hundreds of thousands of years to move from the surface to the repository horizon. Any chemicals left in the surficial material from surface-related activities are not expected to significantly impact site performance during the period of concern for the total-system-release postclosure objective. Therefore, there are no geochemical disturbances that could be expected to lead to impacts on site conditions during the postclosure period of interest.

Potential impacts from thermal/mechanical disturbances

No surface-related activities will involve significantly increased temperatures at depth. The mechanical disturbances to the stress conditions of the site, and thus the fracture apertures and hydraulic conductivity, are expected to be limited to within a few meters of the surface. Mechanical disturbances from preparing the pad for the exploratory shaft would be similarly limited in extent. Because the repository is more than 200 m below the surface, these potential changes to the hydraulic conductivity of the surficial material are not expected to significantly impact the performance of the site.

8.4.3.2.5.2 Potential impacts to the site from drilling activities

The potential transient and permanent impacts to the site from drilling activities are evaluated in this section. The surface-based activities discussed in Section 8.4.2.1.1 categorized the drilling activities by drilling methodology: dry drilling, drilling with mud, and drilling with air foam. For the dry drilling method, the activities were also categorized by depth of the hole. The following evaluation of the potential impacts to the site from drilling activities categorizes the information by shallow borings drilled dry, deep borings drilled dry, geologic core holes drilled with water containing a polymer, and saturated zone boreholes drilled with air foam.

Evaluations of potential impacts on the site resulting from hydrological, geochemical, and thermal/mechanical disturbances from drilling activities are discussed in this section. The detailed summaries of the hydrologic, geochemical, and thermal/mechanical analyses and data discussed earlier in Section 8.4.3.2 provide the basis for evaluating the impacts.

Shallow borings drilled dry

The shallow borings drilled using dry drilling methods include neutron access holes, seismic shotholes, and large and small rain-simulation holes. The current maximum depth of holes included in this category is about 60 m. The details of these drilling activities are discussed in Section 8.4.2.1.1.

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Potential impacts from hydrologic disturbances

Hydrologic disturbances could potentially affect the site performance by increasing the flux at the repository horizon. As discussed in Section 8.4.2.1, an element of construction control for site characterization is the selection of dry drilling and coring methods for some site characterization activities. This drilling method was selected instead of drilling using water to decrease both the potential for fluids affecting cutting samples and in situ hydraulic conditions and the potential for losing fluid to the unsaturated zone. Dry drilling will use compressed air at pressures of about 2 bars to cool the drill bit and carry away drilling cuttings. Analyses discussed in Section 8.4.3.2.1.1 indicate that the effects of drilling with air on the air pressure in the rock are dissipated relatively quickly and that near-initial conditions are reestablished in about one day. The matrix saturation is very slightly decreased because of the movement of air into and out of the matrix during drilling. These changes are, however, small and transient. Any permanent changes to the net infiltration and the percolation flux at the repository level from shallow borings would be insignificant because of the sealing of the boreholes.

Testing performed in the rain-simulation holes will include water-ponding experiments. These experiments will use small heads of water and short contact times between the water and the rock (days). Data and analyses discussed in Section 8.4.3.2.1.1 indicate that water contacting rock surfaces at low pressure and for short times will not significantly change the moisture content in the rock at distances beyond 10 m. Adding a small amount of water to the site from these tests is expected to cause only short duration changes in moisture conditions in the proximity of the borehole. This increase in moisture should be redistributed within the matrix and any water introduced into fractures should be imbibed into the matrix within a few meters to tens of meters. There are no expected permanent changes to percolation flux at the repository horizon because of the sealing of the holes.

Potential impacts from geochemical disturbances

Changes in geochemistry could potentially affect the site performance by altering the environment near waste emplacement, reducing the capability of the tuff to retard transport of radionuclides, or affecting the flux of water. Some of the fluids and materials discussed by West (1988) for the ESF construction will be used during dry drilling of shallow boreholes. For example, a small amount of oil may be introduced into the rock wall during dry drilling. West (1988) estimates that the depth of penetration will generally be a few centimeters and that no significant interactions of oil with other materials should occur. Casings and grouts may be used in some of the boreholes. Fernandez et al. (1988) analyzed the potential geochemical changes from the interaction of grouts with ground water. They concluded that some chemicals may form precipitates, but the effect would be localized and the chemicals would not be transported far from the wall.

Even though these are permanent changes to the geochemistry of the site, they are localized effects that should remain near drillholes. These changes are not expected to affect the environment near the waste package, reduce the capability of the tuff to retard transport of radionuclides, or significantly affect either the water flux at the repository horizon or the postclosure performance.

Potential impacts from thermal/mechanical disturbances

Thermal and mechanical disturbances could potentially affect the site performance by altering the hydraulic conductivity of the rock mass. They could also potentially affect the water flux at the repository horizon by creating preferential pathways. The air drilling of shallow boreholes may result in a temporary increase in the temperature of the rock for a short time. If the temperature of the rock increases to above the boiling point of water, the moisture content of the rock matrix may change slightly. This temperature increase and moisture change should be a temporary effect, and because of the distance of at least 100 m from waste-emplacement areas, the change should not affect the waste-package environment or postclosure performance.

Mechanical disturbances to fracture apertures and hydraulic conductivity from dry drilling are expected to be limited to within a few meters of the borehole walls. The modified-permeability zones around the boreholes are expected to be limited to within a distance of a few radii from the walls, as they are in the results for a shaft Case and Kelsall (1987). The change in permeability around the drillholes may be permanent. But because the repository is over 100 m below the deepest of these holes, the potential changes in permeability are not expected to affect the water flux at the repository horizon.

Shallow boreholes are not expected to become preferential pathways for fluid or gas flow because of their relatively shallow depth (60 m) and because they will be sealed. Therefore, this activity should not result in permanent effects on the site that would affect performance.

<u>Deep borings drilled dry</u>

The plans for deep borings using dry drilling include unsaturated-zone holes, which will include drilling to just above the water table, multi-purpose boreholes drilled to the depth of the nearby exploratory shafts, and the systematic drilling program, which will include drilling to 100 m below the water table.

Potential impacts from hydrologic disturbances

The potential changes in the unsaturated zone for deep borings will be similar to the changes discussed for shallow borings earlier in this section. As discussed for shallow boring, the effects of drilling with air on the air pressure are dissipated relatively quickly and near-initial conditions are reestablished in about one day. According to the results of the analyses discussed in topic 5 of Section 8.4.3.2.1.4, there may be a small decrease of about 0.005 in the moisture content of the rock matrix from the movement of air into and out of the matrix during drilling. This small change in moisture content within a few centimeters of the wall of the drill hole is a transient condition and is not expected to significantly affect the net infiltration and the percolation flux at the repository horizon.

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Potential impacts from geochemical disturbances

The evaluation of geochemical disturbances that could affect site performance by altering the environment near waste packages, reducing the capability of the tuff to retard transport of radionuclides, or affecting the flux of water at the repository horizon for deep dry-drilled boreholes is similar to the evaluation for shallow boreholes previously discussed.

Potential impacts from thermal/mechanical disturbances

The evaluation of thermal and mechanical disturbances that could affect site performance by altering the hydraulic conductivity of the rock mass or changing the environment near areas of waste emplacement is similar to the evaluation for shallow boreholes previously discussed. There may be small temporary increases in temperature that may change the moisture content of the rock matrix near the borehole wall, but this change should not impact postclosure performance.

The change in permeability around the drillholes caused by drilling will be a permanent effect. But since these boreholes will be located, to the extent practicable, in pillars in the proposed repository, they are expected to be approximately 30 m from the nearest waste package. Analyses discussed in Section 8.4.3.2.1.2 suggest that flux through such a modified permeability zone around the borehole will move only a short distance before being imbibed into the matrix. In any event, the boreholes will be sealed if necessary to mitigate any potential effects. Therefore, the permanent change in permeability around these boreholes is not expected to impact postclosure performance.

Deep boreholes are not expected to become permanent preferential pathways for fluid or gas flow because they will be sealed. Furthermore, in the underground facility they will be located in pillars, to the extent practicable.

<u>Geologic coreholes drilled with water</u>

Geologic coreholes using standard wireline coring methods have been drilled to depths of 1,500 m, using water with a polymer additive. No new geologic coreholes are currently planned within the conceptual perimeter drift boundary. But as discussed in Section 8.4.2.1.1, three proposed geologic coreholes are located outside the controlled area and outside the possible expansion area proposed in the Yucca mountain environmental assessment (DOE, 1986b). Three existing holes have been drilled with similar methods in which the principal circulation medium was water with polymer additives. (Bentonite mud and other materials were occasionally used for circulation.) The loss of fluid during the drilling of test well USW G-1 is discussed in Section 8.4.3.2.1.2. Since no additional coreholes are proposed within the proposed repository boundary, there should not be any effects on the hydrologic, geochemical, or thermal/mechanical conditions.

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Saturated-zone boreholes

Eight additional saturated-zone boreholes are planned to explore and sample the water table in the vicinity of the site as part of the site characterization activities. Only one of these additional boreholes will be drilled within the conceptual perimeter drift boundary (CPDB). This borehole, identified as USW H-7, is planned to be drilled to below the water table using dry drilling methods at least through the unsaturated zone. Since borehole USW H-7 is the only saturated-zone borehole within the CPDB, the following discussion will focus on its impacts on site performance.

Potential impacts from hydrologic disturbances

The impacts to the site from hydrologic disturbances will be evaluated by considering the alteration of the amount and distribution of ground-water flux at the repository horizon and changes to the hydrologic characteristics of the unsaturated zone. The potential impacts to the unsaturated zone from the saturated-zone boreholes drilled dry will be nearly identical to the discussion for the shallow boreholes drilled dry. There may be a small decrease in the moisture content of the rock matrix from air moving into and out of the matrix during drilling, as discussed in topic 10 of Section 8.4.3.2.1.1. This change in moisture content near the wall of the borehole would be of short duration and is not expected to significantly affect the characteristics of the unsaturated zone or the ground-water flux at the repository horizon.

Potential impacts from geochemical disturbances

Potential impacts of geochemical disturbances to the unsaturated zone from dry drilling to the saturated zone will be similar to the potential impacts for drilling shallow boreholes. A small amount of oil may be introduced into the rock wall during dry drilling. As discussed in Section 8.4.2.1.2.6, the dry drilling method to be used will be tested and the effects of oil on rock matrix properties evaluated before this borehole is drilled. West (1988) estimated that fluid would only penetrate a few centimeters into the rock matrix and that no significant interactions of oil with other construction materials should occur.

The drilling method selected for the saturated zone is not expected to have a geochemical impact on the unsaturated zone. This change is a localized effect that should remain near the drillhole and not affect the environment near the waste package, reduce the capability of the tuff to retard transport of radionuclides, or significantly affect the water flux at the repository horizon.

Potential impacts from thermal/mechanical disturbances

The thermal/mechanical impacts on site performance by drilling a saturated-zone borehole should be similar to the evaluation of impacts for deep borings that drilled dry. There may be small, temporary increases in temperature that could change the moisture content of the rock matrix near the borehole wall, but they should not affect the hydraulic conductivity of the rock mass or the waste-package environment.

Mechanical disturbances to fracture apertures and the effects on the hydraulic conductivity due to dry drilling are expected to be limited to within a few meters of the borehole wall. Flux through the modified permeability zone around the borehole should move only a short distance before being imbibed into the matrix. Since this borehole will be backfilled and sealed, and there will be a relatively large lateral distance between it and waste emplacement areas, it is not expected to create a preferential pathway for liquid or gas flow.

8.4.3.2.5.3 Potential impacts to the site from construction of the exploratory shafts

The potential transient and permanent impacts from hydrologic, geochemical, and thermal/mechanical disturbances to the site from construction of the two exploratory shafts are evaluated in this section. The detailed summaries of the hydrologic, geochemical, and thermal/mechanical analyses and data discussed in Section 8.4.3.2 provide the basis for evaluating the potential impacts.

The shaft-sinking operation for both shafts will consist primarily of drilling small-diameter blast holes into the rock, loading the blast holes with explosives, and producing detonations. The detonations will be timed to control the blast, which will enhance vertical advance, limit damage to the rock zone, and produce acceptably-sized rock fragments. Following the blast, air will be exhausted to remove smoke, dust, and fumes. The rubble will be sprayed with water for additional dust control before muck is removed. After several blasting rounds, the shaft-liner concrete will typically be installed in 20-ft (6-m) segments. Water use during construction of the exploratory shafts will be controlled to limit potential impacts on the site, and all water used will be tagged with a tracer to distinguish it from natural ground water. The construction of the exploratory shafts is detailed in Section 8.4.2.3.4.

Potential impacts from hydrologic disturbances

Hydrologic disturbances from exploratory shaft construction could affect the site mainly by altering the amount and distribution of flux at the repository horizon and by changing the hydrologic properties of the unsaturated zone (primarily the hydraulic conductivity). The shafts will be approximately 12 ft in diameter, with a region of disturbed rock around the openings. As discussed in Section 8.4.2.3, water use will be controlled to limit potential impacts to the site. However, some of the water used to drill the blast holes and used to control dust will be retained in the walls surrounding the exploratory shafts. Current estimates are that approximately 10 percent of the water used during the drilling and blasting of the shafts will be retained in the walls (West, 1988). Analyses discussed in Section 8.4.3.2.1 indicate that water introduced to the rock formations from the shafts will change the saturation of the rock only slightly, and these changes will generally be limited to approximately 10 m from the opening.

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Equilibration of the water is expected to occur within several months. Analyses presented in Section 8.4.3.2.1.3 predicted that the saturation change at the repository horizon would be less than about 0.002. The farther that the retained water moves from the shaft walls into the rock matrix, the smaller the overall change in saturation. The small change in saturation over the small volume of rock affected is a short-duration change and will not significantly change either the percolation flux at the repository horizon or the value of the unsaturated hydraulic conductivity (which is a function of the degree of saturation). Case and Kelsall (1987) analyzed the potential change to the rock hydraulic conductivity in the modified permeability zone caused by shaft construction and concluded that the change is small after approximately 2 to 3 m from the shaft opening.

West (1988) discusses other fluids besides water (such as antifreeze, hydraulic fluid, and diesel fuel) that will be used during the construction of the exploratory shafts. The quantities of these fluids remaining in the rock walls should be much lower than the volumes of water used for construction and the fluids should remain near the shaft walls. As discussed in Section 8.4.2.3.3, fluids recovered during construction operations will be disposed of to avoid the potential for performance impacts. Therefore, because of the construction controls to be used for the exploratory shaft, no permanent impacts on the site-performance from these fluids could be identified.

Potential impacts from geochemical disturbances

Changes in geochemistry could potentially affect site performance by altering the environment near waste package, reducing the capability of the tuff to retard transport of radionuclides, or changing the flux of water by altering flow paths. West (1988) discusses the type, quantity, and potential interactions of the fluids and materials that will be used during the construction of the exploratory shafts. The construction will introduce explosives, concrete, utility piping, instrument conduits, rock bolts, steel tendon rods, and tagged water. West (1988) did not identify any interactions between fluids and materials used during construction that would have a significant, permanent geochemical impact on the site. West (1988) also evaluated the gaseous products produced from the explosives and the penetration distance using controlled blasting procedures. This evaluation suggested that small amounts of the gases, such as NO, CO, NH_2, and CH_4, and some solids, such as Al_2O_3, will be produced. Although most of the gaseous products will be ventilated to the surface, some of the gaseous products may penetrate 1 to 2 m into the rock.

Fernandez et al. (1988) analyzed the potential effects of the interaction of the shaft concrete liner with ground water. They concluded that some chemicals may form precipitates, but these would be localized and would not be transported far from the shaft wall.

Therefore, the construction of the exploratory shafts could cause some small, permanent geochemical changes to the rock near the shaft wall. But because of the distance between the shafts and areas of waste emplacement, these geochemical changes will not alter the environment near waste packages, nor will they reduce the capability of the tuff to retard transport of radionuclides.

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Potential impacts from thermal/mechanical disturbances

Construction of the shafts will cause permanent changes to the rock mechanical conditions around the shaft openings. As discussed in Section 8.4.3.2.3, changes in these conditions resulting from stress redistribution and blast damage will alter the rock hydraulic conductivity in a modified permeability zone extending a few meters into the wall rock (Case and Kelsall, 1987). The disturbed rock mass conductivity is predicted to be increased by less than a factor of 2 to 3 at distances greater than approximately 5 m from the shaft wall. These changes to hydraulic conductivity were considered previously in this section in evaluating potential changes to percolation flux, hydrologic properties, and the potential to create preferential pathways. They were determined to not significantly affect postclosure performance.

Fernandez et al. (1988) have analyzed the potential for the exploratory shafts to become preferential pathways for liquid and gaseous transport. The exploratory shafts, which will be backfilled and sealed, are permanent features, as is the modified permeability zone (MPZ) around each shaft opening. The MPZ (Case and Kelsall, 1987) is the region approximately 2.2 m from the shaft wall, beyond which the permeability changes to the rock from construction are insignificant. Fernandez et al. (1988) analyzed a flooding scenario to predict the volume of water that could enter the ESF through fracture systems in the uppermost tuffaceous units due to a probable maximum flood. They also analyzed the potential for episodic water to percolate through the shaft fill and the MPZ and concluded that, for both analyses, the backfilled shafts and associated MPZs will not become liquid pathways such that the capability of the site to meet the postclosure performance objectives is affected. The potential for the shafts and MPZs to function as preferential pathways for gaseous transport was also analyzed. Fernandez et al. (1988) concluded that if the air conductivity of the shaft fill is less than about 3×10^{-4} m/min, the exploratory shafts (including shaft fill and MPZ) are not likely to be preferential pathways. The potential impacts of the shafts on total system release is discussed in Section 8.4.3.3.1.

The liner is expected to be removed using existing technology from below the repository horizon and, thus, is not a permanent feature at those depths (Fernandez et al., 1988). Fernandez et al. (1988), identified six techniques for liner removal: hand-held pneumatic breakers, drill and blast, drill and use of a hydraulic splitter, drill and use of a nonexplosive demolition agent, impact breaker, and road header boom. Considering the advantages and disadvantages for each method, the drill and use of hydraulic splitter method is considered the favored approach for liner removal, although the other approaches are technically feasible.

According to these evaluations of potential impacts resulting from exploratory shaft construction, the permanent changes to the site are the creation of two shaft openings and a modified zone of permeability around the openings. These changes are not expected to significantly impact the hydrologic, geochemical, and thermal/mechanical conditions of the site. Changes to the site from introducing fluids and materials are expected to be transient.

8.4.3.2.5.4 Potential impacts to the site from underground construction of exploratory shaft facility drifts and testing alcoves

The potential impacts to the site from underground construction of exploratory shaft facility drifts and testing alcoves are evaluated in this section. Hydrologic, geochemical, and thermal/mechanical analyses and data that provide the basis for evaluating the potential impacts resulting from these activities are summarized in previous sections. Section 8.4.2.3 discusses these construction activities, including construction of the upper demonstration breakout room at a depth of approximately 175 m and the main testing area at the depth of the proposed repository horizon. The underground drifts and testing alcoves will be mined by conventional drill, blast, and muck methods.

Potential impacts from hydrologic disturbances

Like the methods for construction of the exploratory shafts, underground construction methods use water, primarily for drill-and-blast activities and for dust control. The water use will be controlled (Section 8.4.2.3), and approximately 10 percent of the water used is currently estimated to be retained in the rock (West, 1988). The analyses discussed in Section 8.4.3.2.1 indicate that water introduced to the rock formations from underground construction will change the saturation of the rock only slightly. This change will generally be limited to approximately 10 m from the opening. The initial changes to saturation will be transient because equilibration is expected to occur within several months (see analyses in Section 8.4.3.2.1). The predicted saturation change at the repository horizon would be less than 0.002. As the distance the water might move from the shaft increases, the overall change to saturation decreases. The changes to saturation will generally be transient and will not significantly increase either the percolation flux at the repository horizon or the value of the unsaturated hydraulic conductivity. The fraction of volume excavated within the ESF is small and is also not expected to significantly alter the flow field, or percolation flux, around the excavated openings.

Additionally, the ventilation system will remove water from the exposed underground walls. As discussed in Section 8.4.3.2, the ventilation system may remove a volume of water comparable to the volume of water retained during construction. Therefore, the effects of ventilation may further reduce the transient effects to flux and hydraulic conductivity caused by introducing water to the rock formations.

Potential impacts from geochemical disturbances

The potential impacts of geochemical disturbances from underground construction of drifts and testing alcoves will be similar to those from the construction of the exploratory shafts. Changes in geochemistry could potentially affect the site, primarily by altering the environment near waste emplacement. West (1988) discusses the type, quantity, and potential interactions of the fluids and materials that will be used during the construction of the drifts and testing alcoves. As in the evaluations made concerning shaft construction, West (1988) did not identify any interactions between fluids and materials used during construction that would have a significant,

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permanent impact on the site. West (1988) considered geochemical disturbances from such items as explosives, concrete, utility piping, instrument conduits, rock bolts, steel rods, tagged water, hydrocarbons from machinery, and gases and also evaluated the gaseous products of the explosives and the penetration distance using controlled blasting procedures. This evaluation indicated that most of the gaseous products would be ventilated to the surface, with some of the gaseous products potentially penetrating 1 to 2 m into the rock.

Therefore, the construction of the underground drifts and testing alcoves will cause some small permanent changes to the rock near the excavated openings. Because of the distance between the openings and emplaced waste, however, these geochemical changes are not expected to significantly alter the environment near the waste emplacement.

Potential impacts from thermal/mechanical disturbances

The underground drifts and testing alcoves within the ESF will be permanent features, but are not expected to function as preferential pathways for either liquid or gaseous radionuclides. Neither the drifts nor the alcoves directly intersect the accessible environment. The drifts and alcoves are predominantly horizontal features that will be laterally separated from the emplaced waste by at least 30 m. The drifts and alcoves are designed to provide internal drainage for the ESF to the sump for ES-1. They will connect to the shafts; but as discussed in the previous section, the shafts are not expected to function as preferential pathways. Therefore, the drifts and alcoves are not expected to provide a preferential pathway for radionuclide transport to the biosphere.

The underground construction will be performed by drilling rounds of small-diameter shot holes into the rock face, loading them with explosives, and then blasting. As discussed in Section 8.4.3.2.3, changes in stress will occur around the openings, resulting in changes to the rock mass hydraulic conductivity. As with the construction of the exploratory shafts, the changes in conductivity around the drift are expected to be increased by less than a factor of 2 to 3 at distances greater than approximately 5 m from the wall (Case and Kelsall, 1987). Hill (1985) predicted that changes to stress were effectively limited to about one drift diameter around a drift opening. St John (1987b) considered the use of rock bolts and concluded that the bolts have a negligible effect on drift stress and deformation. The permanent changes to hydrologic properties are, therefore, not expected to be significant at distances greater than approximately 5 m from the excavated opening.

According to these evaluations of potential impacts resulting from underground construction of drifts and testing alcoves, the permanent changes to the site are primarily the creation of drift openings and the zone of modified permeability around the openings. Changes to the site from introducing fluids and materials are expected to be generally transient and insignificant. The permanent changes are not expected to significantly impact the hydrologic, geochemical, and thermal/mechanical conditions of the site.

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8.4.3.2.5.5 Potential impacts to the site from exploratory shaft facility activities

The potential transient and permanent impacts to the site from ESF hydrological, geochemical, and thermal/mechanical testing activities are evaluated in this section. The detailed summaries of the hydrologic, geochemical, and thermal/mechanical analyses and data discussed in Section 8.4.3.2 provide the basis for evaluating the potential impacts.

The testing activities in the ESF include the multipurpose borehole (MPBH) tests, construction-phase tests, and in situ tests. The proposed MPBH and construction-phase testing primarily consist of sampling materials and fluids that are encountered during construction and monitoring the effects of construction. Therefore, these two testing activities should not impact the site conditions, and they will not be discussed in this section. The in situ tests will introduce additional fluids into the unsaturated zone and may cause some thermal/mechanical changes. A detailed description of the ESF testing activities is presented in Section 8.4.2.3.1.

Potential impacts from hydrologic disturbances

Hydrologic disturbances from ESF testing activities could potentially impact site performance by increasing the water flux at the repository horizon or by changing the hydrologic properties of the unsaturated zone. Two tests have currently been identified to be performed in the ESF that may introduce water into the unsaturated zone. These tests are the infiltration tests and the cross borehole water injection test.

Because the test block for the infiltration test will be separated from the rock mass and isolated within the drift, the water added to the rock can be recovered. Section 8.4.2.3.1 identifies a cross borehole water injection test as part of the test to evaluate hydrologic properties of major faults encountered at the main test level of the ESF test. Because this test is still in the early planning and development stage, the volume of water to be injected into the fault region has not yet been determined. The volume of water to be injected will, however, be carefully controlled. The potential impacts of the water to be injected will be assessed before testing. Therefore, the currently identified tests will not introduce a significant amount of water to the unsaturated zone, and the water used in these tests will not result in permanent changes.

Potential impacts from geochemical disturbances

Geochemical disturbances during ESF could affect site performance by altering the environment near areas of waste emplacement, reducing the capability of the tuff to retard transport of radionuclides, or affecting the flux of water at the repository horizon. The only test with a potential for chemical disturbances is the diffusion test, which will use a nonsorbing tracer. In Section 8.4.3.2.1, the tracers are estimated to move about 0.1 m into the rock around the test hole. Therefore, the potential geochemical impact from chemicals introduced during testing should be a very local effect near the test.

In summary, the permanent geochemical changes to the site from ESF testing are expected to be small and contained near the testing area. These changes should not affect the environment near waste package emplacement, the capability of the tuff to retard transport of radionuclide, or the ground-water flux at the repository horizon.

Potential impacts from thermal/mechanical disturbances

Thermal/mechanical disturbances could affect site performance by altering the hydraulic conductivity of the rock mass, by causing geochemical changes in the environment near waste packages or by creating preferential pathways for flow. The testing activities include several tests that involve mechanical effects and thermal/mechanical effects. The zone of influence estimated for these tests discussed in Section 8.4.2.3.1 indicates that the disturbances will be constrained to near the testing locations.

Tests that introduce heat into the rocks will be performed in the ESF that may change the moisture distributions around the heaters. The moisture may vaporize and move from the heated regions to the cooler regions where it will be condensed. Section 8.4.2.3.1 identifies the zones of influence for the various heated tests. The maximum zone of thermal influence was about 20 m from the heated room test. Because the heated region for the heated room test is bounded by two access drifts that are ventilated, the region of potential hydrologic alteration is not likely to extend beyond the access drifts. Other than the heated room tests, the maximum zone of thermal influence was about 14 m. The change in matrix moisture content will be relatively local during testing, and at the termination of the testing, the moisture will move back into the rock dried out by the heaters. (These tests will be specifically located at standoff distances large enough to avoid test-to-test interference.) Therefore, the currently identified tests should not have thermal effects that would cause areas of increased flux in the repository horizon or changes to the hydrologic properties of the unsaturated zone that would adversely affect postclosure performance. The ESF tests are not expected to provide preferential pathways for the movement of fluids to the accessible environment.

The tests that introduce heat may cause geochemical changes in the rock from the increase in temperature and from the chemicals remaining in the rock after vaporization of in situ water. As noted earlier, however, the area influenced by thermal effects is a relatively local area near the tests.

8.4.3.3 Potential impacts of site characterization activities on postclosure performance

The impacts of disturbances from site characterization activities on the postclosure performance objectives for total system releases, waste-package containment, EBS release rates, and ground-water travel time are discussed in this section. The issue resolution strategy for each performance objective is briefly summarized. These strategies identify the system elements and the performance measures relied upon to achieve and demonstrate that the performance objectives have been met. The potential impacts of each of the five categories of site characterization activities on the performance measures of

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the system elements are discussed. Because of the comprehensive scope of the performance objective for total system release, the discussion provided for this objective is more extensive than the discussions for the other three performance objectives.

The evaluations of the potential impacts of site characterization activities on postclosure performance are based on the current conceptual model of unsaturated flow discussed in Section 8.4.1.3. Section 8.4.3.1.1 describes the general approach to performance assessment used in this section and indicates that the interpretation of current data is based primarily on physical concepts of unsaturated flow in a porous, fractured rock such as the rock at the potential repository horizon at the Yucca Mountain site. The interpretations of the data will be continuously reevaluated during site characterization as alternative models for unsaturated flow at Yucca Mountain are refined (Section 8.3.1.2.2).

8.4.3.3.1 Impacts on total system releases

8.4.3.3.1.1 Summary of issue resolution strategy

The performance objective for releases of radioactivity from the total system is described in Section 8.3.5.13 (Issue 1.1). In accordance with Section 60.112 of 10 CFR Part 60 and in Section 191.13 of 40 CFR Part 191, the performance measure for the total system is the complementary cumulative distribution function (CCDF) for the normalized, cumulative release of radioactivity to the accessible environment for 10,000 years following permanent closure, owing to the action of all significant events and processes that may affect the geologic repository. As described in Section 8.3.5.13, the CCDF will be numerically constructed by Monte Carlo simulation with a total system simulator, which is composed of mathematical models of the action of significant events, processes, and features on the amount of radioactivity released to the accessible environment in the period of performance. The significant events and processes to be incorporated in these mathematical models--as well as some of the physical principles to be embodied in the models--are to be determined from the information developed during site characterization.

A preliminary identification of potentially significant events, processes, and features is made in Section 8.3.5.13 in order to guide the collection of this information. The requirements in 40 CFR 191 depend on the likelihood of the significant events and processes; thus, Section 8.3.5.13 divides these processes and events into scenario classes. The nominal scenario class contains those events and processes that are reasonably likely to occur in the 10,000-yr period following permanent closure. The disruptive scenario class contains processes and events that are credible enough to warrant consideration but whose likelihoods lie outside the range of those in the nominal class. Section 8.4.3.3.1.2 uses the scenario classes for the evaluation of impacts on total system releases. A more complete discussion of the processes and events, the nominal and disruptive scenario classes, and an explanation of how those scenario classes were selected are given in Section 8.3.5.13. The use of the scenario classes as tools for the analyses and derivations in Section 8.3.5.13 and in this section does not imply that the events and processes are likely to occur. The likelihoods and consequences of most of the scenarios can be established only after site characterization has provided the necessary information.

According to Table 8.3.5.13-8, which lists the preliminary performance allocation for this performance objective, the components to be relied on for meeting the objective vary with the release scenario class. The unsaturated zone, however, will be the primary component to be relied on to mitigate deleterious effects of many of the events, processes, and features that will be considered. For some events, processes, or features, the saturated zone or engineered systems will also be relied on.

8.4.3.3.1.2 Evaluation of impacts on total system releases

This section evaluates whether site characterization activities can be expected to preclude the capability of the site to meet the postclosure performance objective governing the total-system release of radioactivity over the 10,000-yr period following permanent closure (as required by 40 CFR 191.13). These evaluations are based on estimations of the effects of the site characterization activities on current site hydrologic, geochemical, and thermal/mechanical conditions. Section 8.4.3.2 presents the analyses that underlie the estimations, which are summarized in Section 8.4.3.2.5. Some of these effects are transient, becoming insignificant before closure or early in the 10,000-yr isolation period; others are more permanent, persisting well into the isolation period. The estimates of both kinds of effects are used here to evaluate potential effects on current site performance. The more permanent effects are the basis for evaluating whether site characterization activities will, under future conditions, be likely to make the site unable to meet the total system release requirements.

The evaluations of impacts are also based on an understanding of the characteristics of the unsaturated zone (Sections 3.9 and 8.4.1.3), the types of site characterization activities currently planned (Section 8.4.2), and the design features that avoid or mitigate the potential impacts (Sectios 8.3.3.1 and 8.4.1.2). Section 8.4.2.1 identifies five types of site characterization activities: surface-related activities, drilling activities, exploratory-shaft construction, underground construction of drifts and alcoves, and testing activities in the exploratory shaft facility.

For convenience in making these evaluations, this section is organized according to the nominal and disruptive scenario classes developed in Section 8.3.5.13 and briefly summarized in Section 8.4.3.3.1.1. This organization helps to ensure that all the events and processes currently considered worthy of further investigation are examined. The discussion of events and processes in the nominal scenario class is in two parts. The first deals with the events and processes that currently exist at the Yucca Mountain site; these phenomena are summarized in Section 8.4.1.1.3. The evaluation of the effects of site characterization activities on these phenomena examines both the transient and the more permanent effects of the activities.

The second part deals with the processes and events that, though not believed to exist now at the site, the DOE considers worthy of investigation as potentially likely phenomena. These are phenomena that, if proved to be likely during site characterization, will be part of the nominal scenario class used in constructing the CCDF. The 16 processes and events in this category are as follows:

1. Climatic change.
2. Flooding.
3. Geochemical changes.
4. Undetected faults and shear zones.
5. Undetected dikes.
6. Faulty waste emplacement.
7. Undiscovered boreholes.
8. Undiscovered mine shafts.
9. Differential elastic response to heating.
10. Inelastic response to heating.
11. Thermally driven water migration.
12. Local mechanical fracturing.
13. Corrosion.
14. Chemical reaction of waste package with rock.
15. Geochemical alteration.
16. Microbial activity.

Presence on the list does not indicate that the DOE currently believes a process or event is likely. Some of them (e.g., undiscovered mine shafts) are in the list only to request site characterization information that will allow a definitive decision as to whether they can be eliminated from further consideration.

After the two discussions of events and processes in the nominal scenario class, this section investigates how the more permanent effects of site characterization activities would affect site behavior if unlikely disruptive events occur in the future. Initiating events and processes in the disruptive scenario class in the following list are examined in this section.

1. Extreme climate change.
2. Stream erosion.
3. Faulting and seismicity.
4. Magmatic intrusion.
5. Extrusive magmatic activity.
6. Irrigation.
7. Intentional ground-water withdrawal.
8. Exploratory drilling.
9. Resource mining.
10. Climate control.
11. Surface flooding or impoundments.
12. Regional changes in tectonic regime.
13. Folding, uplift, and subsidence.

Again, not all the items in the list are currently considered likely enough to be included in the complementary cumulative distribution function. This list has been developed as a guide for site characterization, and the DOE expects that site characterization will show many of the events or processes to be insignificant because their consequences or their likelihoods are small.

The evaluations pay much attention to the unsaturated zone because it is the primary barrier relied upon to isolate the emplaced wastes from the accessible environment over the 10,000-yr period of performance. Major features in the current conceptual models of the unsaturated zone that are important to these evaluations include the dampening of surface infiltration events at depth in the unsaturated zone; low ground-water flux at depth; ground-water flow mainly through a fractured, porous matrix, with water in the fractures drawn by capillarity into the partially saturated porous matrix; movement of water in fractures when the porous matrix is at or near saturation; and possible perching of ground water in areas of distinct permeability contrast such as a porous, nonwelded tuff overlying a fractured, welded tuff. The evaluations pay less attention to the saturated zone because it is a secondary barrier, few site characterization activities are planned in the saturated zone, and potential impacts of these site characterization activities on waste isolation are expected to be minor.

Because compliance with total system performance objective relies on the hydrologic properties of and conditions within the unsaturated zone between the repository and the water table, all three of the following discussions focus on changes to these properties and conditions as a result of site characterization activities. A significant decrease in the ability of the unsaturated zone to chemically or physically retard the transport of radionuclides would also adversely affect the ability of the site to meet the total system performance objective. The possible adverse effects on the hydrologic properties and conditions in the unsaturated zone fall into three primary classes: (1) significant changes to the amount or spatial distribution of ground-water flux; (2) significant changes to the hydrologic properties, principally hydraulic conductivity; and (3) the creation of pathways for rapid flow of liquids.

Analysis results important to the evaluations of effects

Drawing from the more detailed discussions in Section 8.4.3.2, the next several paragraphs briefly discuss some results of analyses of the effects of site characterization. The expectations based on these results are important in many of the evaluations presented in the three discussions according to scenario classes; they are accordingly reviewed here before the three discussions.

Since they will not be present during site characterization, engineered components will not be directly affected by site characterization activities, but they might be indirectly affected in the future because of changes in site hydrological, geochemical, or thermal/mechanical conditions. The activities are also not expected to significantly affect the performance of the saturated zone because the little testing that will be performed within the saturated zone by drillholes will not significantly change the hydrologic or geochemical conditions around the boreholes. Gas-phase releases from the repository may not be significantly affected if site characterization activities do not create preferential pathways for gas flow. The performance

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allocation in Section 8.3.5.13, however, places primary reliance upon the waste form, not the geologic barriers, to ensure system performance in the presence of gas-phase releases. Additional study during site characterization will better define the roles that natural barriers and engineered barriers, such as seals, can be expected to play in limiting potential gas-phase releases. For example, the backfilled and sealed shafts and boreholes from site characterization would not constitute gas-flow pathways if the backfill material had an air conductivity of less than 3 x 10^{-4} m/min.

Evaluations of water artificially introduced to the site during site characterization have been made in Section 8.4.3.2; those evaluations indicate that water will generally move only a relatively short distance (approximately 10 m or less) from a penetration under small heads and that the final change in saturation of the disturbed volume around the penetration will be extremely small (a few percent or less). Compared with the period of performance (10,000 years), the time required for water introduced by site characterization activities to reach near-equilibrium conditions is extremely short (estimated to be days to months depending on local rock hydrologic properties; Section 8.4.3.2.1). These small and localized changes in saturation around penetrations are not expected to significantly affect the amount or spatial distribution of ground-water flux or the hydraulic conductivity. They are also not expected to affect the release of radioactivity to the accessible environment for either the nominal or the disruptive scenario classes. Furthermore, the initial perturbations due to site characterization activities are short compared with the period of performance and generally will be laterally well separated from emplaced waste.

Analyses in Section 8.4.3.2 indicate that changes in stress and rock mass permeability will be small outside of two opening-diameters (less than 9 m for the exploratory shafts) away from the penetration.

The evaluations of artificially introduced chemicals to the site are made in Section 8.4.3.2. Those evaluations indicate that the distance of geochemical effects around a penetration is constrained by the distance water moves and will be limited to approximately 10 m or less. In addition, the more volatile chemicals will tend to evaporate over time and to diffuse and become diluted within the partially saturated rock matrix. The retardation capability of the rock will not generally be altered outside of this distance.

The evaluations made in Section 8.4.3.2 thus indicate that many of the possible changes to site hydrologic, mechanical, and geochemical conditions are generally limited to distances within approximately 10 m of a penetration and are often short-lived. Because the site characterization activities will be separated from waste-emplacement areas by more than 10 m, and because this objective considers the cumulative release of radioactivity from the entire repository, the localized and limited changes to site hydrologic, geochemical, and mechanical conditions are judged not to be significant. (Further discussion is presented in the evaluations of events and processes in the nominal scenario class where present site conditions are considered.) The focus of the evaluations of potential impacts to this performance objective (if the events or processes listed for the nominal and the disruptive scenario classes should occur) will be whether the penetrations from site characterization could create preferential pathways.

Considerable attention has been given in planning and selecting construction activities to avoid or limit potential impacts (e.g., by selecting dry-drilling methods for boreholes within the repository block, controlling water use during drill-and-blast activities, controlling drill-and-blast activities, and avoiding blockage of natural surface-water drainageways). Most impacts that do occur are expected either (1) to be of short duration or reversible (e.g., the effects of watering for dust control at the ground surface and water introduced during drill-and-blast activities that is quickly removed with the muck or by the ventilation system) or (2) to be spatially limited (e.g., increased infiltration due to ground disturbance and the creation of a modified permeability zone (MPZ) around boreholes, shafts, and drifts).

Impacts that are of primary concern for these evaluations are those that may be pervasive in time and space. Examples of such effects are those that would persist during the period of performance and result in (1) significantly increased flux at the repository depth (e.g., the potential effects of surface-water impoundments); (2) significantly changed hydraulic properties or hydrochemistry (e.g., the potential effects of drill-and-blast activities); and (3) the creation of preferential pathways (e.g., the potential effects of boreholes and shafts). As discussed in Section 8.4.3.2.4, some of the design features that are relied upon to ensure the performance of the natural barriers by limiting the potential impacts of site characterization activities include lateral separation of the waste-emplacement areas from the shafts, underground testing facility, and boreholes; drainage within the ESF away from waste emplacement areas to the sump in ES-1; and the sealing of boreholes, shafts, and drifts as described in detail in Section 8.3.3.1.

In addition to ensuring the performance of the natural barriers in meeting the total-system-release performance objective (10 CFR 60.112), the planning and selection of construction activities mentioned previously and the inclusion of design features mentioned in the previous paragraph demonstrate the incorporation of other provisions in 10 CFR Part 60 that relate to waste isolation within the geologic repository program (e.g., portions of 60.133, "Additional design criteria for the underground facility," and 60.134, "Design of seals for shafts and boreholes").

<u>Nominal scenario class: present site conditions</u>

The potential impacts of site characterization activities on the performance of the site, with respect to present site conditions, have been evaluated for the five types of site characterization penetrations. These five types are briefly summarized here.

Surface-related site characterization activities are not expected to significantly alter the hydrology of the unsaturated zone below a few tens of meters. The potential effects of the planned surface-related activities have been estimated in Section 8.4.3.2.5 as an increase in surface infiltration into the alluvium (e.g., from trenching and ponding studies) or directly into the tuffaceous bedrock (e.g., from pavement studies). These effects,

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however, are of short duration and are damped out within the uppermost tuffaceous units as moisture is redistributed within the partially saturated matrix or is drawn from fractures into the partially saturated matrix.

For drilling activities, about 30 boreholes are currently expected to penetrate from the surface to the repository horizon or deeper within the conceptual perimeter drift boundary for the repository (Section 8.4.2.2). These boreholes will be sealed as described in Section 8.3.3.1 in order to restrict the movement of gaseous or liquid-phase fluids preferentially into or through the penetrations. In addition, the boreholes will be designed to be isolated, to the extent practical, in pillars laterally separated from waste-emplacement areas. The potential geochemical and mechanical changes that boreholes might induce are expected to be limited and confined well within these pillars.

The construction of the exploratory shaft, like the surface-related activities, will produce some small, short-duration increases in the saturation of the surrounding rock. These transient, localized effects will not significantly affect the flux or hydraulic properties of the unsaturated zone (Section 8.4.3.2.5.3). The more permanent effects of exploratory-shaft construction (potential geochemical changes and changes in stress conditions) are of limited spatial extent and are not expected to create preferential pathways. The shafts will be more than 30 m away from the emplaced waste. The shafts will not create preferential pathways because they will be sealed as described in Section 8.3.3.1 to restrict movement of gaseous or liquid-phase fluids preferentially into or through the penetrations. Fernandez et al. (1988) have calculated inflow from saturated near-surface fractures into a backfilled shaft (as described in Section 8.4.3.2.5) and have concluded that the quantity of water inflow will be small and the backfilled shaft will drain as rapidly as water enters. These analyses are also thought to be representative of flow from either saturated fractures or perched-water zones at greater depth. In addition, the analyses are thought to bound, by extrapolation, concerns about inflow into sealed boreholes.

A decision on the depth of penetration for the exploratory shaft ES-1 has been deferred until further evaluations are completed, study plans are prepared, and technical discussions are held with the NRC (Section 8.4.2.2). These evaluations will cover such topics as the need to extend an exploratory shaft and drifting in the Calico Hills unit and the potential impacts of such penetration on waste isolation.

For the activities on underground construction of drifts and testing alcoves and testing activities in the exploratory shaft facility (ESF), the effects on the hydrology of the unsaturated zone, with the exception of the penetration created by excavation, are expected to be of short duration and laterally limited to within approximately 10 meters of the ESF (Section 8.3.2.5). The drifts and alcoves will be sealed as described in Section 8.3.3 in order to restrict movement of gaseous or liquid-phase fluids preferentially into or through penetrations. In addition, the ESF is laterally separated from waste-emplacement areas by at least 30 m, and the ESF will drain water internally to the sump of ES-1 to prevent movement of water from the ESF facility during operations or the waste emplacement areas during the postclosure period.

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In summary, five types of site characterization activities have been evaluated for the present site conditions, and the performance of the site characterization activities as planned is not expected to preclude the capability of the site to meet the postclosure performance objective for total-system release of radionuclides to the accessible environment over the 10,000-year period following repository closure.

Nominal scenario class: potentially likely, but not currently present, conditions

The next paragraphs address the impacts of site characterization activities under those conditions that could be produced by events and processes that (after site characterization has produced the necessary information) may be considered likely to occur in the 10,000-year period following permanent closure. These conditions are listed earlier. For brevity, the evaluations generally assume a familiarity with the brief review of analysis results just presented and with Section 8.4.3.2.5. Plans for sealing are reviewed in Section 8.3.3.

The list of processes and events discussed in this section was developed for guiding site characterization. The DOE expects that site characterization information will show that at least some of them (and probably most of them) are unlikely or ineffective at the Yucca Mountain site. In this section, the list is used simply to ensure that the possible effects of site characterization activities are evaluated against the events and processes currently being considered for inclusion in the nominal scenario class.

This section briefly describes the 16 potentially likely processes and events, and identifies potential pervasive changes in site conditions that may be reasonably expected given the occurrence of the process or event. The section then focuses on the potential effects that site characterization activities might exert on compliance with the total system release performance objective under the conditions that would result if the process or event were to occur. Finally, this section addresses whether the planned site characterization activities can be reasonably expected to significantly affect the frequencies of occurrence or the magnitudes of the processes and events.

In most of these evaluations, the principal consideration is whether the process or event will result in an increased volume of water entering potentially preferential pathways created by the site characterization penetrations (e.g., boreholes, shafts, and drifts), either above the repository horizon (potentially resulting in a localized increase in flux across the repository horizon) or at or below the repository horizon (potentially resulting in gaseous-phase releases or localized drainage through a portion or all of the primary barrier for waste isolation). Other potentially adverse effects considered in the evaluations include significant changes in hydrochemistry (e.g., changes in the waste package environment or decreases in the ability of the unsaturated tuff to chemically or physically retard the transport of radionuclides released during the period of performance).

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Note that this section is not intended to evaluate the potential effects of the processes and events on the total-system-release performance objective. Preliminary analyses of such effects were in the environmental assessment; final analyses, possible only after site characterization, will be in the license application.

Climate change

Climate change consists of a global warming due to increased atmospheric carbon dioxide, accompanied by an increase in summer precipitation of probably less than 50 percent. Subsequently, the onset of a cooler and wetter pluvial period is expected. Thus, climate change could increase flux, which could reasonably be expected to increase the volume of water moving from saturated fractures or perched-water zones into the site characterization penetrations.

Flooding

The flooding scenario consists of rapid runoff during severe summer thunderstorms in the washes draining Yucca Mountain, resulting in increased flux either through the alluvium into the tuffaceous bedrock or by interception of the runoff in open fractures in surficial bedrock. As in the climate-change scenario, the increased flux from the flooding could reasonably be expected to increase the volume of water moving from saturated fractures or perched-water zones into the site characterization penetrations.

Geochemical changes

The geochemical changes consist of the potential precipitation, solution, or alteration of minerals in fractures under current percolation flux that could significantly alter the internal fracture geometry, and consequently, the hydrologic properties of the fractures (e.g., blockage of small aperture fractures and diversion of flow into larger fractures). As in the previous scenarios on climate change and flooding, this scenario may be reasonably expected to increase the volume of water moving from saturated fractures into the site characterization penetrations.

Undetected faults and shear zones

In scenarios that hypothesize the presence of undetected faults and shear zones that might affect the impacts of site characterization activities on postclosure performance, the sequences to be considered include undetected wet zones associated with minor faults above the repository horizon and undetected major faults below the repository horizon through which enhanced moisture flow occurs. As in the previous scenarios, these sequences may be reasonably expected to increase the volume of water moving from saturated fractures into the site characterization penetrations.

Undetected dikes

An undetected dike may provide a feature of very low matrix permeability, but high fracture permeability, thereby providing a pathway for increased volume of water that may be intersected by site characterization penetrations. As in the previous scenarios, the undetected dike may be reasonably expected to increase the volume of water moving from saturated fractures into the site characterization penetrations.

Faulty waste emplacement

The scenarios that begin with faulty waste emplacement include several sequences, such as placing canisters in wet zones, improperly constructing drains around waste canisters, leaving canisters on the floor of the drifts or placing them too close together, improperly manufacturing canisters, or puncturing or abrading canisters during emplacement. These sequences may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Undiscovered boreholes

The undiscovered-borehole scenario begins with a horizontally emplaced waste canister lying in the trace of an old, undiscovered borehole. In addition, moisture conditions are wetter than currently existing conditions. This scenario introduces water directly to the repository horizon, which could result in an increased source term available for release through preferential pathways, if any, created by site characterization penetrations.

Undiscovered mineshafts

The undiscovered-mineshaft scenario consists of an old prospect in the bed of a wash that has filled with rubble and retains water after floods. This area allows a localized increase in infiltration that in turn results in a wet zone in which waste is emplaced. This scenario may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations. Or, in the sequence where a borehole or shaft intersects the wet zone above the repository, the scenario may result in an increased volume of water moving from the wet zone into the site characterization penetration.

Differential elastic response to heating

The scenarios beginning with differential elastic responses to heating consist of several sequences, including diversion of flux into larger fractures in response to closure of small fractures as the result of thermal expansion, creation of open fractures in response to rock movements as the result of thermal expansion, and failure of waste canister in response to stress corrosion or shearing as the result of thermal expansion. The first two sequences could result in localized increases in flux that could reasonably be expected to increase the volume of water moving from saturated fractures or perched-water zones into the site characterization penetrations. The last two sequences could result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

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Inelastic response to heating

The scenario beginning with inelastic response to heating consists of thermally induced fracturing of rocks immediately surrounding the waste canisters, which creates capillary breaks to the movement of moisture between blocks of the rock matrix. For these blocks, the matrix is saturated and water contacts the waste package. This scenario may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Temperature-driven fluid migration

For the scenarios beginning with temperature-driven fluid migration, a two-phase convection system is created, and a saturated zone develops in an area of condensed moisture driven off as vapor by the thermal pulse. When gravity-driven flow again dominates the unsaturated zone, a large volume of water flows through the repository horizon. As a variation, temperature inhomogeneities may lead to localized accumulation of moisture above the repository, creating wet zones that bring water into contact with the wastes. This scenario may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Local mechanical fracturing

For the scenario beginning with local mechanical fracturing, rock bursts are assumed to occur and propel rocks into waste packages, penetrating the canisters. This scenario may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Corrosion

The corrosion scenarios consist of several sequences that lead to failure of the waste canisters, including one sequence in which colloids of corrosion products sorb radionuclides that are normally highly retarded radionuclides and carry them away unretarded by chemical reactions with the rock. As in the previous scenario, this scenario may result in an increased (or, in this case, more mobile) source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Chemical reaction of waste packages with rock

The scenarios that begin with chemical reaction of waste packages with rock include several sequences wherein the dissolution rate of uranium is above that predicted by the equilibrium solubility of uranium and wherein colloids transport radioelements with little or no retardation. As in the previous scenario, this scenario may result in an increased and more mobile source term available for release through preferential pathways, if any, created by the site characterization penetrations.

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Chemical alteration

The chemical alteration scenarios consist of multiple sequences wherein the heating of the rocks around the repository results in mineralogy changes that clog pores and divert flow into fractures. Diversion of flow into fractures could reasonably be expected to increase the volume of water moving from saturated fractures into the site characterization penetrations.

Microbial activity

The microbial activity scenario consists of microbial activity that accelerates canister or cladding corrosion and sorbs radionuclides so that they move at the velocity of ground water, unaffected by sorption or matrix diffusion. This scenario may result in an increased and more mobile source term available for release through preferential pathways, if any, created by the site characterization penetrations.

As indicated previously, the principal consideration in this section is whether, given the occurrence of a process or event, site conditions will be changed such that the site characterization activities will adversely affect the capability of the site to meet the total systems release performance objective. In some scenarios (i.e., climate change, flooding, geochemical changes, undetected faults and shear zones, undetected dikes, undiscovered mine shafts, differential elastic response to heating, temperature-driven fluid migration, and chemical alteration), one of two major potential impacts is expected. Either the flux through the unsaturated zone would increase such that saturated flow conditions would exist in fractures or perched-water zones above the repository, or the site characterization penetrations would function as localized preferential pathways for gaseous or liquid-phase releases from the repository horizon. To the extent that site characterization activities within the conceptual perimeter drift boundary penetrated the Calico Hills formation, these penetrations could locally reduce the effectiveness of the primary barrier for waste isolation if the ground-water flux were to increase substantially in the formation. In several other scenarios (i.e., faulty waste emplacement, undiscovered boreholes, undiscovered mineshafts, differential elastic response to heating, inelastic response to heating, local mechanical fracturing, temperature-driven fluid movement, corrosion, chemical reaction of waste package with rock, and microbial activity), two other major potential impacts are expected. Either the hydrochemistry of ground water contacting the waste package changes or the radionuclide source term available for gaseous or liquid-phase transport through preferential pathways created by the site characterization penetrations increases. In the final three scenarios (i.e., chemical alteration, chemical reaction of waste package with rock, and microbial activity), the potential impacts included changes in the sorption capability of the tuffaceous rock.

As in the expectations for effects under present site conditions, the lateral separation of the site characterization penetrations from the waste emplacement areas, the drainage of the ESF internally to the sump for ES-1, and the sealing of the site characterization penetrations should ensure that these penetrations are neither preferential drainage points nor preferential pathways for gaseous or liquid-phase releases (Section 8.3.3.1). If there is a need to penetrate the Calico Hills formation with a shaft and drifts, further analysis will be needed to determine the potential impacts of these currently deferred site characterization activities on the primary barrier for waste isolation.

Site characterization activities are not expected to significantly change the hydrochemistry of the ground water over a significant time or distance or to significantly change the sorption capability of the tuffaceous rock (Section 8.4.3.2.5).

In summary, the performance of the site characterization activities as planned is not expected to adversely affect the capability of the site to meet the postclosure performance objective for total systems releases of radionuclides to the accessible environment over the 10,000-year period of performance. Site characterization activities are also not reasonably expected to significantly affect either the frequencies of occurrence or the magnitudes of the processes and events that may be considered (in the absence of further site characterization and analysis) likely to occur within the 10,000-year period of performance. Causal relationships were considered between the site characterization activities and the processes and events (e.g., reservoir-induced seismicity in the case of a large surface-water impoundment in the vicinity of an active fault zone). With the possible exception of postulated flooding in the vicinity of the exploratory shafts (which has been analyzed by Fernandez et al. (1988) as not adversely impacting the performance of the site), there do not appear to be any causal relationships whereby the planned site characterization activities are reasonably expected to significantly affect either the frequency of occurrence or the magnitude of the processes and events that may be considered likely to occur within the 10,000-year period of performance.

Disruptive scenario classes

This section describes the effects that low-probability, disruptive scenarios may have on present site conditions (e.g., hydrologic, geochemical, and thermal/mechanical conditions) in order to evaluate whether the site characterization activities (primarily boreholes and shafts) will adversely impact the postclosure performance objective under the conditions of the disruptive scenarios. The previous section described whether the site characterization activities would adversely impact compliance with the postclosure performance objective under anticipated conditions.

This section is not intended to dismiss any of the disruptive scenarios. That will require the evaluation of data collected in the site characterization program. Note that this section is also not intended to evaluate the potential effects of the disruptive scenarios on the total-system-release performance objective except in a general way. Preliminary analyses of such effects were presented in the environmental assessments (DOE, 1986b); final analyses, possible only after site characterization, will be in the license application.

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This section briefly describes the 11 disruptive scenario classes, and identifies potential pervasive changes in site conditions that may be reasonably expected if a scenario occurs. The section then focuses on the potential impacts of site characterization activities on the total systems release performance objective under the conditions that would result if the disruptive scenario were to occur.

For most of the evaluations, the principal consideration is an increased volume of water entering potentially preferential pathways created by site characterization penetrations (e.g., boreholes, shafts, and drifts) either above the repository horizon (potentially resulting in a localized increase in flux across the repository horizon) or at or below the repository horizon (potentially resulting in gaseous-phase releases or localized drainage through a portion or all of the primary barrier for waste isolation). Other potentially adverse effects considered in the evaluations include any significant change in hydrochemistry (e.g., changes in the waste package environment or decreases in the ability of the unsaturated tuff to chemically or physically retard the transport of radionuclides released during the period of performance).

The evaluations generally assume familiarity with the brief review of analysis results given earlier in this section and with Section 8.4.3.2.5.

Extreme climate change

As discussed in Section 8.3.5.13, extreme climate changes (i.e., changes that are not expected to happen during the next 10,000 yr) could potentially result in scenarios that increase the net infiltration into the unsaturated zone. As a further consequence, this increase could (1) increase the ground-water flux through the repository, (2) raise the water table because of the increase in recharge, (3) raise the water table and change the flow pattern, (4) raise the water table and create closer discharge points, (5) perch water above the repository and divert water into localized zones, and (6) perch water below the repository and divert water into fracture zones. Given the occurrence of any of these six sequences, the principal way site characterization activities could potentially affect performance would be by creating preferential pathways for liquid water movement. The summaries of effects on site conditions from performing characterization activities (Section 8.4.3.2.5) indicate that changes to the hydrologic conditions of the site will be small and localized near the penetrations.

Under the scenario of extreme climate change, the penetrations from site characterization activities are not expected to become preferential pathways because, as described previously, these penetrations will be backfilled and sealed. Furthermore, they will be laterally separated from the waste-emplacement areas and therefore distant from sources of radionuclides that the increased ground-water flux might transport. Under this scenario, local perched-water zones of saturated rock-matrix may develop, and ground water could flow into and through fractures intersecting a site characterization penetration. For the reasons just given, however, flow into the penetration--especially flow bearing dissolved radionuclides--would be expected to be very small. Overflow of a large penetration is also not expected according to the evaluations summarized in Section 8.4.3.2. For example, Fernandez et al. (1988) analyzed inflow through fractures to the backfilled

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shaft and showed that water would drain out the bottom of the shaft as fast as it reached the bottom. Therefore, the DOE judges that, given the occurrence of extreme climate change, performing site characterization activities described in this document will not preclude meeting the total system release performance objective.

Stream erosion

No permanent streams occur within the repository drift boundary. Some ephemeral streamflow occurs at the site following intense precipitation events. The only sequence described in Section 8.3.5.13 related to the unsaturated zone is the erosion of the Tiva Canyon welded unit to expose the underlying nonwelded unit. The washes would then form barriers to lateral flow in the Tiva Canyon and divert flow downward, toward the repository. In addition, the NRC has raised the possibility of another sequence: lateral erosion in Coyote Wash such that the streamflow could be diverted into the backfilled exploratory shafts. In the first sequence, the penetrations from characterization activities would not generally be expected to act as pathways for water from the surface unless saturated fractures or perched zones are intersected by the penetrations. For this occurrence, the presence of a penetration would influence the water flow in a manner similar to the presence of a fault discussed in the next evaluation. In a study applicable to the second sequence, Fernandez et al. (1988) has analyzed inflow into a backfilled shaft and has shown that the shaft will drain quickly enough at the bottom to keep from filling to the repository level with water. Potential releases of radioactivity from the total system, given the occurrence of this scenario, thus would not be significantly changed because characterization activities were performed. Therefore, the DOE judges that, given the occurrence of the stream-erosion scenarios, performing site characterization activities described in this document will not preclude meeting the total system release performance objective.

Faulting and seismicity

As discussed in Section 8.3.5.13, faulting and seismicity could potentially shear waste canisters in regions of enhanced downward moisture flux, create enhanced-permeability zones, or cause structural or stress changes that cause the water table to rise. The site characterization penetrations will not occur in waste emplacement areas and are moreover not expected to be preferential pathways because of the backfill and seals. If faulting should cause the water table to rise enough to saturate the repository horizon, the ground-water flow in the saturated zone at the repository horizon probably would be predominantly lateral, following the regional ground-water flow system. The penetrations would not be expected to be preferential pathways because the shafts and boreholes would be vertical penetrations in a lateral flow system. The penetrations could enhance vertical mixing if radionuclides entered the holes; this probably would enhance performance. Therefore, the DOE judges that, given the occurrence of faulting and seismicity, performing site characterization activities described in this document will not preclude meeting the total system release performance objective.

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Magmatic intrusion

As discussed in Section 8.3.5.13, magmatic intrusion into the unsaturated zone would probably affect the distribution and magnitude of ground-water flux, change rock hydrologic properties, and change geochemical properties. Site characterization penetrations that encounter perched water above a magma intrusion would be laterally separated from waste-emplacement areas and would drain small amounts of water due to the borehole seals. This is similar to what would happen if penetrations intersected the saturated fracture. The other effects produced by magmatic intrusion would be independent of the presence of site characterization penetrations or effects. Consequently, the DOE judges that, given the occurrence of magmatic intrusion, performing site characterization activities described in the document will not preclude meeting the total-system performance objective.

Extrusive magmatic activity

Section 8.3.5.13 describes a potential disruptive scenario in which a volcano erupts through the repository and contents of a waste package are borne upward by extruding magma. The effects produced by this scenario would be independent of the presence of site characterization penetrations or effects. The DOE can ascertain no credible manner by which site characterization activities could preclude meeting the total-system performance objective, assuming the occurrence of this scenario.

Irrigation

Section 8.3.5.13 considers an increase in moisture flux through the repository as a result of irrigation in Midway Valley. Site characterization penetrations in these postulated areas of Midway Valley would not be expected to be preferential pathways because of the presence of backfill and borehole seals. In addition, boreholes will be laterally separated from the waste-emplacement areas. Therefore, the DOE judges that, given the occurrence of irrigation, performing the site characterization activities described in this document will not preclude meeting the total system release performance objective.

Intentional ground-water withdrawal

Section 8.3.5.13 considers changes to ground-water recharge, water-table lowering, dewatering below the repository, and increased hydraulic gradients in the saturated zone. With the exception of ground-water recharge, as discussed in the irrigation scenario, these scenarios primarily affect the saturated zone; the hydrologic characteristics of the unsaturated zone will not be significantly affected. Therefore, site characterization activities in the unsaturated zone, given the occurrence of intentional ground-water withdrawal, will not preclude meeting the total system release performance objective.

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Exploratory drilling

Section 8.3.5.13 considers exploratory drilling that occurs after the repository has been closed. Such drilling could potentially intercept waste and bring it to the surface with cuttings, introduce water by future drilling, create preferential pathways by drilling, and introduce chemicals (surfactants) that enhance water movement. Impacts of exploratory drilling after repository closure are independent of the site characterization activities. Therefore, the DOE judges that, given the occurrence of exploratory drilling after repository closure, the site characterization activities described in this document will not preclude meeting the total system release performance objective.

Resource mining

Section 8.3.5.13 considers resource mining that could potentially intercept waste and bring it to the surface, introduce water to the repository, create a preferential flow path, or change hydrologic characteristics by introducing surfactants. The impacts of resource mining after repository closure are independent of the site characterization activities. Therefore the DOE judges that, given the occurrence of resource mining after repository closure, the site characterization activities described in this document will not preclude meeting the total system performance objective. In addition, site characterization would not increase the probability of resource mining. None of the materials that would remain at the site after site characterization (e.g., concrete, dilute aqueous tracers, borehole casing, instrumentation) are likely to be interpreted as geochemical indicators that might lead to exploratory mining.

Climate control

Section 8.3.5.13 considers effects of climate control; these effects could potentially increase percolation through the repository, raise the water table to the repository level, or perch water above or below the repository. Changes in the site due to climate control will be similar to changes from the disruptive scenarios resulting from extreme climate change. The evaluations are similar, and a similar conclusion is made that performing site characterization activities will not preclude meeting the total system performance objective.

Surface flooding or impoundments

Section 8.3.5.13 considers disruptive scenarios produced by potential surface flooding or surface-water impoundments. In these scenarios, groundwater flux is presumed to be increased beneath a wash during a flood or beneath a surface-water impoundment, allowing water to seep into boreholes or shafts.

The site characterization penetrations that might affect performance because of flooding include both site characterization drillholes and exploratory shafts. Two exploratory shafts will be constructed, and approximately 30 boreholes may be drilled to the repository depth within the repository

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drift boundary. According to current plans, both boreholes and shafts will be backfilled and sealed (Fernandez et al., 1987). Figure 8.4.3-2 shows a schematic of the sealing concepts for the exploratory shafts.

Two sets of analyses have investigated effects of flooding on the hydrology of the unsaturated zone due to the presence of an exploratory shaft. Peters (1988; see topic 2 in Section 8.4.3.2.1.1) investigated effects of ponding water on a highly permeable feature (such as a backfilled shaft) in Yucca Mountain for over two days. Their analyses showed that there was no effect on percolation at the proposed repository horizon during the first 1,000 years following the event; the percolation rate only doubled during the time period between 10,000 and 100,000 years. The analyses indicate that a large fraction of the water that moves through a highly permeable material in the unsaturated zone will be gradually imbibed into the matrix material. In these analyses, only a small amount of the initially ponded water penetrated to the repository horizon.

Fernandez et al. (1988) analyze water flow in the backfilled exploratory shafts for flow scenarios that assume the occurrence of a probable maximum flood (PMF) (Table 11 of Bullard, 1986). The analysis provided a reasonable upper bound to the total water entry into the backfilled exploratory shafts through fractures in the boreholes. Figure 8.4.3-3 (taken from Fernandez et al., 1988) shows topographic cross-sections in the vicinity of the current ES-1 and ES-2 locations with the PMF level indicated. As can be seen from the figure, the proposed locations of the shafts are at a higher elevation than the estimated PMF water level, even considering debris. Furthermore, erosion at the shaft location is not expected to lower the ground level below the elevation of the PMF. The exploratory shafts are collared in the Tiva Canyon Member where the potential for erosion of alluvium around the shaft collar is very low. Typical erosion rates expected for hard-rock areas of Yucca Mountain of between 0.8 and 4.7 cm per 1,000 years are given in Table 1-2 of Section 1.1.3.3.1 of this SCP. Maps of the PMF flood channel, including debris flow (Fernandez et al., 1988), show that the surface location of the ESF is 5 m above this flood level at the ES-1 location and 11 m at the ES-2 location. Because of the low erosion rates and the physical separation of the exploratory shaft from the PMF flood channel, erosion is not expected to have an impact on the analyzed scenarios for at least 10,000 years.

A further indication of the low likelihood that flood waters will reach the exploratory-shaft locations is shown in Table 8.4.3-1 (taken from Fernandez et al., 1988). The table lists comparative flood peak discharges in the Yucca Mountain area. The computed peak discharges required to reach the ES-1 and ES-2 are approximately 45 and 240 times, respectively, the amounts of the estimated PMF discharge. Given the same antecedent conditions and drainage area, these extreme peak discharges would require an equivalent increase in the magnitude of precipitation over approximately the same time period. Fernandez et al. (1988) conclude that the likelihood that flood waters will enter the exploratory shafts from the surface is small.

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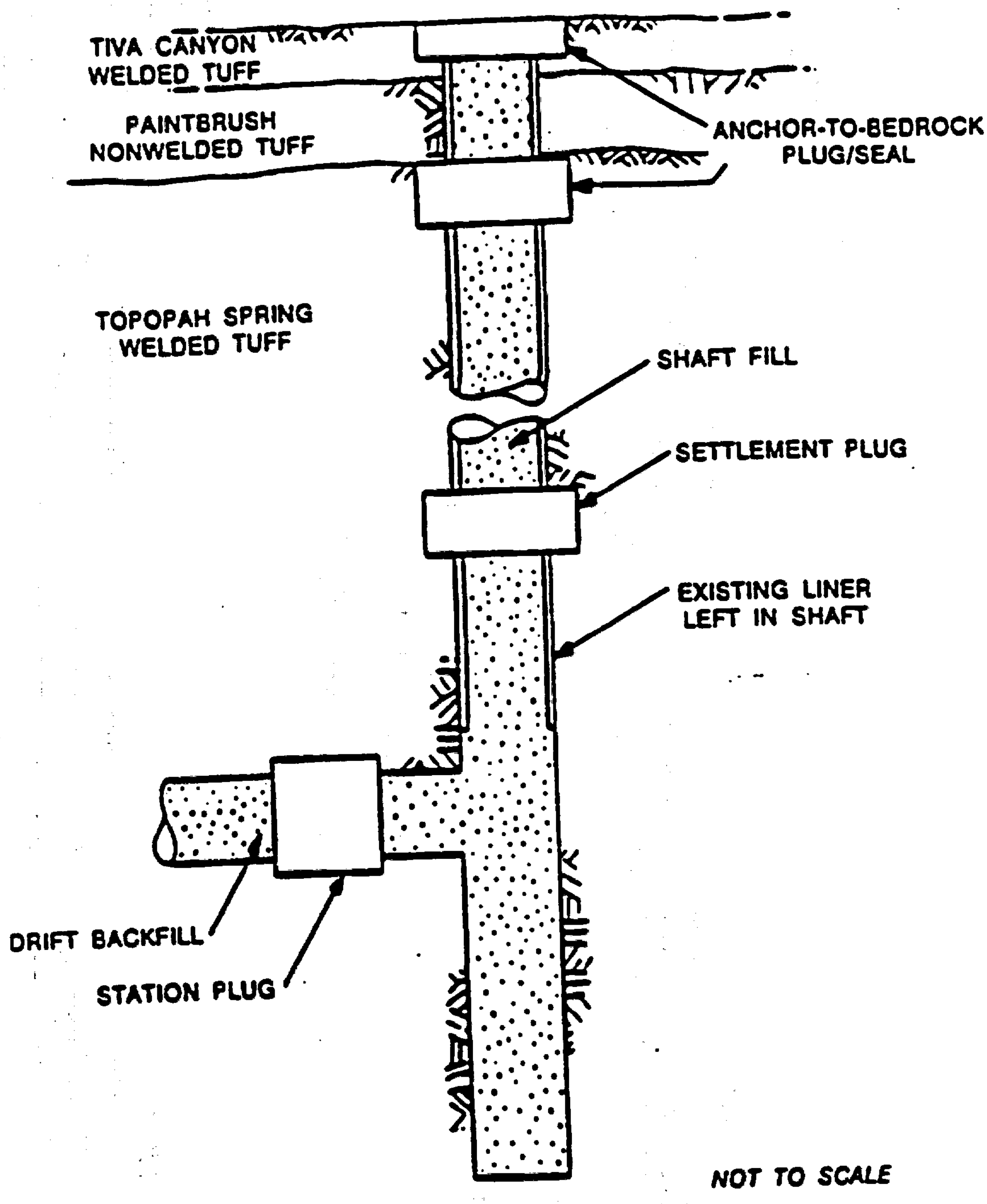

Figure 8.4.3-2. Sealing concepts for the exploratory shafts.

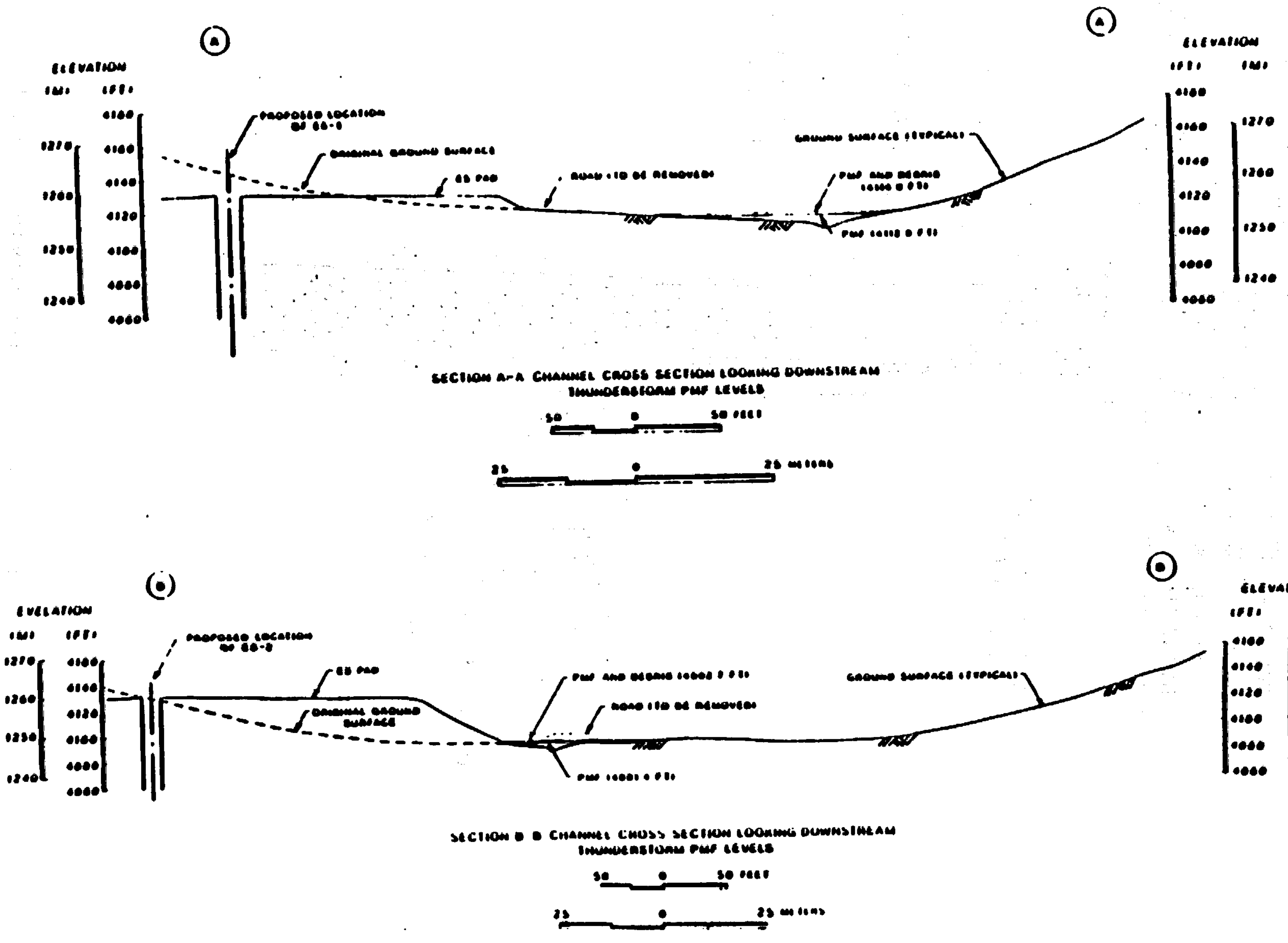

Figure 8.4.3-3. Topographic cross section ˈhe vicinity of exploratory shafts 1 and 2 locations.

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Table 8.4.3-1. Comparative flood peak discharges in Yucca Mountain area

Wash	Drainage area (mi^2)	Peak flood discharge (cfs)
Fortymile	312	540,000[a]
Busted Butte	6.6	44,000[a]
Drill Hole	15.4	86,000[a]
Yucca	16.6	92,000[a]
Coyote	0.2	3,350[b]
Coyote - discharge to reach exploratory shaft-1 collar	0.2	~150,000[c]
Coyote - discharge to reach exploratory shaft-2 collar	0.2	~820,000[d]

[a]From Squires and Young (1984) for the regional maximum flood.
[b]From Bullard (1986) for thunderstorm probable maximum flood (PMF).
[c]Computed peak discharge to reach exploratory shaft-1 collar (>45 times PMF discharge).
[d]Computed peak discharge to reach exploratory shaft-2 collar (>240 times PMF discharge).

The flood scenario analyzed by Fernandez et al. (1988) for the current locations of the exploratory shafts (Section 8.4.2.2.1) depicts fracture flow, originating at the surface from flooding, intercepting the shafts and associated zones of modified permeability due to fracturing around the shafts anywhere below the surface. The exploratory shafts will be constructed using a smooth-wall blasting technique to limit damage to the rock formation (Section 8.4.2.2). Because the shafts are collared in bedrock and are located outside of the PMF storm channels and valley fill alluvium, water is not expected to enter the exploratory shafts directly from the surface but could enter the shaft below the surface from, for example, water flow in fractures. To be conservative, a fracture network was assumed to occur below the surface and to communicate easily within the entire drainage basin, and water was not assumed to be imbibed into the unsaturated matrix tuff. These conditions allowed a greater volume of water to enter an exploratory shaft than may be reasonably expected. The analysis assumed that in a PMF all the rainfall infiltrates into the ground either uniformly or over the more restricted area defined by the existing water courses. For these two cases,

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the total amount of water entering the exploratory shafts was estimated to be 1,250 m^3 and 1,320 m^3 (330,000 gallons and 350,000 gallons). This calculation assumed no runoff or water imbibition from the fractures into the matrix. If allowance is made for runoff and imbibition, then the total water volume entering the exploratory shafts was estimated to be reduced by one to two orders of magnitude, or 10 to 100 m^3 (2,600 to 26,000 gallons) of water. The presence of shaft seals would reduce these volumes even further.

Fernandez et al. (1988) indicate that even the conservative estimated volume of approximately 1,300 m^3 of water entering the backfilled exploratory shafts at the present locations is well within the drainage capability of the exploratory shaft facility. Given the lateral separation of the shafts from waste-emplacement areas and this analysis, Fernandez et al. (1988) concluded that no water is expected to enter the immediate repository environment or to contact the waste packages. The ESF has been designed to drain any water entering the main test level away from potential waste-emplacement areas (i.e., toward ES-1).

Because boreholes are much smaller than the exploratory shafts, the quantity of water entering a borehole from a flooding event would be smaller than that just discussed. Boreholes also will be drilled when practicable so that a buffer of approximately 30 m or more exists between the borehole and emplaced waste (Section 8.4.2.2.1).

On the basis of the above discussions, the DOE judges that given the occurrence of flooding events, the site characterization activities described in this document will not preclude meeting the total-system performance objective.

Regional changes in tectonic regimes

Section 8.3.5.13 considers regional changes in the tectonic regime that could potentially raise or lower the water table. Events and processes that could raise or lower the water table are discussed above under extreme climate changes. The evaluations are similar and a similar conclusion is made. Therefore, the DOE judges that, given the occurrence of regional changes in tectonic regimes, the site characterization activities described in this document will not preclude meeting the total system release performance objective.

Folding, uplift, and subsidence

Section 8.3.5.13 considers events of folding, uplift, and subsidence that could potentially change percolation flux values or lower the underground facility with respect to the water table. As indicated in previous discussions, site characterization activities are not expected to preclude the site from meeting the total system release performance objective in the event of a change in percolation flux. Lowering the underground facility with respect to the water table will have essentially the same effect as raising the water table, which was discussed under extreme climate changes. Thus, the DOE judges that site characterization activities, given the occurrence of changes in the water table elevation, will not preclude meeting the total system release performance objective.

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Summary of conclusions for disruptive scenarios

As indicated previously, this section considers whether, given the occurrence of the disruptive scenario, the potential impacts of the scenario will change site conditions such that the site characterization activities will preclude the capability of the site to meet the total systems release performance objective. In some scenarios (i.e., extreme climatic change, stream erosion, faulting and seismicity, magnetic intrusion, irrigation, climate control, surface flooding or impoundments, regional changes in tectonic regimes, and folding, uplift, and subsidence), one of two major potential impacts is expected. Either the flux through the unsaturated zone would increase such that saturated flow conditions could exist in fractures, or perched water could occur at rock unit contacts with distinct permeability contrast. Site characterization penetrations could then potentially function as localized, preferential drainage points for fractures or perched-water zones above the repository or as localized preferential pathways for gaseous or liquid-phase releases from the repository horizon. To the extent that site characterization activities within the conceptual perimeter drift boundary penetrated the Calico Hills formation, those penetrations could locally reduce the effectiveness of the primary barrier for waste isolation. In other scenarios (e.g., extrusive magnetic activity, exploratory drilling, and resource mining), there does not appear to be any significant relationship between the site characterization activities and the exhumation of wastes or creation of preferential pathways by those scenarios. In addition, the scenario of intentional ground-water withdrawals does not appear to have any significant relationship with the site characterization activities.

As in the expectations for effects under present site conditions, the lateral separation of the site characterization penetrations from the waste emplacement areas, the drainage of the ESF internally to the sump for ES-1, and the sealing of the site characterization penetrations should ensure that these penetrations are neither preferential drainage points nor preferential pathways for gaseous or liquid-phase releases (Section 8.3.3.1). If there is a need to penetrate the Calico Hills unit with a shaft and drifts, further analysis will be needed to determine the potential impacts of these currently deferred site characterization activities on the primary barrier for waste isolation.

In summary, the performance of the site characterization activities as planned is not expected to preclude the capability of the site to meet the postclosure performance objective for total systems release of radionuclides to the accessible environment over the 10,000-yr period of performance. In the absence of further site characterization and analysis, site characterization activities are also not reasonably expected to significantly affect either the frequency of occurrence or the magnitude of the disruptive scenarios that may be reasonably postulated to occur within the 10,000-year period of performance.

Conclusion

The potential impacts to performance from the site characterization activities have been evaluated under assumptions of the occurrence of the nominal scenario; changes resulting from likely processes and events and changes resulting from disruptive scenarios were considered. The principal

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focus of the evaluations was on the potential for increased ground-water flux and for penetrations resulting from site characterization activities to function as preferential pathways for liquid water movement. The DOE judges that no significant impacts to performance will be caused by having performed the site characterization activities described in Section 8.4.2.

8.4.3.3.2 Impacts on waste package containment

The issue resolution strategy to achieve and demonstrate that the substantially complete containment performance objective for the waste package is met is summarized in the first part of this section. The second part of this section evaluates the impacts on the waste package containment of site characterization activities. The impacts are evaluated by considering the effects of hydrological, geochemical, and thermal/mechanical changes from surface-related activities, drilling activities, exploratory shaft construction, underground construction of drifts and testing alcoves, and ESF testing activities on the system elements relied upon for container performance. The system elements that are relied upon are the postemplacement environment of the waste package, the waste container and its properties under these environmental conditions, and the waste form and its properties under these environmental conditions. An evaluation of site characterization activities on applicable design criteria from 10 CFR Part 60 and their implications on postclosure performance of the waste package container are also given.

8.4.3.3.2.1 Issue resolution strategy

This section discusses containment requirements for the waste package and the effects of the construction of the ESF and of testing on the waste package. Issue 1.4 (Section 8.3.5.9) addresses the performance of the waste package as required by 10 CFR 60.113. The performance objective for containment is as follows: "The engineered-barrier system shall be designed, assuming anticipated processes and events, so that containment of high-level waste (HLW) within the waste package will be substantially complete for a period to be determined by the Commission, taking into account factors specified in 60.113(b), provided that such a period shall not be less than 300 yr nor more than 1,000 yr after permanent closure of the geologic repository."

For the purposes of this discussion, the waste package is defined, in 10 CFR 60.2, as "the waste form and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container." Chapter 7 contains graphic representations of typical waste package configurations, identifying specific waste package components.

The DOE understands substantially complete containment to mean that the set of waste packages will fully contain the total radionuclide inventory for a period of 300 to 1,000 years following permanent repository closure, allowing for recognized technological limitations. Implementation of this understanding will be based solely on reliance on the waste package as the major

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component of the engineered barrier system. The container is the primary barrier of the multiple barrier system for the purpose of containment of radionuclides. The waste package will be designed to resist the degrading effects of the repository environment under anticipated processes and events. Containment will be based on the ability of the waste package, by virtue of its intrinsic properties and designs, to maintain a continuous, sealed barrier around the waste.

The DOE expects that demonstrating compliance with the regulation governing the performance of the waste package during the containment period will be best achieved by minimizing the residual uncertainties. The residual uncertainties in predicting performance are due to three factors: (1) the inherent limitations associated with manufacturing, handling, and emplacement operations; (2) the uncertainty in developing a complete understanding of the behavior of waste package materials; and (3) the uncertainty in predicting the future environment of each waste package.

These uncertainties can be divided into preclosure and postclosure considerations. During the postclosure period, the performance of any waste package cannot be accurately predicted over the long time period of the performance objective because of (1) the problems associated with demonstrating the mechanisms of all possible material degradation models under the range of future environmental conditions and (2) the difficulties in extrapolating short-term experimental data to predict long-term performance. Therefore, it is the goal of the waste-package program to provide for complete containment, allowing for only residual uncertainties. The DOE will minimize the uncertainties associated with the technical limitations for the postclosure period through a defense-in-depth concept. This concept introduces conservatism in demonstrating waste package performance through bounding assumptions, using multiple barriers to limit container degradation and waste form releases, and evaluating alternative materials and designs.

The DOE has developed a performance allocation process that is the basis for the testing program. The performance allocation process identifies the system elements that contribute to the demonstration of substantially complete containment and that provide assurance that releases of high-level ·aste occur at very low rates. These elements include the engineered environment, the waste containers, and the waste forms. However, the emphasis on providing containment is placed on the waste container.

To resolve this issue, the DOE will use the following approach to develop the engineered barrier system:

1. Enhance the natural features of the unsaturated zone repository.

2. Evaluate waste package container design to provide a highly reliable sealed containment barrier.

3. Evaluate alternative design concepts and materials.

4. Execute a thorough testing, evaluation, and characterization program.

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5. Fabricate and close waste package containers using detailed specifications and procedures.

6. Identify uncertainties that influence performance predictions, quantify or bound the uncertainties, and then reduce them to a practical minimum through testing and performance confirmation.

7. Use the characteristics of the waste form in conjunction with the other engineered waste package components and with the unsaturated zone environment to ensure that any releases that may occur during the containment period occur at low rates.

In terms of minimizing uncertainties, appropriately combining uncertainty and sensitivity analyses will allow the modeling effort to feed information back to the design/testing effort regarding priorities in reducing those uncertainties that can be experimentally addressed. The iterative nature of this issue resolution strategy becomes evident in identifying those sources of important uncertainties that might be reduced through experimental or design changes. Section 8.3.5.9 provides a detailed discussion of the regulatory basis and resolution strategy for Issue 1.4.

8.4.3.3.2.2 Impacts on waste package containment

The system elements relied upon for container performance are the engineered environment of the waste package, the waste container, and the waste form. This section discusses the potential impacts on these elements of hydrological, geochemical, and thermal/mechanical changes from surface-related activities, drilling activities, exploratory shaft construction, underground construction of drifts and testing alcoves, and ESF testing activities of site characterization.

This section also evaluates the effects of site characterization activities on the design criteria of 10 CFR 60.133, 60.134 and 60.135, and the implied effects on postclosure performance of the waste package container. The design criteria considered in evaluating the impacts on the waste package containment are

1. 10 CFR 60.133(a)--General criteria for the underground facility.
2. 10 CFR 60.133(b)--Flexibility of design.
3. 10 CFR 60.133(d)--Control of water and gas.
4. 10 CFR 60.133(e)--Underground openings.
5. 10 CFR 60.133(f)--Rock excavation.
6. 10 CFR 60.133(h)--Engineered barriers.
7. 10 CFR 60.133(i)--Thermal loads.
8. 10 CFR 60.134--Design of seals for shafts and boreholes.
9. 10 CFR 60.135(a)--High-level-waste package design in general.

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Engineered environment

The three performance measures for the engineered environment of the waste package are (1) quantity of liquid water that can contact the container, (2) quality of liquid water that can contact container, and (3) rock-induced load on the waste package.

Quantity of liquid water

Site characterization activities could affect the quantity of liquid water contacting a container during the complete containment period (300 to 1,000 years after permanent closure) by altering the amount and distribution of ground-water flux at the repository horizon, changing the hydrologic properties of the unsaturated zone (primarily the hydraulic conductivity), or creating preferential pathways for liquid flow.

The unsaturated-zone hydrologic model summarized in Section 8.4.1.3 describes how water moves in fractures and the matrix. According to the model water will not move from the matrix into a waste emplacement borehole unless the matrix is at or near saturation with water. Analyses discussed in Section 8.4.3.2.1.2 show that water moves slowly in the matrix and that a very long time and a large quantity of water are required to saturate the matrix. Section 8.4.3.2.1.2 also describes how the water contained in a fracture is quickly (within hours) imbibed into the matrix. Therefore, it is expected that water in a fracture will be imbibed into the matrix within a few hours after the source of the water flowing into the fracture has stopped.

Surface-related activities are not expected to alter the ground-water flux at the repository horizon, change the hydrologic properties of the unsaturated zone, or create preferential pathways for liquid flow. As discussed in Section 8.4.3.2.5.1, changes to the moisture content of the rock caused by performing surface-related site characterization activities are expected to be transient and to not permanently affect the unsaturated hydraulic conductivity of the near-surface material. Surface-related site characterization activities are not expected to become preferential pathways because the activities are limited to the surface or a few meters beneath the surface. Therefore, surface related activities are not expected to affect the quantity of water that contacts the containers.

As described in Section 8.4.3.2.5.2, drilling activities may cause hydrologic changes within a few meters of the penetrations. These drill-holes, where practicable, will be located in columns in the proposed repository, which will be about 2-drift diameters (about 30 m) from the nearest waste package. Should drillholes penetrate waste-emplacement boreholes, these boreholes would not be used for waste emplacement. As discussed in Section 8.4.3.2.5.2, dry drilling methods will be used for boreholes in the conceptual perimeter drift boundary to decrease the potential for fluids to affect in situ hydraulic conditions. The potential hydrologic impacts from drilling activities are evaluated in Section 8.4.3.2.5.2. This evaluation indicated that, because of the construction

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controls and design features, these activities would not affect the ground-water flux at the repository horizon or create preferential pathways for liquid water flow. Thus, drilling activities should not affect the quantity of liquid water that contacts the container.

During construction of the exploratory shafts and the drifts and alcoves, water will be used for dust control, drilling, and mining. The use of water during construction will be controlled to limit the potential impacts of construction on the site. Most of this water will be removed to the surface by mucking operations. Preliminary estimates indicate that only a small fraction (10 percent) of the water used in the ESF during construction will be retained in the rock mass around the shaft. Because the injection pressure of water introduced during ES construction will be low, the retained water is expected to be a local effect near the shafts. The potential impacts from hydrologic disturbances from the construction of the exploratory shafts are described in Section 8.4.3.2.5.3, while those from the construction of the drifts and alcoves are given in Section 8.4.3.2.5.4. These evaluations of the hydrologic impacts concluded that constructing the ESF would not affect the ground-water flux at the repository horizon or create preferential pathways for liquid water flow. Therefore, the construction of the exploratory shafts, drifts, and alcoves should not increase the amount of water that contacts containers.

During construction and operation of the ESF, the ventilation system will remove water from the exposed walls in the ESF. As was described in Section 8.4.3.2.1.4, the ventilation system may remove, before waste emplacement, a volume of water comparable to that retained during construction, thereby further reducing any potential for construction water to reach a container in the waste emplacement area of the repository.

ESF testing activities will introduce a very small, controlled amount of water to the unsaturated zone and will affect a relatively small volume of rock in which the moisture distribution will be affected by thermal tests, as discussed in Section 8.4.3.2.5.5. These testing activities will be at least 30 m laterally from the waste emplacement area of the repository. The introduction of water during testing and the movement of moisture by heating will not affect the ground-water flux at the repository horizon or the quantity of water contacting a container.

Thermal/mechanical disturbances may affect the quantity of water contacting a container by providing flow paths and the quality of water by enhancing geochemical changes. Section 8.4.3.2.5 discusses the potential impacts on site characterization activities of thermal/mechanical disturbances. The mechanical disturbances to fracture apertures and hydraulic conductivity from borehole, shaft, drift and alcove construction are expected to be contained within 1 to 2 diameters of the penetrations. The increases in fracture permeability are not expected to create preferential pathways for water to flow to waste emplaced areas because (1) boreholes will be sealed (as described in Section 8.3.3.1); (2) boreholes will be located (where practicable) in pillars laterally separated from waste emplacement areas; and (3) shafts and drifts will be located 30 m laterally from waste emplacement areas. Because of the large distance between the surface-related activities and the repository horizon, no effects on water quantity or quality are expected from these activities. Drilling, exploratory shaft construction,

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and underground construction of drifts and alcoves will cause mechanical changes in the rock within 1 to 2 diameters of the penetrations. These mechanical changes may increase the fracture permeability within 1 to 2 diameters of the walls. Because of the relatively long distance between these penetrations and areas of waste emplacement, potential increases in fracture permeability are not expected to create pathways for water to flow to waste-emplacement boreholes and thus affect the quantity of water that contacts a container.

Quality of liquid water

The quality of liquid water that can contact a container is also a performance measure for the engineered environment. For site characterization activities to affect the quality of water that can contact a container, there must be (1) a source of chemical change, (2) a pathway for these chemical changes to reach a container, and (3) a mechanism for transport of the chemicals to the container. During site characterization activities, fluids and materials will be introduced to the surface and into the ESF that may be a source of chemical change. Section 8.4.3.2.5 discusses the potential geochemical impacts from five types of site characterization activities.

As discussed in that section, the potential geochemical disturbances from fluids and materials introduced onto the site surface and into the underground facilities will be local and not transported far from the source. Construction controls on the amount and use of chemicals also decrease the potential geochemical disturbances to the site. During construction of the ESF, fluids and materials will be introduced into the unsaturated zone. West (1988) tabulated the amounts of fluids and materials and evaluated the potential interactions between them. Because of the expected relatively short distance the fluids would penetrate the rock wall and the approximately 30 m lateral distance from the shafts, drifts, and alcoves to waste emplacement areas in the repository, the fluids and materials from ESF construction are not expected to affect the waste package environment or change the quality of water contacting the container. Therefore, site characterization activities should not cause geochemical disturbances that would affect the ground-water flux at the repository horizon or create preferential pathways for liquid flow that could affect the quality of water contacting a container.

Rock-induced loads

Rock-induced loads on the waste package is the third performance measure for the engineered environment. For site characterization activities to affect the rock-induced loads on the waste package, they should enhance rock block movement due to the rock responding to gravitational forces and thermal cycles. Section 8.4.3.2.5 discusses potential impacts on site conditions from thermal/mechanical disturbances.

The surface-related activities are not expected to produce enough rock movement to affect the rock-induced loads on the waste package, because the shallow depth of those activities leaves hundreds of meters of undisturbed-vertical rock between them and waste emplacement. Drilling activities and exploratory shaft construction are not expected to enhance rock movement and promote rock-induced loads on the waste package because of the approximately

30 m of lateral distance between these activities and areas of waste emplacement. Also, the limited number of these penetrations would decrease the potential for these activities to affect rock-induced loads. The drilling activities will, to the extent practical, be located in pillars in the proposed repository or kept a distance of 30 m away from areas of waste emplacement.

The underground construction of drifts and alcoves as part of the ESF also should not enhance block movement and affect rock-induced loads on the waste package because the excavation will meet the same general standards as will be used in the remainder of the underground facility. Hill (1985) analyzed the structural stability of a conceptual model of the ESF main test level and concluded that drifts had to be closer than one-half drift diameter to affect an adjacent drift. The underground construction of alcoves also is not expected to enhance block movement and affect rock-induced loads on the waste package because of the long horizontal distance from the alcoves to areas of waste emplacement. ESF testing activities are not expected to enhance block movement from gravitational forces or thermal cycles. The tests introducing heat into the rock are at least 30 m from areas of waste emplacement and, as discussed in Section 8.4.3.2.5.5, the thermal effects from these tests are not expected to affect rock at this distance.

<u>Waste container</u>

The performance measure for the waste container is the fraction of containers that have failed. (Failure is defined as a breach allowing air flow of 1×10^{-4} atm-cm/s.) For site characterization activities to affect the failure of containers they would need to affect the number of containers that are contacted by water contacts or the rock-induced loads on the container. As discussed for the engineered environment, site characterization activities are not expected to develop preferential pathways, enhance the quantity of liquid water contacting a container, or enhance rock block movement. Therefore, site characterization activities are not expected to affect the fraction of containers that have failed.

<u>Waste form</u>

The performance measure for the waste form is the cumulative release of radionuclides from the ensemble of breached packages. For site characterization activities to enhance the cumulative release of radionuclides from breached packages, they would have to provide water to the waste-emplacement boreholes or create preferential pathways. As discussed for the engineered environment, site characterization activities are not expected to affect the quantity of water that contacts waste packages or to provide preferential pathways. Therefore, these activities should not affect the cumulative release rate of radionuclides from the ensemble of breached packages.

In summary, site characterization activities will not affect the performance measures of the system elements that are relied upon for container performance as specified by 10 CFR 60.113(b).

8.4.3.3.2.3 Impacts of site characterization activities on waste package design features

The ESF is designed with features that will enhance the capability of the waste package to meet the performance objective for containment of 10 CFR 60.113. These design features are itemized in Section 8.4.3.2.4. The potential effects of site characterization activities on the ability to meet applicable design criteria and the implications on postclosure performance of the waste package are discussed in the remainder of this section.

Section 60.133(d) (control of water and gas) states that the design of the underground facility shall provide for control of water or gas intrusion. The ESF has been designed to permit natural drainage of free water to the sump in ES-1. Other mechanisms through which an underground facility design could assist in achieving the performance objectives include material control. Controlling water during construction and carefully selecting and controlling the quantities and types of materials that could chemically interact with the waste container or waste form materials also will help prevent containment and isolation degradation. None of the five types of site characterization activities will impact this design criteria nor will they have adverse affects on the postclosure performance of the waste package container.

Sections 60.133(e) and 60.133(f) are concerned with the creation of fractures and potential flow paths for radionuclide migration. These criteria are specifically concerned with the opening or creating of fractures in the overlying or surrounding rock that could lead to the creation of potential flow and migration paths to the accessible environment. The construction of the exploratory shaft and the drifts and testing alcoves will use control blasting procedures, as well as extraction ratios and drift-span dimensions that are consistent with current repository design. These site characterization activities will not impact the ability to comply with these design criteria nor will they have adverse affects on the postclosure performance of the waste package container.

Section 60.133(h) (engineered barriers) is concerned with the EBS being designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure. The location of the repository in the unsaturated zone has led to design considerations to limit the amount of water contacting the waste package. The repository has been designed to permit natural drainage of free water to the lowest point of the repository. The temperature of the waste canister also contributes to containment. An air gap between the host rock and waste containers may be used to further reduce the contact of water with the waste package. The five categories of site characterization activities should not impact the ability to meet this design criterion or have adverse effects on postclosure performance of the waste package container.

Section 60.133(i) (thermal loads) is concerned that the postclosure waste disposal system must use a thermal loading that does not preclude meeting the performance objective. The design goal is to maintain a thermal load that is low enough not to lead to tectonic or hydrologic impacts on compliance. None of the site characterization activities should affect the thermal loads on the repository.

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The additional design criteria for the underground facility (10 CFR 60.133) that have implications for the postclosure performance of the waste container were identified at the beginning of this section. These criteria include Section 60.133(a), which requires that the underground facility and the engineered barrier system be designed to contribute to containment and isolation of radionuclides, and Section 60.133(b), which requires that the underground facility be designed with flexibility to allow for adjustments to accommodate specific site conditions. The underground facility has been designed to drain water away from emplaced waste and to maintain a lateral separation distance between the ESF and emplaced waste. None of the five types of site characterization activities should have an impact on meeting these design criteria or effects on postclosure performance of the waste package container.

Section 60.134 has implications that the seals for shafts and boreholes are selected to reduce the potential for creating preferential pathways for ground-water to contact waste packages or for radionuclide migration. Boreholes and shafts will be sealed so that surface and ground water will not preferentially move into the penetrations and affect the hydrologic conditions at the repository horizon and so that preferential pathways are not created. Site characterization activities should not impact the capability to seal boreholes and shafts or influence the effects of seals on postclosure performance of the waste package container.

Section 60.135(a) states that the waste package and its interactions with the emplacement environment should not compromise the functions of the waste packages. The effects of site characterization activities on the emplacement environment are being limited by the controls on the use of fluids and materials and on construction. These controls should cause no effects on the emplacement environment and, thus, no effects on the waste package design. Site characterization activities will not have an impact on the waste package or on the postclosure performance of the waste package container.

8.4.3.3.3 Impacts on engineered barrier system release

The issue resolution strategy to achieve and demonstrate compliance with the performance objective for controlled radionuclide releases from the EBS is summarized in the first part of this section. The second part of this section evaluates the impacts of site characterization activities on releases from the engineered barrier system. The impacts are evaluated by considering the effects of hydrological, geochemical, and thermal/mechanical changes from surface-related activities, drilling activities, exploratory shaft construction, underground construction of drifts and testing alcoves, and ESF testing activities on the system elements relied upon to limit releases from the EBS. The system elements that are relied upon are the engineered environment, the container, and the waste form. The effects of site characterization activities on the ability to meet applicable design criteria from 10 CFR Part 60 and their implication on the postclosure performance objective related to the EBS release rate are also evaluated.

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8.4.3.3.3.1 Issue resolution strategy

This section discusses the postclosure performance objective related to the engineered barrier system (EBS) release rate and the impact of the construction and testing in the ESF on the releases from the EBS. Issue 1.5 (Section 8.3.5.10) addresses the performance of the EBS as required by 10 CFR 60.113(a)(1)(ii). This regulation states, in part, that the EBS shall be designed, assuming anticipated processes and events, so that "(B) the release rate of any radionuclide from the engineered barrier system, following the containment period, shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided that this requirement does not apply to any radionuclide which is released at a rate less than 0.1 percent of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

The essence of the waste package strategy lies in an iterative process of performance allocation, performance assessment, and testing to determine if the goals are met. If the objective cannot be met, changes are made in design, materials, etc., and the process is repeated until the design objectives are met with reasonable assurance.

The strategy for resolution of Issue 1.5 is based on the present knowledge of the repository emplacement environment, the data gathered on waste-form performance in environments that can be related to the projected repository environment, and the use of models to assess the performance of various system elements. The system elements relied upon to limit releases are (1) the engineered environment, which limits the quantity and quality of water that can contact the containers and limits the rock-induced load on the waste package; (2) the container, which controls the fraction of containers that have breached and the fractional release due to mass-transfer resistance of breached containers (and cladding); and (3) the waste form, which controls the release fractions or rates from waste components. Strategies are developed for the expected case in which the amount of liquid water contacting the waste form is negligible and for a bounding case that allows 20 L/yr to contact waste forms in up to 10 percent of the waste packages. Two alternate approaches for liquid releases are included in the strategy in the event that the amount of liquid from the reference design is not low enough to meet the requirements of 10 CFR 60.113. The first approach is to take credit for other components and processes that limit access of water to spent fuel. The second approach is to take credit for the possible contribution of the rock in the EBS in limiting release (contingent on an interpretation through a mechanism such as rulemaking that the EBS can include a portion of the host rock).

Current data presented in Section 7.4.3 indicate that it is very likely that the performance objective for control of the release rate from the EBS can be met by the waste forms in an unprotected condition provided that the analysis is done using the conditions of the expected case. For the bounding case, the performance objective can be met, provided credit can be taken for the fraction of waste packages where the waste form is not contacted by

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water, for mass-transfer resistance of breached containers, and for cladding. This resistance to release of radionuclides can be provided by breached containers and cladding, even in their degraded condition. The limitation of wetted waste forms to 10 percent of the total depends on environmental and engineered elements. The existing information is not sufficient to allow a final selection of the components and performance measures. Section 8.3.5.10 provides a detailed discussion of the regulatory basis and resolution strategy for Issue 1.5.

8.4.3.3.3.2 Impacts on engineered barrier system release

The system elements relied upon to limit releases from the EBS following the containment period are the engineered environment, the container, and the waste form. The system elements, and the performance measures, relied upon to limit releases from the EBS are the same elements relied upon to demonstrate compliance with the container lifetime presented in Section 8.4.3.3.2.2, and that discussion will not be totally repeated here. This section also evaluates the effects of site characterization activities on the design criteria of 10 CFR 60 and the implications of the effects on postclosure performance of the EBS release. The design criteria considered in evaluating the impacts on the EBS release are

1. 10 CFR 60.133(a)—General criteria for the underground facility.
2. 10 CFR 60.133(b)—Flexibility of design.
3. 10 CFR 60.133(d)—Control of water and gas.
4. 10 CFR 60.133(e)—Underground openings.
5. 10 CFR 60.133(f)—Rock excavation.
6. 10 CFR 60.133(h)—Engineered barriers.
7. 10 CFR 60.133(i)—Thermal loads.
8. 10 CFR 60.134—Design of seals for shafts and boreholes.
9. 10 CFR 60.135(a)—High-level-waste package design in general.

Engineered environment

The performance measures for the engineered environment for the EBS release following the containment period are the quantity and quality of liquid water that can contact a container and the rock-induced load on the waste package. For site characterization activities to affect the quantity of water that can contact a container, they must provide a source of liquid water and a flow path for liquid water. For site characterization activities to affect the EBS release after the containment period, the effects would have occur at least 300 years after permanent closure, i.e., they would have to be permanent, rather than transient, effects. During this period, the thermal pulse from the emplaced waste would initially move water from near the EBS into the cooler host rock. As discussed for container lifetime in Section 8.4.3.3.2.2, the site characterization activities are not expected to provide a source of increased flux or a preferential flowpath during the containment period that will change the quantity of water that contacts a waste package. Because the source of, and flowpaths for, liquid water would be similar after containment, no site characterization activities are expected to change the quantity of liquid water that can contact a container.

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As discussed in Section 8.4.3.3.2.2, site characterization activities may cause mechanical changes within 1 to 2 diameters of penetrations. Because the distance between the construction of penetrations and the waste emplacement areas in the repository is greater than the expected range of mechanical changes, such changes are not expected to create preferential pathways for water to flow to waste emplacement boreholes and to affect the quantity of water that contacts a container. Therefore, no effects on the quantity of water contacting a container are expected from surface-related activities, drilling activities, exploratory shaft construction, underground construction of drifts and alcoves, or ESF testing activities.

The quality of water that can contact a container during the controlled release period is also a performance measure for the engineered environment. To affect the quality of water, there must be a source of chemical change, a pathway for these chemical changes to reach a container, and transport of the chemicals to the container. As discussed in Section 8.4.3.3.2.2 for the containment period, the chemicals would need to be transported 30 m laterally to contact a container. The current model of Yucca Mountain suggests that ground-water flux is predominantly vertical in the unsaturated zone, which should limit the lateral movement of water and the transport of chemicals to waste emplacement areas of the repository.

As discussed in Section 8.4.3.3.2.2, no enhanced geochemical changes that could contact a container are expected from thermal effects of site characterization. Therefore, no effects on the quality of water contacting a container are expected for surface related activities, drilling activities, exploratory shaft construction, underground construction of drifts and alcoves, or ESF testing activities.

As discussed for the waste package containment in Section 8.4.3.3.2.2, site characterization activities should not enhance rock block movement due to the rock responding to gravitational forces or thermal cycles. Construction controls limiting the number of penetrations of the unsaturated zone, the standards for construction of the underground facility and the distance from site characterization activities to waste emplacement all help decrease the potential for enhancing rock-block movement.

Container

The performance measures for the container are the fraction of containers that have breached and the fractional release due to mass-transfer resistance of breached containers (and cladding). For site characterization activities to affect these performance measures, the number of containers contacted by water must be affected. To affect the number of containers contacted by water, preferential flowpaths would be required, or the quantity of water available to contact containers would have to be increased. As previously discussed in Section 8.4.3.3.2 hydrological, geochemical, or thermal/mechanical changes from site characterization activities are not expected to affect the ground-water flux at the repository horizon, and thus are not expected to affect the number of containers contacted by water.

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Waste form

The performance measure for the waste form is the release fractions or rates from waste form components. The issue resolution strategy considers both liquid and gaseous release. For site characterization activities to affect the liquid release fractions or rates from waste form components inside breached packages, water from site characterization activities would have to contact the waste form. As previously discussed in this section, hydrological, geochemical, or thermal/mechanical disturbances from site characterization activities are not expected to affect the quantity or quality of water available to contact the containers and, therefore, available to contact breached packages and alter the liquid release during the controlled release period.

To affect the gaseous release during the controlled release period, the site characterization activities would have to introduce water in the vicinity of the waste packages or provide preferential pathways to enhance gaseous transport. Boreholes and shafts within the conceptual perimeter drift boundary will be laterally separated from waste emplacement areas and will be sealed so that they will not introduce water in the vicinity of the waste packages. As discussed in Section 8.4.3.2.5.3, the results from Fernandez et al. (1988) suggest that, if the air conductivity of shaft fill was less than about 3×10^{-4} m/min, boreholes and shafts would not be preferential pathways for gaseous transport. Therefore, penetrations from site characterization activities are not expected to provide preferential pathways for gaseous transport and affect gaseous releases from the waste form.

In summary, site characterization activities will not affect the performance measures of the system elements that are relied upon for EBS releases as specified by 10 CFR 60.113(a)(1)(ii).

The ESF is designed with features that will enhance the capability of the EBS to meet the performance objective for the release rate of radionuclides of 10 CFR 60.113. These design features are itemized in Section 8.4.3.2. The design criteria of 10 CFR Part 60 that have implications for the postclosure performance of the EBS releases were identified at the beginning of this section. Because the implications of the design criteria on the postclosure performance of the EBS are identical to the implications on postclosure performance of the waste package containment (Section 8.4.3.3.2.2), they will not be repeated here.

8.4.3.3.4 Impacts on ground-water travel time

8.4.3.3.4.1 Issue resolution strategy

One of the four postclosure performance objectives described in 10 CFR Part 60, Subpart E addresses pre-waste-emplacement ground-water travel time (GWTT) and places a minimum criterion of 1,000 yr for ground-water travel time from the disturbed zone to the accessible environment along the fastest path of likely radionuclide travel. The disturbed zone has been defined in

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10 CFR Part 60 as "that portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive wastes." The definition for underground facility in 10 CFR Part 60 excludes shafts, boreholes, and their seals.

The ability to meet this performance objective depends upon the characteristics of the flow system at the Yucca Mountain site. The current understanding of this system is described in Chapter 3 and is summarized in Section 8.4.1 for the purpose of evaluating the impacts of site characterization. On the basis of this current understanding, a strategy for meeting the GWTT performance objective has been developed.

Section 8.3.5.12 (Issue 1.6) describes the DOE's issue resolution strategy for determining the degree of compliance with the GWTT performance objective. The strategy is developed using the pre-waste-emplacement (liquid) ground-water travel time for each hydrogeologic unit from the disturbed zone to the accessible environment as the performance measure. The unsaturated Calico Hills nonwelded unit has been designated as the primary barrier. This unit was chosen as the primary barrier because preliminary calculations have estimated the average GWTT through the unit to be greater than 10,000 yr (Sinnock et al., 1986). The issue resolution strategy proposes that the pre-waste-emplacement ground-water travel time be calculated for the current hydrological and geological conditions at the site; i.e., before any significant disturbance of the site. Based on the intent of the GWTT performance objective, as discussed above, any significant changes to the site conditions will not be included in the calculation of the GWTT performance measure, except in the manner that those changes affect the definition of the disturbed zone. Therefore, the evaluation of potential impacts to the GWTT performance objective only considers how site characterization activities affect the definition of this boundary.

As discussed in Section 8.4.1, the likely paths for travel of radionuclides carried by ground water are expected to be generally downward through the unsaturated units that underlie the underground facility to the water table and then laterally in the saturated zone to the accessible environment. As explained in Section 8.3.5.12, the DOE expects to rely most heavily on the Calico Hills unit to meet the GWTT performance objective in this case because the current information suggests that the ground-water travel time through this unit is much greater than 1,000 years. The other units in the unsaturated zone and the units in the saturated zone are also expected to contribute to the GWTT.

8.4.3.3.4.2 Impacts on ground-water travel time

The strategy in Section 8.3.5.12 conservatively assumes that the disturbed zone extends to 50 m below the emplaced drifts. Langkopf (1987), however, has preliminarily determined the boundary of the disturbed zone to be a plane less than 10 m below the waste-package boundaries. This value is based on evaluations of significant changes to intrinsic hydrologic properties of the rock. The meaning of "significant" was related specifically to the effects on the pre-waste-emplacement GWTT. The determination of the

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boundary of the disturbed zone considered changes to intrinsic hydrologic properties that could result from repository heating and excavation and considered thermal/mechanical and geochemical effects.

In the following discussions, the potential effects of the categories of site penetrations on the definition of the boundary of the disturbed zone are evaluated.

<u>Surface related activities</u>. The effects on site conditions of the surface related site characterization activities are estimated to extend only to about 10 m below the ground surface. Because the repository horizon is more than 200 m below the surface, these activities are judged not to affect the definition of the disturbed zone boundary.

<u>Drilling activities</u>. Boreholes and their seals are excluded from the definition of the disturbed zone boundary. Therefore, these activities will not affect the definition of the disturbed zone boundary.

<u>Exploratory shaft construction</u>. Shafts are excluded from the definition of the disturbed-zone boundary. Therefore, construction of the exploratory shafts will not affect the definition of the disturbed zone boundary.

<u>Underground construction of ESF drifts and test alcoves</u>. The upper demonstration breakout room is planned to be excavated at a depth of approximately 175 m, which is over 130 m above the main test level. The effects of excavating the room on site conditions are expected to be limited to less than 10 m from the room. Because of the large distance to the main test level and future waste emplacement drifts, construction activities in the upper demonstration breakout room are judged not to significantly affect the definition of the disturbed-zone boundary.

The main test level of the ESF will be constructed at approximately the same elevation as the proposed repository. The effects of constructing drifts and testing alcoves within the ESF main test level on site conditions are expected to be limited to approximately 10 m. This is the same distance that has been preliminarily adopted as the distance to the disturbed zone boundary. Construction of the ESF at the main test level is therefore judged not to affect the definition of the disturbed zone boundary.

<u>ESF testing activities</u>. As described previously, the upper demonstration breakout room is planned to be excavated over 130 m above the main test level. The effects of testing within the room on site conditions are expected to be limited to approximately 10 m. Because of the large distance to the main test level and future waste emplacement drifts, testing activities in the upper demonstration breakout room are judged not to significantly affect the definition of the disturbed zone boundary.

The main test level of the ESF will be constructed at approximately the same elevation as the proposed repository. The effects from testing within the ESF main test level on site conditions are expected to be limited to approximately 10 m. This is the same distance that has been preliminarily adopted as the distance to the disturbed zone boundary. Localized effects within a small volume of rock at distances of greater than 10 m might occur,

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primarily from water movement through fractures. The summary of effects of water movement in fractures indicates that the changes to matrix saturation will be extremely small. Langkopf (1987) considered the effects of small changes to saturation on ground-water travel time and determined that the effects would not likely be significant. These small changes will therefore not alter the definition of the disturbed-zone boundary. The effects of testing within the ESF main test level are therefore judged not to affect the definition of the disturbed zone boundary.

The potential impacts from creating new paths for likely radionuclide travel and increasing ground-water velocity along paths of likely radionuclide travel are discussed in Section 8.4.3.3.1 (impacts on total-system releases).

The effects of site characterization activities on the pre-waste-emplacement ground-water travel time performance objective are judged not to be significant because the activities are not expected to alter the definition of the boundary of the disturbed zone. According to the intent of the regulation governing GWTT, and subsequent interpretations by NRC position papers, the only way this performance objective can be affected by site characterization activities would be by affecting this boundary. Evaluations of the effects from the various categories of activities indicate that the definitions of the boundary would not be affected.

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8.7 DECONTAMINATION AND DECOMMISSIONING

The Nuclear Waste policy Act, as amended (NWPAA, 1987), directs the U.S. Department of Energy (DOE) to prepare plans for the decontamination and decommissioning of the Yucca Mountain site in the event that the site is determined to be unsuitable for development as a repository, and further requires the DOE to mitigate any significant adverse environmental impacts caused by site characterization activities. As set forth in the Mission Plan (DOE, 1987d), the overall objective of decontamination, decommissioning, and mitigation activities is to return areas disturbed by site characterization activities to their original condition, to the maximum extent practicable. These activities would be conducted in compliance with all applicable Federal, State, and local laws and regulations.

As described in previous sections of the SCP, site characterization activities, for the most part, would be similar to the types of activities typical of large construction projects. Impacts caused by such projects and expected from site characterization, are usually limited to land disturbance and are routinely mitigated by a variety of accepted restoration practices. These impacts would be minimized or avoided, to a large extent, by the adoption of standard operating procedures and good engineering practices. In addition, a plan will be developed for monitoring and minimizing of potentially significant adverse environmental impacts. The success of standard operating procedures, good engineering practices, and monitoring and mitigation activities will serve to minimize the extent to which surface areas are disturbed and thereby help to minimize the extent of decommissioning that will be needed at the Yucca Mountain site.

This section presents general plans for decontamination and decommissioning of the Yucca Mountain site and for mitigation of any significant adverse environmental impacts that may be caused by site characterization. Detailed plans for these activities would be prepared as necessary and in consultation with the appropriate Federal and State agencies and any affected Indian Tribes. A reclamation program plan, reclamation implementation plan, and reclamation feasibility plan will be prepared to describe varies aspects of the decommissioning and restoration of the Yucca Mountain site. The reclamation program plan will detail policy issues, the reclamation implementation plan will provide detailed descriptions of the types of procedures to be used in decommissioning-related activities,and the reclamation feasibility plan will describe site-specific studies to evaluate feasibility of reclamation practices at the Yucca Mountain site. Before initiating surface disturbing activities, site-specific reclamation guidelines will be developed.

Since some site characterization activities would occur on lands administered by the Bureau of Land Management (BLM) (including the Nellis Air Force Base Range), consultations with this agency with regard to decommissioning and mitigation would be required. To obtain access to BLM land, a right-of-way plan of development was submitted to and approved by the BLM, as required by the Federal Land Policy and Management Act. This plan of development contains plans to minimize impacts and to stabilize and rehabilitate the site after site characterization activities are terminated. Elements of the right-of-way plan are described in Section 8.7.2.

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Decontamination of the site is discussed in Section 8.7.1 and general decommissioning plans are described in Section 8.7.2. Mitigation of any significant adverse environmental impacts that remain after decontamination and decommissioning activities are complete is discussed in Section 8.7.3.

8.7.1 DECONTAMINATION

The Nuclear Waste Policy Act, as amended, allows for the use of radioactive material during site characterization subject to approval by the Nuclear Regulatory Commission. However, current plans for site characterization activities do not include the use of radioactive tracers or high-level radioactive materials. Although no uncontained radioactive materials are planned to be used during site characterization, it is nevertheless quite common to use radioactive sources and sensors as geophysical logging tools to investigate the movement of ground water during exploratory drilling. These sources are designed to be fully contained and retrievable, as addressed in Chapter 4 of the environmental assessment for Yucca Mountain (DOE, 1986b). Since contained, retrievable geophysical logging tools are the only radioactive materials anticipated for use during site characterization, no decontamination is expected to be required after site characterization. Nevertheless, if other radioactive materials were used, plans for decontamination would be developed in consultation with appropriate Federal and State agencies.

8.7.2 DECOMMISSIONING

Decommissioning is defined as the planned, orderly execution of steps to place a facility in a permanently inoperable, safe condition and includes those activities used to return disturbed areas to their original condition. Decommissioning, as used here, includes the disassembly and removal of man-made materials from the site and the backfilling of excavated areas, as well as activities needed to stabilize and rehabilitate the area.

Decommissioning-related activities would occur in three phases: pre-decommissioning soil stabilization that would occur during site preparation and construction; decommissioning following abandonment or termination of sites; and post-decommissioning monitoring.

Pre-decommissioning oil stabilization procedures implemented prior to site development and during site use would protect against soil loss and provide wildlife habitats. These measures would include gathering information on soil depth and plant cover during preconstruction surveys, removing and stockpiling topsoil, installing or constructing erosion control devices prior to site development, and establishing vegetative cover over topsoil stockpiles where appropriate as soon as possible. Information collected during preconstruction surveys will be used to develop specific reclamation guidelines that will specify items such as location and amount of topsoil to be stockpiled.

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Decommissioning of individual disturbed areas would commence after it was determined that they were no longer needed for the program. All wastes, including garbage, concrete, asphalt, equipment, pipes, drilling muds, sewage, excess excavated material, waste water, and chemical wastes, would be removed or stabilized on site in accordance with Federal and State standards as described in the Environmental Regulatory Compliance Plan. Soils from each area and the topsoil stockpile would be analyzed to determine the chemistry, nutrient levels, and concentration of chemical contaminants present. This information would be used to determine what treatments or amendments, if any, would be required to enable the soil to support plant growth. Next, soil compaction would be relieved through mechanical means such as ripping or disking. Excavated areas such as trenches, borrow pits, ramps, shafts, and drillholes would be backfilled and sealed as appropriate. The area would then be graded to approximately the original contours, and stockpiled topsoil would be redistributed to approximately its original depth. Topsoil would be harrowed to provide an adequate seedbed, and the area would be revegetated using the seed or seedlings of native or adapted species. A mulch may be applied, as necessary, to provide for soil stabilization and moisture retention.

The perimeter of each decommissioned area would be visible marked. These areas would be visited periodically to monitor plant growth and animal use. Quantitative site monitoring will begin on the third spring after decommissioning and continue until the site is judged to be adequately restored.

If the Yucca Mountain site is deemed unsuitable for repository development, it is possible that, after consultation with the appropriate Federal and State agencies and any affected Indian Tribes, an alternative use for the facilities may be identified. If an alternative use for the exploratory shaft facility (ESF) is identified after site characterization is terminated, decommissioning activities would be limited to those areas not needed for future use of the facility. If no alternative use is identified, decommissioning of the entire site would begin as soon as practicable.

Section 8.7.2.1 discusses decommissioning in areas disturbed by surface-based activities; Section 8.7.2.2 discusses decommissioning of the ESF.

8.7.2.1 Decommissioning for surface-based activities

Surface-based activities are those site characterization activities that are not directly related to the ESF. These include activities such as surface trenches, drillholes, seismic surveys, and access roads. Decommissioning of individual areas affected by surface-based activities would occur after it was determined that these areas are no longer needed.

Trenches excavated for surficial geological investigations would be backfilled with material excavated during the trenching operation. The area would be graded to approximate the original contour of the land and

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re-establish natural drainage patterns. Stockpiled topsoil from the site would be replaced to approximately its original depth, and actions would be taken to revegetate the area and stabilize the soil.

Abandoned drillholes would be sealed as described in Section 8.3.3. The area would then be graded to approximate the original topography, stockpiled topsoil from the site would be replaced to its original depth, and efforts would be taken to stabilize the soil and revegetate the area.

Access roads that are no longer needed would be decommissioned. Decommissioning would entail removal of the road-surfacing material and disposal of this material in an approved landfill. The area would then be treated to relieve soil compaction (e.g., through mechanical ripping or disking); it would be regraded to approximate the original topography and restore natural drainage patterns; stockpiled topsoil from the site would be redistributed to approximately its original depth; and steps to stabilize the soil and revegetate the area would be taken. Temporary, unsurfaced access roads or off-road vehicle trails may require some decommissioning. This would probably be limited to disking or ripping the soil surface along the route in order to relieve soil compaction followed by stabilization and revegetation activities.

Other site characterization activities are planned that would disturb relatively small areas. These activities would include pavement studies, ponding studies, seismic lines, infiltration studies, etc. Decommissioning activities for these surface disturbances will be determined as appropriate to ensure adequate rehabilitation and soil stabilization.

8.7.2.2 Decommissioning of the exploratory shaft facility

If it is determined that the Yucca Mountain site is unsuitable for a repository, it is possible that, after consultation with Federal and State agencies and any affected Indian Tribes, an alternative use for the exploratory shaft facility (ESF) may be identified. If a near-term use for the ESF is identified, the utilities and ventilation systems of the ESF would be left in place and periodic maintenance would preserve the structural integrity of the facility. Physical security (adequate to prevent accidents and unauthorized access) would be retained at the surface. Decommissioning of areas not needed for future use of the facility could occur as soon as practicable. If a long-term alternative use for the ESF is identified, a strategy to preserve the ESF for future use could be implemented. This strategy would entail the decommissioning of areas not needed for future use, removing the utilities and any salvageable materials from the interior of the facility, and welding steel covers over the openings to prevent accidents or unauthorized access. The sealed facility would then require only a minimum degree of security to protect the ramps and shafts from vandalism and prevent accidents.

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If the Yucca Mountain site is deemed unsuitable for development of a repository, and if no alternative use for the site is found, the ESF site would be restored, to the maximum extent practicable, to its original condition. Decommissioning would proceed in accordance with all applicable Federal, State, and local regulations. Detailed decommissioning plans adopted by the DOE would be developed after consultation with the appropriate Federal and State agencies and any affected Indian Tribes.

Surface facilities at the ESF would be decommissioned by removing all structures and pads and stabilizing and rehabilitating the land. Facilities would be removed by the most practical and effective methods. Portable and prefabricated buildings would be emptied of their contents, dismantled, and removed from the site. Hoist equipment (including headframes), electric generators, electric and water distribution systems, ventilation equipment, meteorological towers, and communications equipment would also be removed from the site and salvaged. Ramp and shaft collars, drilling-related structures, and other foundations would be reduced to manageable pieces and trucked to appropriate disposal sites. Surfacing material for access roads, parking areas, and other paved or graveled areas would be removed from the site and disposed of in an appropriate landfill. Fluid impoundments (e.g., mud-pits) would be backfilled after the removal and disposal of their contents. Borrow pits would also be backfilled. Buried water, electrical, and sewage lines would be disconnected below the surface and left in the ground.

Structure, equipment, pumps, and material-handling equipment would be removed from the ramp and shaft stations, underground drifts, and test rooms. Horizontal and vertical drillholes extending from the exploratory shaft and rooms would be sealed. Subsurface drifts and rooms would be backfilled with the material that was originally removed during excavation or with an engineered material. The ramps and shafts would be stripped of equipment and structures. The shaft liners would be left in place.

The ramps and shafts may be backfilled with the material that was removed during excavation and placed in the muck-storage area. This would minimize the amount of material to be stabilized or disposed of from the surface. Depending on the specific goals of ramp and shaft decommissioning, other backfill material could be used. For example, information from site characterization may dictate that a grout that matches the density of the various rock layers should be used, rather than material excavated from the ramp and shaft. Stockpiled excavated material that is not used to backfill ramps and shafts or other areas would be stabilized on site or removed from the site and disposed of in an appropriate landfill. Backfill material placed in the ramps and shaft(s) and underground drifts will be specifically designed and emplaced to prevent subsidence.

Once ramps and shafts are sealed, excavated areas are backfilled, and buildings and other surface structures or materials are removed, restoration of the site would proceed. Restoration activities would include regrading the area to approximate the original topography of the area and restore natural drainages; ripping or disking areas where soil compaction is significant (e.g., access routes, parking areas); redistributing stockpiled topsoil to approximately its original depth; stabilizing the soil and adding amendments, if necessary; and revegetating the area with native or adapted plants. Details of these restoration plans would be developed later in accordance with the specific needs of the program and after consultation with appropriate Federal and State agencies and any affected Indian Tribes.

8.7.3 PLANS FOR MITIGATION OF ANY SIGNIFICANT ADVERSE IMPACTS CAUSED BY SITE CHARACTERIZATION ACTIVITIES

It was determined in Chapter 4 of the Yucca Mountain environmental assessment (DOE, 1986b) that conducting site characterization activities at Yucca Mountain would not result in significant adverse environmental impacts. The environmental assessment listed standard operating procedures and good engineering practices (e.g., avoiding or minimizing construction in environmentally sensitive areas such as steep slopes or watercourses) that would reduce the potential for any significant adverse environmental impact. In addition, the DOE has agreed to work with the State and any affected Indian Tribes to monitor the effects of certain site characterization activities and to develop mitigation measures if any significant adverse impacts appear likely to occur. These environmental monitoring activities will be described in a plan for environmental monitoring and mitigation. Implementation of a plan for standard operating procedures, good engineering practices, the monitoring and mitigation plan, and the decommissioning activities described above should eliminate the need for further mitigation. However, should any significant adverse environmental impacts remain after the above preventative steps have been taken, specific mitigation plans would be developed in consultation with appropriate Federal and State agencies.

8.7.4 SUMMARY

This section presented general plans for decontamination and decommissioning of the Yucca Mountain site, should it be deemed unsuitable for repository development, and for mitigation of any significant adverse environmental impacts that may be caused by site characterization. Currently, decontamination and mitigation efforts beyond standard operating procedures, good engineering practices, monitoring and mitigation activities, and decommissioning activities are not expected to be needed, and this section described the types of activities planned for decommissioning. Detailed plans for these activities would be prepared when the extent of work needed is better known and only after consultation with the appropriate Federal and State agencies. Preconstruction reclamation guidelines will be incorporated into site preparation plans and will guide reclamation and decommissioning to the extent practicable at the time surface disturbing activities are initiated.