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Site Characterization
Plan

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CONSULTATION DRAFT

Consultation Draft Site Characterization Plan

- Preface -

The extensive experience gained in this and other programs--including field investigations, underground testing, laboratory studies, design activities, and analyses--causes the DOE to recognize that the development of the SCP and the site-characterization program are evolutionary and iterative processes requiring flexibility in planning. They may be changed in response to comments about plans, to reflect new information from testing and analyses, or in response to comments about test results once testing is begun. Any changes that are identified as necessary will be documented in the semi-annual progress reports that will be made available for review by all parties.

It should also be noted that the issue-resolution strategies and performance allocations in the SCP/CD are preliminary, and the tentative goals identified in Chapter 8 are not criteria that must be met for regulatory compliance. Agreements between the DOE and NRC staffs clearly recognize and accept that these goals are useful for establishing a testing program, but are not necessary for regulatory compliance. As site characterization progresses and more information is acquired, the goals will probably be changed, with some goals being tightened and others relaxed. In the meantime, during the consultation process, these tentative goals are expected to provide an important focus for comments and discussions on performance allocation, goals, and the testing program.

The SCP/CD does not present complete information on the sequencing of activities, the priorities assigned to activities, or a complete schedule for the site-characterization program. Such information is only now being developed through the preparation of detailed study plans for studies and tests to be performed during site characterization. These study plans will be made available before the start of new on-site activities, in accordance with previous agreements with the States, the affected Indian Tribes, and the NRC staff. As the study plans are completed, the DOE will be able to establish sequencing and priorities for the activities found to constitute an adequate and necessary site-characterization program. This will allow a schedule for the entire program to be developed and included in Section 8.5 of the SCP.

As already mentioned, this SCP/CD is being issued to facilitate a consultation process that is expected to enhance the quality of the SCP. This consultation will occur through interactions at the workshops that will be held after the release of this document and through comments received later on. The DOE believes that the benefits of the consultation process would be maximized if the interactions focused on several key questions. For the NRC staff, the key question is as follows: does the SCP/CD provide confidence that the DOE has adequately identified the issues and the kinds of information the NRC will need in its licensing decisions? The key question for the States and the affected Indian Tribes is how well their specific concerns have been identified and addressed. In addition, since Chapter 8 describes the site-characterization program, focus on this chapter is critical.

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The DOE has chosen this SCP/CD as its primary instrument for consultations that will assist in defining in the SCP a technically sound and fiscally prudent site-characterization program that will generate the information necessary for siting, designing, and licensing a geologic repository that will protect the health and safety of the public.

This consultation draft of the site characterization plan (SCP/CD) is being submitted by the Department of Energy (DOE) to the States, affected Indian Tribes, and the Nuclear Regulatory Commission (NRC) as part of the process for the preparation and issuance of the site characterization plan (SCP) required by the Nuclear Waste Policy Act and by the NRC in 10 CFR Part 60. The DOE expects that consultation with the States, affected Indian Tribes, and the NRC will greatly assist the preparation of an SCP representing a site-characterization program that will achieve the DOE's technical and programmatic objectives by being technically sound, timely, and cost effective. In addition, the consultation process is expected to enhance the process for review and comment by the public that will follow the formal issuance of the SCP.

Several observations about this consultation draft should be made to ensure that it is used appropriately. The Act, in Section 113(b), requires that the DOE develop an SCP that is only a general plan for site characterization. This plan is to include a description of the site and is to be accompanied by certain information about the waste package and a conceptual repository design. Essentially the same requirements are specified by the NRC in 10 CFR 60.17. The Act also specifies that the site-characterization activities are to be only the activities that the Secretary of Energy considers necessary to provide data for evaluating the suitability of the site and for compliance (in part) with the National Environmental Policy Act. Although only a general plan is called for, the DOE has, as a matter of policy, prepared a comprehensive and detailed SCP/CD that includes available geotechnical information about the site, a description of the conceptual design of the repository, a description of the waste package, and a detailed discussion of the plans for characterizing the site. The purpose of preparing such a comprehensive and detailed plan is to facilitate the review of the planned site-characterization program by the States and affected Indian Tribes to obtain from the the NRC staff input as to whether the program covered by the plan can be expected to be sufficient for eventual licensing. The comprehensive content and the level of detail reflect earlier consultations with the NRC staff as well as the States and affected Indian Tribes.

The program described in the SCP/CD places primary emphasis on the technical sufficiency of the proposed investigations to ensure that all the potentially needed information will be obtained. The information needed is defined as the geotechnical information necessary to demonstrate the suitability of the site for a repository; to design the repository and the waste package; to select, on the basis of a comparative evaluation, a site for a repository; and to obtain from the NRC an authorization to construct the repository. The DOE has concluded that the compendium of tests, analyses, and activities identified in the SCP/CD is likely to generate all the information needed for siting, design, and licensing. Much less emphasis, however, has been placed on determining the need for each element in the program and for ensuring that there are no unnecessary and redundant

activities. As a result, the DOE considers that the SCP/CD is comprehensive and sufficient, but it may not yet represent the most efficient or cost-effective program for site characterization. Accordingly, during the consultation period, the DOE will carefully evaluate the program described in this SCP/CD, revise it as necessary and appropriate, and document the changes in the SCP. The DOE intends to ensure that each of the tests, analyses, and activities in the site-characterization program is necessary and is included in the plan; that unnecessary or redundant tests, analyses, and activities are not conducted; and that the program is based on sound management and fiscal prudence.

Nuclear Waste Policy Act
(Section 113)

Section 8.0

Consultation Draft

INTRODUCTION

Site Characterization Plan

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

Volume IV

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8.0 INTRODUCTION

This chapter presents the Department of Energy's (DOE) plans for the site characterization program to be conducted at the Yucca Mountain site in the State of Nevada. Such a program is required by the Nuclear Waste Policy Act of 1982, by the regulations promulgated for geologic repositories by the U.S. Nuclear Regulatory Commission (NRC) in 10 CFR Part 60, and by the DOE's general guidelines for siting repositories, promulgated as 10 CFR Part 960. These legal requirements are summarized in the general introduction to this document, which also discusses the DOE's compliance with them.

The site characterization plan (SCP) presented in this consultation draft for the Yucca Mountain site is the DOE's initial general plan; it is based on currently available information about the site and current concepts for the design of the repository and the waste package. It will be provided to the NRC and the State of Nevada for consultation. When formally issued, it will be made available to those same parties and to the public for review and comment. Additional opportunities for interaction will be provided by public hearings and briefings. The DOE expects that, because of these interactions, the plan for site characterization at Yucca Mountain will be modified.

The DOE also expects to modify these plans as more information about the repository system becomes available. The data collected during site characterization will be used in the design of the repository and the waste package, as well as in the analyses of system performance. Characterization, design, and performance assessment activities will all be conducted during site characterization. These activities will depend on each other; for example, the data collected from the site will be used in designing the repository, while the design of the repository will be considered in determining the needed tests and analyses. The site characterization program will be modified, as needed, to meet newly developed design and performance requirements and in response to the data obtained from site characterization itself.

As site characterization proceeds, the results of investigations and any changes to plans will be reported to the NRC, the State of Nevada, and the general public through semiannual progress reports and topical reports. As the DOE revises its plans, it will do so in consultation with the NRC, the State of Nevada, and the general public.

The DOE expects that the process outlined above will help to develop among the DOE, the NRC, the State of Nevada, and the general public a consensus that will lead to the early resolution of issues as part of the siting and licensing process.

The remainder of this introduction is devoted to two topics: the organization and content of Chapter 8 and the top-level strategy that describes the role the features of the site are expected to play in accomplishing the general objectives for the disposal system.

Organization and content of Chapter 8

Chapter 8 is Part B of the SCP. It describes the DOE's plans for the characterization of the Yucca Mountain site. Chapter 8 builds on the existing information about the site (the information that is reported in Chapters 1 through 5 of Part A) and on information about the conceptual designs of the repository and the waste package (the designs of the repository and the waste package are described in Chapters 6 and 7 of Part A, respectively). The information presented in Part A not only summarizes the current technical knowledge about the site, but also constitutes part of the basis for defining the information that needs to be obtained during site characterization.

The first three sections of Chapter 8 present the rationale for the site characterization program and develop from that rationale a detailed description of the tests to be conducted during the program. The discussion that follows describes the content of those sections.

The site characterization program has three principal purposes:

- o To provide the data to be used in the selection of a repository site.
- o To provide the data needed for licensing.
- o To provide the data for design of the repository and the waste package.

In planning a program to achieve these purposes, the DOE has adopted an approach that starts with the regulatory requirements that must be satisfied in siting and licensing the repository, identifies the performance and design information needed to address those requirements, and then develops specific investigations to obtain the needed information. This approach is embodied in an issue resolution strategy, which is discussed in some detail in Section 8.1. An important part of this strategy is an issues hierarchy (Section 8.1.1) that consists of key issues, issues, and information needs. The key issues and issues are based on the regulatory requirements that govern a repository. The information needs define the data and analytical techniques that are needed to resolve each issue. The DOE expects that satisfying the information needs will resolve the issues and that the resolution of the individual issues will lead to resolution of the key issues.

Another important part of the issue resolution strategy and the development of information needs for the issues is the "performance allocation" process, discussed in Section 8.1.2. Performance allocation consists of deciding which repository-system elements will be relied on in resolving an issue, identifying the functions that the elements will be expected to perform and the processes that will affect the performance of each element, making specific quantitative statements about the expected performance, and developing a testing program to obtain the needed information about the performance. The issue resolution strategy will guide the development of the programs for testing and analysis; it will help to make clear what tests and analyses are necessary. As the characterization of

the site proceeds and more information becomes available, the strategy will be refined to support site selection and licensing.

Section 8.2 serves as both a summary of the strategies for resolving the issues and an introduction to them. It first (Section 8.2.1) presents the issues to be resolved and their information needs. It then (Section 8.2.2) presents summaries of the individual strategies, issue by issue, as well as summaries of the specific site characterization programs within the complete program.

Section 8.3 is the full presentation of the material summarized in Section 8.2. Its first section, 8.3.1, is a detailed presentation of the site program that is designed to supply the information identified in the strategies for resolving the issues in the issues hierarchy. Organized according to technical disciplines, Section 8.3.1 describes the investigations, studies, and activities to be carried out. Section 8.3.1 also explains the rationale for the program by referring to the calls for information from the issue resolution strategies.

Section 8.3.2 describes the repository program. It provides detailed resolution strategies for the repository design issues. The section identifies the site information and the design activities needed for issue resolution.

Section 8.3.4 presents the waste-package program. It presents the detailed issue resolution strategies for the issues that deal with the design of the waste-package. The section identifies the site information and the design activities needed for issue resolution.

Section 8.3.5 presents the performance-assessment program. It presents the strategies to address the preclosure and postclosure performance issues and discusses the analytic techniques needed for the safety and performance assessments for these strategies. The section identifies the site information and the performance-assessment activities needed for resolving the issues.

Much of the information presented in Section 8.3 is summarized in tables. A careful study of these tables will provide the most easily achieved understanding of the linkages between the information provided by the site program and the strategies for resolving the design and performance issues.

Section 8.4 of the SCP discusses site-preparation plans for site characterization activities, which consist of surface-based field studies, the construction of an exploratory-shaft facility, and the tests conducted in that facility. The field studies are directed at obtaining information on the geologic, hydrologic, geochemical, climatologic, and engineering characteristics of the site and the surrounding areas through exploratory drilling and testing, the testing of rock and water samples, geophysical surveys, and mapping.

The exploratory-shaft facility will consist of two exploratory shafts that will provide for access to the host rock, the transport of people and equipment, and ventilation; underground testing areas; and surface facilities

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needed to support construction and testing. The shafts and the underground testing areas will be used to conduct tests and make observations and measurements of site conditions.

Section 8.5 identifies and explains milestones, decision points, and schedules. In this consultation draft, schedule information is provided through the sequencing, relative durations, and decision points in Section 8.5. Dates are provided only for major program milestones at this time; dates for other milestones will be developed before SCP issuance. Section 8.6 discusses the quality-assurance program. The last section in Chapter 8, Section 8.7, describes plans for the decommissioning of the site if the site is not selected for development as a repository.

Top-level strategy

This section presents the "top-level strategy," that is, a brief explanation of the role the features of the Yucca Mountain site are expected to play in achieving the general objectives for the system. As a consequence of this role, which will be explained, the program for characterizing this site places considerable emphasis on the flow conditions in the unsaturated rocks in which the waste would be emplaced. The program also emphasizes the geochemistry and other characteristics of the unsaturated rocks. These characteristics could affect performance of the waste packages and radionuclide transport through the unsaturated rocks. In addition, the geohydrology of the saturated rocks deep beneath the site will be characterized. Reliance on these features requires the investigation of unlikely processes and events that might alter the features. The top-level strategy also emphasizes pre-closure radiation safety and the effects of seismicity on the surface and underground facilities. This section discusses the basis for the emphasis on these features in the site characterization program.

The principal role of a disposal system is to isolate waste for a long period into the future. Therefore, the general objective for the entire system is to limit any radionuclide releases to the accessible environment. This objective will be achieved by selecting a site that contains natural barriers against radionuclide releases and by providing an appropriate system of engineered barriers. To provide additional insurance that the system will perform adequately, individual objectives have also been defined for the engineered and natural barriers to radionuclide release and for the design of the disposal system. The general objective for the engineered barriers is that they should limit the release of radionuclides to the natural barriers. The general objective for the natural barriers is that the time of radionuclide travel to the accessible environment through these barriers should be very long. In particular, since ground water may transport radionuclides, the ground-water travel time should be very long. The general objectives for the design of the disposal system are that its operation should be safe and that its construction should not compromise its ability to meet the other general objectives.

These general objectives are compatible with the regulations promulgated by the NRC in 10 CFR Part 60. In the regulations, the NRC specifies post-closure performance objectives, including the environmental standards set by the Environmental Protection Agency for releases to the accessible environment, individual protection, and ground-water protection; requirements on the

containment to be provided by the set of waste packages and on the rate of release of radionuclides from the engineered-barrier system; and an objective for the pre-waste-emplacement ground-water travel time. The regulations also specify design criteria for the disposal system to ensure the postclosure performance objectives would be met, and they set preclosure objectives for radiation protection. Detailed strategies that explicitly address the NRC regulations are presented in Sections 8.1, 8.2, and 8.3. The remainder of this section describes the top-level strategy to address the general objectives for the disposal system.

General objective for the disposal system

The major system elements that are expected to affect waste isolation at the Yucca Mountain site can be seen in Figure 8.0-1. As explained in detail in Chapter 3, the currently available information suggests that small amounts of water are available to percolate slowly downward through Yucca Mountain. If the Yucca Mountain site is developed for a repository, water that moves through the unsaturated rock above the repository could continue down to the unsaturated rock unit in which the underground repository would be constructed. If any of this water could reach the emplaced waste, it might dissolve radionuclides and carry them in solution through the unsaturated rock below the repository to the saturated rock that underlies the unsaturated zone. After reaching saturated rock (Figure 8.0-1), the water joins the much larger, horizontal flow there. Radionuclides that are carried by the water could therefore be transported by the flow in the saturated zone and move toward the accessible environment.

To reach the emplaced waste, the water would have to penetrate the engineered-barrier system. For the purposes of defining the top-level strategy, the major elements of this system are the container and the waste form inside the container. There would also be an air gap between the container and the wall of the borehole in which the container would be emplaced.

This sequence of events--downward water movement, water penetration into the engineered-barrier system, downward transport of radionuclides to saturated rock, and horizontal transport--provides a way by which radionuclides could move from the Yucca Mountain repository to the accessible environment. According to the available evidence, the percolation flux at and below the repository horizon is very low. Furthermore, it appears that the percolation of water through the unsaturated rock units at this depth is primarily in the rock matrix rather than through fractures. If the water is tightly confined within the rock matrix, as it appears to be, the water would not be expected to move from the rock across the air gap to the waste container; the water would therefore not be expected to reach the waste. Furthermore, the results of preliminary studies have suggested that the quantity of moving water is so small that any corrosion of the disposal container and dissolution of radionuclides would be limited even if the water could cross the air gap. The evidence also suggests that the movement of water in the rock matrix is very slow and that therefore the transport of any radionuclides dissolved in this water downward through the unsaturated rocks below the repository would be very slow. An additional characteristic of the unsaturated rock and the water is their geochemistry, which will determine the radionuclide dissolution and the retardation of radionuclide transport.

Figure 8.0-1. Major system elements expected to affect waste isolation at the Yucca Mountain site.

Therefore, the elements of the system that the DOE will investigate in the site characterization program to evaluate the system with respect to the general objective are

- o The unsaturated rock units.
- o The saturated rock that lies below the unsaturated rock.
- o The engineered-barrier system.

Concentrating on the characteristics of only one of these features, such as the slow movement of water through the unsaturated rocks below the repository, could reduce the cost of the site characterization program. The DOE has decided, however, that it is prudent to consider initially the characteristics of all three of these features. Future evidence may show, for example, that the current estimates of ground-water travel time are too long. If so, the DOE's strategy may need to focus on the other features. Choosing all of these features is a way of dealing with the uncertainties in each of them; it ensures that the site characterization activities, guided by the strategy, will collect the data needed to evaluate the site with respect to the general objective. Analyses conducted during site characterization may indicate that other features may need to be considered as well. Conversely, information obtained during site characterization may show that fewer features need to be taken into account. In either case, the top-level strategy can be revised appropriately.

One further sequence of events might contribute to a release under the current conditions at Yucca Mountain. If the waste containers were breached, radionuclides that exist in the waste in gaseous form might move upward through the air spaces in the unsaturated rock above the repository. They might then reach the accessible environment at the ground surface above the repository. The available information is not complete enough to decide definitively whether this sequence is capable of producing significant releases. It is not clear, for example, that the waste form can release gaseous radionuclides rapidly enough or in sufficient quantities to be important. The DOE will evaluate the potential for gaseous release to determine the significance of this mode of release. The elements of the system that may affect gaseous releases at the site are the unsaturated rock above the repository and the engineered-barrier system. The current evidence is not sufficient to indicate if the unsaturated rock would be effective. The available evidence does suggest, however, that the waste form is likely to allow only negligible amounts of volatile radionuclides to escape. The top-level strategy therefore focuses primarily on the ability of the engineered-barrier system to limit the rate of release of gaseous radionuclides.

General objective for performance of the engineered-barrier system

The general objective for the engineered-barrier system is to limit release of radionuclides to the natural barriers. In the top-level strategy, the DOE has chosen to focus on three particular components to evaluate the performance of the engineered-barrier system.

- o The air gap between the container and the host rock.
- o The container.
- o The waste form.

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The container is expected to provide the principal barrier to the release of radionuclides from the engineered-barrier system. This barrier will be designed to provide substantially complete containment of the wastes during the early period when the heat and radiation emitted by the waste are at their peak. The limited availability of water in the unsaturated zone is expected to contribute to the ability of the container to limit the release of radionuclides to the natural barriers. In addition, the container materials will be chosen to be compatible with the geochemistry of the water in order to limit degradation of the containers in contact with any water.

The air gap between the container and the host rock is expected to increase the ability to limit the release of radionuclides. That is, because the percolation flux is expected to be low and because the water is expected to be tightly confined to the rock matrix, little water would be available to leave the rock and cross this air gap. Therefore, the amount of water available to contact the waste packages is expected to be even less than the small amount in the host rock.

The waste form is chosen as an additional barrier to limit the rate of radionuclide release from the engineered-barrier system. Because of the low probability of early container failure and because of the small quantities of water available for waste-form dissolution and the leaching of radionuclides, the spent fuel or glass matrix is expected to limit the rate of release.

General objective for the performance of the natural barriers

As explained above, one natural barrier within the geologic setting that can contribute to the isolation of the waste and to the overall system performance is the long ground-water travel time to the accessible environment. The DOE has chosen to focus on two barriers to determine the ground-water travel time:

- o The unsaturated rock units below the repository.
- o The saturated rock below the unsaturated rock.

The current evidence suggests that the travel time from the repository through the unsaturated units to the saturated zone is longer than 10,000 years. Furthermore, many of the radionuclides important for waste isolation will have an even longer travel time than the ground water because of geochemical and mechanical retardation processes. Therefore, these units are expected to provide an effective barrier to radionuclide transport. According to the available evidence, the saturated rock units can add at least a few hundred years and possibly a few thousand years to the total time that radionuclides would take to move to the accessible environment.

General objectives for the design of the disposal system

The general design objectives to ensure safe operation without compromising the ability to meet the other general objectives have a number of implications for the site characterization program. In particular, the surface and underground facilities must be designed to withstand potential ground motion or surface rupture at the site. The available evidence suggests that the design can accommodate the range of seismic activity expected at the site. Information regarding the expected frequency and magnitude of

earthquake-related activity at the site will be needed to support the detailed design.

The design of the repository system must also address radiation protection of the surface and underground facilities. It is expected that standard techniques will be adequate to assess preclosure radiation safety. Although these assessments will not rely heavily on features of the site, some investigations will be conducted to support them.

Priorities for the site characterization program

Priorities for the testing program can be inferred from the choices made for the top-level strategy; that is, the elements identified and the expected role of these elements with regard to the general objectives suggest the priorities for the investigations in the site characterization program. The top-level strategy to address these objectives at the Yucca Mountain site leads to the following areas of emphasis:

- o Unsaturated-zone flow characteristics.
- o Site characteristics (e.g., geochemistry) affecting performance of the container and the waste form and transport of the radionuclides in the unsaturated zone and the geohydrologic characteristics of the saturated rocks that underlie the unsaturated zone.
- o Unlikely processes or events that disturb site characteristics.
- o Preclosure radiation safety and the effects of seismicity on the surface and underground facilities.

The top-level strategy focuses strongly on the investigations of the characteristics of the flow in the unsaturated zone, relying heavily on the current view that the percolation flux is low and that the water in the unsaturated zone is tightly confined within the rock matrix. If these concepts can be confirmed, then the general objective for the system and for the postclosure performance of the engineered and natural barriers are very likely to be met. Therefore, the investigations of these concepts have the highest priority in the program. As part of these investigations, the program will address alternative concepts including flow in fractures, lateral movement of water at rock interfaces in the unsaturated zone, and the effect on the flow of structural features such as faults. The ability of the unsaturated rock to hold water and limit contact of water with the waste packages will also be investigated.

Because of uncertainties in these concepts and to add confidence that the general objective will be met, other site characteristics will also be investigated. The top-level strategy also places emphasis on other characteristics of the site as discussed above. Therefore, at a somewhat lower level of priority, the program will give attention to the geochemistry and other characteristics of the unsaturated rocks that may affect the performance of the waste packages and the transport of radionuclides in the unsaturated rocks and the geohydrology of the saturated rocks deep below the site.

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The design of the repository system must address preclosure concerns such as the effect of seismic activity. Accordingly, an extensive program to investigate seismicity affecting the site is planned. This program will evaluate the probability and magnitude of ground motion and potential surface rupture at the Yucca Mountain site.

Because the top-level strategy emphasizes the site characteristics listed in this discussion, the site characterization program must also investigate unlikely processes and events that could affect the site characteristics significantly. For example, the possibilities for extreme climatic changes and faulting will be investigated to evaluate effects on percolation and the elevation of the water table. The probability of occurrence and potential effects of volcanism at the site will also be investigated.

This description of the general priorities that the top-level strategy leads to serves primarily as a broad introduction to the detailed discussions in Sections 8.1. through 8.5. Readers who wish to understand fully the planned investigations and the reasons for them must consult those sections, that provide complete strategies, derive investigation plans from the strategies, and explain the investigations in detail.

Nuclear Waste Policy Act
(Section 113)

Section 8.1

Consultation Draft

RATIONALE

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

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Washington, DC 20585

8.1 RATIONALE FOR THE SITE CHARACTERIZATION PROGRAM

The site characterization program and Chapter 8 follow two organizing principles. The first is the issues hierarchy, which states the questions the DOE feels must be resolved about the performance of the mined geologic disposal system (i.e., the waste package, the engineered repository, and the natural system at the site) to demonstrate compliance with the applicable Federal regulations. The second principle is a general procedure, or "strategy," for determining how those issues are to be resolved. This general strategy can be used to develop a specific strategy for the resolution of each issue. One step in the application of the specific strategies results in the identification of the site information needed to support the resolution of the issues. An understanding of these principles is helpful in following the discussions in the rest of this document; this section therefore discusses them briefly.

8.1.1 THE ISSUES-BASED APPROACH TO PLANNING SITE CHARACTERIZATION

The issues hierarchy states questions about the performance of the disposal system and identifies the information that must be known before a site can be selected and licensed. It is based on the issues-hierarchy concept presented in the Mission Plan (DOE, 1985b). The discussion that follows explains the derivation, structure, scope, and objectives of the issues hierarchy. More information can be found in the Issues Hierarchy for a Mined Geologic Disposal System (DOE, 1986d).

8.1.1.1 Derivation, structure, and scope

The issues hierarchy is a three-tiered framework consisting of key issues, issues, and information needs. On the first, or highest, tier there are four key issues, which embody the principal requirements established by the regulations governing geologic disposal. Each of the key issues is followed, in the second tier, by a group of several issues that expand on the requirements stated in the key issue they represent. The third tier consists of still more detailed sets of information called the "information needs"--one set for each issue. This framework provides a convenient means for distinguishing broad questions of overall performance and suitability (key issues) from more specific questions about the characteristics of the site, the design of the repository and the waste package, and the performance of the total geologic disposal system. It also distinguishes the key issues and issues from requirements for the basic information needed to resolve the issues.

The issues hierarchy, then, defines issues that must be resolved to demonstrate compliance with key regulatory requirements. Other, detailed requirements that the disposal system must satisfy, such as functional requirements, are included in the specifications given in the Generic Requirements for a Mined Geologic Disposal System (DOE, 1986c), the Waste Management System Requirements and Descriptions (DOE, 1986f), and in the requirements document that will be issued for a repository at the Yucca

Mountain site. As the definition of requirements progresses, the requirements and the issues hierarchy will be compared and correlated to ensure consistency and completeness in each. The role of the system requirements and descriptions in the issue resolution strategy is described in Section 8.1.2.

The key issues and the issues are common to all candidate sites. The information needs, though generally similar for all sites, have been developed specifically for the Yucca Mountain site, taking into account the characteristics of the site and the host rock as well as the data collected to date. The entire issues hierarchy for the Yucca Mountain site is presented in Section 8.2.1.1. Although care has been taken to ensure that this issues hierarchy contains a comprehensive list of siting and licensing issues, it will be revised as necessary during site characterization to encompass any additional issues that may arise.

Key issues

The key issues embody the principal requirements established by the regulations governing repositories and have been adopted nearly verbatim from the key issues in the Mission Plan. They are stated as questions that must be answered affirmatively if a site is to be found suitable for development, selected, and licensed. The key issues are derived from the four system guidelines of the DOE siting guidelines promulgated in 10 CFR Part 960 and are therefore concerned with (1) the performance of the repository system after closure; (2) radiological safety before closure; (3) the environmental, socioeconomic, and transportation impacts of the repository; and (4) the ease and cost of repository siting, construction, operation, and closure.

Key Issue 1 (postclosure performance) is derived directly from the post-closure system guideline (10 CFR 960.4-1), which defines the general long-term performance requirements for the disposal system as a whole. These performance requirements reflect the general objectives of protecting the health and safety of the public and the quality of the environment; they are based specifically on the standards promulgated by the Environmental Protection Agency (EPA) in Subpart B of 40 CFR Part 191, and adopted by the Nuclear Regulatory Commission (NRC) of 10 CFR Part 60.

Key Issue 2 (preclosure radiological safety) is derived from the preclosure system guideline (10 CFR 960.5-1(a)(1)). It requires compliance with the applicable requirements of the EPA standards in Subpart A of 40 CFR Part 191, and the NRC criteria in 10 CFR Part 60 and 10 CFR Part 20. Because compliance with these regulatory requirements depends mainly on the design and operating procedures of the repository rather than on the geologic characteristics of the site, not all aspects of Key Issue 2 are directly addressed in the site characterization plan (SCP). Little information from the site characterization program is required for the resolution of Key Issue 2. Instead most of the information needed to resolve this issue will be obtained from design studies for the repository and the waste package and from studies conducted concurrently with site characterization. (Plans for such studies will be presented in an environmental program plan and a repository design plan for the Yucca Mountain site.)

Key Issue 3, which is concerned with the environmental, socioeconomic, and transportation impacts associated with a repository, is derived from the preclosure system guideline (10 CFR 960.5-1(a)(2)). The resolution of this issue does not directly depend on information from site characterization activities and therefore this key issue is not addressed in the SCP. The information needed to resolve this issue will be collected during the environmental and socioeconomic investigations performed concurrently with site characterization. Plans for these studies will be presented in environmental and socioeconomic program plans, prepared concurrently with the SCP.

Key Issue 4 (the ease and cost of repository siting, construction, operation, and closure) is derived from the preclosure system guideline (10 CFR 960.5-1(a)(3)). The requirements of this issue are derived from those of the referenced preclosure system guideline, which requires that the technical feasibility and cost of repository siting, construction, operation, and closure be evaluated in light of the site characteristics and related design requirements. The resolution of this issue depends in part on site conditions and in part on information that can be developed independently of the description of site conditions. Plans to acquire this independent information will be presented in a repository-design plan; these plans are not presented in this SCP, because the activities they describe do not fall within the definition of site characterization in the Nuclear Waste Policy Act.

Matrices that correlate each issue with specific regulatory requirements are presented in Section 8.2.1.2, which also discusses the relationship of the issues hierarchy to other sets of issues--for example, those proposed by the NRC in the draft issue-oriented site technical positions.

Issues

The issues defined for each key issue are also stated as questions (Section 8.2.1.1). When each group of issues was constructed, an effort was made to include in the group all the questions that must be answered to resolve the key issue. Taken together, the issues therefore provide a conceptual strategy for resolving each key issue. The issues defined for each key issue are identical in overall scope to the issues in the Mission Plan, but the structure and the wording are different. The issues are derived, in part, from the DOE siting guidelines of 10 CFR Part 960, from the NRC performance objectives and design criteria of 10 CFR Part 60, and from the EPA requirements of 40 CFR Part 191.

To accommodate the structure and the intent of the regulations in 10 CFR Part 60 and 10 CFR Part 960, the issues are divided into performance issues and design issues. The NRC criteria in 10 CFR Part 60 clearly make a distinction between performance objectives and design criteria; though obviously related, performance objectives and design criteria have different purposes and must be addressed from different perspectives.

The performance issues generally address questions about compliance with regulatory requirements for the performance of the disposal system. They are generally related directly to the highest level of regulatory requirements to be satisfied. For example, there are performance issues that correspond to each of the postclosure performance objectives stated in 10 CFR 60.113.

There are also performance issues that correspond to the requirement to make higher-level findings for the postclosure guidelines and for each set of preclosure guidelines in 10 CFR Part 960.

The design issues address questions about the design of the repository, the shaft and borehole seals, and the waste package. They address the design criteria specified in 10 CFR 60.130 through 60.135, the design-related considerations of preclosure guideline 10 CFR 960.5-1(a)(3), and information required to support the resolution of performance issues.

The resolution of both the performance and the design issues requires information about the site, and to provide this information the site program described in Section 8.3.1 has been developed. This program will evaluate the site characteristics, processes, and events that may affect the design and the performance of the waste package and the repository; the results will provide the detailed site information that will be used to develop site descriptions and to support the resolution of design and performance issues, including the demonstration of compliance with the siting guidelines. The site program is organized by technical discipline (e.g., geohydrology, geochemistry, and rock characteristics), and it provides a means of controlling and integrating the investigations in each technical discipline.

The relationship among the two categories of issues and the site program can be summarized as follows: The performance and the design issues establish requirements and priorities for the site program, while the site program produces data for the analyses needed to address design and performance issues. An investigation or other type of activity in the site program will take place only if it is necessary to provide information needed to resolve a design or a performance issue.

Information needs

On the third tier of the issues hierarchy is a set of statements called "information needs." Unlike the key issues and issues, the information needs are stated as requirements for technical information rather than as questions. In developing the information needs, an attempt was made to list the categories of information needed for resolving the issues. In principle, then, acquiring all the information called for at the third tier of the hierarchy will allow all the issues to be resolved through analyses and evaluations that use the information. If the issues are resolved affirmatively, the key issues will also have been resolved.

Site-specific information needs for the Yucca Mountain site have been identified and are listed in Section 8.2.1.1.

8.1.1.2 Application in the site characterization plan

The issues hierarchy, which is presented in Section 8.2.1.1, is useful in the SCP because it is a framework for developing the site characterization program described in Section 8.3 and for explaining why the proposed program is adequate and necessary. In simple terms, the site characterization program will be adequate if it addresses all the information needs in the third

tier of the issues hierarchy. And the necessity for any particular planned study can be established by determining its role in supplying an information need. For these reasons, the issues hierarchy in Section 8.2.1.1 is used as an organizing principle for many parts of the SCP. In particular, Section 8.3, which describes the characterization program, is organized around the investigations and studies that are required to satisfy the information needs in the issues hierarchy. The defining of these issues was itself a part of the issues-based approach to site characterization described in this section and the issue resolution strategy described in the next section.

8.1.2 ISSUE RESOLUTION STRATEGY

To resolve the issues in the issues hierarchy, the DOE has adopted a general "issue resolution strategy" that guides the development of specific plans for resolving each issue. This general strategy is a procedure consisting of as many as 12 steps; it is outlined in Figure 8.1-1. Three of the steps, applied separately to each issue, lead to the identification of the information necessary to resolve the issue. Once the information needs have been identified, another step leads to the development of plans for acquiring that information. The reasoning used in carrying out those four steps is, then, the rationale for the particular site characterization activities that are intended to resolve the issue. The rationale and the plans for these activities are described in Sections 8.2 and 8.3. An understanding of the general issue resolution strategy is important for understanding these four steps and the site characterization program presented in Section 8.3.

8.1.2.1 Issue identification

The first section of the strategy, labeled "issue identification" in Figure 8.1-1, consists of three steps. Two of these steps (1 and 2) are the development of the issues hierarchy itself. Step 1 identifies the regulatory requirements; from them the issues are derived (step 2), as explained in Section 8.1.1. Also before specific plans for the resolution of each issue can be formulated, detailed description of the disposal system is needed (step 1a). This description for the Yucca Mountain site will be presented in site-specific requirements and system-description documents.

8.1.2.2 Performance allocation

The second section of the strategy, called "performance allocation," consists of the steps that provide the rationale for the establishment of particular site characterization activities. (In the issue resolution strategy the term "performance allocation" refers only to the four steps (steps 3 through 6) shown in Figure 8.1-1). Applied separately to each issue in the hierarchy, this section produces the principal guidance for planning the activities needed to resolve the issue. The performance-allocation concept was developed in formal discussions and documented in a written agreement between the DOE and the NRC.

Figure 8.1-1. Issue resolution strategy.

The steps in performance allocation were defined with several objectives in mind: to provide uniform guidance for site characterization at all candidate sites, to ensure Program-wide consistency in implementing the process of performance allocation, and to provide specific kinds of information requested by the NRC.

Licensing strategy

For each issue, the first step in performance allocation (step 3 in Figure 8.1-1) is the adoption of a "licensing strategy." This step uses available information to develop, for planning purposes, a statement of the site features, engineered features, conceptual models, and analyses that the DOE expects to use in resolving the issue. The statement is called a licensing strategy because the combined statements developed in step 3 for all the issues are the basis for the current DOE plans to show compliance with regulatory requirements. Eventually, plans developed from the current plans will support the selection of a site for development and the demonstration of compliance with NRC requirements for the construction, operation, closure, and decommissioning of a repository.

In this document, the licensing strategy is necessarily preliminary: not enough information is now available to make a definitive plan, because site characterization is only beginning. But the strategy is developed well enough to guide the preparation of the plans for tests and analyses and to make clear what activities are necessary and whether they will be sufficient to resolve the issue. As site characterization proceeds and additional information becomes available, the licensing strategy may be revised, and the performance allocation may be changed. The licensing strategies described in this document are likely to change before the submission of the license application to the NRC; for the purposes of this SCP, they are simply the basis for initial planning.

For guiding the development of the SCP, the principal product of step 3 is a statement of the disposal-system components on which the DOE currently intends to rely in resolving the issue; if these components perform as the licensing strategy expects them to perform, the issue is likely to be resolved. The statement may also identify, for each of the components, specific features or characteristics that the DOE expects will contribute to the performance of the component and, hence, to the resolution of the issue. The performance and design issues provide the statement of disposal-system components for use in later steps as a basis for deciding what specific information is needed for resolving the issue.

Performance measures and tentative goals

Step 4 carries the strategy further by establishing "performance measures" for each of the components identified in step 3. A performance measure is a physical quantity that describes the performance of the component in meeting the licensing strategy. The measure may be a directly measurable quantity, or it may be a quantity derived from other, more directly measurable quantities.

For each performance measure step 4 establishes a tentative "goal." The word "goal" is written with quotation marks in Figure 8.1-1 to show that it

has a special meaning in performance allocation. The tentative goal is not a target that the performance measure must attain if the repository is to perform properly, and therefore it does not have to be met. Instead, it is simply a guide for the development of a testing program--a guide that states the licensing strategy quantitatively and can be changed or discarded once the testing program has been established. In assigning goals to the performance measures, the DOE will specify values that are consistent with the licensing strategy for the issue. If the tests and analyses can demonstrate that a goal is attained, the licensing strategy for the issue will be satisfied, and the issue will be likely to be resolved. The goals are, therefore, guides for deciding, in the later steps of performance allocation, what information must be provided by the testing program. Whenever a goal is identified, the reasoning that led to its selection is also presented.

As a further guide for testing, step 4 accompanies each tentative goal with an "indication of confidence," a statement that further clarifies the role of the component in meeting the licensing strategy. The indication of confidence expresses, as quantitatively as possible, the confidence with which the licensing strategy desires the testing program to show that the goal has been attained.

For some goals, it is possible to use statistically rigorous numerical values as indications of confidence; for most of them, however, only a qualitative expression is now possible. When qualitative indicators are assigned, they are accompanied by further explanation of their intended meaning.

Because they depend on a licensing strategy that is preliminary, the goals and indications of confidence are also preliminary. As site characterization progresses and more information is acquired, these goals and indicators will probably be changed to guide continued testing toward the collection of the needed information.

Information needs

The performance allocation process now proceeds to develop specific requirements for future work. Step 5 identifies "information needs," which state, for each issue, the categories or types of information needed to resolve the issue. The information needs identified for the Yucca Mountain site are listed in Section 8.2. Section 8.3 explains how these information needs were derived from the licensing strategy developed earlier in the performance allocation process.

Part of the development of an information need is the identification of the "parameters" needed to evaluate the performance measures. As already mentioned, many performance measures (e.g., the time of ground-water travel through a particular geohydrologic unit) are not directly measurable quantities. Often, however, they can be expressed by an equation in which quantities that can be measured more directly appear as parameters (e.g., hydraulic conductivity). Step 5 furthers the development of plans for testing by listing these parameters. Sometimes the performance measures cannot be expressed simply as an equation containing associated parameters; then in step 5, by an extension of the notion of mathematical parameters, lists are made of whatever quantities must be measured to demonstrate that the goal associated with the performance measure has been met. The performance allocations reported

in later sections of this chapter call these quantities, as well as the quantities derived from rigorous equations, "parameters". Parameters derived for the resolution of design issues are usually called "design parameters"; those for performance issues are "performance parameters."

In step 5 a tentative goal is assigned to each parameter. Like the goals for performance measures, these goals are not values that must be achieved by the disposal system. They are simply quantitative statements about the values that the licensing strategy expects to use for the parameters in showing that the issue has been resolved. Frequently, the goals are expressed as inequalities because the licensing strategy may require only that the value of a parameter be shown to lie within a stated range or to be greater or smaller than some stated value.

If the results of site characterization can successfully demonstrate that the tentative goal has been met, the DOE plans for getting a license will be fulfilled as far as that parameter's contribution to the associated performance measure is concerned. The demonstration will not, of course, guarantee a successful license application because many other parameters will enter the calculations in support of the license. Moreover, failure to meet the goal would not be reason to suspect that the license application will be unsuccessful because the goals are not values that, by themselves, are essential to the performance of a disposal system. The reason for setting the goals is simply to guide the specification of tests in the characterization program--to tell quantitatively what information will lead to the resolution of the performance and the design issues.

As a further guide to the detailed specification of tests, step 5 also specifies two indications of confidence for the goal assigned to each parameter. Like the indicators for goals for performance measures, these indicators are not numerically rigorous but are expressed in qualitative terms: high, medium, and low.

The first of these two indications, called "needed confidence" in the performance allocation tables in this chapter of the SCP, answers the following question: When the DOE presents its license application, how confident must it be that the goal has been met? In other words, what confidence does the licensing strategy require for the demonstration that the goal has been met? In assigning the indicators of needed confidence, the DOE is guided primarily by two considerations:

1. Importance. How important to the licensing strategy is the associated goal? Usually the goal is so important that a value of "high" is assigned to the needed confidence. When the goal is a request for information that is not crucial to the license application, an assignment of low or medium confidence is usually appropriate.
2. Sensitivity of the parameter associated with the goal. In addition to considering the importance of a goal, the DOE may examine the sensitivity with which the associated parameter contributes to performance measures and other parameters. If a performance measure or

another parameter is highly sensitive to the likely or expected variations in the parameter for which a goal is assigned, the needed confidence may be higher than it would be for a parameter whose variations make little difference.

The second indication of confidence, called "current confidence" in the performance allocation tables, answers the following question: If the DOE were to present its license application today and could use only currently available data in the presentation, how confident would it feel that the associated goal has been met? In assigning the indicators of current confidence, the DOE is guided by considering the amount and the quality of the available data.

Step 6 in Figure 8.1-1 uses the information needs, expressed in the terms adopted during step 5, to define the work that will produce the needed information. The parameters derived in step 5 are usually not directly measurable quantities, but must be derived from other quantities that can be measured through testing. For example, hydraulic conductivity, mentioned previously as a possible parameter for calculations of ground-water travel time, is not directly measurable in a field test. Step 6, then, identifies additional, more directly measurable, quantities that can contribute to determining values for the performance and design parameters derived in step 5. These additional quantities are generally called "characterization parameters." Some of the SCP sections describing the site program also use other kinds of parameters, called by different names, in explaining how characterization parameters are being developed.

Step 6 also defines a "testing basis," whose purpose is to give further information about the way in which the characterization parameters need to be measured. Some of the testing bases appearing in the later sections of this chapter describe the accuracy with which the associated characterization parameters need to be measured; some describe the confidence that the measurements should produce for licensing. As the later sections explain, the particular descriptions of a testing basis are tailored to the parameters they explain and to the development status of those parameters.

The parameters, confidences, and testing bases are the foundation for the strategy detailed in Section 8.3 in the descriptions of the planned site characterization work. That section describes the planned tests; it identifies the experimental variables and the parameters (from steps 5 and 6) that the tests will measure. It also describes plans for developing the needed analytical models and design information.

Because the issues in the hierarchy cover widely different topics, the four steps in performance allocation are intended to be applied flexibly. For example, the strategy for resolving design issues may differ from the strategy adopted for performance issues. And although the goals assigned to performance measures for engineered components can be useful in guiding design, the goals assigned to the properties of natural components cannot be altered by design. For reasons like these, the four steps cannot be applied with rigid uniformity to all issues; Section 8.2 therefore briefly summarizes the rationale behind the indicated allocation for each issue, and Section 8.3 the complete performance allocation.

8.1.2.3 Investigations

After the performance allocation has produced the plans for resolving issues, the issue resolution strategy proceeds with the investigations called for in the plans (step 7 in Figure 8.1-1).

The analyses of the results of the investigations and the studies they encompass (step 8) begin as soon as the results are available and continue throughout the site characterization period and beyond. These analyses include all the evaluations needed to resolve the issues. The collection of needed information continues until the information needs have been satisfied (step 9). The collected information is then used in a concluding set of analyses that finally resolve the issues (step 10), and the resolution is documented (step 11).

8.1.2.4 Application of the issue resolution strategy

The entire issue resolution strategy is intended to be an iterative process. As explained previously, the licensing strategy, as well as the tentative goals and the indications of confidence for the performance measures and related parameters, may be changed to reflect new information or in response to comments about plans or test results. If they are changed, the steps that follow in the issue resolution strategy will also be reexamined and their products revised. The analyses of the results of the investigations (step 8) may produce new understandings that require the rethinking of earlier steps. Any of the steps may, in fact, lead to revisions of earlier steps. Sections 8.2 and 8.3, in presenting DOE plans for issue resolution and site characterization, report the current status of the issue resolution strategy.

This iterative process will furnish a vehicle by which the DOE will communicate to the NRC and the State the approaches that it intends to use in resolving the issues in the issues hierarchy. As already mentioned, the current versions of the strategies are preliminary and intended simply as a basis for initial planning; they are expected to be the primary focus for comments and discussions between the DOE and the reviewers of the SCP.

The rationale for future changes to the issue resolution strategies (e.g., revised licensing strategies and performance allocations) will be documented in the site characterization progress reports, which will also report the results of site characterization studies. The reviews, interactions, and reports will continue until the license application is submitted to the NRC.

Nuclear Waste Policy Act
(Section 113)

Section 8.2

Consultation Draft

ISSUES

Site Characterization Plan

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

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8.2 ISSUES TO BE RESOLVED AND INFORMATION REQUIRED DURING SITE CHARACTERIZATION

As described in Section 8.1, the concept of the issues hierarchy is one of the two themes underlying the site characterization program that has been developed for the Yucca Mountain site. The key issues, making up the highest tier in the hierarchy, are the key issues identified in the Mission Plan (DOE, 1985b). Statements of these issues, which are derived from the four system guidelines of the DOE general siting guidelines (10 CFR Part 960), are provided in Table 8.2-1. Key Issue 1 addresses the requirements related to containment and isolation; Key Issue 2 covers protection of the general public and workers from radiological exposures; Key Issue 3 addresses the protection of the quality of the environment; and Key Issue 4 covers the DOE concerns that the mined geologic disposal system is cost effective and can be constructed, operated, closed and decommissioned on the basis of reasonably available technology. The key issues address the primary NRC postclosure requirements for containment and isolation, and the preclosure radiological safety requirements.

8.2.1 ISSUES TO BE RESOLVED

The issues within each key issue in the Office of Geologic Repositories (OGR) Issues Hierarchy (DOE, 1986d) represent the current DOE understanding of the questions that should be answered in order for the key issue to be resolved. Issues are often correlated with the principal NRC requirements addressing a specific repository design or site feature, and thus final resolution of an issue may be confirmed only at the time of licensing. As described in Section 8.1.2, issue resolution strategies have been developed for each issue in the issues hierarchy. From these strategies, preliminary site-specific data needs have been derived and a site characterization program has been designed to obtain sufficient data to satisfy the information requirements. The issues in Key Issue 3 are not included in the SCP, because the definition of site characterization in the Nuclear Waste Policy Act (NWPA) excludes socioeconomic, transportation, and environmental studies. Details of the information requirements for environment-related topics will be presented in other DOE documents.

Table 8.2-2 lists all performance and design issues associated with Key Issues 1, 2, and 4, arranged by issue. Site-specific information needs, relevant to resolution of each issue are also presented in Table 8.2-2. Identification of these information needs is described later in this section.

Figures 8.2-1, 8.2-2, and 8.2-3 display the relationships between the regulatory requirements of 10 CFR Part 60, 10 CFR Part 20, 40 CFR 191, Subpart A, and 10 CFR Part 960 and the performance and design issues. These relationships are explained more fully in DOE (1986d). A site is not expected to receive a license from the NRC if the key issues and issues cannot be answered affirmatively.

In parallel with the development of issue resolution strategies for each of the issues, the physical elements of the repository system were defined. This system definition is called the Yucca Mountain mined geologic disposal

Table 8.2-1. Statements of the key issues in the Office of Geologic Repositories issues hierarchy

Issue	Statement of key issue
Key Issue 1	Will the mined geologic disposal system at Yucca Mountain isolate the radioactive waste from the accessible environment after closure in accordance with the requirements set forth in 40 CFR Part 191, 10 CFR Part 60, and 10 CFR Part 960?
Key Issue 2	Will the projected releases of radioactive materials to restricted and unrestricted areas and the resulting radiation exposures of the general public and workers during repository operation, closure and decommissioning at Yucca Mountain, meet applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191?
Key Issue 3	Can the mined geologic disposal system at Yucca Mountain be sited, constructed, operated, closed, and decommissioned, and can the associated transportation system be sited, constructed, and operated so that the quality of the environment will be protected and waste-transportation operations can be conducted without causing unacceptable risks to public health or safety?
Key Issue 4	Will the construction, operation (including retrieval), closure, and decommissioning of the mined geologic disposal system be feasible at Yucca Mountain on the basis of reasonably available technology, and will the associated costs be reasonable in accordance with the requirements set forth in 10 CFR Part 960?

Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 1 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 1		
<u>Performance issues</u>		
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
	1.1.2	A set of potentially significant release scenario classes that address all events and processes that may affect the geologic repository
	1.1.3	Calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release scenario classes
	1.1.4	Determination of the radionuclide releases to the accessible environment associated with realizations of potentially significant release scenario classes
	1.1.5	Probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios
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
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 years after disposal could exceed the limits established in 40 CFR 191.16.

Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 2 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 1 (continued)		
<u>Performance issues (continued)</u>		
Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?	1.4.1	Waste package design features that affect the performance of the container
	1.4.2	Material properties of the container
	1.4.3	Scenarios and models needed 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
	1.4.5	Determination of whether the requirement for substantially complete containment of the waste packages is met for anticipated processes and events
Issue 1.5: Will the waste package and repository engineered barrier systems meet the performance objective for limiting radionuclide release rates as required by 10 CFR 60.113?	1.5.1	Waste package design features that affect the rate of radionuclide release
	1.5.2	Material properties of the waste form
	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

Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 3 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 1 (continued)		
<u>Performance issues (continued)</u>		
Issue 1.6: Will the site meet the performance objective for prewaste-emplacement ground-water travel time 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 ground-water travel time along that path
	1.6.2	Calculational models to predict ground-water travel times between the disturbed zone and the accessible environment
	1.6.3	Identification of the paths of likely radionuclide travel from the disturbed zone to the accessible environment and identification of the fastest path
	1.6.4	Determination of the prewaste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment
	1.6.5	Boundary of the disturbed zone
Issue 1.7: Will the performance-confirmation program meet the requirements of 10 CFR 60.137?		Information needs to be determined
Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?		No additional information needs identified
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 evaluations required by 10 CFR 960.3-1.5 be made?		No information needs identified.

Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 4 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 1 (continued)		
<u>Design issues</u>		
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?	1.10.1	Design information needed to comply with postclosure criteria from 10 CFR 60.135 (a) for consideration of the interactions between the waste package and its environment
	1.10.2	Reference waste package designs
	1.10.3	Reference waste package emplacement configurations
	1.10.4	Postemplacement near-field 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
	1.11.2	Characteristics of waste package needed for design of the underground facility
	1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility to contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions
	1.11.4	Design constraints to limit water usage and potential chemical changes
	1.11.5	Design constraints to limit excavation-induced changes in rock mass permeability
	1.11.6	Repository thermal loading and predicted thermal and thermomechanical response of the host rock
	1.11.7	Reference postclosure repository design
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

Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 5 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 2		
<u>Performance issues</u>		
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
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
	2.2.2	Determination that projected worker exposures and exposure conditions under normal conditions meet applicable requirements
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

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 6 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 2		
Performance issues (continued)		
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
	2.4.2	Determination that access to the waste emplacement boreholes can be provided throughout the retrievability period for normal and credible abnormal conditions
	2.4.3	Determination that access to the waste packages can be provided throughout the retrievability period for normal and credible abnormal conditions
	2.4.4	Determination that the waste can be removed from the emplacement boreholes for normal and off-normal conditions
	2.4.5	Determination that the waste can be transported to the surface and delivered to the waste-handling surface facilities for normal and credible abnormal conditions
	2.4.6	Determination that the retrieval requirements set forth in 10 CFR 60.111(b) are met using reasonably available technology
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?		No additional information needs identified

Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 7 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 2 (continued)		
<u>Design issues</u>		
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
	2.6.3	Waste acceptance specifications
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 objective pertaining to the design and protection of structures, systems, and components important to safety have been met
	2.7.3	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met
	2.7.4 ^a	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to compliance with mining regulations have been met
	2.7.5 ^a	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to waste treatment have been met

Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 8 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 4		
<u>Performance issues</u>		
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?		No additional information needs identified
<u>Design issues</u>		
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
Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues?	4.3.1	Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package
Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?	4.4.1	Site and performance assessment information needed for design
	4.4.2	Characteristics and quantities of waste and waste packages needed for design
	4.4.3	Plan for repository operations during construction, operation, closure, and decommissioning
	4.4.4	Repository design requirements for construction, operation, closure, and decommissioning
	4.4.5	Reference preclosure repository design
	4.4.6	Development and demonstration of required equipment
	4.4.7	Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity

Table 8.2-2. Site specific information needs for the Yucca Mountain site (page 9 of 9)

Issues	Information Need #	Statement of information need
KEY ISSUE 4 (continued)		
<u>Design issues</u> (continued)		
	4.4.8	Identification of technologies for surface facility construction, operation, closure, and decommissioning
	4.4.9	Identification of technologies for underground facility construction, operation, closure, and decommissioning
	4.4.10	Determination that the seals for shafts, drifts, and boreholes can be emplaced with reasonably available technology
Issue 4.5: Are the costs of the waste packages and the repository adequately established for the resolution of the performance issues?	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

^aInformation need does not require site-specific data.

		REGULATION	ISSUE	PERFORMANCE										(POSTCLOSURE) DESIGN	
				1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12
10 CFR 960	960.3-1-6	SITE EVALUATIONS										●			
	960.4-1	POSTCLOSURE SYSTEM										●			
	960.4-2-1	GEOHYDROLOGY										●			
	960.4-2-2	GEOCHEMISTRY										●			
	960.4-2-3	ROCK CHARACTERISTICS										●			
	960.4-2-4	CLIMATIC CHANGES										●			
	960.4-2-5	EROSION										●			
	960.4-2-6	DISSOLUTION										●			
10 CFR 60	960.4-2-7	TECTONICS										●			
	960.4-2-8	HUMAN INTERFERENCE										●			
	60.112	SYSTEM PERFORMANCE OBJECTIVE	●								●				
	60.113	SUBSYSTEM PERFORMANCE OBJECTIVES				●	●	●							
	60.122	SITING CRITERIA									●				
40 CFR 191	60.133	UNDERGROUND FACILITY DESIGN CRITERIA												●	
	60.134	SEAL DESIGN CRITERIA													●
	60.135	WASTE PACKAGE DESIGN CRITERIA											●		
	60.137	PERFORMANCE CONFIRMATION REQUIREMENTS							●						
	191.13	CONTAINMENT REQUIREMENTS	●												
40 CFR 191	191.15	INDIVIDUAL PROTECTION REQUIREMENTS		●											
	191.16	GROUND-WATER PROTECTION REQUIREMENTS			●										

Figure 8.2-1. Correlation of performance and design issues for Key Issue 1 (postclosure performance) with regulatory requirements.

KEY ISSUE 2
(PRECLOSURE RADIOLOGICAL SAFETY)

		REGULATION	ISSUE	PERFORMANCE				(PRECLOSURE) DESIGN	
				2.1	2.2	2.3	2.4	2.5	2.7
			2.1 PUBLIC RADIOLOGICAL EXPOSURES--NORMAL CONDITIONS						
			2.2 WORKER RADIOLOGICAL SAFETY--NORMAL CONDITIONS						
			2.3 ACCIDENTAL RADIOLOGICAL RELEASES						
			2.4 RETRIEVABILITY						
			2.5 DOE GUIDELINE FINDINGS-RADIOLOGICAL SAFETY						
			2.6 WASTE PACKAGE CHARACTERISTICS						
			2.7 REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY						
10 CFR 960	960.5-1	PRECLOSURE SYSTEM--RADIOLOGICAL SAFETY						●	
	960.5-2-1	POPULATION						●	
	960.5-2-2	SITE OWNERSHIP						●	
	960.5-2-3	METEOROLOGY						●	
	960.5-2-4	OFFSITE INSTALLATIONS						●	
10 CFR 60	60.111	RADIOLOGICAL PROTECTION AND RETRIEVABILITY	●	●		●			
	60.131	GENERAL DESIGN CRITERIA							●
	60.132	PRECLOSURE RADIOLOGICAL DESIGN							●
	60.133	UNDERGROUND FACILITY DESIGN CRITERIA							●
	60.135	WASTE PACKAGE DESIGN CRITERIA						●	
	40 CFR 191, SUBPART A	STANDARDS FOR MANAGEMENT	●						
	10 CFR 20	RADIATION PROTECTION STANDARDS	●	●					

Figure 8.2-2. Correlation of performance and design issues for Key Issue 2 (preclosure radiological safety) with regulatory requirements.

Figure 8.2-3. Correlation of performance and design issues for Key Issue 4 (preclosure performance) with regulatory requirements.

system (MGDS) (Figure 8.2-4) and serves as a basis for a functional description of the repository. The physical elements of the Yucca Mountain MGDS are the natural site features, engineered features, and institutional features arranged in a hierarchical format. These elements are the components of the system that are used as the basis for developing issue resolution strategies. As shown in Figure 8.2-4, the highest level categorization of the MGDS results in elements related to either the preclosure or postclosure waste disposal systems. Within the preclosure element, the next level in the hierarchy is composed of three elements--site, repository, and waste emplacement package. At a similar level within the postclosure waste disposal element are natural barriers, engineered barriers, and institutional barriers. Further subdivisions of the MGDS are shown in Figure 8.2-4.

As described in Section 8.1.2, the first step in developing an issue resolution strategy for a performance or design issue is to select the system element upon which reliance will be placed. As a part of issue resolution, performance allocation has been used as a means for focusing site characterization on acquisition of data that will be most useful in demonstrating that reliance on a particular element of the MGDS will result in acceptable repository designs and performance. Refer to Sections 8.2.2.1 through 8.2.2.3 for summaries of the resolution strategies for performance and design issues associated with Key Issues 1, 2, and 4. Sections 8.3.2 through 8.3.5 provide complete discussions of each issue resolution strategy summarized in this section.

8.2.1.1 Site-specific issues hierarchy

Table 8.2-2 provides the NNWSI Project site-specific information needs within the context of the OGR issues hierarchy. Information needs were developed as convenient categories of data, parameters, and other information items necessary to support resolution of performance and design issues. Information needs include calculational models, descriptions of processes, and information about conditions and characteristics of the site and the engineered repository system. Those information needs requiring site data are described in detail in Sections 8.3.2 through 8.3.5. Site data will be, in turn, provided by site programs described in Sections 8.3.1.2 through 8.3.1.17.

8.2.1.2 Other issues

The wording of the OGR issues (DOE, 1986d) differs slightly from the wording of issues in the DOE Mission Plan (DOE, 1985b). A correlation matrix provided in Figure 8.2-5 shows that all issues in the DOE Mission Plan are addressed by one or more of the OGR issues.

Although this site characterization plan has been developed and is organized on the basis of the OGR issues, specific technical concerns related to site suitability for repository development and repository performance that have been raised by the public and the NRC have been addressed. The

Figure 8.2-4. Hierarchy of functions and components that make up the Yucca Mountain mined geologic disposal system.

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OGR ISSUES		MISSION PLAN ISSUES																			
		1.1 GEOHYDROLOGY	1.2 GEOCHEMISTRY	1.3 ROCK CHARACTERISTICS	1.4 EROSION	1.5 CLIMATE	1.6 DISSOLUTION	1.7 TECTONICS	1.8 HUMAN ACTIVITIES	1.9 WASTE PACKAGE & ENGINEERED BARRIER SYSTEM	2.1 RADIOLOGICAL SAFETY- PUBLIC	2.2 METEOROLOGY	2.3 OFFSITE ACTIVITIES	2.4 WORKER RADIOLOGICAL SAFETY	4.1 WASTE PACKAGE COST EFFECTIVENESS	4.2 SURFACE CHARACTERISTICS	4.3 ROCK THERMAL & MECHANICAL CHARACTERISTICS	4.4 PRECLOSURE HYDROLOGY	4.5 PRECLOSURE TECTONICS	4.6 OVERALL REPOSITORY COST-EFFECTIVENESS	4.7 COST-EFFECTIVE CLOSURE
1.1	RELEASES TO ACCESSIBLE ENVIRONMENT	●	●			●		●	●	●											
1.2	INDIVIDUAL PROTECTION	●																			
1.3	GROUND-WATER PROTECTION	●																			
1.4	WASTE PACKAGE CONTAINMENT								●												
1.5	RELEASE RATE		●						●												
1.6	GROUND-WATER TRAVEL TIME	●																			
1.7	PERFORMANCE CONFIRMATION								●								●				
1.8	NRC SITING CRITERIA	●	●	●	●	●	●	●	●												
1.9	DOE GUIDELINE FINDINGS - POSTCLOSURE	●	●	●	●	●	●	●	●												
1.10	WASTE PACKAGE		●					●	●								●				
1.11	REPOSITORY	●		●				●									●				
1.12	SEALS	●																●			
2.1	PUBLIC SAFETY-NORMAL OPERATION									●	●	●									
2.2	WORKER SAFETY										●	●	●								
2.3	PUBLIC SAFETY DURING ACCIDENTS									●	●	●	●								
2.4	RETRIEVABILITY			●									●				●				
2.5	DOE GUIDELINE FINDINGS - RADIOLOGICAL SAFETY									●	●	●	●								
2.6	WASTE PACKAGE DESIGN		●												●						
2.7	REPOSITORY DESIGN									●	●	●	●			●	●	●	●		
4.1	DOE GUIDELINE FINDINGS - AVAILABLE TECHNOLOGY														●	●	●	●	●	●	●
4.2	NONRADIOLOGICAL WORKER SAFETY															●	●	●	●		
4.3	WASTE PACKAGE PRODUCTION								●						●						
4.4	ADEQUACY OF TECHNOLOGY										●				●	●	●	●	●	●	●
4.5	COSTS														●	●	●	●	●	●	●

Figure 8.2-5. Correlation of the Department of Energy Mission Plan issues and Office of Geologic Repositories (OGR) issues.

matrices in Tables 8.2-3 and 8.2-4 provide a correlation to the appropriate section in this document where specific technical concerns are addressed.

8.2.2 APPROACH TO ISSUE RESOLUTION

As explained in Sections 8.1.1 and 8.1.2, the performance and design issues were used as a convenient framework for structuring this document. Each of the sections in Section 8.3 covering a performance or design issue contains an issue resolution strategy explaining the performance allocation developed for the issue and describing the site data needed to resolve the issue. The site data needs identified by the performance and design issues are also categorized into a series of specific site programs. Section 8.2.2.4 summarizes the site characterization programs that are presented in detail in Sections 8.3.1.2 through 8.3.1.17. Each program section is divided into a number of site investigations containing related studies and activities. Details of the testing programs to obtain site data are provided in study plans, according to an agreement between the DOE and the NRC.

Summaries of the resolution strategies for performance and design issues are provided in Sections 8.2.2.1 through 8.2.2.3, organized according to key issues. Detailed discussions of the issue resolution strategies can be found in Sections 8.3.2 through 8.3.5. Table 8.2-5 provides an overview of the arrangement of the performance and design issues and the site programs in Section 8.3. This table should allow a reader to more readily locate information of interest.

8.2.2.1 Key Issue 1

8.2.2.1.1 Performance Issues for Key Issue 1

8.2.2.1.1.1 Summary for total system performance -- Issue 1.1: Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?

Regulatory background

Issue 1.1 (discussed in Section 8.3.5.13) addresses the requirements for releases of radioactive material to the accessible environment following permanent closure. These requirements are stated in the NRC's Overall System Performance Objective (proposed amendment to 10 CFR 60.112 to conform 10 CFR Part 60 to the requirements of 40 CFR 191 (NRC, 1986a)) as follows:

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

- (a) So that, for 10,000 years following permanent closure, cumulative releases of radionuclides to the accessible environment, from

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 1 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY					
EA CRD ^a	3.1.1.3	Hydraulic features	Impacts of hydraulic features on system performance	2.2.2 Mechanical properties of discontinuities in rocks 8.3.1.4.2 Spatial distribution of thermal and mechanical properties	Covers fractures, joints, and effects of water References thermal and mechanical properties needed for other information needs
EA CRD	3.1.1.4	Intention of guidelines	Technical approach	8.3.5.6, 8.3.5.7, 8.3.5.18 Technical basis for DOE higher level findings issues 1.9, 2.5, 4.1	Technical basis addressed individually for issues throughout Chapter 8
EA CRD	5.3	Matrix and fracture flow	Proportion of fractures vs matrix flow unknown	3.9.2.2.2 Transmissivity and hydraulic conductivity	Contains existing material on fracture vs matrix flow

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 2 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY (continued)					
				8.3.1.2.1.3 Characterization of regional groundwater flow system	Activities including fracture vs matrix flow
EA CRD	5.4	Basin boundary	Effects of climatic on hydrologic conditions due to boundary conditions of basins	1.1 Geomorphology	Discusses basin geology
ISTP(1) ^b	1.5	Effects on ground water	Natural changes affecting ground-water flow	8.3.1.5.2.2 Climatic effects on hydrology	Studies on the effects of climate on hydrologic characteristics
EA CRD	3.1.3.2	Unsaturated zone hydrology	Unsaturated zone data base is inadequate	3.9 Site hydro-geologic system	Includes unsaturated zone monitoring and characteristics
	4.1.2.2	Ground-water travel time	Tritium analyses	8.3.1.2.2.1 Characterization of unsaturated zone infiltration	Studies include hydrologic characteristics and future infiltration

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 3 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY (continued)					
	4.1.2.2	Ground-water travel time	Determine flux value		
	8.3	Perched water	Improve data base on perched water		
NRC comment Final EA ^c	7	Uniform infiltration	Uniform infiltration does not allow for preferential paths		
	7	Flux values	Adequate evaluation of flux values		
NRC comment draft EA ^d	3	Ground-water travel time	Uncertainties, alternate models		
EA CRD	5.1	Saturated and unsaturated zone hydrology	Further characterization of the saturated and unsaturated zone hydrology	3.6 to 3.8 Hydrology	Includes existing information on regional ground water of the site

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 4 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY (continued)					
PHPR ^e	5.1	Ghost Dance fault	Potential for Ghost Dance fault as a fluid conduit	8.3.1.2 Geohydrology (postclosure)	Contains studies of the regional, unsaturated, and saturated zones of the site
	5.1	Water table	Water table profile	8.3.1.16.3 Ground-water conditions	Includes studies for moisture content and perched water
	7.2	Ground-water basins	Further characterization of Devils Hole basin		
	1.02.02	Hydrologic system	Identify ground-water flow paths, rates, and fluxes		
ISTP(1)	1.1	Hydrology	Nature of present hydrology		
NRC comment Final EA	4	Hydrothermal activity	Hydrothermal activity affecting flow paths	1.5.2.1 Effects of faulting	Potential effects of faulting
PHPR	1.02.03	Hydrologic system	Effects of fractures and structural features on flow paths	3.7.2 Principal ground-water flow paths	Covers existing material on ground-water flow paths Activities include tectonic and igneous characteristics

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 5 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY (continued)					
				8.3.1.8.3	Studies of changes in hydrology due to tectonic processes
				8.3.1.8.3.1	Effects of igneous activity on hydrologic characteristics
				8.3.1.3.2	Mineralogy, and petrology, rock chemistry
				8.3.1.3.3	Stability of minerals
				8.3.1.9.2, 8.3.1.9.3	Natural resource evaluation and exploitation
EA CRD	4.1.2.2	Aquifers	Flow between aquifers	3.6 Regional hydrology	Includes existing information on hydrogeologic units

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 6 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY (continued)					
NRC comment Final EA	7(4)	Hydrogeologic properties	Interrelationships of hydrogeologic properties	8.2 Information required for site characterization	and their inter-relationships
PHPR	1.02.04	Aquifer flow	Flow between aquifers	8.3.1.2.1 Regional hydrology	Includes studies for hydraulic head and gradient
PHPR	1.02.05	Discharge and recharge	Location of natural discharge and recharge areas	3.7.1 Identification of discharge and recharge areas	
1.02.09	Amargosa	Hydrologic relationship with the Valley	ship with the Amargosa Valley River system	8.3.1.2 Studies of of the hydrologic system	Includes studies of discharge and recharge areas
PHPR	1.02.06	Flow paths and rates	Identify the flow paths and rates to the accessible environment	3.7 Regional groundwater flow system	
	1.02.11	Hydrology transport model	Information necessary for the hydrologic transport model	Assessment of groundwater travel time	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 7 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY (continued)					
	1.02.29	Tectonic alteration	Potential for tectonic alteration of ground-water flow path		
PHPR	1.02.07	Seismic effects on ground-water travel time	Effects of seismicity on ground-water travel time	1.5.2.1 Effects of faulting 8.3.1.5 Assessment of ground-water travel timePHPR	Discusses the potential effects of faulting
1.02.08	Effects of exploration	Effects of exploratory drilling on ground-water travel time	Effects of exploratory drilling on ground-water travel time	3.7 Regional ground-water flow system 8.2 Information required for site characterization	Describes flow system
	1.02.18	Human intrusion	Potential of mining intrusion of repository	8.3.1.9.3 Human interference	Studies exploration effects on hydrology

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 8 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY (continued)					
ISTP(1)	1.6	Human intrusion	Effects of human intrusion on hydrology	8.3.5.13.5 Probabilistic radiation releases	Radiological releases from anticipated and unanticipated scenarios
PHPR	1.02.10	Radionuclide transport	Potential for radionuclide transport through the flow system	3.9. Site hydrology system 8.3.5.13.3 Calculational model	Assess radiological releases to accessible environment
PHPR	1.09.11	Site characterization information	Benefit of site characterization information to surrounding area	Chapters 1 to 5 contain existing site information	
	1.11.04	Site characterization activities	Detailed descriptions of site characterization activities	8.3.1. Contains site information needed	
	1.12.01	Detailed information	Development of detailed site information		

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 9 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
HYDROLOGY (continued)					
	1.12.03	Issue resolution	Description of issues to be resolved during site characterization		
PHPR	1.02.01	Site-qualifying hydrologic issues	Identify site-qualifying hydrologic issues examined during site characterization	Chapter 3 Hydrology 8.3.5.18 Higher-level findings	Current information on hydrology Findings required for technical guidelines
PHPR	1.02.17	Pluvial conditions	Effects of pluvial climate on unsaturated zone	5.2.2 Future climate variation	Includes climate prediction and model validation
ISTP(1)	1.3	Natural changes	Natural (climatic) changes altering ground-water flow	8.3.1.5 Climatic change	Includes effects of climate on site elements
PHPR	1.02.27	Ground-water migration	Ground-water migration in the Great Basin	1.1 Geomorphology 8.3.1.2.1.3 Regional ground-water flow system	Discusses Great Basin geology Includes recharge and potentiometric level studies

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 10 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: MECHANICS					
PHPR	1.02.28	Radionuclide migration	Characterization of radionuclide migration in the unsaturated zone	8.3.5.13.5 Probabilistic radiological releases to the accessible environment	Radiological releases from anticipated and unanticipated scenarios
EA CRD	3.4.1.4	Porosity	Large-scale porosity tests	2.4.2.4 Porosity and density	Provides existing information on porosity and density
				8.3.1.15.1.1 Density and porosity characterization	Includes studies characterizing rock density and porosity
EA CRD	3.4.1.4	Fracturing	Thermally induced fracturing	2.4 Thermal and thermomechanical properties--intact rock	Provides existing information on thermal properties of intact rock
				8.3.1.15.1.6 Thermal properties from in situ experiments	Thermal properties from in situ experiments

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 11 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: MECHANICS (continued)					
EA CRD	4.1.1	Regional stress regime	Lack of information on the regional stress regime	2.6 Existing stress regime	Regional and site stress regime
	8.2	Rock properties	In situ rock properties and stress	8.3.1.15 Ambient stress 8.3.1.15.2 Ambient stress	Studies cover in situ stress testing
EA CRD	5.3	Thermo-mechanic properties of rock	Limitations of models	2.4 to 2.5 Thermal and thermomechanical properties of rock	Includes existing material on thermo-mechanical properties of rock
			Effects of percentages of lithophysae on thermomechanical properties of the in situ rock	8.3.1.15.1 Thermal and mechanical properties of rock	Studies to determine the thermal and mechanical properties of the in situ rock

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 12 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: MECHANICS (continued)					
EA CRD	8.2	Rock properties	Topopah Spring vs Grouse Canyon rock properties	1.8.2.1 Relation of geology to repository design	Includes repository operations
PHPR	1.01.08	Tuff properties	Integrity of tuff maintained during repository operations	Chapter 2 Geoengineering 8.2 Information required for site characterization 8.3.1.15.1 Thermal and mechanical properties	Provides existing material on large scale rock properties
PHPR	1.02.30	Characterization effects	Effects of characterization on the integrity host rock	8.3.3.2 Borehole seals 8.3.5.12.3 Disturbed zone ground-water travel time	Designs for borehole seals Ground-water travel time resulting from characterization

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 13 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: SURFACE CONDITIONS (continued)					
GEOLOGY: SURFACE CONDITIONS					
EA CRD	4.1.1	Surface conditions	Soil conditions, wind and water erosion	1.1.3.2 Erosion rates	Provides information on average erosion rates at the site
				8.3.1.14.2 Soil and bedrock properties	Studies include physical properties of soil
				8.3.1.6.2.1 Future climatic conditions on the nature and rate of erosion	Studies include wind and water erosion
				8.3.1.6 Erosion	States erosion will not affect the minimum burial depth
EA CRD	5.4	Erosion	Further data on erosion rates needed	1.1.3.2 Erosion rates	Existing material on erosion rates of site and area

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 14 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: SURFACE CONDITIONS (continued)					
EA CRD	4.1.2.1	Flooding	Maximum probable flood	3.2.1 Floods	Contains flood history and potential for future flooding
	8.1	Flooding	Probable maximum flood	8.3.1.16.1 Flood recurrence levels and intervals	Includes studies for the characterization of flood potential
EA CRD	4.1.3.3	Precipitation and evapotranspiration	Annual precipitation and evapotranspiration rates and variations	3.9.3.3 Recharge and discharge	Includes information on evapotranspiration and precipitation
				8.3.1.2.1 Regional hydrology	Contains studies for precipitation and evapotranspiration data
EA CRD	4.1.3.3	Climatic regime	Detail of the climatology and meteorology of the site	5.1 to 5.2 Recent and long-term climate and meteorology	Provides existing information on climatic regime
	7.2	Climatic regime	Further study of the climatic regime	8.3.1.5.1 Future climatic conditions	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 15 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: SURFACE CONDITIONS (continued)					
				8.3.1.12.1 Meteorological conditions at the site	
EA CRD	6.3	Meteorology	Data on extreme weather conditions	5.1 to 5.2 Recent and long-term meteorology and climate	Provides existing information on meteorological conditions
				8.3.1.12.1 Meteorological conditions at the site	Includes studies on extreme weather
				8.3.1.12.4 Recurrence intervals of extreme weather	
EA CRD	4.1.3.7	Background radiation	Radiation levels in soil and water	4.1.2.6 Background radioactivity	Includes information on ground-water background radioactivity
	6.5	Natural radiation	Natural radiation hazard	8.3.5.4.1 Natural radiation environment	References studies to determine the natural radiation environment

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 16 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: SURFACE CONDITIONS (continued)					
EA CRD	4.1.3.1	Land use	Detailed studies of land use	8.3.1.11.1.2 Land ownership and control	Includes interactions with the Department of Interior and Bureau of Land Management
EA CRD	5.8	Future communities	Development of future communities	8.3.1.10 Population patterns and forecasts	Includes studies on population pattern development
PHPR	1.02.25	Drainage patterns	Effects of alteration of drainage pattern	3.1 Surface hydrology	
ISTP(1)	1.2	Surface water	Nature of present surface water system	8.3.1.2.1 Descriptions of surface hydrology	Includes recharge and discharge flooding
GEOLOGY: TECTONICS AND MINERALOGY					
EA CRD	5.7	Seismic patterns	Increase seismic pattern data base	1.4 Seismology of the site	Provides existing material on seismic patterns of the area

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 17 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
				8.3.1.17.4.1 Seismology	Contains seismologic data compilation
EA CRD	5.6	Secondary volcanism	Significance of secondary volcanic processes	1.3.2.1 Volcanic history 8.3.1.8.1 Studies on releases resulting from volcanic activity	Includes the volcanic history and petrology of the site
EA CRD	5.2	Lateral and vertical extent	Inadequate information on the usability of areas outside the primary area	1.2 Stratigraphy and lithology 8.3.1.4.2 Stratigraphy and structure	Provides existing material on stratigraphy and lithology Contains activities on the extent of lithologic units
EA CRD	5.2	Fracture mineralogy	Lack of information on fracture mineralogy	4.1.1.3.1.2 Mineralogy of fractures	Contains existing information on fracture mineralogy

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 18 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
EA CRD	3.1.3.2	Postclosure tectonics	Tilting and warping rates and directions	1.1.3 Geomorphic processes	Covers significant late Quaternary geomorphic processes
NRC comment Final EA	1	Fault activity	Movement of north trending faults within the last 1,000 yr	1.3.2.2.2. Structure of Yucca Mountain	
	2	Northeast trending faults	Relationship of northeast trending faults to younger basaltic activity	8.3.1.17.4.5 Detachment faults	
NRC comment Draft EA	1	Northeast trending and fault activity	Northeast trending faults and fault activity	8.3.1.17.4.7 Geometry of faults	
				8.3.1.8.1.2 Effects of eruptions	
EA CRD	3.4.1.8	Seismic hazards	Site-specific estimates of seismic hazards	1.4.1.5 Seismic hazards at the candidate site	Provides existing information on seismic hazards

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 19 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
PHPR	1.01.03	Seismic activity	Potential for and associated uncertainties of seismic activity	8.3.1.17.4 Quaternary faulting	
	1.01.04	Seismic disruption	Estimated potential for seismic disruption of the repository	8.3.1.8.1.2 Effects of eruptions	
	1.01.05	Distance to fault	Determine a safe distance to a fault	8.3.1.8.2 Tectonic processes	8.3.1.17 Studies include estimates of the probability of future earthquakes and faulting
				8.3.1.17.2 Potential fault movement	Studies include probabilities of rupture
NRC comment Draft EA	2	Volcanism and hydrothermal activity	Origin of calcite/silicate vein deposits	8.3.1.3.2.1 Fracture mineralogy	Contains activity on determining fracture mineralogy

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 20 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
				8.3.1.5.2 Future climate	Contains studies on calcite and silicates
				1.3.2.2.2 Structure of Yucca Mountain	
EA CRD	5.3	Fault density	Actual fault density	1.5.2.1 to 1.5.2.3 Faulting effects, likelihood, and relation to weapons tests	Contains information on fault types, locations, and effects
NRC comment Final EA	3	Detachment faulting	Potential for the presence of detachment faults and other fault movement	8.3.1.17.3 Ground motion	
		Faulting styles	Fault movement styles of Yucca Mountain	8.3.1.17.4.6 Quaternary faulting	
NRC comment Draft EA	1	Detachment faulting	Studies addressing detachment faulting	8.3.17.4.7 Geometry of faults	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 21 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
PHPR	1.01.06	Fault source	Faulting resulting from weapons tests	8.3.1.13.2 Impact of nearby installations and operations	Includes effects of weapons testing
PHPR	1.07.03	Dust generated	Potential for hazardous fibers within dust	4.1 Geochemistry of the host rock 8.3.1.3.2 Mineralogy petrology, chemistry of the host rock	Discusses mineralogy of host rock Determines material constituency of host rock
EA CRD	5.8	Mineral resource	Further mineral resource evaluations	1.7 Mineral and hydrocarbon resources	Provides existing information on mineral resources
		Geothermal	Potential for extraction of geothermal resources	8.3.1.9.2 Value of resources	Includes studies on resource value
NRC Comment Final EA	5	Economic deposits	Potential for economic deposits associated with Calderas	8.3.1.9.3 Effects of exploiting natural resources	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 22 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
		Breccia deposits	Potential for economic deposits associated with breccias	8.3.1.9.2.1 Present and future value of natural resources	
NRC comment Draft EA	2	Natural resources	Potential for undiscovered mineral resources	8.3.1.5.2 Future climate	Contains studies on calcite and silicate deposits
PHPR	1.01.07	Mineral resources	Presence of mineral resources	8.3.1.16.2 Identification of water supplies	Includes identification, assessment, and effects of water supply exploitation
ISTP(1)	1.4	Ground-water withdrawal	Water resource development		
PHPR	1.01.01	Site-qualifying geology issues	Determine site-qualifying issues examined during site characterization	Chapter 1 Geology	Chapter 1 contains current geology material
ISTP(5) ^f	5.1	Geologic system	Present nature of geologic system	8.3.5.18 Higher level findings	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 23 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
	5.2	Future geology	Future changes altering geology		
	5.3	Geologic system	Human-induced changes altering geology		
	5.4	Geologic system	Repository-induced geologic alterations		
	5.5	Future geology	Natural changes affecting future geology		
	5.6	Future geology	Future human-induced changes altering geology		
	5.7	Future geology	Future repository-induced alterations to geology		
PHPR	1.01.09	Physical processes	Physical processes in the unsaturated zone affecting repository behavior	1.8.2.1	Relation of geology to repository design

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 24 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
				8.2 Information required for site characterization	
				8.3.1.2 Includes processes occurring in the unsaturated zone	
				8.2 Information required for site characterization	
				8.3.1.2 Includes processes occurring in the unsaturated zone	
EA CRD	5.1	Ground-water chemistry	Unsaturated vs saturated zone chemistry	4.1.2 Ground-water geochemistry	Contains existing information on ground-water geochemistry
				8.3.1.3.1 Water chemistry	Development includes model of unsaturated and saturated zone water composition

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 25 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
EA CRD	4.2.2	Vadose water	Analysis of vadose water	8.3.1.2.2 Descrip- tion of the unsaturated zone	
EA CRD	5.6	Dissolution	Equilibrium of mineralogy and aqueous chemistry		
		Topopah Spring Member	Dissolution potential of Topopah Spring Member	4.1.2 Ground-water geochemistry	Provides existing material on ground- water chemistry
				8.3.1.7.1 Dissolution rates	
EA CRD	5.1	Sorption	Sorption and varying water compositions	4.1.3.3. Sorption	Provides current information on sorption
				8.3.1.3.4.1 Geo- chemistry sorption	Includes studies of sorption as a func- tion of ground- water composition

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 26 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
EA CRD	5.1	Particulates, colloids, complexes	Formation and transport of particulates, colloids, and complexes	4.1.2.7 Particulates and colloids	Provides existing information on particulates and colloids
				4.1.3.5 to 4.1.3.6 Diffusion and radionuclide transport	Provides existing information on diffusion and transport
				8.3.1.3.4.1.4 Sorption on particulates and colloids	
				8.3.1.3.5.2 Colloid behavior	
EA CRD	5.2	Actinide complexes	Effects of carbon-rich waters on actinide complexing	8.3.1.3.6.1.5 Filtration	
				4.1 Geochemistry	Contains geochemistry background information

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 27 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
				8.3.1.3.5 Studies for radionuclide retardation	Contains studies and activities on carbonate waters and actinide speciation
EA CRD	4.1.1	Gaseous radionuclide	Gaseous transport of radionuclide	4.1.3.6 Radionuclide transport	Includes radionuclide transport by gas
				8.3.1.3.8.2 Retardation of gaseous radionuclides	
EA CRD	3.4.1.3	Geochemistry data base	Insufficient geochemistry data base	4.1 Geochemistry of the host rock and surrounding units	Provides background on site geochemistry
	7.1.1	Geochemistry	Composition of percolating waters	8.3.1.2.1.3.5 Regional hydrochemical test and analyses	
NRC comment Draft EA	3	Geochemical environment	Oxidation-reduction conditions	8.3.1.2.3 Characterization of site hydrochemistry	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 28 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
ISTP(3) ^g	3.1	Geochemistry	Present geochemistry		
NRC comment Draft EA	8	Radionuclide transport	Radionuclide transport increases due to geohydrologic changes resulting from climatic alterations	3.7 Regional ground-water flow system 8.3.1.5.2 Climatic effects on hydrologic characteristics 8.3.1.3.7.1 Retardation sensitivity	Provides existing information on recharge systems
NRC comment Final EA	6	Matrix retardation	Can matrix retardation overcome increases in ground-water flow due to climate change	4.1.3.5 Matrix diffusion 8.3.1.3.7.1 Retardation sensitivity analysis	
NRC comment Draft EA	6	Retardation	Retardation of radionuclides	8.3.1.3.6.1 Dynamic transport column experiments	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 29 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)					
NRC Comment Final EA	8	Retardation	Value of matrix diffusion and colloid sorption on the retardation of radionuclides	8.3.1.3.6.2 Diffusion 8.3.1.3.4.1.4 Sorption on particulates and colloids	
ISTP(3)	3.3	Retardation	Future geochemistry effecting retardation		
PHPR	1.05.02	Water courses	Chemical composition of water courses	4.1 Geochemistry of the host rock	Discusses mineralogy and retardation
				8.3.1.3.2 Mineralogy, petrology, chemistry, of the host rock	Includes material along water courses
				8.3.1.3.4-8 Radionuclide retardation	Studies the chemical composition along flow paths

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 30 of 30)

Footnotes

^aEA CRD = site specific comment response document for the environmental assessment for the Yucca Mountain site (DOE, 1986b).

^bISTP(1) = Draft Issue-Oriented State Technical Position (ISTP) for Nevada Nuclear Waste Storage Investigations (NNWSI) Project - Hydrology (NRC, 1984).

^cNRC comment = NRC Comments on the Final Environment Assessment, Yucca Mountain site (Kale, 1986).

^dNRC comment = NRC comments on the draft environmental assessment for the Yucca Mountain site (NRC, 1987).

^ePHPR = These comments are taken from the Public Hearings Panel Report, NVO 263, dated November 1983 (DOE/NVO, 1983).

^fISTP(5) = Draft ISTP for NNWSI Project--Geology/Geophysics, (NRC, 1984).

^gISTP (3) = Draft ISTP for NNWSI Project--Geochemistry, (NRC, 1984).

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (1 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
EA CRD ^a	4.1.1	Seismic effects	Potential effects of seismic activity on repository operation and performance	8.3.2.1.4 Repository modeling	Includes design considerations for seismic activity
EA CRD	5.4	Sealing program	Detailed description of sealing program	6.2.8 Shaft and borehole seals	Contains existing material on shaft and borehole seals
ISTP(4) ^b	4.6	Seal design	Will seal design meet 10 CFR 60.112	8.3.2.5.10 Construction of seals 8.3.3.1. Seal system	States the results from other seals development tests Contains planned seals design and modeling
EA CRD	5.11	Radionuclide releases to ground water	Predicted radionuclide releases to accessible environment at 100,000 yr	6.4. Design issues 8.3.5.13.2 Post-closure system performance	Covers preliminary analysis of repository performance Includes design concepts and calculational models for releases

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (2 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
EA CRD	5.11	Waste package corrosion	Corrosion testing	7.4 Waste package design and geochemical interactions	Provides existing material on waste package design
PHPR ^c	1.02.12	Water chemistry	Water chemistry and effect on corrosion	8.2 Information required for site characterization	
	1.02.14	Ground-water effects	Effects of ground water on repository components	8.3.1.2 Hydrologic system	
				8.3.1.3 Geochemistry	
				8.3.5.9-10 Assessment of containment within waste package	Contains waste package design information and containment assessment
NRC Comment Draft EA ^d	10	Waste package	Detailed materials plan	7.2-7.3 Waste package design basis, reference designs, and alternative designs	
ISTP(2) ^e	2.5	Waste package	Waste package releases within 10 CFR 20	8.3.4.3 Waste package	

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (3 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
	2.6	Waste package	Waste package retrievability design		
	2.7	Waste package	Waste package design		
	2.9	Waste package	Waste package monitoring	8.3.5.9 Assessment of containment within waste package	Contains waste package design and modeling accounting for the performance objective for the waste package Contains waste package design information and containment assessment
PHPR	1.01.13	Resulting radiation doses	Potential for radiation releases to jeopardize individuals	8.3.5.13.5 Probabilistic radiation releases	Radionuclide releases from anticipated and unanticipated scenarios

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (4 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP(4)	4.1	10 CFR 60.111	Repository design to maintain 10 CFR 60.111	8.3.5.14 Doses to individuals	Describes allowable doses
PHPR	1.03.13	Weapons testing	Safety factors provided against weapons testing or impact	6.1.2 Reference repository design 8.3.1.13.2 Offsite installations	Provides offsite impact data to repository data base
	1.08.03	Weapons testing	Compatibility of weapons testing and waste disposal		
PHPR	1.02.20	Flood protection	Identify flood protection measures for repository (surface)	8.3.2.5.8 Technology of surface facility construction	Design parameters include climate and flooding
PHPR	1.03.14	Nuclear criticality	Potential for waste to go critical	7.2.2 Waste forms	Describes considerations of waste form
				8.3.4.3.2 Waste form criteria	

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (5 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.03.19	Integrity of openings	Engineering methods used to maintain openings	6.1.1 Repository design requirements	Includes operation and decommissioning as design requirements
				8.3.2.5.9 Techniques for underground construction	Includes construction of safe openings
PHPR	1.03.20	Mining effects	Potential for continual mining affecting emplaced waste	6.4.10.2.2 Repository operations	Discusses expected repository operations
	1.03.23	Repository stability	Stability of repository maintained during coupled effects of excavation and thermal stress from emplaced waste	8.3.2.5.3 Repository operations plan	Includes considerations for operation during construction
ISTP(2)	2.8	Stability	Vicinity conditions affecting waste criticality		

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (6 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.03.21	Weapons testing	Effects of weapons-induced seismicity on the repository	6.1.2 Reference repository design basis 8.3.2.5.4 Repository design requirements	Includes requirements from 10 CFR 60 and 10 CFR 960
PHPR	1.03.25	Interaction effects	Results of long-term interaction between the barrier and host rock	8.3.5.13 Assessment of postclosure system performance	Includes models and scenarios of postclosure performance
PHPR	1.03.26	Waste package degradation	Degradation of waste package adversely altering the waste package environment	7.4.1 Waste package environment modification	Discusses interaction of waste package with emplacement environment
ISTP(2)	2.2	Waste package	Ground-water penetration of waste package	8.3.4.2.4 Post-emplacement near field	Studies the changes in the near field
ISTP(3) ^f	3.2	Waste package environment	Changes in geochemistry due to waste package	8.3.2.1.2 Coupled-interaction tests	Studies include interactions between waste package and environment

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (7 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.03.27	Backfilling	Complications due to backfilling	6.2.7 Backfilling	Discusses backfilling and techniques
ISTP(2)	2.1	Backfill	Ground-water penetration of backfill	8.3.2.2.7 Post-closure repository design	Includes backfill degradation
ISTP(4)	4.3	Backfill	Retardation ability of backfill		
	4.4	Backfill	Does backfill compromise waste package		
	4.5	Backfill	Does backfill control radiological releases		
PHPR	2.04.02	Suitability	Suitability of Yucca Mountain resulting from factual evidence	8.3.5.18 Assessment of postclosure system and technical guidelines	
	3.01.03	Human engineering	Replacement of non-existent favorable geologic conditions with engineered components		

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan' (SCP) sections where concerns are addressed (8 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	3.04.18	Existing technology	The use of existing international experience with waste disposal	Chapters 6,7 Conceptual design and waste package	Contain existing information and technology on repository and waste package design
				8.3.2.1.3 Design optimization	Studies improving the design to better meet performance objectives
PHPR	3.03.03	Storage	Long-term storage experiments	8.3.4.1 Waste package program	Includes waste form testing
PHPR	1.03.17	Licensing requirements	Identify the licensing requirements for the repository and their limitations	8.1.1 to 8.1.2 Derivation of site characterization and issue resolutions strategy	
				8.2 Issues to be resolved through site characterization	

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (9 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.01.10	Model uncertainties	Level of confidence of uncertainties in models	6.4.10.3 Planned work for model validation	
				8.3.2.5 Adequate techniques	Assigns level of confidence
PHPR	1.03.05	Waste package performance	Long-term performance characteristics of the waste package	7.4.2.3 Degradation modes of waste package materials	
	1.03.06	Waste package performance	Waste package integrity under corrosive or thermal conditions	8.3.4.1.3 Waste package designs	Describes performance objectives of waste package
	1.03.22	Waste package design	Methods for waste stabilization	8.3.4.2.2 Reference waste package designs	Includes long-term corrosive and thermal properties
NRC EA Final ^g	9	Waste package performance	Uncertainties in performance models or parameters of waste package design		

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (10 of 10)

Source	Comment ID number	Major concern	Specific concern . . . SCP cross-reference	Content
ISTP(2)	2.3	Waste package releases	Radiological release rates from waste package	
	2.4	Waste package releases	Radiological migration rates through failed waste package	
ISTP(4)	4.2	Retrieval	Will underground facility allow retrieval	8.3.5.2 Issue resolution strategy for Issue 2.4; retrievability

^aEA CRD = site specific comment response document for the environmental assessment for the Yucca Mountain site (DOE, 1986b).

^bISTP(4) = Draft ISTP for NNWSI Project--Geologic Repository Operations Area Design/Rock Mechanics, (NRC, 1984).

^cPHPR = These comments are taken from the Public Hearings Panel Report, NVO 263, dated November 1983 (DOE/NVO, 1983).

^dNRC Comment = NRC comments on the draft environmental assessment for the Yucca Mountain site (NRC, 1985a).

^eISTP(2) = Draft ISTP for NNWSI Project--Waste Package, (NRC, 1984).

^fISTP(3) = Draft ISTP for NNWSI Project--Geochemistry, (NRC, 1984).

^gNRC Comment = NRC comments on the Final Environmental Assessment, Yucca Mountain site (Kale, 1986).

Table 8.2-5. Overview of contents of Section 8.3 showing order of presentation of site programs and performance and design issues within major programs

Section 8.3.2 Repository Program	Section 8.3.3 Seal Program	Section 8.3.4 Waste Package Program	Section 8.3.5 Performance Assessment Program	Section 8.3.1 Site Program
8.3.2.2 Configuration of underground facilities (postclosure), Issue 1.11	8.3.3.2 Seal characteristics (postclosure), Issue 1.12	8.3.4.2 Waste package characteristics (postclosure), Issue 1.10	8.3.5.2 Waste retrievability, Issue 2.4	8.3.1.2 Geohydrology
8.3.2.3 Repository design criteria for radiological safety, Issue 2.7		8.3.4.3 Waste package characteristics (preclosure), Issue 2.6	8.3.5.3 Public radiological exposures--normal conditions, Issue 2.1	8.3.1.3 Geochemistry
8.3.2.4 Nonradiological health and safety, Issue 4.2		8.3.4.4 Waste package production technologies, Issue 4.3	8.3.5.4 Worker radiological safety--normal conditions, Issue 2.2	8.3.1.4 Rock characteristics
8.3.2.5 Preclosure design and technical feasibility, Issue 4.4			8.3.5.5 Accidental radiological releases, Issue 2.3	8.3.1.5 Climatic change
			8.3.5.6 Higher level findings--preclosure radiological safety, Issue 2.5	8.3.1.6 Erosion
			8.3.5.7 Higher level findings--preclosure system and technical guidelines, Issue 4.1	8.3.1.7 Dissolution
			8.3.5.9 Waste package containment, Issue 1.4	8.3.1.8 Postclosure tectonics
			8.3.5.10 Engineered barrier system release rates, Issue 1.5	8.3.1.9 Human interference
			8.3.5.12 Ground-water travel time, Issue 1.6	8.3.1.10 Population density
			8.3.5.13 Total system performance, Issue 1.1	8.3.1.11 Site ownership
			8.3.5.14 Individual protection, Issue 1.2	8.3.1.12 Meteorology
			8.3.5.15 Ground-water protection, Issue 1.3	8.3.1.13 Offsite installations
			8.3.5.16 Performance confirmation, Issue 1.7	8.3.1.14 Surface characteristics
			8.3.5.17 NRC Siting Criteria, Issue 1.8	8.3.1.15 Thermal and mechanical rock properties
			8.3.5.18 Higher-level findings--postclosure system and technical guidelines, Issue 1.9	8.3.1.16 Hydrology
				8.3.1.17 Preclosure tectonics

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all anticipated and unanticipated processes and events, shall:

- (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated in accordance with Section 60.115.
- (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated in accordance with Section 60.115.

"Accessible environment" is understood by the DOE to mean the atmosphere, land surfaces, surface waters, oceans, and the portion of the lithosphere that is outside the controlled area. Likewise, the term "anticipated processes and events" is understood to mean "those natural processes and events that are reasonably likely to occur during the period the intended performance objective must be achieved", assuming that the "processes operating in the geologic setting during the Quaternary Period continue to operate but with the perturbations caused by the presence of emplaced waste superimposed thereon." "Unanticipated processes and events" are understood to be those processes and events "that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration."

The proposed 10 CFR 60.115 (NRC, 1986a) presents a table that lists the maximum release to the accessible environment allowable for each radionuclide species. These release limits are based on the EPA containment standard (40 CFR 191.13) and the release limits, stated in 40 CFR 191 Appendix A.

Technical background and licensing strategy

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

The identification of significant processes and events which are to be taken into account in these performance assessments will be accomplished by developing scenarios that each specify a sequence of processes and events potentially resulting in significant impacts on the variables of the system important to waste isolation. Scenarios will be developed for undisturbed conditions, i.e., those due to likely natural events, and for disturbed conditions, which although due to unlikely natural events and processes are sufficiently credible to warrant consideration.

The repository system consists of the natural barriers and the engineered barriers, including the waste package and the shaft and borehole seal system. For the Yucca Mountain site, the proposed location of the repository is in the unsaturated Topopah Spring welded tuff unit, about 250 meters above

the water table and 200 to 300 meters below the ground surface. The present and future characteristics of the engineered and natural barrier systems will be evaluated to determine their effectiveness in limiting radionuclide releases to the accessible environment.

There are two aspects of isolation that must be considered: the rate of release of radionuclides from the engineered barrier system must be predicted and the transport of radionuclides through the natural barrier system to the accessible environment must be evaluated. The evaluation of the release of radionuclides from the engineered barrier system will take into account the assessments of performance of the engineered barrier system for Issues 1.4 and 1.5 (SCP Sections 8.3.5.9 and 8.3.5.10). The overall system performance assessment for Issue 1.1 will use the results of the engineered barrier system performance assessments to develop a radionuclide source term for the evaluation of radionuclide transport through the natural barriers and to the accessible environment.

There are three possible radionuclide transport modes from the engineered barriers through the natural barriers to the accessible environment. One of these modes, direct release, results from the direct mechanical transport of radioactive material to the accessible environment due, for example, to igneous extrusion or as the result of human intrusion. The other two modes are liquid transport and gas transport. The geohydrologic, geochemical and rock characteristics of the elements of the natural barrier system determine the effectiveness of the natural barriers in limiting the liquid and gaseous transport of radionuclides from the engineered barrier system to the accessible environment. These characteristics include such variables as percolation flux, fracture density, stratigraphic unit thickness and bulk porosity. During the next 10,000 years, certain events and processes could occur that would alter the characteristics of the elements of the natural barrier system and possibly the engineered barrier system elements. Sequences of these processes and events, referred to as scenarios, could alter present conditions in such a way that the isolation capabilities of the site would be adversely affected.

The strategy for the resolution of this issue is to determine the contribution to total radionuclide releases to the accessible environment for the scenarios that are likely to occur during the next 10,000 years as well as for those scenarios that are unlikely, yet sufficiently credible to warrant consideration. Generic lists of processes and events that could affect a repository system are evaluated together with site-specific information to identify the significant processes and events. Significant processes and events are those that could have a significant impact on the variables of the system important to waste isolation, and that are sufficiently credible to warrant consideration. Scenarios are then developed, based on the set of significant processes and events. Scenarios will be developed for both undisturbed and disturbed conditions. Undisturbed conditions are the natural processes and events that are likely to occur, coupled with perturbations that result from repository construction and waste emplacement. Disturbed conditions are the natural processes and conditions and human activities that are considered unlikely yet sufficiently credible to warrant consideration.

To evaluate the effects of the scenarios on repository performance, mathematical models are constructed. To reduce the number of mathematical

models required to assess the effects of the scenarios, the scenarios are grouped into "scenario classes". The nominal scenario class include all the scenarios that are associated with undisturbed performance. The scenarios associated with disturbed performance are grouped into scenario classes according to the manner in which the repository system would be effected if they were to occur. A preliminary set of eight scenario classes has been identified. These classes have been grouped into five supercategories: nominal performance, direct releases, partial failure of the engineered barrier system, partial failure of unsaturated zone barriers, and partial failure of saturated zone barriers. The scenarios are grouped such that the scenario classes are exhaustive and mutually exclusive in their coverage of the scenarios and significant events and processes. The preliminary set of scenario classes and the supercategories are shown in Table 8.2-6.

As discussed, mathematical models for each scenario class are constructed. The independent variables of each scenario class model are the state variables needed to determine initial conditions and boundary conditions. The dependent variable of each scenario class model is the contribution to the total cumulative normalized release that would result from the occurrence of the scenarios of the j^{th} scenario class. This dependent variable is used as a partial performance measure, M_j , and is defined mathematically by

$$M_j = \sum_i \frac{Q_{ji}}{L_i} \quad (8.2-1)$$

where j indexes the scenario class being considered, and Q_{ji} is the cumulative release of radioactivity in curies released to the accessible environment in the 10,000-year period following disposal, in the form of the i^{th} radionuclide species, through the realization of one or more of the scenarios included in the j^{th} scenario class. The quantity L_i is the release limit for the i^{th} radionuclide as specified in the standards (40 CFR Part 191, Appendix A). Since the scenario classes are constructed to be exhaustive and mutually exclusive,

$$M = \sum_j M_j \quad (8.2-2)$$

where M is the total cumulative normalized release from the repository system. M serves as a performance measure for the total repository system.

Available information can be used to obtain an estimated value for the expected partial performance measure for a scenario class. A scenario or scenario class can be eliminated if it can be shown via the estimated expected partial performance parameter that the scenario or scenario class would have low relative or absolute consequences. Also, the models of the scenario classes that remain can be simplified by the elimination of insensitive independent variables through sensitivity analyses.

The mathematical models for the scenario classes will be implemented by computer codes. These codes can be exercised for deterministic point estimates of the release or to develop an overall probability distribution. In the later case the values for the performance measures are obtained by Monte Carlo sampling from a joint probability distribution of values for the

Table 8.2-6. Preliminary set of scenario classes for resolution of Issue 1.1

Nominal performance of all barriers.

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

Disturbed performance of barriers.

- (A) Direct Releases:

- 1) direct release in an extrusive magmatic event;
- 2) direct release associated with human intrusion.

- (B) Partial failure of engineered barrier system (included in (C) and (D))

- (C) Partial failure of unsaturated zone barriers:

- 1) accelerated releases to the water table attending increased flux from sources above the repository;
- 2) accelerated releases to the water table attending a rise in the water table (foreshortening of unsaturated zone);
- 3) accelerated releases to the water table attending changes in unsaturated zone rock-hydrologic properties or geochemical properties.

- (D) Partial failure of saturated zone barriers:

- 1) accelerated releases to the accessible environment owing to appearance of discharge points within 5 km downgradient of controlled area (foreshortening of the saturated zone).
 - 2) accelerated releases to the accessible environment owing to increased linear water velocity in the saturated zones, changed rock-hydrologic properties, or changed geochemical properties.
-

dependent variables of the system. By repeated sampling, a distribution of calculated releases can be generated. This distribution can then be used to construct the overall probability distribution for normalized cumulative release.

The results of the preliminary performance allocation for this issue are summarized in Table 8.2-7 and is based upon preliminary evaluation of cumulative release using available information. Performance measures and goals are selected in terms of the scenario classes specified in Table 8.2-6. Column 1 lists the general categories of scenario classes identified in Table 8.2-6. (Section 8.3.5.13 gives the bases for these classes and discussion to support the table entries.) Column 2 indicates the mode(s) of radionuclide transport to the accessible environment that are appropriate for each scenario class. Column 3 shows the preliminary assignment of the barriers for which credit will be taken in meeting the performance goals, which are described in Section 8.3.5.13. Possible back-up barriers are also indicated.

Column 4 shows the component(s) of the primary barrier that are believed to contribute most to the achievement of the performance goal. Column 5 gives the process or condition characteristic of the primary barrier which is being relied on to limit transport.

The elements in this table help to orient the testing program toward the information needed to support the calculation of cumulative release to the accessible environment for the resolution of Issue 1.1. The testing will focus on the barriers and processes identified in this table. Goals for the testing program in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of the issue are identified in the detailed strategies discussed in Section 8.3.5.13.

8.2.2.1.1.2 Summary for individual protection -- Issue 1.2: Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15?

Regulatory background

Issue 1.2, which is discussed in Section 8.3.5.14, addresses the EPA requirements of 40 CFR 191.15 that limit the annual dose equivalent from the repository system to any member of the public in the accessible environment following permanent closure. The regulations require that, for 1,000 years after disposal and assuming undisturbed performance of the repository system, the annual dose equivalent to any member of the public in the accessible environment shall not exceed 25 mrem to the whole body or 75 mrem to any critical organ. All potential pathways associated with undisturbed performance from the repository to people shall be considered, and it shall be assumed that individuals consume 2 L/day of drinking water from any significant source of ground water outside the controlled area.

The EPA defines "undisturbed performance" as meaning the predicted behavior of the disposal system, including consideration of the uncertainties

Table 8.2-7. Primary performance allocation for Issue 1.1 (page 1 of 2)

Release scenario class	Pathway	Primary barriers	Primary barrier components	Primary processes or conditions
Nominal case E	Water	Unsaturated zone; saturated zone, EBS ^a as backup	Combined facies of Calico Hills; other units (backup)	Equivalent-porous-media transport through matrix with adsorptive retardation
	Gas	EBS; overburden as backup	Cladding and structural components	Limited rapid release of carbon-14 as carbon dioxide
Direct releases A-1, A-2	(No allocation: See Section 8.3.5.13 for explanation)			
Failure of unsaturated zone barriers				
C-1	Water	Repository overburden	Paintbrush Tuff unit and Topopah Spring	Flooding-pulse delay times less than 10,000 yr
	Gas	None	None	None
C-2	Water	Unsaturated zone; saturated zone, EBS as backup	Combined facies of Calico Hills	Equivalent-porous-media transport, with adsorptive retardation
	Gas	EBS; overburden as backup	Cladding and structural components	Limited rapid release of carbon-14 as carbon dioxide
C-3	Water	Saturated zone; EBS and residual unsaturated zone as backup	Saturated zone to boundary of AE ^b (or discharge points)	Equivalent-porous-media transport with adsorptive retardation

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Table 8.2-7. Primary performance allocation for Issue 1.1 (page 2 of 2)

Release scenario class	Pathway	Primary barriers	Primary barrier components	Primary processes or conditions
Failure of saturated zone barriers	Gas	None	None	None
D-1	Water	Residual saturated zone + residual unsaturated zone, EBS as backup		Equivalent-porous-media transport with adsorptive retardation
D-2	Water	Residual saturated zone + residual unsaturated zone, EBS as backup		Equivalent-porous-media transport with adsorptive retardation

^aEBS = engineered barrier system.

^bAE = accessible environment.

in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events. The term "accessible environment" means (1) the atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all the lithosphere that is beyond the controlled area, a surface location that encompasses no more than 100 km and extends horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system.

Technical background and licensing strategy

Radionuclides may be released from the waste container via several mechanisms. Under undisturbed conditions no radionuclides will be released from the waste container in solid form (e.g., direct releases due to human intrusion). The only other mechanism for release of radionuclides from the solid waste form and waste package are through formation of gaseous species (e.g., carbon dioxide containing carbon-14) and through dissolution in ground water that comes in contact with the waste form.

Once released from the waste container, there are only two significant mechanisms for transport of the radionuclides from the waste package to humans in the accessible environment under undisturbed conditions, i.e., ground-water transport and gas-phase transport. The probable flow paths for each transport mechanism lead to quite different and separate exposure sources for any released radionuclides and will, therefore, be treated separately. The strategy for resolving Issue 1.2 for the ground-water transport is to determine whether any exposure to the public will occur during the 1,000-yr period following permanent closure. For gas-phase transport, the reference case will examine whether the upper bounding value of the exposure to the public will be less than the 25 and 75 mrem/yr dose limits based on the amount of the carbon-14 inventory that can be released in gaseous form. Alternatively, it may be possible to show that gaseous carbon-14, the only potentially important gaseous release, may never reach the accessible environment during the 1,000-yr period.

Ground-water transport

Under undisturbed conditions, no significant amounts of liquid water are expected to be present in or adjacent to the emplacement borehole for at least 300 years after disposal. For 300 to 1,000 years after disposal, a limited amount of water (less than 5 liters per year per package) may be available to contact some waste containers, although most of the containers are expected to remain in a dry environment for well over 1,000 years (Section 8.3.4). Under very conservative assumptions, however, up to 20 percent of the waste containers may be breached and radionuclides may be released and transported via ground water downward through the unsaturated zone and laterally through the saturated zone before reaching the accessible environment. Non-sorbing radionuclides would not travel faster than the ground-water itself along the path of likely radionuclide travel, and sorbing species of the radionuclides would travel slower than the ground-water because of retardation. Thus, for ground-water transport, this issue will be resolved if it can be established with high confidence that the ground-water travel time, and therefore radionuclide transport time, along any likely and significant path of radionuclide travel to the accessible environment exceeds 1,000 years. Current estimates on the ground-water travel time show a mean

value of about 43,000 yr with a standard deviation of 13,000 yr (Sinnock et al., 1986) thus providing an initial level of confidence that the contaminant transport time will be substantially longer than 1,000 yr.

Gas-phase transport

There are three radionuclides that could be transported as gaseous species under the expected conditions at Yucca Mountain: carbon-14, tritium, and krypton-85. Of these, only carbon-14 is readily available for rapid release from a breached waste container. The other radionuclides, both of which have short half-lives, are expected to be contained within the waste form (Sections 8.3.5.9 and 8.3.5.10). Both spent fuel and glass waste forms contain carbon-14. Most of the carbon-14 in the spent fuel is locked inside the UO_2 fuel pellets, Zircaloy cladding, and fuel assemblies and will be released slowly after the containment is breached. Only a small fraction of the total carbon-14 inventory, that is contained in the oxidized skin of the Zircaloy cladding of the spent fuel, could be rapidly released by reaction of the oxygen in the pore spaces of the unsaturated host rock with the carbon in the cladding oxidation layer (Oversby and McCright, 1985). Oversby and McCright (1985) estimate that no more than one percent of the carbon-14 inventory in spent fuel could be rapidly released in this way during the first 100 to 1,000 years following closure when high temperature and gamma radiation are expected (Section 8.3.5.9). There is no mechanism for rapid release of carbon-14 from glass waste forms, which have smaller carbon-14 inventories than spent fuel. A bounding calculation for the carbon-14 releases is presented in Section 8.3.5.14.

The carbon-14 released from the spent fuel during the initial breach of the container is expected to be in the form of gaseous carbon dioxide, which will move upward through air-filled pores in the unsaturated tuffs. In the course of the upward movement of carbon-14 dioxide, isotopic exchange of carbon-14 with the normal carbon of the carbon dioxide gas in the pore space will occur, thus retarding the movement of the carbon-14 to the atmosphere above the repository. In addition, precipitation of calcite ($CaCO_3$), if it occurs, will irreversibly remove carbon-14 from the system. If the residence time of the carbon-14 in the overburden is established with high confidence to exceed 1,000 years, this part of Issue 1.2 will be resolved. Actual residence times of carbon-14 in the pore spaces of the repository overburden could, in principle, be estimated by solving a transport equation that takes the isotope exchange and chemical models into account. However, site-specific data that would permit realistic estimates of the carbon-14 residence time are presently lacking.

For the resolution of Issue 1.2, a bounding-value calculation will be used. The inventory of carbon-14 available for rapid release, a total of 200 Ci for 1,000 years, is relatively small compared with an average release of 5 to 10 Ci/yr into the atmosphere from each operating nuclear power plant (boiling water and pressurized water reactors) and with the design-basis release of approximately 800 Ci/yr from a 1,500-MTHM (metric tons of heavy metal)-per-yr fuel-reprocessing plant. Because the dose consequences expected from the assumed release of carbon-14 through the repository overburden are very small, bounding calculations will be done for a hypothetical maximally exposed individual on the ground surface above the repository assuming a ground-level release of the total 200 Ci in one year.

Internal dose due to ingestion has not been calculated because of the lack of site-specific data. This dose is, however, expected to be significantly smaller than the inhalation dose because of the lack of vegetation at the Yucca Mountain site.

A preliminary performance allocation for this issue, for both ground-water and gas-phase transport, is summarized in Table 8.2-8. Because Issue 1.2 is concerned with only the undisturbed performance of the disposal system, it is appropriate to allocate performance against the expected transport pathways. The table shows the primary barriers that will be relied upon to limit radionuclide transport along each pathway. Also shown are the measures that will be used to evaluate the performance of the barriers. More detailed performance measures are used for the gaseous pathway than for the ground-water pathway. For the gaseous pathway, possible doses can be received externally, as well as internally by either inhalation or ingestion. For the ground-water pathway, only an ingestion dose is possible. For the gaseous pathway, however, no significant individual external dose is expected through the skin from the weak, carbon-14 beta radiation. The only significant pathways for internal dose are through inhalation of carbon-14 dioxide in breathing air and by ingestion of food items grown in the area that contain carbon-14.

Goals for the testing program in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue are identified in the detailed strategies discussed in Section 8.3.5.13. Identification of primary barriers and performance measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

Table 8.2-8. Transport pathways, barriers, and performance measures for Issue 1.2 (individual protection)

Transport mode	Primary barriers	Performance measure
Ground water	Unsaturated zone and saturated zone	Individual dose (whole body)
Gas phase	Waste container and overburden	Individual dose (whole body)
		External
		Internal
		Inhalation
		Ingestion

8.2.2.1.1.3 Summary of ground-water protection -- Issue 1.3: Will the mined geologic disposal system meet the requirements for the protection of special sources of ground water as required by 40 CFR 191.16?

Regulatory background

Issue 1.3, which is discussed in Section 8.3.5.15, addresses the U.S. EPA requirements of 40 CFR 191.16 that limit the concentrations of radioactive waste products allowed in special sources of ground water. The regulations require that, for 1,000 years after disposal and considering undisturbed performance, the average annual radionuclide concentration in water withdrawn from a special source of ground water shall not exceed:

1. 5 picocuries per liter of radium-226 and radium-228.
2. 15 picocuries per liter of alpha-emitting radionuclides.
3. The combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body, or any internal organ, greater than 4 millirems per year if an individual consumed 2 liters per day of water.

If the average annual concentration of radionuclides in a special source of ground water exceeds these limits before construction of the repository system, then the repository system may not cause an increase in the average annual concentration of radionuclides greater than these limits.

"Special source of ground water" is defined in 40 CFR 191 as a Class I ground water source that (1) is located within the boundaries of the controlled zone or less than 5 km from the controlled zone boundary, (2) is supplying drinking water for thousands of persons as of the date that Yucca Mountain was chosen for site characterization, and (3) is irreplaceable in that no reasonable alternative source of drinking water is available to that population.

"Undisturbed performance" means the predicted behavior of the disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.

Technical background and licensing strategy

Three sources of ground water exist within 5 km of the controlled zone boundary. They are (in stratigraphic order) the valley-fill aquifer, the tuff aquifer, and the lower carbonate (Paleozoic) aquifer. Preliminary hydrologic and demographic water-use data presented in Chapter 3 suggest that none of these aquifers meet all three special-source criteria. All the aquifers meet the criterion for location (criterion 1). But only the valley-fill aquifer was serving a population of thousands at the time Yucca Mountain was chosen for site characterization (criterion 2). Also, only the lower carbonate aquifer supplies baseflow to a critical habitat and is therefore considered to be irreplaceable (criterion 3).

Presently, none of the three aquifers is considered vulnerable to contamination within 1,000 years of waste emplacement, on the basis of the hydrologic and geochemical characteristics of the unsaturated zone within which the repository would be located. In addition to being protected by the unsaturated zone, the lower carbonate aquifer has a higher potentiometric head than does the overlying tuff aquifer, in the vicinity of the site. Therefore, the potential flow direction is upward from the lower carbonate aquifer rather than downward into it.

A dual licensing strategy will be used in resolving Issue 1.3, either element of which can be used to demonstrate that the issue is resolved. The first part of the strategy consists of demonstrating with a high level of confidence that ground-water sources do not meet the three criteria and, therefore, that no special sources of ground water exist, in the vicinity of the site. The second part of the strategy is to show that the concentrations of radionuclides in any of the ground-water sources during the first 1,000 yr after disposal will not exceed the limits specified in 40 CFR 191.16.

Site investigations planned within the geohydrology and human interference programs will aid in establishing with a high level of confidence whether any of the three aquifers meet all the criteria for special-source status. Demonstrating that the EPA limits will not be exceeded will be done only if (1) it is not possible to show with a high level of confidence that no special sources of ground water exist, or (2) a special source of ground water is in fact identified in the vicinity of the site. The approach will be to calculate the quantity of waste products that could be released and transported to a special source of ground water during the first 1,000 years after disposal. This will be demonstrated by using an assessment similar to that used by Issue 1.1 (total system performance). The difference between the assessments is that the parameters and scenarios to be considered by Issue 1.3 will cover only the first 1,000 years after disposal under expected conditions, whereas Issue 1.1 examines releases over 10,000 years under both normal and disturbed conditions.

Table 8.2-9 summarizes the system elements and performance measures associated with both possible strategies for resolving Issue 1.3. Goals for the testing program in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue are identified in the detailed strategy discussed in Section 8.3.5.13. Identification of primary barriers and performance measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue. The required site data will be compiled and evaluated through the geohydrology and human interference characterization programs.

Table 8.2-9. Performance measures and parameters

System element	Performance measure
Saturated zone	Existence of special source of ground water
Engineered barrier system with unsaturated zone as backup	Waste concentration in special source aquifer within 1,000 yr after disposal

8.2.2.1.1.4 Summary of waste package containment -- Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?

Regulatory background

Issue 1.4 addresses the requirement for containment by the set of waste packages as required by 10 CFR 60.113. In addition, Issues 1.1 (total system performance) and 1.5 (engineered barrier system release rates) require information developed under this issue as input to their analyses. Section 8.3.5.9 provides a detailed discussion of the regulatory basis and resolution strategy for Issue 1.4.

The NRC regulations, specifically 10 CFR 60.113, address the performance of the waste package during the period when temperatures and radiation levels are highest. This regulation states in part

the engineered barrier system shall be designed, assuming anticipated processes and events, so that: (A) Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account factors specified in 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.

The NRC does not define substantially complete containment.

Technical background and licensing strategy

One of the first steps in the discussion of this issue involves interpretation of the regulatory term "substantially complete containment." A precise interpretation depends to a great degree on the level of waste package performance needed at the site. This cannot be determined until additional information regarding site conditions and the characteristics of alternative materials and waste package designs subject to these site conditions is available. For the purpose of the SCP, tentative design

objectives have been developed to guide the testing and design programs. Information developed during site characterization may dictate both the need for additional testing and design activities and for other design objectives to guide these activities. Therefore, the design objectives may evolve during the site characterization program.

The following three design objectives have been set as current program goals for substantially complete containment:

1. By virtue of the intrinsic properties and design of the waste package components subjected to the range of conditions anticipated in the underground facility, 80 percent or more of the waste packages will retain all their radioactivity for a containment period of 1,000 yr after permanent closure of the repository.
2. At any time during the containment period, at least 99 percent of the radioactivity resulting from the original waste emplaced in the underground facility will be retained within the set of waste packages.
3. Any releases from the waste packages that occur during the containment period should be gradual such that releases from the engineered barrier system in any one year during this period should not exceed one part in 100,000 of the total inventory of radionuclide activity present in the geologic repository system in that year.

The components of the waste package, together with the near-field environment as altered through engineering design, has been chosen as the basis for the strategy to achieve and demonstrate that the substantially complete containment performance objective has been met. The system elements relied upon in the reference case to achieve and demonstrate the performance objective are (1) the container, (2) the engineered environment, and (3) the waste form.

The first design objective for substantially complete containment, i.e., that more than 80 percent of the containers will remain unbreached, will be achieved by selecting a proper container material and design such that the time to loss of substantially complete containment is longer than 1,000 years. The approach to projecting the time to loss of substantially complete containment utilizes a series of computational models representing the container degradation modes and the environmental conditions.

The second design objective would be automatically met if the third design objective is met, since the engineered barrier system boundary release and the waste package release are the same under the current engineered barrier system design and performance allocation. The third objective is more stringent than the second because it restricts the amount of release on an annual basis. In addition, the dominance of the total inventory by the gap and grain boundary elements during early periods forces the performance allocation to meet the third objective on a radioisotope specific basis. It is believed that reliance on the three system elements stated earlier will be sufficient to demonstrate that the second and third objectives are met.

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The resolution of Issue 1.4, therefore, hinges on two important considerations, i.e., degree of containment and duration of containment for ensemble of waste packages, which are closely interrelated. Projections of both the duration and the degree of containment will determine if the objectives for substantially complete containment have been met.

Breach of a container does not necessarily constitute the loss of containment. Thus, container integrity alone does not determine the degree of containment. Breaching of a container is a necessary condition for release of radionuclides from the waste form, but not a sufficient condition for this release, except for the release of radionuclides in the form of gas which could occur for any carbon-14 that exists on the surface of spent-fuel cladding and other assembly hardware.

The period of concern is the first 1,000 years after closure of the repository, when the temperatures and radiation levels are high. During this period, the containers will continuously degrade, the environmental conditions will continuously change, and the specific radionuclides that dominate the repository inventory will change significantly due to differing decay rates.

The projection of degradation of the metal container and releases from the waste package over such a long time period (1,000 years) will involve considerable uncertainty. Information regarding the characteristics of container materials and degradation modes, and information from Issue 1.5, such as the models for radionuclide release from the waste package, will be used to estimate the distribution of times to loss of substantially complete containment of the ensemble of waste packages under anticipated processes and events, taking into account the uncertainties in such estimates. This result will be used in the resolution of the issue.

The duration of containment depends on the integrity of the waste container. An investigation of container materials will be conducted to determine which will provide the characteristics desired for the container. At present, six candidate materials from two alloy groups are being considered. They are, from the copper alloy group, high-purity oxygen-free copper (CDA 102), aluminum bronze (CDA 613), and 70/30 copper-nickel (CDA 715), and, from the austenitic alloy group, AISI type 304L and 316L stainless steel and nickel-based Alloy 825. Material selection criteria will be developed, taking into account factors such as material degradation, predictability of material behavior, interaction with other system elements, fabricability, and uncertainties. Note that no container material has been selected yet, although 304L stainless steel has served the function of a reference material only to provide necessary information for the waste package and repository design analysis. In an unlikely event that no metal from the six candidates or other metal alloy group could be chosen to satisfy the requirements, an alternative ceramic-lined container will be evaluated. Currently, alumina (Al_2O_3) is being considered as the prime candidate, although other ceramic materials will also be considered.

Factors important to the metal degradation that will be considered in the above investigation include low temperature corrosion, general aqueous corrosion, hydrogen effects, localized attack such as pitting and crevice

corrosion, intergranular and transgranular attack, stress corrosion cracking, and other metallurgical and mechanical effects. The results will be used in developing models needed to predict the rate of degradation of the container material, which in turn will be used in selecting the container material and in estimating the performance of the container in the repository environment for significant processes and events.

The results of these evaluations will be used to predict the distribution of failure times for the containers. The time estimated for failure of 20 percent of the containers will address the question of the duration of containment with respect to objective 1. The percentage of containers estimated to have failed within any given interval of time will provide the basis for estimates of releases from failed packages in addressing objectives 2 and 3, which relate to the degree of containment.

The degree of containment depends on the inventory and distribution of radionuclides present inside the waste form and the factors influencing the release of the radionuclides. These factors include the condition of the container, the condition of the waste form (e.g., cladding and state of UO_2 oxidation), and the environment (quantity and quality of water contacting the containers).

During the early years after closure (zero to approximately 100 years, when the number of failed packages is expected to be low), the waste package and near-field rock will experience temperatures exceeding the boiling point of water. As a result, although there may be some adverse effects of these temperatures in this period (e.g., oxidation of fuel within failed cladding), the environment will be dry for the majority of the waste packages, thus precluding the possibility of liquid water contacting these packages. The dominant contribution to the total radioactivity during this period comes from only four radionuclides with relatively short half-lives. These include Cs-137 and Sr-90, and their very short-lived daughter products, Ba-137m and Y-90. Cs, and to a lesser extent Sr, can migrate during reactor operation to grain boundaries and the pellet-cladding gap in the fuel, where they are readily accessible and releasable when contacted by water. In addition, there are significant quantities of the radionuclides Kr-85 and H-3 present in the spent fuel. A small percentage of the Kr-85 may be available for immediate release in gaseous form from the pellet-cladding gap. This period is also characterized as the period when a significant amount of oxidation of the UO_2 fuel may occur in the failed containers with failed cladding due to the high temperature and the availability of oxygen in the repository air-steam environment. The oxidation of UO_2 has two significant effects: (1) to increase the fraction of gap and grain boundary elements available for rapid release in water and (2) to increase the fraction of Kr-85 inventory in such oxidized fuel to be released rapidly as a gas.

During the next two hundred years (approximately 100 to 300 years after closure), the inventory of Kr-85 and H-3 will have decayed to an insignificant level, and the inventory of gap and grain boundary radionuclides (Cs, Sr, and their short-lived daughters), will have decayed to a small percentage of the total activity. The percentage of the inventory accounted for by the actinides rises during this period and the inventory is dominated by the Am and Pu isotopes 300 years after closure. Borehole temperatures will be

considerably lower than in the first 100 years but will still in most instances exceed the boiling temperature of water. The rate of fuel oxidation will be slower than the rate during the first 100 years since temperatures in the emplacement boreholes will be decreasing. These temperatures are expected to remain above the boiling point of water for most waste packages, however. Therefore, the possibility of container and cladding corrosion will still be relatively low.

From 300 to 1,000 years after closure, slow cooling of the repository will continue. Nevertheless, a substantial fraction of the waste packages could remain above the boiling point of water throughout this period. During this period, the total inventory decreases significantly, and Am and Pu continue to dominate the inventory. By 300 years after closure, the makeup of the gap and grain boundary inventory has changed significantly from earlier times. The contribution of Tc-99 to the fraction available for rapid release is comparable to that Cs and Sr at 300 yr and becomes the dominant radioactivity in this fraction by 1,000 yr. The C-14 inventory remains essentially constant during this period so that relative contribution of carbon-14 to the total inventory increases with time. Fuel temperatures are expected to drop to a value at which oxidation of UO_2 fuel proceeds quite slowly.

Because of the different radionuclide compositions, different potential release characteristics and the continuously changing environment at different time intervals previously discussed, the licensing strategy for Issue 1.4 is to allocate different performance levels to system elements at different time intervals. Table 8.2-10 shows the system elements relied on to resolve Issue 1.4 and the associated performance measures. Goals for the testing program, in terms of specific characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue, are identified in the detailed strategy discussed in Section 8.3.5.13. Because of the difference in behavior of the glass and spent fuel waste forms, different performance parameters are assigned to them. Identification of elements and performance measures, and associated goals and parameters, helps to orient the testing program toward obtaining the information to resolve this issue.

Activities for Issue 1.4 concentrate on the metal container performance. The quantity of releases and the mechanisms of release during the containment period are closely tied to the assessment of releases during the post-containment period (Issue 1.5). Discussion of all activities related to waste-form characterization and performance, such as matrix dissolution, cladding degradation, and UO_2 fuel oxidation, are discussed in the strategy for Issue 1.5. Resolution of both Issues 1.4 and 1.5 depends on the engineered environment discussed in the strategy for Issue 1.10.

Table 8.2-10. System elements and performance measures to resolve Issue 1.4

System element	Performance measure
Container	Fraction of containers that have failed
Engineered environment	Quantity of liquid water that can contact the container
	Quality of liquid water that can contact the container
Waste form	Release rate of radionuclides from the ensemble of breached packages

8.2.2.1.1.5 Summary of the engineered barrier system release rates --
 Issue 1.5: Will the waste package and repository engineered barrier systems meet the performance objective for radionuclide release rates as required by 10 CFR 60.113?

Regulatory background

Issue 1.5 (discussed in Section 8.3.5.10) addresses the requirement for gradual release from the engineered barrier system as required by 10 CFR 60.113. In addition, the resolution strategies for Issues 1.1 (total system performance) and 1.9 (postclosure higher-level findings) require information which is developed under the strategy for this issue. Section 60.113 states in part that the engineered barrier system shall be designed so that, assuming undisturbed performance of the geologic repository, "Any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times" and

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 question of whether a part of the host rock is included in the engineered barrier system has not yet been resolved. For the purpose of the SCP, the following interpretation for the EBS boundary has been adopted:

The boundary for evaluation of releases from the engineered barrier system relative to the requirements of 10 CFR 60.113 is . . . conservatively chosen to coincide with the surfaces of the excavations within the underground facility. In making this evaluation, the release rates calculated are those corresponding to the net flux of radionuclides transported into the host rock.

Technical background and licensing strategy

Issue 1.5 deals with the release from the engineered barrier system (EBS) boundary as interpreted in the regulatory background description. The requirements for the EBS annual release are isotope-specific and based on the inventory of each radionuclide present at 1,000 years after permanent closure. Radionuclides released at a rate less than 0.1 percent of the calculated total release rate limit are excluded from this requirement. This reduces the number of radionuclide species that need to be considered.

For most radionuclides, the rates of release from the EBS depends primarily on (1) the quantity and quality of the water contacting the waste form and transporting the dissolved radionuclides to the EBS boundary, and (2) the release characteristics of the waste form itself. The quantity and quality of water are discussed in the strategy to resolve Issue 1.10 (Section 8.3.4.2). The strategy to resolve Issue 1.5 uses information developed for the resolution of Issue 1.10 and concentrates on the waste form performance.

The projection of the release rate for long times into the future will necessarily involve considerable uncertainty. Models developed through the activities to resolve Issue 1.5, including the EQ3/6 geochemical model, together with information regarding container degradation and the waste package environment from the strategy for resolving Issues 1.4 and 1.10, will be used to determine the release rates of radionuclides from the waste package and the EBS boundary.

An additional investigation is included in the activities for Issue 1.5 to determine the amount of radionuclides leaving the near-field environment of the waste package. The purpose of this investigation is to provide information to predict a source term for use in Issue 1.1, as well as for use in the comparative evaluations of the sites required by 10 CFR Part 960.

The strategy for resolving Issue 1.5 is based on (1) present knowledge of the repository emplacement environment, (2) the data gathered on waste form performance in environments that can be related to the projected repository environment, and (3) the use of models to assess the performance of various system elements. The primary system elements that are relied on and associated performance measures are shown in Table 8.2-11.

Because the candidate repository horizon is in the unsaturated zone, only a negligible amount of water is expected to come into contact with the majority of the waste packages. Strategies are developed, however, for both

Table 8.2-11. Performance measures and parameters for waste form for Issue 1.5 (engineered barrier system performance)

System element	Performance measure
Engineered environment	Quantity of liquid water that can contact the container
	Quality of liquid water that can contact the container
Waste form	Release rate from bare waste form inside failed containers

the expected case (no liquid water) and the bounding case, in which all containers are allowed to experience a bounding water flux even though this is not expected to occur.

Under the expected conditions (i.e., no liquid water), the only radionuclide of concern would be the carbon-14 on the exterior of cladding and assembly components, which could be released in a gaseous state. Data are insufficient at present to assess the rapid release of carbon-14 dioxide from spent fuel. However, because of the lower gamma fluxes and temperatures in the controlled release period, the present data suggest that the release rate will be sufficiently low to meet the requirement of 10 CFR 60.113. Because of the uncertainties in the release rates, mechanisms, and locations of carbon-14, alternative approaches to carbon-14 control have been developed in Section 8.3.5.10.

Although incomplete, data presently available regarding the dissolution of the actinides and fission products in the whole matrix show that their individual dissolution rate can meet the 1×10^{-5} per year requirement on individual isotopes. Most of these elements are limited by their solubilities. In addition, the release rate may be constrained by the rate of dissolution of the waste form. The results of activities for Issue 1.5 will be used to develop models for the waste form dissolution and water flow into and out of a breached container.

Under the bounding case where all containers can experience a bounding flux of liquid water, the actinides and other matrix elements will be controlled by the limitations in their dissolution and precipitation as discussed above. Radionuclides present in the gap and grain boundary inventory both from oxidized (but not wet during the containment period) fuels and from unoxidized fuel (that breached during the post-containment period) could be released in an amount such that the release rate limit is exceeded in the bounding case. Additional system elements, such as cladding, and the dilution resulting from the accumulation of liquid water in the container through

a long period of time will be relied upon for the gap and grain boundary element control. The existing information is not sufficient, however, to allow selection of the specific system elements to be relied on and to allocate quantitative performance goals for these elements. Detailed strategy for the bounding case will evolve as more waste-form testing data and information from site characterization become available.

- 8.2.2.1.1.6 Summary of pre-waste emplacement ground-water travel --
 Issue 1.6: Will the site meet the performance objective for pre-waste-emplacement ground-water travel time as required by 10 CFR 60.113?

Regulatory background

Issue 1.6, which is discussed in Section 8.3.5.12, addresses the NRC performance objective for pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment. As stated in 10 CFR 60.113(a)(2), this travel time should be "at least 1,000 years or such other travel time as may be approved or specified by the Commission." The disturbed zone is defined in 10 CFR 60.2 as that portion of the controlled area where the physical or chemical properties have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive wastes such that performance of the repository may be significantly affected. The accessible environment is defined as the atmosphere, the land surface, surface water, oceans and the portion of the lithosphere that is outside the controlled area. The controlled area as defined in 40 CFR 191.12(g) is the surface location and the underlying subsurface that encompasses no more than 100 km² and extends horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system.

Technical background and licensing strategy

A repository at Yucca Mountain would be located in the unsaturated zone at distances ranging from about 150 to 400 m above the water table. The simplest conceptual model for the paths for likely radionuclide travel has two parts between the disturbed zone and the accessible environment. One part is generally vertically downward through the unsaturated zone to the water table, and the second part is generally horizontal through the saturated zone to the accessible environment boundary. The activities to resolve this issue (described in Section 8.3.5.12) are designed to provide the information necessary to determine distribution of pre-waste-emplacement ground-water travel times along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment. Ground-water travel time is assumed to be the time that it would take inert tracer particles released at the disturbed zone to reach the accessible environment. This is a valid approach since, statistically, the rate of motion for some water molecules and hence for any entrained species may be greater than the bulk rate of ground-water flow. The important consideration relative to 60.113 is the

rate of radionuclide travel along the fastest such path, ignoring sorption or other contaminant retardation processes. Both dispersion and diffusion will tend to spread travel times.

Current understanding of ground-water travel through the unsaturated zone suggests that it is practical to consider two general modes of flow: matrix and fracture. Matrix flow is through pores in the rock matrix. Fracture flow is defined for this issue as continuous flow through fractures or faults, which may occur in instances where water is laterally diverted to a fault, or as the result of episodic high-intensity infiltration events or other means that cause the local flux to exceed the saturated hydraulic conductivity of the matrix. Under current moisture flux conditions in the unsaturated zone at the site, matrix flow with potential discontinuous localized regions of flow through fractures is expected to predominate in the unsaturated zone. In the saturated zone, the dominant mode of water movement is expected to be fracture flow.

The strategy for demonstrating compliance with the NRC's ground-water travel time performance objective is to rely on each of several hydrogeologic units as a barrier to flow. Within each unit, different types of processes will be operating (e.g., dispersion and advection in rock pores, fracture flow, and diffusion) that will affect the flow. These processes, as well as uncertainties with respect to flow pathways, flow mechanisms, and the spatial distribution of rock characteristics, are specifically addressed in the strategy.

Six steps are recognized in the performance allocation phase of the resolution strategy for Issue 1.6. These are (1) the identification of the hydrogeologic units along potential flow paths to the accessible environment, (2) the identification of processes acting within each unit, (3) the prioritization of hydrogeologic units and flow processes within these units as primary, secondary, and auxiliary contributors to meeting the 1,000-year ground-water travel time requirement, (4) the establishment of measures of performance for each unit, (5) the assignment of goals to each performance measure, and (6) the identification of parameters judged sufficient to predict the performance measure with reasonable assurance for each of the hydrogeologic units.

Table 8.2-12 lists the hydrogeologic units that are to be considered in the evaluation of the ground-water travel time, starting with the Topopah Spring welded unit and proceeding downward to the saturated zone. Prioritization of the hydrogeologic units is presented in the second column of Table 8.2-12, and the flow processes expected to act within the units are indicated in the third column. The performance measure for each hydrogeologic unit given in the last column is the ground-water travel time through the unit. The goals for the performance measures and the parameters needed to evaluate the travel times are discussed in detail in Section 8.3.5.12. Identification of barriers and performance measures, and associated parameters and goals, helps to orient the testing program toward obtaining the information to resolve this issue.

Table 8.2-12. Summary of performance allocation for Issue 1.6

Components	Reliance priority	Process	Performance measure
Topopah Spring welded unit	Secondary	Darcy flow ^a	GWTT ^b
Calico Hills vitric unit	Primary	Darcy flow	GWTT
Calico Hills zeolitic unit	Primary	Darcy flow	GWTT
Prow Pass welded unit	Auxiliary ^c	Darcy flow	GWTT
Prow Pass nonwelded unit	Auxiliary	Darcy flow	GWTT
Bullfrog welded unit	Auxiliary	Darcy flow	GWTT
Bullfrog nonwelded unit	Auxiliary	Darcy flow	GWTT
Saturated zone	Secondary	Darcy flow	GWTT

^aDarcy flow with both advection, dispersion and diffusion will be relied upon if substantial continuous fracture flow is identified during characterization.

^bGWTT = ground-water travel time.

^cClassed as auxiliary if a significant thickness of the unit occurs along the flow path.

A series of activities will be conducted to support resolution of this issue. Evaluations will be conducted to determine the appropriate calculational models for the hydrologic flow system and for identifying the fastest likely flow path within that system. The location of this path will be determined, and flow characteristics along the path will be established. The nature and availability of calculation models will be assessed to help determine the relative importance of the various parameters to the calculation of travel times. Finally, the cumulative distribution of pre-waste-emplacement ground-water travel times along the fastest likely path will be predicted. An evaluation will also be conducted to establish the boundaries of the disturbed zone, which must serve as the origin for the travel time calculation. A complete discussion of the resolution strategy for Issue 1.6 is given in 8.3.5.12.

8.2.2.1.1.7 Summary of performance confirmation -- Issue 1.7: Will the performance confirmation program meet the requirements of 10 CFR 60.137?

Regulatory background

Issue 1.7, discussed in Section 8.3.5.16, addresses the NRC requirements for performance confirmation. Section 60.137 of 10 CFR Part 60 requires that the repository be designed to permit implementation of a performance confirmation program in accordance with the requirements of Subpart F of 10 CFR Part 60. Subpart F gives both general and specific requirements for a program directed toward confirming that the actual performance of the repository is within the limits assumed in the license application.

As defined in 10 CFR Part 60.2, "performance confirmation means the program of tests, experiments, and analyses conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met." The DOE understands the intent of Subpart F to be the confirmation, where practicable, that site and design conditions and the performance of engineered and natural barriers are within the ranges predicted in the license application. The DOE considers that the repository conditions and design assumptions integral to demonstrating compliance with the performance objectives should be the subject of the performance confirmation program. The testing and monitoring program for performance confirmation is one part of the DOE's confirmation and monitoring program.

The DOE confirmation and monitoring program is composed of two aspects: preclosure monitoring and confirmation, and postclosure performance confirmation. The preclosure monitoring and confirmation program consists of those activities associated with the preclosure performance objectives of 10 CFR 60.111. Both aspects are included under one larger program because the baseline information (description follows) and the testing and monitoring activities for both programs share many common components. Because Issue 1.7 is concerned with the confirmation of postclosure performance as outlined in 10 CFR Part 60, Subpart F, the remainder of the discussion here will focus on the postclosure performance confirmation program.

Technical background and licensing strategy

The postclosure performance confirmation program is essentially the program of testing and monitoring activities associated with the confirmation of the performance assessment calculations presented in the license application. These calculations will provide reasonable assurance that the repository will meet the NRC's postclosure performance objectives. The purpose of the confirmation program is to supply added confidence beyond that supplied in the license application that the repository will meet the long-term performance objectives for containment and isolation.

During site characterization, information is gathered to select a site, to develop a suitable design, and to make defensible performance assessments to establish with reasonable assurance that the performance objectives will be met. The postclosure performance issues have been designed to address the

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NRC's performance objectives. Through the resolution of these issues (Issues 1.1 through 1.6), information will be made available to demonstrate compliance with the performance objectives. The issue resolution process is an iterative loop of testing and analyses. When sufficient information is gathered to prepare defensible performance assessments for the license application, the issue resolution process with respect to site characterization is complete. The information supporting the resolution of performance issues, and thus demonstrating compliance with the performance objectives, is included in the license application. This information then becomes the subject of postclosure performance confirmation program testing and monitoring. Plans for the confirmation of the license application predictions will be available at the time of the license application.

The testing and monitoring activities of the postclosure performance confirmation program are developed in parallel with the issue resolution process. The resolution of Issue 1.7, therefore, is linked closely to the resolution of Issues 1.1 through 1.6. The performance assessments and issue resolution strategies developed during site characterization to support issue resolution in the license application will determine the detailed content of the postclosure performance confirmation program. At the beginning of site characterization, only very general plans for the program can be defined, which will mature in parallel with the development of assessments needed for the license application. Preliminary design provisions for accommodating performance confirmation testing and monitoring in the repository are given in the SCP Conceptual Design Report (SNL, 1987). Early interactions with the NRC before the license application will define the general scope of the program. As issues are resolved, the testing and monitoring needed for the confirmation can be more clearly defined. By the time of license application submittal, these testing and monitoring activities should be well defined. More formal interactions with the NRC during the license application review may further develop the plans in response to the NRC concerns at these times. Results of the testing and monitoring program are to be reviewed by the NRC as part of the license amendment for permanent closure.

As stated previously, Issue 1.7 focuses on the postclosure performance confirmation program responding to Subpart F of 10 CFR Part 60. Based on the content of Subpart F, the objectives to be met by the postclosure performance confirmation program can be described as follows:

1. Develop baseline information -- develop information on subsurface conditions important to the performance assessments to be given in the license application and those aspects of design integral to the assessments. Predict changes in this information as a result of construction and operation.
2. Confirm baseline information -- confirm that actual subsurface conditions and the changes in those conditions resulting from construction and operation are within the limits described in the license application.

3. Confirm barrier and seal performance -- confirm that natural and engineered systems and components that are designated or assumed to operate as barriers after permanent closure are functioning as intended and anticipated within the limits described in the license application.

Table 8.2-13 shows the sequencing of activities in the performance confirmation program relative to the stages of the overall repository program. The program is divided into the baseline and confirmation phases, with the docketing of the license application serving as a convenient demarcation line between phases. Before the license application, baseline data on conditions, predicted changes in those conditions as a result of construction and operation, and performance predictions are developed based on site characterization testing. With the docketing of the license application, the DOE begins the formal licensing process with the NRC.

The two-fold division of the confirmation phase corresponds to the license application review period and the construction and operation period of repository development. During license application review, the DOE will continue to conduct testing around the site and in the exploratory shaft facility. This testing will serve to confirm baseline conditions and support the predictions of changes to these conditions. Once construction and operation take place, predicted changes in conditions as well as performance can be confirmed by the testing and monitoring programs.

The baseline phase of the performance confirmation program extends up to the docketing of the license application. The testing conducted during site characterization will provide the baseline data needed for performance confirmation. As the issue resolution strategies evolve during site characterization, additional baseline data may be found necessary to satisfy the requirements of performance confirmation.

Performance confirmation activities during the baseline phase will consist of those activities necessary to develop baseline information that, except for the performance confirmation requirements, would not otherwise have been conducted. However, all the baseline information necessary on parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities is expected to be collected during site characterization activities necessary to support the license application. If any additional information is required, it will be collected under the baseline phase of the postclosure performance confirmation program during site characterization. Some baseline testing will extend beyond the license application docketing date because of the nature of the testing. For these tests, the distinction between the baseline and the confirmation phases is somewhat artificial.

Site characterization activities in support of the license application will (1) establish conditions important to performance, (2) predict changes in these conditions due to repository construction and operation, and (3) validate models. The baseline phase performance confirmation program will produce plans for the confirmation of the accuracy and adequacy of the information used to determine that the performance objectives will be met.

Table 8.2-13. Phases of the performance confirmation program

Objectives of performance confirmation	Baseline phase	Confirmation phase	
		Interim confirmation	Construction and operation confirmation
1. Develop baseline and predicted changes in baseline	X		
2. Confirm baseline conditions and changes		X	X
3. Confirm barrier and seal performance			X
	Site characterization/ site selection	License Application Review	Construction and operation
	License Application		
PHASES OF THE OFFICE OF GEOLOGIC REPOSITORY PROGRAM			

Both the postclosure performance confirmation program and the preclosure monitoring and confirmation program, associated with preclosure performance objectives, draw upon baseline data collected during site characterization. This baseline data, some of which are common to both programs, determines the extent of the testing and monitoring activities needed for the pre- and post-closure programs. During the baseline phase, details of the performance confirmation program will evolve in parallel with the development of the performance assessments. In the license application, the final assessments of site performance are presented, accompanied by information that describes the testing, monitoring, and any remaining model validation work needed to evaluate the accuracy and adequacy of the information used in those assessments. The repository design given in the license application will also contain any features (test rooms, monitoring stations, etc.) determined necessary for the testing and monitoring described by the plan. To design the repository facilities needed to support the confirmation testing and monitoring, the content of the performance confirmation program must be well developed at the license application stage.

The confirmation phase follows the baseline phase. During the confirmation phase, predictions of baseline conditions and the changes caused by repository construction and operation are to be confirmed, along with barrier and seal performance. As shown on Table 8.2-13, the confirmation phase consists of two divisions: the interim confirmation period (the period after the license application docketing until issuance of the construction authorization) and the construction and operation period (beginning with repository construction). During the confirmation phase, objectives 2 and 3 (Table 8.2-13) will be achieved as described in the following paragraphs.

As mentioned previously, postclosure performance is predicted based on the results of modeling calculations that extrapolate data into the post-closure time frame. To confirm these performance assessments, surrogates for the barrier performance must be defined, that can be measured by field and laboratory testing. These surrogates are appropriately referred to as confirmation measures. These measures are not substitutes for performance but rather testable measures that, if they achieve target values or goals, will give confidence that the performance objectives will be met. These measures are then the focus of the testing, monitoring, and analysis efforts designed to confirm their predicted behavior. For example, corrosion rates could be used as a confirmation measure for the waste-package containment performance objective.

The identification of confirmation measures will likely have a genetic relationship to the original performance allocation process begun during site characterization. The confirmation measures will probably be closely related to some of the performance measures developed through the performance allocation process and used in the performance assessments in the license application. Confirmation measures will be derived, at a minimum, for waste package containment, engineered barrier release, and backfill and seals behavior. Based on site-specific needs, additional measures may be required. Testing to confirm the predicted values of confirmation measures may be initiated as early as site characterization, but will most likely take place in the construction/operation phase.

Postclosure performance predictions are largely based on numerical modeling and therefore a program for the verification of the codes and validation of the models is an important part of the confirmation program. The models of concern to the performance confirmation program are those used in the license application to predict the values of the confirmation measures and extrapolate to long-term performance. Validation of these models will have begun during the site characterization period and will continue until permanent closure, as needed, until the relevant models are considered validated.

8.2.2.1.1.8 Summary of Siting Criteria -- Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?

Regulatory background

Issue 1.8 (discussed in Section 8.3.5.17) addresses the NRC Siting Criteria. These criteria, set forth in 10 CFR 60.122, are given in terms of two sets of conditions associated with various human activities and natural characteristics. The NRC states that these conditions, if present at a site, could affect the site's ability to isolate waste. The first set lists 8 favorable conditions that could enhance isolation. The second set lists 24 potentially adverse conditions that could adversely affect isolation.

The Siting Criteria consist of requirements for the demonstrations that must be made for each of these conditions. For each potentially adverse condition, it must be shown that

- (i) The potentially adverse human activity or natural condition has been adequately investigated, including the extent to which the condition may be present and still be undetected, taking into account the degree of resolution achieved by the investigations; and
- (ii) The effect of the potentially adverse human activity or natural condition on the site has been adequately evaluated using analyses which are sensitive to the potentially adverse human activity or natural condition and assumptions which are not likely to underestimate its effect; and
- (iii)(A) The potentially adverse human activity or natural condition is shown by analysis pursuant to paragraph (a)(2)(ii) of this section not to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste, or
- (B) The effect of the potentially adverse human activity or natural condition is compensated by the presence of a combination of the favorable characteristics so that the performance objectives relating to isolation of the waste are met, or
- (C) The potentially adverse human activity or natural condition can be remedied.

The demonstration requirements given for the favorable conditions in 10 CFR 60.122(a)(1) state 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.

As discussed, for the favorable and potentially adverse conditions, the effects on isolation must be evaluated. Isolation is defined by the NRC in 10 CFR 60.2 as "inhibiting the transport of radioactive material so that amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits." The release of radioactive material to the accessible environment during the postclosure period is addressed by the Overall System Performance Objective of 10 CFR 60.112. The NRC postclosure performance objectives for particular barriers, 10 CFR 60.113, state performance requirements for the engineered barrier system and the ground-water travel time. 10 CFR 60.122 requires that it be demonstrated that the potentially adverse conditions do not have a significant effect on the ability of the geologic repository to meet the performance objectives. Investigations related to the favorable conditions are needed only to the extent that existence of these conditions could be expected to lend confidence to the assessment of compliance with the performance objectives and in some way compensate, if necessary, for the effects on waste isolation of potentially adverse conditions.

Technical background and licensing strategy

The technical background for resolving Issue 1.8 is essentially the same as that for Issue 1.1 (Section 8.3.5.13). Both issues must consider the natural processes and human-induced effects operating on the site in order to evaluate the site's performance. Therefore, both issues are interdependent and interactive. 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; it will rely on qualitative reasoning primarily for the justification of the conceptual models it uses and for showing the reasonable assurance required by 10 CFR 60.101. Because 10 CFR 60.122 makes explicit reference to meeting the waste-isolation performance objectives, the resolution of Issue 1.8 cannot be wholly qualitative. It can, however, be a forum for full expression of sound qualitative technical judgment on the site's ability to isolate waste. The DOE expects that frequently such judgments can 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.

Issue 1.8 calls for an examination of the natural conditions and processes that exist, or may exist, at the site relative to their potential effects on performance. The potential effects of human interference are also included in the conditions listed in 10 CFR Part 60.122. As with Issue 1.1,

these conditions are included in scenario analyses used to evaluate the effects on performance of the potentially adverse and favorable conditions. The scenarios to be evaluated in Issue 1.1 are based on current understanding of the site. This understanding was developed by considering the natural processes and conditions embodied in the 10 CFR Part 60.122 siting criteria, including both favorable and potentially adverse conditions. The scenarios considered in Issue 1.1, for both nominal (undisturbed) conditions and disturbed conditions, should include all the conditions, processes, and events contained in the siting criteria. As site characterization proceeds, this assumption will be confirmed by the program of geologic investigations to be conducted in and around the site. The characterization investigations will examine the processes and conditions at the site in an iterative fashion with the assessments of performance (Issue 1.1). In this way, any scenarios not initially described will be identified and included in the quantitative performance assessments of Issue 1.1.

Issues 1.1 and 1.8 are therefore interactive in that the qualitative and quantitative analyses of subsystem performance done in Issue 1.8 serve as a confirmation that the quantitative total system performance assessments of Issue 1.1 include all the significant conditions and processes important to site performance. In turn, the identification of the major system performance parameters and their interrelationships in Issue 1.1 serves as a guide to focus and bound the site studies concerned with conditions and processes operative at the site. In developing the program of site characterization testing and analyses, each of the siting criteria has been examined to assume that the data needed to evaluate its presence or absence and potential effects on performance are included in the issues concerning postclosure performance.

Logically, if all concerns of the potentially adverse conditions that are present or could be present at the site are addressed by the performance assessment scenario set, then the effects of the potentially adverse conditions on postclosure repository performance will be evaluated in the performance assessment. The assessment will rely on favorable site characteristics and the repository system design in determining if compliance with the overall system performance objective can be demonstrated. Upon completion of the performance assessment, the effects on postclosure performance of the scenarios associated with the potentially adverse conditions and the way that these effects, if significant, were compensated for will be obtained from the performance assessment. This information is expected to be sufficient for the demonstrations required by 10 CFR 60.122 for the potentially adverse conditions.

The investigation of the favorable conditions of the Siting Criteria is inherent in the overall system performance assessment. The performance assessment evaluates the geohydrologic, geochemical, and rock characteristics of the site. This evaluation will look at the favorable characteristics of the site and assess the potential for these characteristics to enhance isolation and, if necessary, compensate for any adverse effects of the disruptive scenarios that could occur at the site during the postclosure period. The

investigation of the site's favorable characteristics during the overall system performance assessment and the evaluation of the effects of these characteristics on postclosure performance are therefore expected to be sufficient for the demonstrations required for the favorable conditions of 10 CFR 60.122.

More detailed descriptions of the issue resolution strategies for Issues 1.8 and 1.1 are provided in Sections 8.3.5.17 and 8.3.5.13, respectively. The results of the performance allocation of Issue 1.1 identifies the performance parameters, associated goals, and levels of confidence required to address the characteristics of the repository system and the disruptive scenarios. These parameters, goals, and confidence levels are given in Section 8.3.5.13. The parameters needed to address the potentially adverse and favorable conditions of 10 CFR 60.122 are a subset of those for Issue 1.1 and are shown in Section 8.3.5.17.

8.2.2.1.1.9 Summary of issue resolution strategy for postclosure siting guidelines -- 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 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. Part (a) of Issue 1.9 addresses those guidelines that are concerned with the postclosure performance of the repository system. These siting guidelines are set forth in 10 CFR Part 960.4. The manner in which the siting guidelines must be addressed during the siting process is described by the Implementation Guidelines (10 CFR Part 960.3).

Part (b) of Issue 1.9 addresses the two evaluations required by the DOE to predict radionuclide releases to the accessible environment under expected conditions during the next 100,000 years (10 CFR 960.3-1-5). These evaluations will be used to compare the expected postclosure performance of acceptable sites. The first comparison will emphasize the performance of the natural barriers; the second will emphasize the performance of the total system. Because of the differences between the guidelines and the comparative evaluations, this issue will be described in two parts. Issue 1.9 is fully described in Section 8.3.5.18.

Regulatory background for Issue 1.9(a)

The postclosure 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 on postclosure performance of the repository system. Each technical guideline is concerned with the effect of some specific

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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 present. The technical guidelines also identify favorable conditions and potentially adverse conditions that describe characteristics of the setting that, if present, could contribute to or detract from the postclosure performance of a site.

The Implementation Guidelines require that the qualifying and disqualifying conditions of the system and technical guidelines be evaluated and that specific findings be made for each condition at principal decision points in the siting process. These findings are stated in 10 CFR Part 960, Appendix III. There are four levels of findings (Table 8.2-14). Lower-level findings (Levels 1 and 3) 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 (Levels 2 and 4) 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.

The findings that have already been made and the evidence supporting these findings are given in the NNWSI Project environmental assessment (DOE, 1986b). The available evidence was sufficient to support positive higher-level findings for the qualifying and disqualifying conditions of the dissolution technical guideline and positive lower-level findings for the qualifying and disqualifying conditions of the other 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 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 Overview of the Guidelines section of the Supplementary Information (DOE, 1984c) for 10 CFR Part 960, 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.

Technical background and issue resolution strategy (Issue 1.9(a))

To resolve Issue 1.9(a), sufficient evidence must be available to support either a positive or negative higher-level finding for each qualifying

Table 8.2-14. Findings for qualifying and disqualifying conditions

Disqualifying condition -- lower-level findings

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

Disqualifying condition -- higher-level findings

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

Qualifying condition -- lower-level findings

- Level 3 (a) The evidence does not support a finding that the site is not likely to meet the qualifying condition.
- (b) The evidence supports a finding that the site is not likely to meet the qualifying condition, and therefore the site is disqualified.

Qualifying condition -- higher-level findings

- Level 4 (a) The evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.
- (b) The evidence supports a finding that the site cannot meet the qualifying condition or is unlikely to be able to meet the qualifying condition, and therefore the site is disqualified.
-

and disqualifying condition associated with postclosure repository performance. Each of the qualifying conditions makes reference to regulatory requirements of the NRC (specifically, 10 CFR Part 60). To support higher-level findings for the qualifying conditions, evidence must show that the geologic setting was taken into consideration in the evaluations of compliance with the associated NRC regulatory requirements and that the geologic setting as a whole (for the system guideline) and the various aspects of the setting (for the technical guidelines) will not prevent compliance with the NRC regulations. The disqualifying conditions are also related to NRC regulations, but not always as explicitly as the qualifying conditions.

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 true for the qualifying and disqualifying conditions of the dissolution technical guideline. Next, for each remaining condition, it is determined whether evidence presently available is sufficient to support a higher-level finding. This evidence consists of the information presented in the NNWSI Project environmental assessment (DOE, 1986b) and in Chapters 1 through 7 of the SCP.

For the qualifying and disqualifying conditions for which the available evidence is not adequate, the planned site characterization studies are reviewed to determine if the conditions will be investigated. For most of the conditions, this is accomplished by evaluating the resolution strategies of the other postclosure performance issues (Issues 1.1 through 1.6 and Issue 1.8). These other performance issues are responsible for assessing the ability of the site to comply with the postclosure regulatory requirements of the NRC. As previously discussed, most of the qualifying and disqualifying conditions reference NRC regulatory requirements, and evidence to support a higher-level finding must show that the condition does not prevent compliance with the referenced requirements. Therefore, if the conditions are being considered in the assessments of compliance, the assessments are expected to make the evidence available to support higher-level findings. Higher-level findings for the remaining conditions (e.g., the disqualifying condition for the erosion guidelines which requires a repository depth of at least 200 meters) will be based on available site and design information.

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 is disqualified. This evaluation continues 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, it is found that the information is insufficient to support a higher-level finding for a qualifying or disqualifying condition, the resolution strategies of the appropriate performance issues are again reviewed to determine if, in fact, the condition was considered. If not, the strategy is revised to incorporate the condition, new information needs are identified as necessary, and compliance is reassessed.

Regulatory background for Issue 1.9(b)

Following the characterization of candidate sites and before recommending a site for repository development, the DOE will require comparisons of the postclosure performance of the repository systems proposed for each candidate site. The Implementation Guidelines, in 10 CFR 960.3-1-5, provide rules for these site comparisons. The guidelines state that these comparisons will "evaluate predicted releases of radionuclides to the accessible environment." These releases will be evaluated by combining "releases of different radionuclides ... by the methods specified in Appendix A of 40 CFR Part 191."

Two evaluations are required to predict releases for the 100,000-year period following repository closure. First, the sites shall be compared with emphasis placed on the natural barrier system of each site. The second comparison will evaluate the expected performance of the total repository system, including both the natural and engineered barrier systems. In making the comparative evaluations, only those natural processes and events that are considered likely to occur or exist at the site over the next 100,000 years need to be taken into account.

Technical background and issue resolution strategy (Issue 1.9(b))

The resolution of Issue 1.9(b) will rely on the activities of Issue 1.1 (Section 8.3.15.13). Issue 1.1 addresses the NRC's overall system performance objective (10 CFR 60.112). For the resolution of Issue 1.1, an assessment of the total system performance is made to predict the performance of the total repository system over the next 10,000 years. This assessment will consider both expected conditions and disruptive conditions.

To resolve 1.9(b), a few modifications will be made to the strategy of Issue 1.1. The set of conditions expected during the 10,000 year period will be expanded to include any additional conditions that may be expected over the 100,000-year period. Some of the conditions that were considered unexpected over the 10,000-year period will therefore be included. The same total system model and submodels used to resolve Issue 1.1, however, will be adequate to address Issue 1.9(b).

Preliminary evidence indicates that the only conditions that need to be added to the 10,000-year expected case to address the 100,000-year expected case are those associated with climatic changes. Such changes could affect aspects of the repository system, including water table altitudes, percolation flux, and gradients in the saturated zone. These changes could have a significant effect on releases to the accessible environment. Information to assess these conditions in the 100,000-year calculation will be made available through the Climate program.

A complete discussion of both parts of Issue 1.9 can be found in Section 8.3.5.18.

8.2.2.1.2 Design issues for Key Issue 1

- 8.2.2.1.2.1 Summary of waste package characteristics (postclosure) --
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?

Regulatory background

In addition to providing information on the postemplacement environment and waste package designs to support resolution of several performance

issues, Issue 1.10 (discussed in 8.3.4.2) is concerned with ensuring compliance with the postclosure design criteria given in 10 CFR 60.135. These criteria specify that the waste package shall be designed so that its properties and its interactions with the emplacement environment do not compromise the function of the package, or the performance of the underground facility or the geologic setting. The design criteria recognize that the inherent characteristics of high-level waste will impact both the package and the surrounding environment. These characteristics include high levels of radiation and the heat generated within the waste form resulting from radioactive decay, especially during the early containment period.

In addition to the impact of the emplacement of the waste package, the environment surrounding the waste package is also impacted by repository construction and operation. To ensure that the functions of the waste package and its environment are not compromised, it is necessary to understand the condition of the surrounding environment before waste emplacement and the interaction between the waste package and the environment over time. Such an understanding of the waste package and its environment will allow the development of a waste package design that will consider the effect of these interactions.

Technical background and licensing strategy

The waste package, which consists of highly radioactive waste inside of a metal container, is to be placed in a hole bored out of tuff in the repository horizon. The radiation field from the waste, mostly neutrons and gamma radiation, will penetrate through the waste package and interact with the environment. Neutrons can damage material by displacing atoms as a result of atomic collisions. Such radiation damage in the container materials, and host rock minerals, and the effect on the water chemistry are expected to be small at the radiation flux levels that would be present. Gamma radiation interacts with matter by ionization mechanisms. The effect of gamma interaction with tuff will largely be transient and is not expected to cause significant change in the rock or mineral properties. However, gamma radiation can cause changes in water chemistry due to the production of radiolytic species. Gamma radiation may also enhance the oxidation of C-14 in the surface layers of Zircaloy cladding during the containment period.

The thermal load imposed by the waste on the near-field environment will be a function of the waste type. The actual thermal output from the waste will depend on burnup, the time since discharge from a reactor, and the quantity of waste stored in the containers. The heat generated by the waste will result in a rise in temperature that could alter the local hydrologic system, causing the pore water contained in rock in the vicinity of waste packages to vaporize. In this case, following dehydration, rehydration of the near-field environment could occur as heat generation declines and the temperature drops. Performance of the containment barrier and the waste form is closely tied to the quantity of water that contacts the packages and to the flow mechanisms operating in the vicinity of the waste packages. The elevated temperature in the host rock could also affect the water chemistry.

The waste package environment, upon initial emplacement of the package, will depend on the ambient conditions at the repository horizon and on the way in which those conditions are altered by repository construction and

operation. The environment following emplacement will depend on the initial emplacement conditions and on how those conditions are altered by the waste package characteristics. There is, therefore, an interactive process of design and environment characterization. The design is initially based on the ambient conditions and a prediction of how those conditions will be altered under the stresses applied by repository construction and waste emplacement. Once a design is available, analysis of that design provides a set of environmental stress factors. Testing is then done to determine the effects of those stresses, such as thermal and radiation fields and mechanical stresses, on the package environment. On the basis of those tests and subsequent analyses, designs may be modified and the test and analysis cycle repeated.

The performance measures of the system elements for resolving Issue 1.10 that deal with the interaction between the waste package and the surrounding environment are shown on Table 8.2-15. These measures form the basis for the activities necessary to characterize the ambient, preemplacement environment and the attributes of the environment that may be influenced by waste package emplacement. Each system element has a function or a characteristic for which a process or condition must be well understood. Issue resolution is accomplished by using models to describe the interactions of concern and incorporating these into waste package design considerations. The waste package environment model uses a number of submodels to define water quality, water quantity, and mechanical and thermal loading. Each model uses a series of input parameters that will be quantified through various characterization activities described in Section 8.3.4.2. Goals for the testing program in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue are identified in the detailed strategy discussion in Section 8.3.4.2. Identification of barriers and performance measures and associated goals and parameters helps to orient the testing program toward obtaining information to resolve this issue.

- 8.2.2.1.2.2 Summary of configuration of underground facilities (postclosure)
 -- 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?

Regulatory background

Issue 1.11 (discussed in Section 8.3.2.2) is concerned with those aspects of underground facility design that have implications for the postclosure behavior of the repository, particularly as expressed in 10 CFR 60.133, additional design criteria for the underground facility. The additional design criteria of 10 CFR 60.133 specify that the underground facility and the engineered barrier system be designed to (1) contribute to the containment and isolation of radionuclides, (2) incorporate sufficient flexibility to accommodate site specific conditions identified through in situ monitoring, testing, or excavation, and (3) assist the geologic setting in

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Table 8.2-15. Performance measures and parameters to resolve Issue 1.10
(waste package characteristics -- postclosure)

System element	Performance measure
Engineered environment	Rock-induced load on waste package Temperature vs. time in waste package environment Water quality and quantity Tectonic Processes
Waste package	Select waste package material to contribute to containment Constrain waste handling operations so as to not degrade isolation and containment performance of the waste package

meeting the performance objectives. There are two design criteria that specifically address the potential for creating fractures in the rock mass and the attendant possibility of creating preferential pathways for ground-water movement and radionuclide migration to the accessible environment. These design criteria require that the underground openings be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock. Such fracturing or rock movement could lead to the creation of potential paths for groundwater flow or radionuclide migration, which could impact the ability of a site to comply with the postclosure performance objectives of waste package containment, engineered barrier system release rate, and the overall system compliance with the standard for releases at the accessible environment boundary. Finally, 10 CFR 60.133 has an additional postclosure design criterion that specifically requires the consideration of the predicted thermal and thermomechanical response of the host rock, surrounding strata and groundwater system.

Technical background and licensing strategy

The regulatory basis for this issue, as identified in the design criteria of 10 CFR 60.133, covers both the design of the underground facility and the design of any engineered barriers that are part of the underground facility. Such engineered barriers include the drift seals that are intended to control ground-water movement into or through the underground facility. The activities related to design of drift seals (components of the engineered barrier system) and those related to design of shaft and borehole seals

(components separate from the engineered barrier system) will be similar, even though the related performance objectives may be different. The strategy and investigations for seal design have, therefore, been combined and are discussed under Issue 1.12 (Section 8.3.3.2). Issue 1.11 is concerned only with the criteria that relate directly to the design of the underground facility.

The strategy for resolution of this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria. Performance measures and goals are set consistent with the desire to meet the design criteria. The licensing strategy is based upon evaluation of the performance measures which address the general functions that the repository design is expected to achieve in order that compliance with the intent of the postclosure aspects of 10 CFR 60.133 can be achieved.

The four functions that the postclosure waste disposal system must perform were chosen so that there is a direct correlation between the functions and the design criteria expressed in 10 CFR 60.133. These functions can be described as follows: (1) underground layout should contribute to containment and isolation, (2) limit water usage and potential chemical changes so as not to adversely affect postclosure performance, (3) limit excavation induced permeability changes to avoid adverse impacts on performance, and (4) select thermal loads so that performance objectives will be met, considering thermomechanical responses.

The first function that the postclosure waste disposal system must perform involves contributing to containment and isolation through the postclosure effects of underground layout selection. A repository at Yucca Mountain would be located in a welded tuff that is at an average distance of 250 m above the water table and which is therefore only partially saturated. The geometry, orientation, layout, and depth of the repository have been considered in the development of the current repository conceptual design. Because the repository at Yucca Mountain would be in the unsaturated zone, the distance above the water table is considered as important as the overall depth of the facility. Orientation of the repository relative to existing fracture and principal stress directions is of importance for long-term stability of the excavations and creation of potential flow or migration paths. The repository orientation relative to stress and fracture directions, depth, and inclination could result in certain fractures opening and others closing. The goal of Issue 1.11 from this perspective is to ensure that the repository layout contributes to containment and isolation or, at least, does not detract from it. It is not possible, however, to orient each drift excavation optimally, and the functional requirements of operations also must be considered in repository layout.

The repository underground facility design is also required to incorporate flexibility to accommodate site specific conditions identified through testing, monitoring, or excavation. At Yucca Mountain, requirements for flexibility will probably be related to the subsurface character of faults, particularly the presence and amount of water and difficulties, if any, in excavation and ground control. Accommodation of these conditions, if found, could involve offsets of waste package emplacement holes from water bearing fractures or faults, or possible avoidance of faults with obvious

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recent movement. Alternately, subsurface investigations could demonstrate no impediment to mining or waste emplacement in areas of suspected or possible faults. Demonstration that the repository area could be extended laterally would provide additional flexibility to deal with site specific conditions.

A second function of the postclosure waste disposal system is to limit water usage and potential chemical changes so as not to adversely affect postclosure performance. There are two criteria in 10 CFR 60.133 that require the design of the engineered barrier system to contribute to isolation and containment and to assist the geologic setting in meeting the performance objectives for the period following permanent closure. For a repository at Yucca Mountain, several approaches to implement these criteria are being investigated. The location of the repository in the unsaturated zone has led to design considerations to limit the amount of water contacting the waste packages to lengthen the effective containment period and inhibit radionuclide transport during the isolation period. The repository has been designed to include a slight incline to permit natural drainage of free water to the lowest point of the repository. The temperature of the waste canister itself also can contribute to containment; in a partially saturated medium, the rock adjacent to the emplacement holes will dry out as the interstitial moisture vaporizes. Other mechanisms through which an underground facility design could assist the geologic setting in achieving the performance objectives involve material control. Adding as little water as is practicable to the engineered barrier system or site during construction and carefully selecting and perhaps controlling the quantities and types of materials that could chemically interact with waste container or waste form materials also act to avoid degrading containment and isolation.

A third function that the postclosure waste disposal system must accomplish is to limit excavation induced permeability changes. Two of the design criteria deal with the creation of fractures and potential flow paths for radionuclide migration. One criterion is concerned with fractures induced by the excavation method. For a repository at Yucca Mountain, the current conceptual design incorporates site-specific controlled-blast procedures; techniques limiting damage during emplacement-hole drilling will also be investigated. The other criterion on fracturing is concerned with opening or creating fractures in the overlying or surrounding rock that could lead to creation of potential flow and migration paths to the accessible environment. The extraction ratio for the facility, as well as drift span dimensions, are the primary mechanisms for control of rock mass movements in a hard rock facility such as that at Yucca Mountain.

The remaining function that the postclosure waste disposal system must accomplish is to use a thermal loading that does not preclude meeting the performance objectives. Evaluation of the performance objectives of 10 CFR Part 60 also requires explicit consideration, in the design, of the thermal and thermomechanical responses of the host rock and surrounding strata. For a repository at Yucca Mountain, specific rock mass technical concerns involve surface uplift and the associated creation or opening of fractures. Also of concern for temperature-induced responses are those that could possibly impact the ground-water regime, including fluid state in the unsaturated zone. Also specific to Yucca Mountain is a question of whether temperature-induced stresses, when superposed on the existing stress regime at Yucca Mountain, could affect tectonics at the site in such a way as to impact

compliance with the postclosure performance objectives. The design goal is to maintain a thermal load that is low enough not to lead to tectonic or hydrologic impacts on compliance.

Performance allocation for Issue 1.11 results in the identification of site data to be acquired by the characterization program, as well as requirements on the design and specific design products to be used to resolve the issue. The former information is used in the characterization program, while the latter is considered in the strategy for Issue 4.4 (Section 8.3.2.5). Issue 4.4 addresses preparation of a repository design that satisfies the requirements of all design and performance issues. Figure 8.3.2.1-1 illustrates the relationships between Issue 4.4 and the other issues that introduce design requirements.

Slightly more detail about the functions relevant to the issue resolution strategy for Issue 1.11 can be found in Tables 8.2-16, -17, -18 and -19. These tables list, for each function, the processes available to ensure that the function requirement is accomplished, and also indicate whether primary reliance is placed on the process or if it serves as a backup. The performance measures for each process are defined in the last column of the tables.

The performance allocation for Issue 1.11, as well as details on performance goals and relevant parameters, can be found in Section 8.3.2.2. Identification of measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

- 8.2.2.1.2.3 Summary seal characteristics -- 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?

Regulatory background

The regulation from which Issue 1.12 (discussed in Section 8.3.3.2) is derived is concerned with those activities required to develop designs and evaluate performance of seals to be placed in shafts, ramps, and boreholes associated with the development and closure of a repository.

There are several sections in 10 CFR Part 60 that specifically relate to sealing; 10 CFR 60.134 requires seals for shafts and boreholes to be designed so that following permanent closure they do not become pathways that compromise the ability of the geologic repository to meet the performance objectives for the period following permanent closure. That section further requires that materials and placement methods for seals be selected to reduce, to the extent practicable, (1) the potential for creating a preferential pathway for ground water, or (2) radioactive waste migration through existing pathways.

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Table 8.2-16. Performance measures for underground facility location and layout function -- Issue 1.11 (configuration of underground facilities -- postclosure)

Function	Process		Performance measures
	Possible	Relied on	
Select orientation, geometry, layout, and depth of underground facility to contribute to containment and isolation, taking into account flexibility to accommodate site-specific conditions	Vary depth, dip, orientation, and lateral extent of underground facility to provide host rock with favorable containment and isolation characteristics	Yes	Usable area; is usable area adequate for 70,000 MTU of waste
	Select emplacement borehole orientation and design to limit potential for adverse effects	Backup	Performance measures as defined by Issues 1.1, 1.6, and 1.10 will be used as part of choosing borehole orientation
	Limit the amount of water in contact with container to provide favorable isolation and containment environment	Yes	Regions of dehydration and condensation and drainage pattern
	Skip and isolate unfavorable areas	Yes	Ground quality (technical feasibility performance measure)
			Extent of change in saturation and water chemistry
			Distance from ground with unfavorable properties
	Adjust thermal load to accommodate local conditions	Yes	Temperature (to limit potential for adverse geochemical, etc. effects on the host rock)
			Postclosure rock movements within acceptable limits under thermal loads

Table 8.2-17. Performance measures for function limiting water use and chemical change -- Issue 1.11 (configuration of underground facilities -- postclosure)

Function	Process		Performance measures
	Possible	Relied on	
Limit water usage and potential chemical changes	Limit adverse chemical changes by using acceptable materials and fluids	Yes	Type and quantity of materials (including materials for seals) Quantity of concrete Quantity of shotcrete Quantity of grout for bolt anchors Quantity of organics
	Limit the amount of water used in construction, operation, emplacement of seals, and decommissioning to provide favorable containment and isolation environment	Yes	Net water from operations that remains in host rock at emplacement

Table 8.2-18. Performance measures for function limiting potential excavation effects -- Issue 1.11 (configuration of underground facilities -- postclosure)

Function	Process		Performance measures
	Possible	Relied on	
Limit potential for excavation-induced changes in rock mass permeability	Limit magnitude and extent of blast-induced permeability change by blast control	Backup	Permeability change due to blasting should not cause a change in disturbed zone boundary (compare Issue 1.6, Section 8.3.5.12) or unnecessarily complicate seal evaluation and emplacement
	Limit potential for subsidence by limiting extraction ratio and drift size	Backup	Extraction ratio Drift spans
	Backfill drifts at decommissioning	Backup	Amount of fill

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Table 8.2-19. Performance measures for design thermal loading -- Issue 1.11
(configuration of underground facilities -- postclosure)

Function	Process		Performance measures
	Possible	Relied on	
Design thermal loading taking into account performance objectives and thermomechanical response of host rock	Limit temperature changes in selected barriers	Backup	Temperature
	Limit deleterious rock movement or preferred pathways	Backup	Potential for significant displacement (see Issue 1.1, Section 8.3.5.13)
	Limit impact on surface environment	Backup	Temperature Surface uplift
	Vary borehole and drift spacing to control thermal loading and container temperature	Yes	Thermal loading Borehole wall temperature Rock mass temperature
	Limit potential for borehole collapse	Yes	Stress, deformation, factor of safety, and potential rock fall
	Limit corrosiveness of container environment	Yes	Time container is above boiling temperature of water (see Issue 1.10, Section 8.3.4.2)

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Section 60.112 of 10 CFR Part 60 addresses the overall system performance for the geologic repository after permanent closure. The section requires the geologic setting to be selected and the engineered barrier system and the shafts, boreholes, and their seals to be designed to ensure that releases of radioactive materials to the accessible environment following permanent closure conform to release standards.

Technical background and licensing strategy

The primary objective of the NNWSI Project repository sealing program is to design seals that will ensure that water will not compromise the containment and isolation of radionuclides from the accessible environment. The regulatory basis limits the concern of this issue to shaft and borehole seals. However, since many of the activities associated with resolution of this issue would also pertain to the design of drift seals, which are considered to be part of the engineered barrier system, drift seal design will also be addressed here. Certain repository design criteria of 10 CFR 60.133 are therefore applicable to development of the strategy and information requirements for this issue. The design of drift seals must also address any requirements placed on the drift seal components of the engineered barrier system in meeting the performance objective of 10 CFR 60.113.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria. Performance measures and goals are set consistent with the current strategy for meeting these criteria. The resolution strategy is based upon an evaluation of those aspects of seal performance related to these performance measures. The performance measures address three general functions that the design is expected to achieve in order that the intent of the sealing aspects of 10 CFR 60.133, 10 CFR 60.134, 10 CFR 60.112, and 10 CFR 60.113 can be met. The three components of the sealing system are (1) shaft and ramp sealing functions, (2) borehole sealing functions, and (3) underground facility sealing functions.

To meet the functional requirements for shaft and ramp sealing, the components of the seals being considered are surface cover, shaft collar cores, anchor-to-bedrock plug and seal, settlement plugs, shaft fill, and the repository station seal. Section 6.2.8 presents a further discussion of the components. For the Yucca Mountain site, ramps are planned (in addition to shafts) as a means of repository access. The seal components for the ramps are similar to those for the shafts. For the current concepts, the principal component of the seals for the boreholes is the seal in the portion of the borehole that penetrates the tuffaceous beds of Calico Hills; the remainder of the borehole may be filled with a granular material or a cementitious material. Further, not all boreholes in the vicinity of the site are expected to require sealing (e.g., boreholes that are upgradient or long distances from the repository). The decisions on the need to seal will be made independently for each specific borehole near the site.

To address the functional requirements for repository seals, the principal concern is related to options for sealing a discrete fault or fracture zone that may contain water. Options under consideration are discussed in Section 8.3.3.2 for a wide range of inflow. The determination

of whether or not such inflow is credible at the Yucca Mountain site is one of the reasons for tests to be conducted in the exploratory shaft relative to structural features (Ghost Dance fault, Drill Hole Wash). Potential components for these options range from excavating a channel in a drift floor to constrain flow, to placing small dams in drifts to impede lateral flow of water, to emplacing of physical barriers of bentonite, clay, or cementitious materials on each side of the flow to divert the flow downward and away from the waste packages.

The sealing program is somewhat different from other design-related activities because of the timing of the activities. The repository surface facilities, the accesses, and portions of the underground facility will be constructed shortly after the construction is authorized; the waste packages and the remainder of the underground facilities will be constructed during repository operations. The seals, on the other hand, will not generally be installed until the repository is decommissioned. This delay in emplacing seals is partly a result of the anticipated hydrology at the site; specifically, the lack of aquifers above the waste emplacement horizon at the Yucca Mountain site makes it unnecessary to install any of the permanent shaft or ramp seal components during access construction.

The site hydrology (described in Chapter 3) is the dominant aspect of the environment for the seals. The partially saturated nature of the Topopah Spring Member in which the repository would be located, the anticipated relatively low water flux through the unit, and the potential for flow through discrete fractures or faults are important hydrologic aspects of the functions that the seal system is required to perform. Other aspects of the seal environment that must be considered are related to surface rainfall and the potential for flooding, the stress and temperature fields to which the seals would be exposed, the bulk chemistry of the formation, the chemistry of the ground water, the potential for seismically induced forces or motion, and the flow-related characteristics of the regions in the saturated zone below the repository (principally for the borehole seals).

Specific site information needed for the design and evaluation of the seals is identified in Section 8.3.3.2.1. Information such as the saturated hydraulic conductivity, gravitational analyses, compressibility of shaft fill, borehole construction, and geologic logs associated with specific boreholes will support the design process in the selection of the appropriate methods to emplace sealing components. Site information needed to validate analytical methods may include hydrological characterization of the Topopah Spring welded unit. Specific properties required are unsaturated matrix properties and the drainage capacity of the Topopah Spring welded unit. Prevalence of water-producing zones, if any, and the hydrologic nature of the Ghost Dance fault, the area underlying Drill Hole Wash, and the rock matrix will all be important site information needed to select the most appropriate sealing designs. The description of data needed in support of establishing or confirming the seal environment is based in part upon the analysis work completed to date and the seal design concepts being used; these analyses and designs are summarized in Sections 6.4.3.2 and 6.2.8, respectively.

More detail about the functions relevant to the issue resolution strategy for Issue 1.12 can be found in Tables 8.2-20, -21 and -22. These tables

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Table 8.2-20. Functions, processes, material properties, and performance measures for the shaft and ramp sealing component

Shaft and ramp seals			
Function	Process	Material properties	Performance measure
Reduce amount of water that could potentially reach the waste disposal rooms	Water entering the upper portion of the shaft or ramp	Permeability	Quantity of water
Reduce the potential for human intrusion into the repository	Penetrability through sealing components	To be determined through design trade-off studies	Physical presence
Reduce the amount of water that could potentially reach the waste disposal rooms	Infiltration of surface and subsurface waters reaching the base of the shafts	Permeability of fill	Quantity of water
Reduce the air flow up through shafts	Air flow up through the shaft due to convective air movement	Permeability of fill to air	Percentage of gaseous radionuclides preferentially exiting shafts
Reduce the potential for human intrusion into the repository	Penetrability through sealing components	To be determined through design trade-off studies	Physical presence
Reduce the amount of water that could potentially reach the waste disposal rooms	Water passage from the base of shaft to the waste emplacement drifts	Permeability	Quantity of water
Encourage drainage from base of shafts	Flow through the bulk rock, at base of shaft, both lined and unlined cases	Bulk rock hydraulic conductivity	Drainage capacity

Table 8.2-21. Functions, processes, material properties, and performance measures for the underground facility sealing component

Underground facility seals			
Function	Process	Material properties	Performance measure
Retain and drain water entering emplacement drifts where water entry occurs	Lateral migration of water in drifts	Permeability	Quantity of water
Retain and drain water entering nonemplacement drifts	Lateral migration of water in drifts	Permeability	Quantity of water
Retain and drain water entering drifts	Drainage through bulk rock in floor of drift	Bulk permeability of rock at floor of drift	Quantity of water
Divert water away from waste emplacement areas	Drainage through fill	Permeability of fill	Quantity of water
Reduce the amount of water entering horizontal emplacement boreholes	Infiltration through fault system	Permeability	Quantity of water
Reduce the potential for subsidence	Failure of rock mass above drifts	To be determined through design trade-off studies	Amount of fill
Reduce the potential of human intrusion into the repository	Penetrability through sealing components	To be determined through design trade-off studies	Physical presence

Table 8.2-22. Functions, processes, material properties, and performance measures for the exploratory borehole sealing component

Exploratory borehole seals			
Function	Process	Material properties	Performance measure
Reduce the potential for water-transported radionuclides to be preferentially transported through boreholes	Preferential ground-water flow through the repository, Calico Hills unit and the saturated zone	Equivalent hydraulic conductivity of the borehole systems	Percentage of flow

^aThe borehole system includes the borehole seals, the interface zone, and the modified permeability zone surrounding the borehole seal.

list, for each function, the processes available to ensure that the functional requirement is accomplished. Relevant natural properties and the performance measures for each process are also defined.

The performance allocation for Issue 1.12, as well as details on performance goals and relevant parameters, can be found in Section 8.3.3.2. Identification of processes and measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

8.2.2.2 Key Issue 2

8.2.2.2.1 Performance issues for Key Issue 2

- 8.2.2.2.1.1 Summary of public radiological exposures: normal conditions -- 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?

Regulatory background

Issue 2.1 (discussed in Section 8.3.5.3) is concerned with the radiation exposure to the general public associated with normal conditions during operation, closure, and decommissioning of the repository. As stated in this issue, the allowable exposure limits are those specified in 10 CFR 60.111, 40 CFR Part 191 Subpart A, and 10 CFR Part 20. 10 CFR 60.111 actually only requires conformance with 10 CFR Part 20 and "such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency" (i.e., 40 CFR Part 191 Subpart A). No additional requirements are imposed by 10 CFR 60.111; therefore, the only directly applicable regulatory requirements are those in 10 CFR Part 20 and 40 CFR Part 191 Subpart A.

The objective of 10 CFR Part 20 is to limit the radiation dose that members of the public in unrestricted areas may receive to less than 0.5 rem per year to the whole body and to establish limits for particular organs. In addition, 10 CFR Part 20 states that exposures should be maintained as low as reasonably achievable (ALARA).

EPA's 40 CFR Part 191 requires that "management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) discharges of radioactive material and direct radiation from such management and storage and (2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ."

In addition, there are other sections of 10 CFR Part 60 that require compliance with 10 CFR 60.111 and 10 CFR Part 20; these sections, however, do not contain any additional exposure limits relevant to this issue.

Technical background and licensing strategy

Issue 2.1 is concerned with the radiation exposure to the general public from the normal operation, closure, and decommissioning of the repository. The issue is divided into two parts: (a) the exposure to members of the public in a highly populated area (a highly populated area is defined in 10 CFR 960.2), and (b) the maximum exposure to any member of the public. The lower radiation dose limit stated in part (a) is intended to reduce the total man-rem exposure and, thus, the cumulative risk to the public as a whole. To address part (a) of this issue, the locations of the highly populated areas must be determined in relation to the repository site. To address part (b) of this issue, the dose to individuals in the vicinity of the site must be evaluated. The assessment of the potential doses will allow an evaluation of the impact of the operation, closure, and decommissioning of the repository on the surrounding population. The assessments will be conducted periodically (i.e., at each design phase) throughout the design of the repository to provide feedback to the design process. A monitoring program will provide verification of the results of the analyses. The "as low as reasonably achievable" (ALARA) criterion will be applied in designing the repository to minimize the potential radiation dose to the public. DOE is presently

evaluating how the limits in 40 CFR Part 191 relate to the ALARA criterion. Any decisions will be incorporated in the issue resolution strategies for this issue.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals, that are derived from performance criteria. These goals are the direct result of a preliminary performance allocation concerned with the expected average radiation doses received by members of the public within any highly populated area or in an unrestricted area in accordance with 10 CFR Part 960, 10 CFR 60.111, 40 CFR Part 191, Subpart A, and 10 CFR Part 20. The licensing strategy for this issue is concerned only with normal operating conditions. Accident conditions are dealt with under Issue 2.3 (Section 8.3.5.5); worker radiologic safety is dealt with under Issues 2.2 (Section 8.3.5.4) and 2.3. The aspects of repository facility performance that are relevant to public radiologic health and safety under normal conditions are grouped into five functions that the repository design is expected to perform in order to comply with the intent of the preclosure public health and safety aspects of the applicable regulations. Issue resolution corresponds to the acceptance of the arguments in support of compliance by the NRC.

A complete logic diagram of the iterative design and assessment process required to obtain resolution of this issue may be found in Section 8.3.5.3. A portion of this process, the performance allocation, is responsible for the five repository functional groupings just mentioned. Table 8.2-23 lists these repository system functions, along with the activities or processes required to perform these functions and the measure that will be used to assess the level of success in performing the functions.

The first function of the repository design necessary for public health and safety is to provide a remote location. This is simply accomplished by locating the repository in a low population area. Success is measured by the population density of the area. Yucca Mountain is located in Nye County, which has an average population density of 0.5 persons per square mile. This is significantly lower than the continental U.S. average of 76 persons per square mile. The remaining functions are less obvious but are still relatively easy to understand.

The second and third functions are related to the natural environment surrounding the repository and its effects on the dispersion and transport of radionuclides to the public. These functions require analyses of the atmospheric and environmental transport mechanisms that operate in the area of the repository. The measures used to assess these two functions are the predicted and measured radionuclide concentrations in environmental media and the predicted individual public doses.

Environmental transport mechanisms are not expected to be significant because of the small amount of food production and absence of perennial surface water sources available in the desert-like environment. Preliminary meteorological measurements in the area indicate that the transport and dispersion characteristics should aid in reducing radiation exposures to the public. These measurements indicate high average annual wind speeds, which favor effective dispersion. The region surrounding the site experiences some

Table 8.2-23. Functions, performance measures, and performance goals for Issue 2.1 (public radiological exposures--normal conditions)

Function	Process or activity	Performance measure
Provide remoteness from highly populated areas and members of the public	Locate repository in a low population area	Population density
Provide dispersion and transport of routine radioactive releases to the unrestricted area through water pathways, crops, and animals	Analyze dilution, transportation, bioaccumulation of radionuclides in rivers, streams, and food stuffs	Radionuclide concentrations in environmental media and individual doses
Provide transport, dispersion, and diffusion of routine airborne radioactive effluents to the unrestricted area	Analyze atmospheric transport by wind and convection, including dispersion and diffusion	Radionuclide concentrations in environmental media and individual doses
Provide containment of potential sources of radiation to the unrestricted area	Limit releases of routine gaseous, liquid, and solid radioactive effluents	Radionuclide concentrations in environmental media and individual doses
Verify that there are no nuclear (uranium) fuel cycle facilities that need to be considered in assessing the public dose	Locate and analyze nearby nuclear (uranium) fuel cycle facilities	Number of nuclear (uranium) fuel cycle facilities requiring consideration in assessing the public dose

of the deepest atmospheric mixing layers in the United States, a condition favorable to atmospheric mixing and dispersion (DOE, 1986b).

The fourth function of the repository with respect to the public health and safety is to provide containment of potential sources of radiation. This function is performed by limiting releases of routine gaseous, liquid, and solid effluents containing radionuclides. Again, success is measured in terms of the predicted and measured radionuclide concentrations in environmental media and the predicted individual public doses. Certain features of the conceptual design already provide some means of limiting releases of radioactive materials. These include filtration systems on ventilation exhausts to remove most airborne particulates and plans for radiation monitoring systems to promptly warn of increased levels of radiation levels in repository effluents, and thereby allow prompt corrective actions.

The final function of the design relevant to public health and safety under normal conditions is to verify that there are no other nuclear fuel cycle facilities in the area that could contribute to the predicted public dose. This is performed simply by locating any nuclear fuel cycle facilities in the area and analyzing the available data for normal releases from these facilities. The measure of success in this instance is the number of nearby nuclear fuel cycle facilities that could affect the public dose. It is expected that there are no other nuclear fuel cycle facilities in the area of Yucca Mountain that could contribute significantly to the public dose. Currently, no other nuclear fuel cycle facilities have been located in the area of Yucca Mountain.

More details about the performance allocation for Issue 2.1 including tentative goals for performance measures, parameters needed to evaluate performance measures, and goals and expected values of these parameters are contained in Section 8.3.5.3.

- 8.2.2.2.1.2 Summary of worker radiological safety: normal conditions --
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?

Regulatory background

Issue 2.2 (discussed in Section 8.3.5.4) is concerned with the radiation exposure to workers at the repository under normal conditions during construction, operation, closure, and decommissioning.

While this issue refers to the requirements of both 10 CFR 60.111(a) and 10 CFR Part 20 for limiting radiological exposure to workers, 10 CFR 60.111(a) simply refers to 10 CFR Part 20 and 40 CFR 191, Subpart A. Because 40 CFR 191, Subpart A is only applicable to members of the public, 10 CFR Part 20 (Standards For Protection Against Radiation) is the only regulation directly relevant to worker protection and, thus, this issue. In addition, there are other sections of 10 CFR Part 60 that either require conformance with 10 CFR Part 20 or for which compliance with 10 CFR Part 20 is relevant.

Sections 21, 131, 132, and 133 of 10 CFR Part 60 specifically address effluent control and monitoring, ventilation and repository design in terms of the protection requirements of 10 CFR Part 20.

The regulation 10 CFR Part 20 specifies the requirements for control of occupational radiation exposure. The concept and application of "as low as reasonably achievable" (ALARA) also applies to worker radiation exposure. In addition to the requirement that worker doses be maintained less than regulatory limits and the recommendation that they adhere to an ALARA philosophy, design guidelines are generally established at a fraction of the limits to ensure that necessary operations can be performed and occupational doses maintained below allowable limits. Design criteria for radiological safety are established under Issue 2.7 (Section 8.3.2.3). Issue 2.7 uses the performance criteria established in this issue in developing the design criteria.

Regulations 10 CFR Part 20 and Part 60 also require a monitoring program during repository operations that ensures area radiation levels, airborne activity concentrations, contamination levels, and criticality controls are known and routinely verified. These operational requirements necessitate including systems to perform the verification of the design and operation of the facility. To ensure that the occupational radiation doses from the operation of the repository are less than the allowable levels, regulatory requirements must be known, both by designers to produce a compatible design and by evaluators to ensure that requirements are met by the design and operating procedures.

Technical background and licensing strategy

Issue 2.2 addresses the radiological safety of workers during normal operations. To resolve this issue, the mined geologic disposal system will be designed to limit the normal radiation doses to workers during construction, operation, closure, and decommissioning of the repository to less than the limits specified in 10 CFR Part 20. The design process will be an iterative process as the design proceeds through the various phases. Design criteria and assumptions will be needed for both repository system operation and worker radiation safety. Many of the same parameters will apply to both areas and will require appropriate input from design development. Further, the policy to maintain radiation doses as low as reasonably achievable (ALARA) imposes additional iterations on the design in order to implement the differential cost-benefit analyses for the ALARA process. In these iterative design activities, DOE and other guidelines will be used in designing for repository worker radiation safety. For any operational activities for which design features are not able to preclude the possibility of dose rates to personnel above the guidelines, administrative procedures will be required to limit personnel exposure.

The NRC requirements for verification of radiological performance necessitate special considerations for radiation measuring and monitoring systems. These requirements include "each licensee shall make or cause to be made such surveys as (1) may be necessary for the licensee to comply with the regulations in this part and (2) are reasonable under the circumstances to evaluate the extent of radiation hazards that may be present," (10 CFR 20.201(b)) and "the effluent monitoring systems shall be designed to measure

the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirements for effluent control" (10 CFR 60.132(c)(2)). In addition, a "means to monitor and control the dispersal of radioactive contamination" (10 CFR 60.113(a)(4)) and "a radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity in effluents" (10 CFR 60.131(a)(6)) are required. Radiological measurement and monitoring systems that will be required for performance verification include air monitoring systems, criticality monitoring systems, gaseous effluent monitoring and sampling systems, and liquid effluent monitoring and sampling systems. The criteria for the testing, operation, and performance of these systems are found in documents issued by various organizations responsible for setting standards.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals, that are derived from performance criteria. These goals are the direct result of a preliminary performance allocation concerned with the radiation exposure to workers at the repository under normal conditions in accordance with 10 CFR Part 60 and 10 CFR Part 20. The licensing strategy for this issue is concerned with normal operating conditions. Accident conditions are dealt with under Issue 2.3; public radiologic safety is dealt with under Issues 2.1 and 2.3. The aspects of repository facility performance that are relevant to worker radiologic health and safety under normal conditions are grouped into three general functions that the repository design is expected to achieve in order to comply with the intent of the preclosure worker health and safety aspects of the applicable regulations. Issue resolution corresponds to acceptance of the arguments in support of compliance by the NRC.

A complete logic diagram of the iterative design and assessment process required to obtain resolution of this issue is presented in Section 8.3.5.4. A portion of this process, the performance allocation, is responsible for the repository functional grouping mentioned previously. Table 8.2-24 lists these repository system functions, along with the activities or processes required to perform these functions and the measure that will be used to assess the level of success in performing these functions.

The first function necessary to ensure the health and safety of the workers under normal conditions is related to the natural environment surrounding the repository surface facilities and its effects on the dispersion and transport of radionuclides. As in Issue 2.1, this function requires analyses of the atmospheric transport mechanisms and the resulting doses to workers from radionuclides outside the repository facilities. In this instance, the performance measures are the transport characteristics of the surrounding atmosphere and the predicted and measured doses to the workers. Preliminary meteorological measurements in the area indicate that the transport and dispersion characteristic should aid in reducing radiation exposures to the public. These same characteristics should contribute to reducing exposure to workers. These measurements indicate high average annual wind speeds, which favor effective dispersion. The region surrounding the site experiences some of the deepest atmospheric mixing layers in the United States, a condition favorable to atmospheric mixing and dispersion (DOE, 1986b).

Table 8.2-24. Functions, processes or activities, and performance measures for Issue 2.2
(worker radiological safety--normal conditions) (page 1 of 2)

Function	Processes or activity	Performance measure
Provide transport, dispersion, and diffusion of routine airborne radioactive effluents within site boundaries	Analyze atmospheric transport, dispersion, and diffusion characteristics within the site boundaries	Transport characteristics of atmosphere within site boundaries
	Analyze worker doses from outdoor airborne radionuclides within site boundaries	Doses resulting from airborne radionuclide concentrations around repository facilities
Provide assurance that doses to workers underground are not excessive	Analyze shielding of workers from direct radiation using properties of the host rock	Effective attenuation of direct radiation by host rock
	Analyze the natural radiation released in the underground facilities	Release rates and concentrations of naturally occurring radionuclides
	Analyze radiation levels from miscellaneous sources of radiation such as calibration and testing sources	Direct radiation and contamination levels from miscellaneous sources
Provide containment of radiation and limit radiation doses to repository workers	Analyze direct radiation levels in all areas of the repository	Direct radiation levels in all areas of the repository
	Analyze high-level waste containment and handling operations	Doses due to worker occupancy in direct radiation areas

Table 8.2-24. Functions, processes or activities, and performance measures for Issue 2.2
(worker radiological safety--normal conditions) (page 2 of 2)

Function	Processes or activity	Performance measure
Provide containment of radiation and limit radiation doses to repository workers	Analyze site-generated waste containment, handling, and treatment operations	Doses due to worker occupancy in direct radiation areas
	Analyze radiation levels from miscellaneous sources of radiation such as calibration and testing sources	Direct radiation and contamination levels from miscellaneous sources
	Analyze shielding provided by structures, containments, equipment, and waste packages	Effective attenuation of direct radiation levels
	Analyze ventilation and filtration of repository airstreams	Contamination and airborne radionuclide concentrations in repository airstreams

The second function relates to the underground facilities of the repository and is to provide assurance that doses to workers underground are not excessive. Performing this function requires three analyses: (1) an analysis of the effectiveness of the host rock in shielding workers from direct radiation from the emplaced waste packages, (2) an analysis of the natural radiation released in the underground facilities, and (3) an analysis of the radiation levels from miscellaneous sources of radiation underground. The performance measure for the first analysis is simply the effective attenuation of direct radiation by the host rock. Although it is not yet known just how effective the host rock is as a radiation shield, the rock is expected to provide some shielding of the workers from the emplaced waste. For the second analysis, the performance measures are the release rates and concentrations of naturally occurring radionuclides in the underground openings. Preliminary measurement of radon levels in underground openings near the site indicate that while radon can build up in unventilated openings, release rates should be low enough that radon levels can be controlled through normal ventilation. Finally, the performance measures for the third analysis are the direct radiation levels and contamination levels from the miscellaneous radiation sources. The use of radiation sources in construction is now relatively commonplace. No difficulties are foreseen in controlling these sources of radiation through established safety procedures.

The third function of the repository is to provide containment of radiation and limit radiation doses to repository workers. This function requires six analyses be performed to assess its performance. The first of these analyses is the determination of direct radiation levels in all areas of the repository, and its performance measure is simply direct radiation levels. Preliminary estimates of expected direct radiation levels in the repository (Dennis, et al., 1984a; Stinebaugh and Frostenson, 1987) indicate that all areas can be made safe by using shielding or remote handling equipment. The next two analyses involve the investigation of high-level and site-generated waste operations, and the performance measures are the predicted and measured doses to workers from these operations. Preliminary estimates of expected worker exposures from waste-handling operations indicate that there are no expected problems in keeping worker exposures below design levels (Dennis, et al., 1984a; Stinebaugh and Frostenson, 1987).

The fourth analysis is an analysis of the radiation levels from miscellaneous sources. In this instance, the performance measure is the radiation levels from the miscellaneous sources. The use of radiation sources in construction is now relatively commonplace. No difficulties are foreseen in controlling these sources of radiation through established safety procedures. The last two analyses deal with the shielding of workers and the ventilation and filtration of repository airstreams. Performance measures are simply the effective attenuation of direct radiation levels by repository structures and the contamination and airborne concentration levels in the repository airstream. Numerous other facilities for handling radioactive materials have been designed, built, and safely operated using technology similar to that proposed for use in the repository.

More details about the performance allocation for Issue 2.2 including tentative goals for performance measures, parameters needed to evaluate performance measures, and goals and expected values of these parameters are contained in Section 8.3.5.4.

- 8.2.2.2.1.3 Summary of preclosure accidental radiological releases --
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?

Regulatory background

Issue 2.3 (discussed in Section 8.3.5.5) is concerned with the radiation exposure to the general public and workers under credible accident conditions during construction, operation, closure, and decommissioning. Although Issue 2.3 states that radiation exposures resulting from credible accidents must be maintained below applicable limits, there presently are no specified limits for radiation exposures to either members of the public or repository workers from accidents at a repository. The DOE is developing a regulatory position on what the accident dose limit for the general public should be and will seek the agreement of the NRC. There are regulatory criteria relevant to radiological protection of the repository workers and the general public under accident conditions.

The NRC, 10 CFR 60.2, defines structures, systems, and components important to safety as "those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure." The regulation does not, however, provide criteria for what constitutes a credible accident and does not specify accident dose limits for members of the public or workers. Criteria for what constitutes a credible accident will be developed as part of the preclosure risk assessment methodology (PRAM) described in Section 8.3.5.1.

Technical background and licensing strategy

Resolution of this issue requires the assurance that during the preclosure period the repository will not pose any undue radiological risk to the health and safety of the public and repository workers as a result of credible accidents. This will be initially established by an analysis documenting the adequacy of structures, systems, and components provided for the prevention of accidents and mitigation of consequences. The structures, systems, and components to be analyzed are those that will be presented to the NRC in the safety analysis report (SAR) of the license application.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals, that are derived from performance criteria. These goals, established to orient the testing program toward obtaining the information to resolve this issue, are the direct result of a preliminary performance allocation concerned with projected radiological exposures to the general public in the unrestricted area or workers in the restricted area as a result of credible accidents. Exposures under normal conditions are dealt with under Issues 2.1 and 2.2 (Sections 8.3.5.3 and 8.3.5.4). The aspects of repository facility performance that are relevant

to public and worker radiological health and safety under credible accident conditions are grouped in three general functions that the repository design is expected to achieve in order to comply with the intent of the preclosure worker and public health and safety aspects of the applicable regulations. Issue resolution corresponds to the acceptance of the arguments in support of compliance by the NRC.

A complete logic diagram of the iterative design and assessment process required to obtain resolution of this issue is presented in Section 8.3.5.5. A portion of the process, the performance allocation, is responsible for the repository functional grouping mentioned previously. Table 8.2-25 lists these repository system functions along with the activities or processes required to perform these functions, and the measures that will be used to assess the level of success in performing these functions.

The first function of the repository is to provide a location that assists in limiting potential radiation exposure to the public and workers from accidents. There are four analyses that are needed to assess the performance of this function. First, the remoteness of the site must be analyzed. This is relatively straightforward and the measure used to assess remoteness is the population density of the region. Yucca Mountain is surrounded by Nye County, which has an average population density of 0.5 persons per square mile. This is significantly lower than the continental United States average of 76 persons per square mile. Second, the frequencies and consequences of initiating events caused by natural or site-related phenomena need to be analyzed. This is an important aspect of the site and the repository. The measure applied to this activity is the consequences of credible site-related initiating events. Consequences will be evaluated mainly in terms of radiation exposure; however, consequences can also include other types of "damage" to the repository, the environment, and people. A preliminary study (Appendix F of the Site Characterization Plan-Conceptual Design Report (SCP-CDR) has indicated that there are few credible accidents with consequences that could be considered serious. Further, this study also identified some changes that could be made to eliminate some of these credible accidents.

The last two analyses needed to assess the performance of the first function are really required to determine initiating event consequences. These are an analysis of the short-term public and worker radiation exposure mitigation features of the site and an analysis of the long-term public and worker radiation exposure mitigation features of the site. Short-term radiation exposures are dominated by the quick-acting radiation transport mechanisms such as atmospheric dispersion, dilution, and transport of radionuclides. The atmospheric transport characteristics of the site are the measures used to evaluate the short-term radiation exposure mitigation features of the site. Preliminary meteorological measurements in the area indicate that the transport and dispersion characteristic should aid in reducing radiation exposures to the public. These measurements indicate high average annual wind speeds, which favor effective dispersion. The region surrounding the site experiences some of the deepest atmospheric mixing layers in the United States, a condition that is favorable to atmospheric mixing and dispersion (DOE, 1986b).

Table 8.2-25. Functions, processes or activities, and performance measures for Issue 2.3 (page 1 of 2)

Function	Processes or activity	Performance measure
Provide location that assists in limiting potential radiation exposure to the public and workers from accidents	Analyze "remoteness" of repository location	Population density of region
	Analyze probabilities and consequences of initiating events caused by natural or site-related phenomena	Consequences of credible site-related initiating events
	Analyze short-term public and worker radiation exposure mitigation features of the site	Quick-acting dispersion, dilution, and transport characteristics of the site
	Analyze long-term public and worker radiation exposure mitigation features of the site	Long-term dispersion, dilution, diffusion, and bioaccumulation characteristics of the site
Provide prevention, containment, and mitigation of accident consequences and limit radiation exposures to workers and public	Analyze probabilities and consequences of design-related initiating events	Consequences of credible design-related initiating events
	Analyze design for vulnerability to effects of natural, site-related, and design-related initiating events	Sensitivity of repository design to possible accidents
	Analyze design for effectiveness of preventive features	Effectiveness of preventive design features

Table 8.2-25. Functions, processes or activities, and performance measures for Issue 2.3 (page 2 of 2)

Function	Processes or activity	Performance measure
	Analyze design for effectiveness of mitigative features	Effectiveness of mitigative design features
Provide assurance that repository and workers are safe from effects of offsite accidents	Analyze vulnerability of repository and workers to effects of offsite accidents	Consequences of credible off-site accidents that could affect repository and workers

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Long-term radiation exposures are dominated by the slow-acting radiation transport mechanisms such as transport of radionuclides through the surface water and food chain pathways. The long-term dispersion, dilution, diffusion, and bioaccumulation characteristics of the site are the measures used to evaluate the site's ability to limit long-term exposures. The long-term pathways at Yucca Mountain are expected to be a small contributor to worker and public dose because of the small amount of food production and limited surface water sources available in its desert-like environment.

The second function of the repository design related to this issue is to prevent accidents, contain radioactive materials, mitigate accident consequences and limit radiation exposures to workers and the public through design features. This function also requires four analyses to assess its performance. The first is an analysis of the frequencies and consequences of design-related initiating events. This analysis is similar to the analysis of site-related initiating events mentioned previously. Again, the measure applied to this aspect of the repository is the consequences of credible design-related initiating events. The second analysis is actually a subset of the initiating event consequence analyses. It is an analysis of the design for vulnerability to the effects of natural, site-related, and design-related initiating events. The measure applied here is the sensitivity of the repository to all these credible accidents. This analysis will use both probabilistic methods and deterministic methods in a complementary manner. Some important results that could arise from this analysis include the refinement of the NNWSI Project Q-list (items important to safety portion only) and the development of a set of design-basis accidents to use in the repository safety analysis report (SAR).

The last two analyses are evaluations of the effectiveness of preventive and mitigative design features. These analyses will most likely be implemented as part of the deterministic design-basis accident analyses. The obvious measure of these analyses is effectiveness; effectiveness itself is measured in many different ways. These analyses will ensure that the design of the repository will exhibit the necessary response when subjected to design-basis accidents. Numerous other facilities for handling radioactive materials have been designed, built, and safely operated using technology similar to that proposed for use in the repository.

Finally, the third function of the repository design related to this issue is to provide assurance that both the repository and workers are safe from the effects of offsite accidents. The function requires only the analysis of the vulnerability of the repository and the workers to offsite accident consequences, and the measure used to assess the function is the consequences of credible offsite accidents to the repository and to the workers. There are few facilities of any kind in the area of Yucca Mountain. Offsite accidents that could adversely affect the repository or workers are not expected, however, possible offsite accidents associated with the nearby Nellis Air Force Range or the Nevada Test Site will be considered. The current policy of the DOE Nevada Operations Office requires the removal of workers from underground mines within about 80 km of an underground test of approximately 80 kilotons or larger (Vortman, 1980). Because the DOE exercises control over the schedule of activities at the NTS, compatible arrangements for nuclear testing and repository construction-operation activities can be made. The removal of workers from the underground

repository facility would be a standard industrial practice to guarantee the safety of workers. Other preparations might include the purging of contaminated hot-cell atmospheres or the securing of waste disposal containers and spent fuel assemblies. Plans for the evacuation of facilities that are judged particularly sensitive could also be developed, if warranted, although this is not considered to be a likely situation.

More details about the performance allocation for Issue 2.3 including tentative goals for performance measures, parameters needed to evaluate performance measures, and goals and expected values of these parameters are contained in Section 8.3.5.5.

8.2.2.2.1.4 Summary of waste retrievability -- 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?

Regulatory background

Issue 2.4, which is discussed in Section 8.3.5.2, is concerned with the ability to retrieve emplaced waste as required by 10 CFR 60.111(b). As a result, this issue must ensure that the repository is designed, constructed, operated, and maintained with the option to retrieve any or all of the emplaced waste. The regulations concerning the retrieval of high-level radioactive waste from geologic repositories, as specified by the Nuclear Waste Policy Act (NWPA, 1983) are contained in the NRC regulation 10 CFR Part 60.

The principal NWPA reference to retrieval is contained in Section 122, and requires any repository to be designed and constructed to permit the retrieval of any spent nuclear fuel during an appropriate period of operation of the facility. Retrieval could be required for reasons pertaining to public health and safety, the environment, or the recovery of the economically valuable contents of such spent fuel.

The principal NRC reference to retrievability is in Section 111(b) of 10 CFR Part 60, which requires the geologic repository operations area to be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and NRC review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area will be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are begun.

Technical background and licensing strategy

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design (developed in Issue 4.4) meets the design criteria, expressed as performance measures and associated goals, that are derived to ensure retrieval. These goals directly result from a preliminary performance allocation concerned with maintaining the

option to retrieve any or all of the emplaced waste. The licensing strategy is based upon evaluation of aspects of the repository design that are relevant to the requirement of maintaining the capability to retrieve the waste from the repository should it become necessary or desirable.

A complete logic diagram of the iterative design and assessment process required to resolve this issue is presented in Section 8.3.5.2. A portion of this process, the performance allocation, has resulted in identification of the four functions that must be performed for retrievability:

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

Table 8.2-26 lists the processes or activities required to perform these functions and the performance measures that will be used to assess the level of success in performing these functions. These four functions are the organizing principle upon which the retrieval discussions, information needs, and plans for future evaluations are based.

The first function is to provide a safe and reliable access from the surface facilities to the emplacement boreholes. To do this, the underground openings must be usable and the environment within them must be acceptable under normal and credible abnormal conditions. A time period of at least 84 years has been selected as the period for which drifts and accesses must remain usable. This time period is a significant and potentially severe restriction that impacts the design, construction, and operation of the repository. For example, the materials selected for the rock-support system, the necessity for a continual, long-term monitoring and maintenance program for the underground openings, the timing for backfilling operations, and the selection of an acceptable emplacement mode are all significantly impacted by this time period. Evaluations of the thermal and mechanical effects on stability of shafts, ramps, and drifts have been the focus of about 15 reports and studies; a synopsis is given in Section 6.4.10.2. The common preliminary conclusions drawn from the multiple approaches used to date are that the openings are predicted to remain stable during preclosure and that excavation-induced effects would be expected to be similar to those in the Grouse Canyon tuff in G-tunnel on the Nevada Test Site. Substantial additional information on drift and support system behavior is expected to be gathered as part of the exploratory shaft facility observations. To help ensure the feasibility of retrieval operations, design constraints have been established to ensure that the temperature in selected drifts will remain below 50°C for the first 50 years after waste emplacement. Similarly, the drifts are not planned to be backfilled until after the retrieval period. Preliminary analyses indicate that the requirements for providing adequate ventilation can be met for inspection and retrieval operations using currently available equipment. More detailed evaluations, planned for future design phases, will evaluate the effects of specific particulates, humidity, and selected potential contaminants. Particular emphasis will be placed on evaluating the potential presence and consequences of credible abnormal conditions that may occur in the openings.

Table 8.2-26. The functions, processes or activities, and performance measures involved in providing the ability to retrieve waste--Issue 2.4 (waste retrievability) (page 1 of 3)

Function	Process or activity	Performance measure
Provide access to the emplacement boreholes for normal and credible abnormal conditions	Design and construct the accesses and drifts to be usable throughout the retrievability period for normal and credible abnormal conditions	Time during which the drifts and accesses will remain usable
	Develop rock support concepts that ensure maintainability	Amount of spall, opening displacement, and frequency of maintenance
	Develop backfill removal concepts (if needed)	Time and level of effort for backfill removal
	Monitor drifts and accesses to determine maintenance needs	Localized rock and rock support displacement
	Design for a specific temperature and air quality environment with the accesses and drifts	Drift temperature and air quality
	Verify environment for maintenance and retrieval operations	Air quality
	Modify environment (as necessary)	Time required to modify the environment for retrieval

Table 8.2-26. The functions, processes or activities, and performance measures involved in providing the ability to retrieve waste--Issue 2.4 (waste retrievability) (page 2 of 3)

Function	Process or activity	Performance measure
Provide access to the waste package	Design waste emplacement envelope to allow access to the waste package throughout the retrievability period for normal and credible abnormal conditions	Borehole usability (rockfall, displacement of borehole wall, borehole liner lifetime, displacement and curvature radius)
	Assess the condition of the emplacement envelope and waste package before removal (as required)	Borehole liner displacement
	Perform corrective actions (as required)	Time required to perform corrective actions
Remove the waste package	Design the waste package and transporter with the option to remove the waste for normal and credible abnormal conditions	Radiation protection Time required to perform waste removal Removal latch and pull strength Structural strength of the waste package or dolly
	Verify conditions of equipment and waste package	Waste package structural failure detection Removal equipment checks
	Verify operator training	Operator competency certification

Table 8.2-26. The functions, processes or activities, and performance measures involved in providing the ability to retrieve waste--Issue 2.4 (waste retrievability) (page 3 of 3)

Function	Process or activity	Performance measure
Transport and deliver waste to the surface facilities	Design the transporter with the ability to transport the waste to the surface for normal and credible abnormal conditions	Transporter design characteristics (braking ability, maximum speed, cornering ability, radiation protection) Time required to transport the waste to the surface
	Design the surface waste-handling building and the transporter with the ability to unload waste at the surface facilities for normal and credible abnormal conditions	Time required to unload waste Radiation protection Transporter unloading capability
	Assess the ability to transport the waste to the surface facilities	Transporter drive system performance Operator competency certification
	Assess the ability to unload the waste at the waste handling building	Transporter unloading system performance Surface facility unloading system Operator competency certification

The second function necessary for retrieval is to provide a safe and reliable access to the waste packages. The waste emplacement envelope (borehole, liner, shield plug, and collar) must, therefore, be designed to allow for retrieval of emplaced waste packages under normal and credible abnormal conditions. Borehole usability is one of the principal performance measures for this function; specifically, goals have been established that seek to limit rockfall, rock displacement, and liner curvature and to establish the needed lifetime of the liner. Preliminary analyses (see Section 6.4.2.10) indicate that under normal conditions waste emplacement boreholes are predicted to remain stable during preclosure, although, for horizontal waste emplacement, some potential exists for negligible amounts of rock to fall on the liner. For credible abnormal conditions, substantial additional work remains to be done particularly as related to evaluating effects of tectonic events.

The third and fourth functions are related to the waste-handling operations of removing the package from the emplacement borehole and delivering the waste to the surface facilities. The principal site-related concern relative to these functions is determination of shielding characteristics of the host rock to ensure that design limits for worker doses are not exceeded. Nonsite-related concerns are focused upon designing and evaluating the equipment necessary to perform the functions. Equipment concepts and designs are presented in various sections of the SCP and SCP-CDR (Section 8.3.5.2 provides a directory of related discussions). Even though the equipment designs use currently available technology, the usage will generally be unique to a repository. Removing the waste package under normal conditions will use the same technology and equipment as the emplacement operations. However, the ability to perform this function for credible abnormal conditions could be among the most difficult repository operations because of the high temperatures, the radioactive environment, and uncertainties regarding the condition of the boreholes and containers. Proof-of-principle demonstrations will probably be done for selected pieces of equipment.

More details about the performance allocation for Issue 2.4 (waste retrievability), including tentative goals for the performance measures, parameters needed to evaluate performance measures, and goals and expected values of these parameters are presented in Section 8.3.5.2. Identification of these measures, parameters, and associated goals helps to orient the testing program toward obtaining the information to resolve this issue.

- 8.2.2.2.1.5 Summary of preclosure radiological safety higher-level findings -- 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?

Regulatory background

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 are set forth in 10 CFR Part 960. The siting guidelines 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 DOE Implementation Guidelines (10 CFR 960.3) describe the manner in which the siting guidelines must be addressed during the siting process.

Issue 2.5 (discussed in Section 8.3.5.6) is concerned with the DOE's preclosure guidelines that relate to preclosure radiologic safety under normal and anticipated operating conditions. These guidelines consist of a system guideline and four technical guidelines. The system guideline is concerned with the expected performance of the repository system as a whole during the period before permanent closure, while each technical guideline is concerned with the effect of some specific aspect of the site on the preclosure performance. Each preclosure technical guideline has one qualifying condition that must be met for a site to be acceptable. In addition, two of the technical guidelines have one or more disqualifying conditions. 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 benefit or detract from preclosure radiological safety.

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. There are four levels of findings (Table 8.2-14). 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 (Levels 1 and 3). Higher-level findings must be made to determine if a site may be recommended for the development of a repository (Levels 2 and 4). Thus, 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.

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 (DOE, 1984c) for 10 CFR Part 960, 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.

Technical background and issue resolution strategy

To resolve Issue 2.5, sufficient evidence must be available to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with preclosure radiologic safety. Each of the qualifying conditions refers to regulatory requirements of the NRC (specifically, 10 CFR Part 60). To support higher-level findings for the qualifying conditions, evidence must show whether the preclosure radiological releases under normal and projected operating conditions will be within the limits set by the NRC and the EPA, given the conditions that exist at the site. The system guideline looks at the site conditions as a whole, while the technical guidelines are concerned with the effects of specific site conditions. The disqualifying conditions are also related to NRC regulations, but not always as explicitly as the qualifying conditions.

The findings that have been made previously for the preclosure radiological safety guideline qualifying and disqualifying conditions and the evidence supporting these findings are given in the NNWSI Project environmental assessment (DOE, 1986b). The available evidence was sufficient to support a positive higher-level finding for two of the three disqualifying conditions of the Population Density and Distribution technical guideline, and positive lower-level finding for the other qualifying and disqualifying conditions. 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 information necessary to support higher-level findings will be made available through the resolution strategies of other issues. For each condition, available evidence is evaluated to determine if it is sufficient to support a higher-level finding for any of the conditions. For the qualifying and disqualifying conditions for which there is not sufficient evidence available, the planned site characterization studies are reviewed to determine if the conditions will be investigated. This is accomplished by evaluating the resolutions strategies of other preclosure radiological safety performance issues (Issues 2.1 and 2.2) that assess the ability of the site to comply with the NRC's preclosure radiological safety regulatory requirements. If the concerns of the conditions are being considered in the resolution strategies of the other issues, it can be expected that the evidence to support higher-level findings for these conditions will be available.

8.2.2.2.2 Design issues for Key Issue 2

- 8.2.2.2.2.1 Summary of waste package characteristics (preclosure) --
 Issue 2.6: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues?

Regulatory background

In addition to providing information on the waste package designs and the integration of those designs into the repository system to support requirements derived from several performance issues, Issue 2.6 (discussed in Section 8.3.4.3) is concerned with ensuring compliance with the design criteria established in 10 CFR 60.135. In addition to general design criteria for waste package design, specific design criteria are provided for the waste package and the waste form. The amount of explosive, pyrophoric, and chemically reactive materials and the quantity of free liquids are limited to the extent that the performance of the waste package will not be compromised. The radioactive waste is to be in solid form, and the availability and generation of particulates is to be limited. There are also criteria covering requirements for handling and identification of the waste packages.

Technical background and licensing strategy

This issue involves the actual development of the waste package designs and the integration of the designs into the repository system. Highly radioactive wastes are received at the repository surface facilities where they are handled and processed for disposal. The wastes are placed in containers to produce waste packages that then must be handled and emplaced in the underground facilities. These operations continue while the underground facilities are filled over a period of several years. Requirements and constraints are placed on the waste form, the container, and the waste package assembly during this preclosure period. It is important that containment of the waste is maintained both during processing and after emplacement. During this period, it is also important that the waste form and container are not subjected to conditions that could impact their performance during the postclosure period.

Issue 2.6 is closely related to Issues 1.10 (waste package characteristics--postclosure) and 4.3 (waste package production technologies). The tasks to be undertaken for these three issues are closely related to issues discussed in several other sections of this document. Requirements and constraints are imposed on the waste package designs by the postclosure regulatory performance objectives for containment and for releases from the engineered barrier system. The performance issues that address these objectives (Issue 1.4, waste package containment, and Issue 1.5, engineered barrier system release rates) provide the properties of the waste forms and container materials that are needed to design the packages. The waste package designs are closely coupled to the repository designs because the repository must accommodate the fabrication, assembly, emplacement, and disposal of the waste packages.

In one important respect, the division of the waste package design issues into preclosure and postclosure categories is somewhat artificial. Although the requirements and constraints on the package designs differ for the two time frames, there will only be one set of package designs. After emplacement, the environment that the packages will experience does not strongly depend on whether the repository is operational or closed.

The approach used in resolving this issue involves combining the requirements of Issue 2.6 with those of Issue 1.10 and developing a consolidated design. Specific features of this design are then evaluated for consistency with the performance requirements of these issues. In this framework, the design criteria and constraints that are derived within Issue 2.6 from the preclosure functional requirements through the performance allocation process are consolidated with the requirements and other design inputs developed in Issue 1.10 (Section 8.3.4.2). An integrated document, the waste package design requirements document, will be compiled and will provide the definitive guidance for development of the designs.

A significant product of the waste package design effort will be the specification of the production processes to be used in the fabrication, closure, and inspection of the containers. A direct supporting element to the design process is therefore identified separately in Issue 4.3 (Section 8.3.4.4), where the evaluation and testing of these production technologies are described.

The performance allocations to the system elements for resolution of Issue 2.6 are defined in Table 8.2-27 which lists the major preclosure functions or characteristics that are derived from the regulatory criteria. Information on the physical characteristics of the spent fuel and high-level waste that is to be accepted into the disposal system will be provided to the NNWSI Project by other elements of the DOE Office of Civilian Radioactive Waste Management (OCRWM) in the form of waste acceptance specifications, receipt rate projections by waste type and characteristics, and other descriptions. Information on other materials used in the waste package will be obtained from published sources or through various tests.

None of the information needed to address the preclosure waste package design criteria mentioned previously requires the acquisition of site characterization data, as it primarily involves information about, or restrictions on, the waste forms and specific criteria for characteristics of the waste packages. Therefore, no site specific parameters have been identified for characterization. The following nonsite-related parameters must be addressed in the design as required by 10 CFR 60.135:

1. Explosive, pyrophoric, and chemically reactive materials.
2. Free liquids.
3. Containment during transportation, emplacement, and retrieval.
4. Unique identification.

An analysis of the designs, including the waste forms, and the repository operations will be required to show that classes of materials in items 1 and 2 will not be present or, if present, the quantities will not exceed the criteria. An analysis of the containment capability of the waste packages under both normal and abnormal loads will be performed. Also, an assessment of the alternatives available for complying with the identification requirement and an analysis of the selected method will be performed.

Table 8.2-27. Performance allocation for Issue 2.6 (preclosure waste package characteristics)

System element	Function or characteristic	Performance measure
Waste package	Contain waste during repository operations	Fraction of containers intact at end of preclosure
	Limit potential criticality in waste packages	Effective neutron multiplication factor
	Provide unique identification of packages	Identification legible at end of preclosure
Waste form	Comply with Nuclear Regulatory Commission criteria for acceptance	Waste form characteristics
Container	Capable of being handled by repository systems	Package handling fixtures

8.2.2.2.2.2 Summary for repository design criteria for radiological safety-- 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?

Regulatory background

The regulatory bases for addressing Issue 2.7 (Section 8.3.2.3) arise primarily from two sources: (1) 10 CFR Part 60 provides the repository design criteria, in Sections 60.131 through 60.133 and (2) Issues 2.1, 2.2, and 2.3, which address radiological exposures to the workers and public under normal and accident conditions, impose criteria upon the design of the repository as a result of EPA, NRC, and DOE-imposed limits on the exposures to the public and workers. These two bases for Issue 2.7 will be treated individually in the discussions that follow.

In 10 CFR Part 60, the NRC has laid out design criteria for the geologic repository, which are found in Sections 60.130 through 60.135. In addition to the brief statement of the general scope of the design criteria given in 60.130, the sections of particular importance to design of surface and underground facilities with respect to radiological safety, containment, and waste isolation are 60.131 through 60.133. Section 60.134 addresses the design

criteria for shaft and borehole seals which are not part of the underground facility or the engineered barrier system; these criteria are addressed by Issue 1.12 (Section 8.3.3.2). Section 60.135 addresses design criteria for the waste package, which are covered under Issue 2.6 (Section 8.3.4.3). General design criteria for the geologic repository operations area are given in 10 CFR 60.131. This section covers two main topics: (1) methods of radiological protection and (2) systems, structures, and components important to safety. Additional design criteria for the surface facilities are given in 60.132, and additional design criteria for the underground facilities are given in 60.133.

Technical background and licensing strategy

Not all the design criteria stated in these sections are related to preclosure radiological safety; some are related to postclosure containment and isolation. Therefore, not all these design criteria are addressed in Issue 2.7. The division of responsibility and relationships between the design issues are described in Section 8.3.2.1 (see Figure 8.3.2.1-1), and the specific issues responsible for addressing each criterion stated in 10 CFR 60.131 through 60.133 are presented in Table 8.3.2.3-1. In addition, the table also indicates which criteria require site parameters to accomplish the design and analyses needed to address the criteria. Only those criteria that result in the need for site data will be addressed in detail in the SCP. A full consideration of all criteria, as well as the plans to account for all criteria in the design of the repository, will be provided in the repository design plan.

This issue is concerned with the features (i.e., characteristics and configurations) of the repository that relate to radiological safety. These features consist of a subset of the total set of engineered systems and components that make up the repository. The features also address some aspects of the natural setting (i.e., the site) by accounting for the impact of these aspects on the engineered systems and components. For example, the presence of radon in the rock at the site, and its release into the mined openings, should be accounted for in the design of the ventilation system.

The role and responsibilities of this issue in addressing the features of the repository related to radiological safety must be placed in context with the roles of other issues. An illustration of the relationship of Issue 2.7 to the other issues with which it is directly tied is illustrated in Figure 8.3.2.1-1. That figure defines the ties among these issues by indicating what major information items are transferred, as well as the connection of these issues with the site characterization program. A strong tie between Issue 2.7 and Issue 4.4 is indicated and, in particular, the reliance of Issue 2.7 upon Issue 4.4 for development of the design and supporting analyses is depicted.

This issue requires that the repository design incorporate the general design criteria specified in 10 CFR 60.131 through 60.133 such that the preclosure performance objectives identified in 10 CFR 60.111 can be met. The general objective of these criteria is to ensure that the geologic repository operations area will be designed in such a way that the general public and repository workers are adequately protected from both routine and

accidental releases of radioactive material during repository operation, including retrieval operations. The primary means of resolving this issue is by reflecting the preclosure design criteria of 10 CFR 60.131 through 60.133 in the design of the geologic repository operations area and by demonstrating through analyses that the performance objectives of 10 CFR 60.111 will be met. As stated in 10 CFR 60.130, the design criteria specified in 10 CFR 60.131 through 60.133 are a minimum set. Other design criteria that are consistent with and compliment the criteria in 10 CFR 60.131 through 60.133 could be specified. The information needed to resolve this issue is primarily design information. Very little site characterization data is required to perform the design functions of this issue. Site data that is required pertains mainly to the identification of design-basis accidents and to the use of the properties of the site to aid design features in enhancing radiological safety. The resolution of Issue 2.7 will be complete when it has been demonstrated that each item listed in 10 CFR 60.131 through 60.133 has been adequately addressed in the license application design. The analysis of additional design features will provide added assurance of radiological safety beyond the regulatory requirements. Note that Issue 2.7 will ensure that radiation safety design criteria are met while Performance Issues 2.1 through 2.3 will ensure that regulatory limits are met.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals. These goals directly result from a preliminary performance allocation concerned with the preclosure radiological design criteria of 10 CFR 60.131 through 10 CFR 60.133. The licensing strategy is based upon the evaluation of aspects and safety features in the design of specific facility features of the geologic repository operations areas. These aspects are grouped into five general categories, referred to as functions in the following text, that the design is expected to achieve in order to comply with the intent of the preclosure design aspects of 10 CFR 60.131 through 10 CFR 60.133. Issue resolution corresponds to acceptance of the arguments in support of compliance by the NRC.

The five functions that the geologic repository operations area facilities must perform in order that this issue be resolved were selected such that there is a direct correlation between the functions and the preclosure design criteria of 10 CFR 60.131 through 60.133. The functions are (1) radiation protection, (2) design and protection of structures systems and components important to safety, (3) criticality control, (4) compliance with mining regulations, and (5) waste treatment.

A complete logic diagram of the iterative design and assessment process required to obtain resolution of this issue may be found in Section 8.3.2.3. A portion of this process, the performance allocation, is responsible for the repository functional groupings just mentioned. The activities or processes required to perform these functions and the measures that will be used to assess the level of success in performing the functions have been identified through the performance allocation process. Goals for the testing program, in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue, were

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also identified. Identification of the processes and measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

The first major function of the repository design is radiation protection. Radiation protection is further subdivided into ten subfunctions (Table 8.2-28). These subfunctions are derived from 10 CFR 60.131 through 60.133 design criteria, and they are the necessary functions of radiation protection. The first two subfunctions include limiting concentrations of radioactive materials in air and limiting the time required to perform work in the vicinity of radiation sources. The measures used to assess these subfunctions are the predicted and measured concentrations of radioactive material in air, time to perform tasks, and doses to workers in the vicinity of radiation sources. Another necessary subfunction is to provide shielding for workers to protect them from direct radiation exposures. Measures of this subfunction include dose reduction factors and radiation attenuation factors.

An important subfunction of radiation protection is to monitor and control the dispersal of radioactive contamination. This can be accomplished in various ways, including the use of stationary monitors, portable monitors, personnel dosimeters, access control mechanisms, ventilation control and cleanup methods, decontamination procedures, and the collection and treatment of waste generated onsite. Measures used to assess radiation control and monitoring include measured contamination levels and personnel doses.

Radiation alarm systems are to be provided both for the workers and worker areas and for the repository effluents. These alarm systems will alert workers to levels of radiation in work areas or repository effluents that exceed established design levels. The alarms will be both visual and audible. Measures for alarm systems include accuracy, reliability, and noticeability (both visibility and loudness).

Ventilation systems that protect against radiation exposure are also to be provided in the repository facilities. This can be accomplished by providing separate ventilation systems for waste-handling areas and non-waste-handling areas both on the surface and underground. If necessary close-capture ventilation system can be provided in areas where the potential to generate airborne radionuclides exists. Ventilation filtration is a standard method of ensuring clean air and decontaminating airstreams, and filtration will be used where prudent. Another method of controlling exposure through ventilation is to design flow pattern such that potential contamination is always carried away from personnel.

All of these subfunctions and some others are necessary to perform the major function of radiation protection. Table 8.2-28 contains a more detailed list of these subfunctions along with their required processes or activities and their performance measures.

The development of the conceptual design has led to identifying numerous means of limiting releases. For the surface facilities, these include compartmentalization of surface facility operations, design of hot cells for negative-pressure operation, shielding selected operations, and zoned ventilation systems in the surface buildings. In addition, filtration

Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 1 of 5)

Subfunction	Process or activity	Performance measure
Limit concentrations of radioactive materials in air	Monitor concentrations of radioactive material in repository airstream	Concentrations of radioactive materials in repository air-streams
	Filter exhaust air from potentially contaminated areas	Concentrations of radioactive materials in repository air-streams
	Maintain gaseous radionuclides in repository airstreams below acceptable levels	Concentration of radioactive materials in repository air-streams
Limit time required to perform work in the vicinity of radioactive materials	Limit time of occupancy for tasks in radiation field greater than 0.5 mrem/hr	Time required to perform tasks in radiation fields greater than 0.5 mrem/hr
	Provide remote-handling capability for long-term task in radiation fields greater than 0.5 mrem/hr	Dose reduction due to use of remote-handling equipment
Provide suitable shielding materials	Provide shielding to reduce radiation fields to below 0.5 mrem/hr in normally occupied work areas	Radiation fields in normally occupied work areas
	Use shielding properties of the host rock in limiting exposure of workers to direct radiation	Dose reduction factor attributable to host rock shielding properties

Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 2 of 5)

Subfunction	Process or activity	Performance measure
Monitor and control the dispersal of radioactive contamination	Monitor contamination by using stationary radiation monitoring systems	Contamination levels outside of contamination areas
	portable radiation monitors	Contamination levels outside of contamination areas
	personnel dosimetry	Contamination on personnel
	Control dispersal of contamination by	
	providing access control to potential contamination areas	See access control function
	providing ventilation control and cleanup of airstreams	See ventilation functions
	decontamination of contaminated items	Residual contamination
	collection of site-generated waste	Residual contamination due to site-generated waste

Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 3 of 5)

Subfunction	Process or activity	Performance measure
Control access to high radiation areas	Provide signs and personnel barriers to prevent access by unauthorized personnel	Visibility of signs Distribution and location of signs Effectiveness of personnel barriers
	If necessary, provide guards to prevent access by unauthorized personnel	Effectiveness of guard
	Provide procedural requirements to control access to high radiation areas	Effectiveness of procedures
Provide radiation alarm systems for work protection	Provide visual alarm systems to alert workers if radiation levels exceed established design levels	Visibility of alarm systems Accuracy and reliability of alarm system
	Provide audible alarm systems to alert workers if radiation levels exceed established design levels	Loudness and noticeability of alarm Accuracy and reliability of alarm system
Monitor and control radioactive materials in repository effluents	Detect radioactive materials in repository effluent	Ability to detect radioactive materials in repository effluent streams

Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 4 of 5)

Subfunction	Process or activity	Performance measure
	Detect radioactive materials in repository effluent streams	Ability to control radioactive materials in repository effluent streams
Provide radiation alarm systems for repository effluents	Provide visual alarm systems to alert workers if radiation levels in effluents exceed established design levels	See worker radiation alarm function
	Provide audible alarm systems to alert workers if radiation levels in effluents exceed established design levels	See worker radiation alarm function
Provide safe handling and temporary storage of waste whether awaiting emplacement or being retrieved	See function to limit work time in vicinity of radioactive materials	See function to limit work time in vicinity of radioactive materials
	See function to provide suitable shielding	See function to provide suitable shielding
	Maintain combined individual worker doses from all sources of radiation below annual design objective	Combined annual individual worker doses from all sources of radiation

Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 5 of 5)

Subfunction	Process or activity	Performance measure
Provide repository facility ventilation systems that will protect against radiation exposure	Maintain airflow in direction from areas of lower contamination potential to areas of higher contamination potential	Pressure differentials between radiation zones Potential for accidental flow reversals Flow rate in high contaminated areas
	Separate ventilation systems of surface waste-handling areas and other surface areas	Leakage between systems Pressure differential between separate systems
	Separate ventilations systems of underground waste-handling and emplacement areas and mining development areas	Leakage between systems Pressure differential between separate systems
	Provide close-capture ventilation exhaust systems when necessary	System capture efficiency
	Filter airstream and exhausts when necessary	Decontamination factor (DF) Number of filter banks
	Flow pattern of ventilation should direct potential contamination away from personnel	Flow patterns of ventilation system

systems for gaseous effluents, strippable wall coatings in selected areas, removable liners from selected equipment, and automated systems where possible are used in the current design. Placement of the waste-handling building and its effluent exhaust systems has considered the prevailing wind direction as a means of limiting contamination of other surface facilities. Access control is also provided for the surface facilities. Collection and treatment of site-generated waste is reflected in the current design as are specified areas for decontamination activities.

Ventilation systems and design are the primary means of limiting releases in the underground facilities. In the ventilation system, filters are provided on the underground exhaust building, and a positive-pressure differential will exist between the development and waste emplacement areas to ensure leakage is always toward the emplacement side. For the equipment program, shielding is installed in the transporter cask, transporter cab, and shield plugs designed for the waste emplacement boreholes. Additionally, speed limitations and braking criteria have been established for the transporter as a means of limiting the consequences of potential accidents. Assess control is provided.

Many of the planned repository operations have established means of limiting releases. For example, operations are sequenced so that workers should not be consistently downstream from waste emplacement operations. Similarly, airflow related to muck removal from the development area will be exhausted along the tuff ramp, thereby having minimal potential for ingestion by workers. Extensive inspections are planned for waste upon arrival and during processing. Where possible maintenance operations are being designed to be conducted outside the hot cells, although some maintenance will require using remote systems.

The second major function of the repository is the design and protection of structures, systems, and components important to safety (Table 8.2-29). Structures, systems, and components important to safety must be protected from a number of events, including natural phenomena, environmental conditions, dynamic effects of equipment failures, fires, and explosions. This can be accomplished by designing housing structures, systems, and components important to safety in buildings or structures (1) to withstand credible natural phenomena and environmental conditions, (2) to withstand the dynamic effects of equipment failures and similar events, (3) with fire and explosion detection and suppression systems, and (4) to respond adequately to design-basis accidents. The design of structure, systems, and components important to safety must also provide for the (1) maintenance of control of radioactive materials, (2) prompt termination of unessential operations, and (3) evacuation of personnel during emergencies. During emergencies, utilities that are important to safety must be able to continue their safety functions during emergencies, and timely backup power must be available for structures, systems, and components important to safety. Finally, structures, systems, and components important to safety must be designed to facilitate inspection, testing, and maintenance. The processes and activities necessary to perform all these functions and performance measures for these functions are shown in Table 8.2-29.

Table 8.2-29. The subfunctions, processes or activities, and performance measures involved in providing the function of design and protection of structures, systems and components important to safety (Issue 2.7, repository design criteria for radiological safety) (page 1 of 3)

Subfunction	Process or activity	Performance measure
Protect structures, systems, and components important to safety against natural phenomena and environmental conditions	Structures, systems, and components important to safety are housed in buildings designed to withstand credible natural phenomena and environmental conditions	Effects of credible natural phenomena and natural conditions on structures, systems, and components important to safety
Protect structures, systems, and components important to safety against dynamic effects of equipment failure and similar events	Structures, systems, and components important to safety are housed in structures designed to withstand dynamic effects of equipment failures and similar events	Response of structures, systems, and components important to safety to dynamic effects of equipment failure and similar events
Protect structures, systems, and components important to safety against fires and explosions	Structures, systems, and components important to safety are housed in structures with fire and explosion detection and suppression equipment	Effects of fires, explosions, and suppression systems on structures, systems, and components important to safety
Ensure that structures, systems, and components important to safety will maintain control of radioactive materials, permit prompt termination of operations, and allow evacuation of personnel during emergencies	Structures, systems, and components important to safety are designed to maintain control of radioactive material during emergencies	Maintenance of control of radioactive material during design-basis accidents

Table 8.2-29. The subfunctions, processes or activities, and performance measures involved in providing the function of design and protection of structures, systems and components important to safety (Issue 2.7, repository design criteria for radiological safety) (page 2 of 3)

Subfunction	Process or activity	Performance measure
Ensure that structures, systems, and components important to safety will maintain control of radioactive materials, permit prompt termination of operations, and allow evacuation of personnel during emergencies	Structures, systems, and components important to safety are designed to permit prompt shutdown of nonsafety related operations during an emergency	Time to shutdown nonsafety related operations during all design-basis accidents
	Structures, systems, and components important to safety are designed so that they facilitate the evacuation of personnel from the repository during an emergency	Effects of structures, systems, and components important to safety on evacuation of personnel during design-basis accidents
Ensure that utilities important to safety will continue their safety functions during emergencies	Utilities important to safety are designed to continue their safety functions during conditions anticipated during an emergency	Ability of utilities important to safety to continue safety functions during all design-basis accidents
Ensure that structures, systems, and components important to safety will facilitate inspection, testing, and maintenance	Structures, systems, and components important to safety are designed to facilitate inspection, testing, and maintenance	Complexity of inspection operations for structures, systems, and components important to safety
		Complexity of testing operations for structures, systems, and components important to safety

Table 8.2-29. The subfunctions, processes or activities, and performance measures involved in providing the function of design and protection of structures, systems and components important to safety (Issue 2.7, repository design criteria for radiological safety) (page 3 of 3)

Subfunction	Process or activity	Performance measure
		Complexity of maintenance operations for structures, systems, and components important to safety
Provide timely backup power to structures, systems, and components important to safety when needed and during emergencies	Design power systems with backup power capability (diesel generators or other suitable means)	Capacity of backup power supply Time for backup power supply to become operable
Provide instrumentation and control systems to monitor and control structures, systems, and components important to safety for all anticipated ranges of operation	Design structures, systems, and components with instrumentation and control system	Range of operation of monitoring instrumentation Range of operation of control instrumentation Ability to control structures, systems, and components important to safety

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The third major function of the repository design relevant to radiological health and safety is criticality control (Table 8.2-30). Three main factors can be used to control criticality. The first, and easiest to manipulate, is geometry. The geometry in which the spent fuel is placed in containers, stored, and emplaced can be easily dictated by design, and so configurations unfavorable to criticality can be maintained. The second factor is critical mass or total fissile content. A critical mass is the smallest amount of fissile material that could attain criticality under the most favorable conditions. If assemblies and containers are kept below a critical mass, then a criticality incident is not possible. In many instances, however, the critical mass may be too small to be practical; therefore, in general, combinations of factors affecting criticality are used to ensure that a criticality incident is not possible. The third factor used to control criticality is neutron moderation (slowing down neutrons to speeds where the fission reaction is possible). Light (low atomic weight) materials such as water or graphite are used to moderate neutrons. Controlling the introduction of these light materials into waste arrays is an effective way of controlling criticality.

Another way to control criticality events is by introducing neutron absorbers into the waste arrays. This is the same principle that is used to control power reactors. Reactor control rods are simple neutron absorbers that "steal" neutrons from the fuel and shut off the fission reactions. This method of control is not currently under consideration; however, it will be considered if such measures are needed. The processes and activities necessary to maintain criticality control are contained in Table 8.2-30.

Compliance with the relevant mining regulations is the fourth major function of the repository mentioned earlier (Table 8.2-31). 10 CFR 60.131(b)(9) requires that the repository design "include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended safety functions." This means that those workers that are assigned specific safety functions must be able to perform those functions, and if protection is required, it must be provided. Those workers that do not perform assigned safety functions are evacuated during emergencies and therefore do not require protection beyond that normally provided.

The final major function of the repository is waste treatment. There are three basic activities associated with waste treatment: (1) collection of site-generated waste, (2) treatment and stabilization of collected waste, and (3) packaging of treated site-generated waste for disposal. These activities along with their performance measures are contained in Table 8.2-32.

More details about the performance allocation for Issue 2.7, including tentative goals for performance measures, parameters needed to evaluate performance measures, goals, and expected values of these parameters, are contained in Section 8.3.2.3.

Table 8.2-30. The subfunctions, processes or activities, and performance measures involved in the criticality control function (Issue 2.7, repository design criteria for radiological safety) (page 1 of 2)

Subfunction	Process or activity	Performance measure
Criticality control	Maintain control of geometry of waste configurations in all phases of waste handling and disposal	Geometry of waste storage arrays
		Geometry of waste package configurations
		Geometry of emplaced waste
		Possibility of accidental disruption of waste geometry leading to unfavorable configuration
	Maintain subcritical assemblies and masses of fissile material in all phases of waste handling and disposal	Mass/fissile content of waste storage arrays
		Mass/fissile content of waste package configuration
		Possibility of accidental disruption of waste leading to unfavorable concentrations of fissile materials
	Control the introduction of any neutron moderating materials to waste containing areas	Moderating materials in or around waste storage arrays
		Moderating materials in or around waste package configurations

Table 8.2-30. The subfunctions, processes or activities, and performance goals involved in the criticality control function (Issue 2.7, repository design criteria for radiological safety) (page 2 of 2)

Subfunction	Process or activity	Performance measure
Criticality control (continued)		Moderating materials in or around emplaced waste
		Possibility of accidental introduction of moderating materials into areas containing waste
	Neutron multiplication	K_{eff} of fissile materials

Table 8.2-31. The subfunctions, processes or activities, and performance measures involved in providing the function of compliance with mining regulations (Issue 2.7, repository design criteria for radiological safety)

Subfunction	Process or activity	Performance measure
Compliance with mining regulations	Protection of workers who perform assigned safety functions	Ability of workers to perform assigned safety function

Table 8.2-32. The subfunctions, processes or activities, and performance measures involved in providing waste treatment function (Issue 2.7, repository design criteria for radiological safety)

Subfunction	Process or activity	Performance measure
Waste treatment	Collect secondary site-generated generated radioactive waste handling areas	Fraction of site-generated waste collected
	Treat and stabilize or recycle secondary site-generated waste collected	Fraction of site-generated waste treated and stabilized or recycled
	Package treated and stabilized secondary site-generated waste for disposal offsite	Fraction of treated and stabilized site-generated waste packaged

8.2.2.3 Key Issue 4

8.2.2.3.1 Performance issues for Key Issue 4

- 8.2.2.3.1.1 Summary of the ease and cost of higher-level findings -- 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?

Regulatory background

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, 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 DOE Implementation Guidelines (10 CFR 960.3) describe the manner in which the siting guidelines must be addressed during the siting process.

Issue 4.1 (discussed in Section 8.3.5.7) is concerned with the DOE's preclosure guidelines that relate to ease and cost of construction. These guidelines consist of a system guideline and four technical guidelines. The system guideline is concerned with the technical feasibility and relative cost of siting, constructing, operating, and closing a repository at a given site. Specific concerns are (1) whether special engineering measures beyond those provided by reasonably available technology may be necessary for repository construction, operation, and closure, and (2) whether the cost of repository construction, operation, and closure may be unreasonable in comparison with other repository siting options if a large number of special measures are necessary for these phases. Each technical guideline is concerned with the effect of some specific aspect of site conditions on the concerns expressed in the system guideline. Each technical guideline has one qualifying condition that must be met for a site to be acceptable. In addition, three of the technical guidelines have a 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 benefit or adversely affect the ease or cost of constructing, operating, or closing a repository.

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. There are four levels of findings (Table 8.2-14). 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 (Levels 1 and 3). Higher-level findings must be made to determine if a site may be recommended for the development of a repository (Levels 2 and 4). Thus, 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.

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 Overview of the Guidelines section of the Supplementary Information (DOE, 1984c) for 10 CFR Part 960, 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.

Technical background and issue resolution strategy

To resolve Issue 4.1, sufficient evidence must be available to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with ease and cost of repository siting, construction, and operation. Each of the qualifying conditions references requirements for technical feasibility based on reasonably available technology and reasonable costs relative to other siting options. In making higher-level findings for the qualifying and disqualifying conditions, specific aspects of the geologic setting must be considered in the evaluations of these requirements.

The findings that have been made previously for the qualifying and disqualifying conditions related to ease and cost, and the evidence supporting these findings, are given in the NNWSI Project environmental assessment (DOE, 1986b). The available evidence was sufficient to support a positive lower-level finding for each of the qualifying and disqualifying conditions. To determine if the Yucca Mountain site is suitable for the development of a repository, therefore, higher-level findings must be made for the qualifying and disqualifying conditions.

The information necessary to support higher-level findings will be made available through the resolution strategies of other issues. For each condition, available evidence is evaluated to determine if it is sufficient to support a higher-level finding for any of the conditions. For the qualifying and disqualifying conditions for which there is not sufficient evidence available, the planned site characterization studies are reviewed to determine if the concerns of the conditions will be investigated. This is accomplished by evaluating the resolution strategies of Issues 4.2 through 4.5, the preclosure design issues that are relevant to the evaluation of Performance Issue 4.1. If the concerns of the conditions are being considered in the resolution strategies of the other issues, the evidence to support higher-level findings for these conditions should be available.

8.2.2.3.2 Design issues for Key Issue 4

- 8.2.2.3.2.1 Summary of nonradiological health and safety -- Issue 4.2: Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues?

Regulatory background

Issue 4.2 (discussed in Section 8.3.2.4) is concerned with those aspects of underground facility design that have an implication for the preclosure nonradiological health and safety of repository workers. The DOE, in the preclosure system guideline for ease and cost of repository development (10 CFR 960.5-1(a)(3)), requires a demonstration that repository construction, operation, and closure be technically feasible. The technical guidelines related to this system guideline require that the characteristics and conditions at the site do not necessitate the use of engineering measures beyond the bounds of reasonably available technology for repository development and protection of worker safety. The strategy for resolving this issue considers worker nonradiological health and safety to be a significant element in the demonstration of feasibility using reasonably available technology.

Technical background and licensing strategy

Although not cited in the DOE guidelines that are the basis for this issue, the NRC requires, in 10 CFR 60.131, that the design of the geologic repository operations area should include provisions for worker protection adequate to ensure that structures, systems, and components important to safety can perform their intended functions. For the underground facility, such provisions are to comply with Mine Safety and Health Administration (MSHA) regulations for mine safety. The question of worker nonradiological health and safety in 10 CFR 60.131 is strictly concerned with how such safety measures can provide reasonable assurance that all systems, structures, and components important to safety can perform their intended functions. The DOE and the MSHA have signed a memorandum of understanding (dated December 23, 1986) to formalize a working arrangement whereby the MSHA will assist the DOE by inspecting repository operations so that the DOE can implement its policy of compliance with MSHA standards as though the repository were a commercial mine.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals. These goals are the direct result of a preliminary performance allocation concerned with the preclosure nonradiological health and safety design criteria. The licensing strategy is based upon evaluating the functions of repository design that are relevant to preclosure nonradiological health and safety. Nine general groupings of functional requirements for the repository design have been identified in order to ensure compliance with the intent of the preclosure nonradiological safety concerns of the DOE guidelines for ease and cost of repository development.

The resolution of this issue requires that designs and operating procedures that ensure worker nonradiological health and safety during the pre-closure period be selected and implemented. Certain aspects of the designs must also be demonstrated to verify that the design approach produces designs that are safe. Design aspects that must be demonstrated are related to the designs of the underground system elements located within the underground areas heated by the emplaced waste; this heating presents a unique design environment. The overall design process is described in Issue 4.4.

The relationship of Issue 4.2 to Issue 4.4 is graphically described in Figure 8.3.2.1-1. In Issue 4.2, those aspects of the overall design that impact worker health and safety are defined, goals necessary to meet the regulatory requirements are designed, and the design goals are transmitted to Issue 4.4 for incorporation into the overall design.

The goal of Issue 4.4 is to ensure that the design, construction, and operation of the repository can be accomplished with reasonably available technology. The implication of Issue 4.4 is that the repository will be able to draw upon an existing experience base in the design and the development of procedures for ensuring worker nonradiological health and safety. To this end, Issue 4.2 will draw upon regulatory requirements to establish goals for the design and operation to ensure worker health and safety. These goals will be imposed on Issue 4.4 in the form of requirements and constraints on the overall design and operating procedures.

The nine general groupings of functional design requirements address specific elements of the mined geologic disposal system at Yucca Mountain. The specific system elements of concern are drifts and access, emplacement boreholes, retrieval, mining and waste ventilation, nonradiological monitoring, maintenance, and underground closure. The functions and processes that the various system elements must accomplish are frequently similar for several system elements. Accordingly, the relevant aspects of the site characteristics and licensing strategy that are presented in the following text often address groups of system elements.

The major factors that impact worker safety are associated with the underground facilities. These factors are opening stability and ventilation. At the Yucca Mountain site, ground-water inflow sufficient to cause a worker safety problem is not expected (Issue 4.8, Section 8.3.1.16). The natural rock temperature at Yucca Mountain does not present a concern, but the rock temperatures and hence the work environment during retrieval could be of concern. Equipment-related accidents should not be caused by restrictive site conditions. Accesses and drifts will be sized to allow adequate room for maneuvering of equipment without endangering personnel. To ensure rock stability, the characteristics of the rock must be known and a design procedure must be established to accommodate conditions expected in construction, waste emplacement, and waste retrieval.

Opening stability is an important aspect of access and drift construction, retrieval, and maintenance. The strata within which a repository at Yucca Mountain would be constructed have some characteristics that could be favorable with regard to opening stability. Chapter 6 describes the current conceptual design, and the rock support system that has been selected based on currently available data. Attributes of the site that are important to

the licensing strategy are reflected in that design. The repository construction would take place primarily in welded tuff that is relatively competent and jointed. The repository would be relatively shallow and neither high stresses, high temperature, and dangerous gases are not expected. The primary support system envisioned for the repository is rock bolts and wire mesh.

The goals of worker nonradiological health and safety are completely consistent with design goals to maintain stable openings with minimal maintenance for at least up to 84 years, should retrieval be necessary. Current NTS underground opening support practice includes a small amount of development in a welded fractured tuff that is similar in many respects to the horizon in which the repository would be constructed. The currently planned support system, with primary emphasis on rock bolts and wire mesh, is consistent with current NTS practice. Furthermore, the planned excavation support can be increased by adding extra or longer bolts and shotcrete.

An evaluation of potential excavation hazards to underground workers in a repository at Yucca Mountain was presented in the NNWSI Project environmental assessment (DOE, 1986b). That evaluation was based upon experience at the NTS in weapons-effect testing tunnels. The data presented by DOE (1986b) clearly indicated a significantly better safety record for NTS tunneling operations than is typical of commercial mining industry practice. NTS practice heavily emphasizes worker safety. It incorporates the concepts of MSHA, California Department of Mines safety orders, and DOE order 5480.4 on safety and uses the most stringent governing standards from these regulations. The weapons-effect tunnels at NTS are designed and constructed for long-term serviceability and stability. Information relevant to resolution of this issue will be developed with that relevant experience that can be drawn from existing NTS practice.

There are ventilation and induced-temperature concerns relevant to worker nonradiological safety and thus to resolution of this issue. The NRC in 10 CFR 60.133(g) requires a separation of the ventilation circuitry for the excavation and waste emplacement areas. The current conceptual design calls for the circuitry to be separate and to meet MSHA standards and ACGIH (American Conference of Governmental Industrial Hygienists) standards. The design goals for ventilation, with respect to worker nonradiological health and safety, include two independent systems for the underground ventilations facility, one for the waste emplacement operations area and one for the development area. Redundancy in the ventilation fans for each area is planned. In addition, a forcing circuit is planned for the development area, and an exhausting circuit is planned for the emplacement area. The pressure differential thus established should ensure that any leakage would be away from the development areas.

Temperature of the working environment is of concern for worker nonradiological health and safety. Current design goals directly address the question of temperature-induced rock stress and potential instabilities. Also, the design criteria introduced for retrieval considerations place temperature limits on the workings that directly relate to worker nonradiological health and safety.

More detail about the functions relevant to the issue resolution strategy for Issue 4.2 can be found in Table 8.2-33. For each system element, this table lists the functions and processes available to ensure that the functional requirement is accomplished. The performance allocation for Issue 4.2, as well as details on performance goals and relevant parameters, can be found in Section 8.3.2.4. Goals for the testing program, in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue are identified. Identification of processes, measures, and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

8.2.2.3.2.2 Summary for waste package production technologies -- Issue 4.3:
Are the waste package production technologies adequately
established for the resolution of the performance issues?

Regulatory background

Issue 4.3 (discussed in Section 8.3.4.4) arises from the provision of the preclosure system guideline for ease and cost of repository development 10 CFR 960.5-1(a)(3), which requires that repository operations shall be demonstrated to be feasible on the basis of reasonably available technology. The waste packages are a necessary element of repository operations and, therefore, must be technically feasible on the same basis.

Technical background and issue resolution

In addition to questions of technical feasibility, the processes selected for producing the waste packages affect the design of the packages, the design and operation of the repository surface facilities where they are assembled, and the performance of the packages after they are emplaced in the repository underground facilities. Rather than differentiate among technical feasibility, waste package and facility design, and waste package performance aspects of the production processes and describe the plans for each separately, the planned activities to provide information for all production-related requirements are addressed in this issue.

The waste packages consist of several components that must be fabricated and assembled according to requirements imposed to ensure containment of the waste form for 1,000 years. It is estimated that approximately 30,000 waste packages will be required to contain the 70,000 MTHM of waste to be emplaced in the first repository. Fabricating and assembling components in these quantities must be done with well understood and predictable techniques.

The parameters of Issue 4.3 involving fabrication technologies include process criteria definition, process identification, process testing and evaluation, process selection, and prototype fabrication and testing. Fabrication includes all processes required to produce the package components other than the waste form.

For a waste package using metal containers, the components include an internal basket, the container body, and a top closure. The processes to be

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety)

System element	Function and process	Performance measure
Access construction	Underground facility access and egress	<p>Safe access to underground facilities (usable access for 100 yr)</p> <p>Limit overbreak</p> <p>Limit blast induced fracture extent</p> <p>Access closure (combined performance of rock and opening support)</p> <p>Closure rate in shafts and ramps</p> <p>Total closure in ramps</p> <p>Total closure in shafts</p> <p>Maximum rock fall size (rockfall in ramps contained by support system)</p> <p>Average shaft liner space (all rockfall or liner spall to be retained (by supplemental support or liner system)(shafts))</p> <p>Acceptable maintenance frequencies</p> <p>Minor maintenance (continuing basis)</p> <p>Major maintenance frequency</p> <p>Access sizes and grades compatible with requirements for personnel and material transport and utility routing</p> <p>Waste ramp grade</p> <p>Tuff ramp grade</p> <p>Minimum diameter</p> <p>Roadway width</p> <p>Clearance between ramp or ramp equipment</p>

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Access construction (continued)	Underground facility access and egress (continued)	Tuff ramp diameter adequate for conveyor-movement of equipment
	Removal of broken rock	Compliance with 30 CFR 57 Clearance for rock removal equipment Presence of safety systems (conveyors) Barriers and guards Heat sensors Slack sensors Back run preventers Dust suppression
	Ventilation supply and exhaust	Pressure drops in accesses Accesses sized to limit air velocities and to accommodate future changes in air demands < 3,000 ft/min in shafts < 1,500 ft/min in ramps > 60 ft/min in all accesses
	Emergency egress	Compliance with 30 CFR 57 Accesses designed to provide safe egress during emergencies
Drift construction	Underground facility access	Safe and usable access for 100 yr Limit overbreak Limit blast-induced fracture extent
		Drift closure (combined performance of rock and opening support system) Rate of closure in mains and access drifts Rate of closure in waste emplacement drifts Total closure

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Drift construction (continued)	Underground facility access (continued)	Rockfall quantity and retention Maximum rock or slab size Rockfall retained by support system
		Acceptable maintenance frequencies Inspection and minor maintenance performed on a continuing basis
		Major maintenance frequencies
		Drift size and grades for personnel and material transport and utility routing Drift size wider than equipment Drift grades
	Removal of broken rock	Compliance with 30 CFR 57
		Adequate clearance
		Safety systems (conveyors) Barriers and guards Heat sensors Slack sensors
	Ventilation supply and exhaust	Dust control and suppression
		Pressure drop in drifts
		Drifts sized to limit air velocities and to cover changes in future air needs
	Emergency egress	
		Compliance with 30 CFR 57 Ventilated emergency escapeways present

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Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Borehole construction	Construct borehole	Compliance with 30 CFR 57 and ACGIH ² (1986) Air quality compliance with 30 CFR 57 and threshold limit values (TLVs) and bioindices specified in ACGIH (1986) Concentrations of SiO ₂ , O ₂ , CO, and radon daughters Personnel radon exposure Air cooling power
Mining ventilation	Provide adequate quantity of air to all work areas Provide quality air to all work areas	Air quantity compliance with 30 CFR 57 Adequate quantity Minimum air Air quality compliance with 30 CFR 57 and TLVs and bioindices specified in ACGIH (1985-86) Concentrations of SiO ₂ , O ₂ , CO, and radon daughters Personnel radon exposure Air cooling power
Retrieval	Provide access to emplacement borehole	Temperature in retrieval area Surface rock temperature in shafts and ramps Temperature in access drifts Air temperature during retrieval

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Retrieval (continued)	Provide access to emplacement borehole (continued)	Rock movement Rock and support movement in accesses Rock movement in access drifts Rock movement in emplacement drifts Total closure in shafts Total closure in ramps and drifts Rockfall in ramps and drifts Maximum rock or slab size Rockfall amount in shaft (all rockfall to be retained by support system) Maintenance Inspection and minor maintenance will be done on a continuing basis Major maintenance frequency
Waste ventilation	Air quality Cooldown of rock for reentry of emplacement drifts to perform heavy maintenance or retrieval	Air cooling power Rock surface temperature
Underground closure	Backfill of drifts and installation of post-closure seals	Temperature Air cooling power Rock surface temperature Air temperature Compliance with 30 CFR 57 and ACGIH (1985-86) Concentrations of SiO_2 , O_2 , CO , and radon daughters Personnel radon exposure

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Maintenance	Access (shaft and ramps) maintenance	Closure and rockfall Rock movement Amount of rockfall Maximum rock or slab size (rockfall retained by support system)
	Drift maintenance	Usability for 100 yr Inspection and maintenance will be done on a continuing basis Major maintenance frequency
Nonradiological monitoring	Monitor usability of shafts, ramps, and drifts during construction, operation, retrieval, closure, and decommissioning	Items important to operational safety monitored and displayed in repository control center Temperature Rock movement Rock support system (visual) Air quality Water inflow Seismic activity

²ACGIH: American Conference of Governmental Industrial Hygienists.

used for assembling this waste package may include rolling, welding, casting, forging, extruding, heat treating, and nondestructive testing.

Since the performance of the waste package can be impacted by the production technology used, it is crucial that processes are selected that will minimize these impacts and that allow these impacts to be mitigated through proper treatment. Welding processes are particularly important in this regard. Proper resolution of this issue is considered of equal importance to the other waste package issues.

The approach to resolving this issue will involve a set of studies directed at identifying and evaluating production processes in each of the

technology areas. Selection criteria for each technology will be established. Candidate processes will be identified and evaluated against the selection criteria, and the leading candidate processes will be used to produce representative test specimens. These test specimens will be analyzed to determine their properties and the properties will be compared with the criteria derived from the performance requirements. Process selection will then be made on bases that will include performance, as well as other criteria such as reliability, adaptability to repository facility operations, and cost. The final step in the analyses will be the use of the selected processes to produce full-scale prototype components, assembly of these components, and testing of the prototypes to demonstrate both feasibility and compliance with the requirements.

- 8.2.2.3.2.3 Summary for preclosure design and technical feasibility --
Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?

Regulatory background

Issue 4.4 (discussed in Section 8.3.2.5) is concerned with the question of whether or not the repository can be designed, constructed, operated, and closed using reasonably available or proven technologies given the characteristics of the site. The regulatory basis for addressing this issue and its subsidiary information needs is expressed in the preclosure guidelines related to ease and cost of repository development.

Technical background and licensing strategy

Issue 4.4 questions whether the repository can be designed, constructed, operated, and closed using reasonably available or proven technology or whether it will be necessary to extrapolate beyond current techniques in order to perform the functions identified by this issue. An additional constraint imposed on this issue by Key Issue 4 is that the cost for construction, operation, and closing of the repository be reasonable.

In addition to consideration of design concerns related to the preclosure guidelines which are the basis for this issue, a decision has been made to make Issue 4.4 the focus for repository design activities. To serve this purpose, Issue 4.4 must be concerned with design constraints developed directly by and for resolution of the issue as stated; it must also be concerned with design and performance-derived design constraints developed under other issues, which address the performance and design criteria of 10 CFR Part 60. Postclosure design constraints developed under Issue 1.11 (configuration of underground facilities--postclosure) and Issue 1.12 (seal characteristics) are factored into the design developed under Issue 4.4. Similarly, preclosure constraints for worker and public radiological health and safety developed under Issues 2.1, 2.2, 2.3, and 2.7 and worker non-radiological health and safety considerations developed under Issue 4.2 are factored into the design developed under Issue 4.4. Additionally, retrieval objectives developed under Issue 2.4 are considered in the design developed under Issue 4.4.

The strategy for resolving this issue involves development of an evolving design that meets the design criteria, expressed as performance measures and associated goals developed jointly with several design-related issues. Those goals are the direct result of a preliminary performance allocation concerned with the design criteria of 10 CFR Part 60 and 10 CFR Part 960. The licensing strategy is based upon evaluations about the reasonable availability of technologies, consistent with the design goals being achieved. The conclusion that the repository can be constructed, operated, closed, and decommissioned using reasonably available technology will be based on the technology requirements for each system element. The technology requirements will be developed by a design process for the element that includes configuration determination, design analysis (requiring site or nonsite data), and material selection to meet the performance goals for that element. The assessment that the technology is reasonably available will be based on criteria that includes (1) the previous successful demonstration elsewhere of construction or design techniques, (2) the ability to demonstrate new technology applications before license application, and (3) combinations of empirical, observational, and analytical procedures to provide reasonable assurance of the success of the design.

The current conceptual design of the repository is described in Chapter 6. Relevant technical aspects of the design include development of the underground facility at relatively shallow depth (approximately 335 m) in a welded tuff formation. The relatively shallow depth permits ramp access to the repository horizon; separate ramps are currently planned for waste emplacement activities and construction activities. The ramps are augmented by shafts for ventilation, personnel and materials handling; separate ventilation circuits are planned for construction and waste emplacement activities. The repository horizon at Yucca Mountain would be in the unsaturated zone; ground water is not expected to be a major factor in facility construction. Additionally, the repository horizon is currently planned to slope toward the northeast, both to develop the repository in rock strata of expected similar properties and to enhance drainage away from waste packages should isolated zones of perched water be encountered. A relatively dry underground facility is expected to be conducive to lengthened waste package lifetimes. Previous excavation experience in tuff formations at the nearby Nevada Test Site lends confidence to the expectation that stable openings can be developed and maintained with reasonably available technology.

Twelve groups of functional requirements have been identified that are relevant to resolution of this issue. These functional requirements are associated with specific elements of the Yucca Mountain mined geologic disposal system. The specific functional requirements addressed in the design developed for resolving this issue originate, for the most part, in the issue resolution strategies for other issues. Issue 4.4, as has been pointed out previously, has as its primary responsibility the development of the repository design for a facility at Yucca Mountain. As such, it must incorporate the site specific postclosure design concerns of Issues 1.11, 1.12, and 1.10 (Sections 8.3.2.2, 8.3.3.2, and 8.3.4.2). Issue 4.4 must also address the site specific concerns of the issue resolution strategies of the design issues concerned with radiologic health and safety, specifically Issues 2.6 and 2.7 (Sections 8.3.4.3 and 8.3.2.3). Functional requirements originating from retrieval concerns (from Issue 2.4, Section 8.3.5.2) are also addressed in the design prepared for resolution of Issue 4.4. Finally,

functional requirements for the design originate in the issue resolution strategy for the nonradiologic health and safety issue, Issue 4.2 (Section 8.3.2.4). The relationships and interfaces between the various design issues are illustrated in Figure 8.3.2.1-1. That figure also illustrates the manner in which performance assessment related concerns are conveyed to Issue 4.4 for treatment in the design.

Information about the 12 functional areas relevant to the issue resolution strategy for Issue 4.4 can be found in Table 8.2-34. This table lists, for each system element, the functions and processes that are relevant to a viable repository design. The complete performance allocation for Issue 4.4, as well as details on goals for the performance measures and relevant parameters, can be found in Section 8.3.2.5.

8.2.2.3.2.4 Total system costs -- Issue 4.5: Are the costs of the waste packages and the repository adequately established for the resolution of the performance issues?

Regulatory background

To make the higher-level findings required for the related performance issue (Issue 4.1), the DOE must develop comparable cost estimates for construction, operation (including maintaining the retrieval option), closure, and decommissioning of a repository at the Yucca Mountain site and at each of the candidate sites that have been characterized. Cost estimates must also be developed for design and fabrication of the waste packages to be used at each site. Estimating costs for a specific site requires that the designs for the waste packages and repository be developed to a suitable level of detail, that the procedures for waste-package fabrication and for repository construction and operation be adequately identified, and that there be a model available to evaluate the associated costs. For the eventual comparative evaluation of costs to be valid, the basis for estimating the costs for each site must be similar.

Issue 4.5 addresses the need to provide the information necessary to satisfy the second requirement of the preclosure system guideline related to ease and cost of siting, construction, operation, and closure (10 CFR 960.5-1(a)(3)): the costs associated with repository siting, construction, operation, and closure shall be demonstrated to be reasonable relative to other available and comparable siting options. The results of this evaluation will support the requirement to make a higher-level finding for the qualifying condition of this system guideline for the Yucca Mountain site, and will be considered in selecting a site for recommendation for development as a repository. The comparative evaluation of costs will be based on waste package and repository designs developed to meet the applicable performance objectives and design criteria specified or referenced in 10 CFR Part 60. These designs must be deemed to be feasible on the basis of reasonably available technology and developed to accommodate those site characteristics identified in the related technical guidelines (10 CFR 960.5-2-8 to 960.5-2-11) that may affect design, and hence overall system costs.

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 1 of 8)

System element	Function and process	Performance measure
Surface	Provide sufficient area for surface facilities	Space to accommodate surface facilities (with contingency) Area for central surface facility Area for material storage Area for underground access location
	Provide usable access for waste delivery vehicles	Grades for rail and truck delivery Road grades Rail grades
	Provide facility sites (including underground accesses) that are not jeopardized by natural or man-made phenomena	Location above floodplain Location for surface facilities Important to safety (FITS) Not over potentially active geological structures Potential for vibratory ground motion Potential for volcanic eruption at surface facilities Design basis ash fall thickness at surface facility locations (including shaft and ramp portals)
	Provide facility sites (including underground accesses) that have acceptable soil and rock conditions	Soil and rock conditions under static and dynamic conditions Stable foundations on soil and rock under static load conditions (for FITS) Stable retaining walls on soil and rock under static load conditions Stable slopes for static and dynamic loading conditions Hydraulic related soil conditions Volume change in soils

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 2 of 8)

System element	Function and process	Performance measure
Surface (continued)	Protection and confinement of operational activities	Facilities adequate to withstand natural weather phenomena without damage to functional capability
	Provide proper environment for personnel and equipment	Proper environment for personnel and equipment under normal weather extremes Heating and cooling design values
Subsurface	Provide adequate area for distributing waste (with contingency) and required overburden	Area for 70,000 metric tons of waste and overburden >200 m
	Provide underground sites (including accesses) that are not jeopardized by natural or manmade phenomena	Sites for underground facilities Not located in areas of potentially active faults Potential for fault activity Potential for volcanic activities Acceptable potential for vibratory ground motion Levels of vibratory ground motion in underground facility Potential for volcanic eruption through underground facility
	Provide host rock thickness for drift construction and waste emplacement	Thickness for drift construction and waste emplacement
	Provide physical properties adequate for construction and operation of stable (safe) underground accesses, drifts, emplacement boreholes, and support facilities for normal and credible abnormal conditions	Usable openings of required size

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Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 3 of 8)

System element	Function and process	Performance measure
Subsurface (continued)	Dissipate heat from emplaced waste	Waste package temperature
	Provide adequate water for water for repository operations	Available water
Access construction	Underground facility access for personnel, support materials, waste-handling systems during construction, operation (including retrieval), and decommissioning	Accesses (shafts and ramps) usable for 100 yr with reasonable maintenance
		Compliance with 10 CFR 60.133f
		Limit overbreak
		Limit extent of fracturing of intact rock
		Access closure (combined performance of rock and opening support system)
		In accesses (shafts and ramps)
		Total closure in ramps
		Total closure in shafts
		Rockfall
		Amount
		Maximum size of rock or slabfall
		Rockfall contained by support system (ramps)
		No rockfall to disrupt or damage waste transporter (ramp)
		Rockfall or liner spall in shafts
		Maintenance frequency
		Inspection and minor maintenance done on continuing basis
		Major maintenance frequency

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 4 of 8)

System element	Function and process	Performance measure
Access construction (continued)	Underground facility access (continued)	Access sizes and grades compatible with requirements for personnel and material transport and utility routing Shaft diameter Waste ramp roadway width Vehicle clearance Clearance for conveyor, movement of equipment Waste ramp grade Tuff ramp grade
	Ventilation routing (supply and exhaust)	Pressure drop in shafts and ramps Shaft and ramp size Ramp air velocities Shaft air velocities
	Sealing	Shafts and ramps compatible with requirements for repository sealing Material type Construction methods capability to remove exploratory shaft-1 liner Penetration into Calico Hills Water storage capacity at base of shafts
Drift construction	Underground facility access for personnel, support materials, waste handling systems during construction, operation (including retrieval) and decommissioning	Drifts usable for 100 yr with reasonable maintenance
		Compliance with 10 CFR 60.133f Limit overbreak Limit extent of fracturing in intact rock Drift closure (combined performance of rock and rock support system) Rates in main and access drifts Rates in waste emplacement drifts Total closure

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Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 5 of 8)

System element	Function and process	Performance measure
Drift construction (continued)	Underground facility access (continued)	Rockfall (performance of rock support system)
		Quantity (rockfall contained by support system)
		Maximum size of rock or slab fall
		Disruption of or damage to waste transporter
		Acceptable maintenance frequency
		Inspection and minor maintenance on a continuing basis
		Major maintenance frequency
		Drift sizes and slopes compatible with requirements for personnel and material transport and utility routing
		Drift cross section size
		Drift grade
		Ventilation routing (supply and exhaust)
		Pressure drop in drifts
Borehole	Provide for emplacement	Drift size
		Drifts (underground layout) compatible with repository sealing
		Water drainage to designated locations
		Constructability of usable borehole for waste disposal envelope
		Borehole length
		Borehole diameter
	Provide waste emplacement envelope	Installation of borehole liner
Rock handling	Removal of mined rock	Ability to remove mined rock at rate of generation

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 6 of 8)

System element	Function and process	Performance measure
Water removal	Removal of process water	All process water removed Removal capacity
	Removal of natural water	Removal rate equal to rate of inflow Removal capacity
	Removal of water resulting from condensation in ventilation returns (potential during operations)	Removal rate equal to rate of condensation Removal capacity Potential rate of condensation
Mining ventilation	Supply quality air to working area (considering: temperature, humidity, dust content, and other pollutants)	Compliance with 30 CFR Part 57 Ventilation horsepower
		Compliance with threshold limit values and biological exposure indices specified in ACGIH ^a (1986) Air cooling power Quantity of air per worker Minimum air velocity in work areas Concentration of SiO ₂ , O ₂ , and radon daughters ² Personnel exposure to radon daughters
	Provide flexibility to allow changes in air quantities and routing	System design flexibility to allow changes in air quantities and routing
	Provide safe escape routes for work force	Ventilated escape routes available for all active work areas
	Provide independence between ventilation systems	Compliance with 10 CFR 60.133g Independence of systems Leakage from mining ventilation to waste emplacement ventilation system

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Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 7 of 8)

System element	Function and process	Performance measure
Emplacement	Transport waste to emplacement location	Ability to transport the required number of waste packages per day using methods which will ensure personnel safety Number of waste packages Compliance with ALARA Compliance with other requirements relating to worker radiation dose
Retrieval	Retrieval of emplaced waste	Access to emplacement borehole Access to waste package Rock temperature at borehole wall Borehole liner deformation Liner corrosion
	Waste retrieval	Retrieval time Emplacement time Construction time Operator safety Radiation dose rate
	Waste transport	Operator safety
Waste	Supply air to waste disposal areas during emplacement and retrieval	Compliance with threshold limit values and biological exposure indices specified in ACGIH (1985-86) Air cooling power Quantity of air per worker Minimum air velocity in work areas Concentration of SiO ₂ , O ₂ , and radon daughters Personnel exposure to radon daughters Air cooling power for retrieval preparation

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 8 of 8)

System element	Function and process	Performance measure
Waste (continued)	Radiological safety	Detection of airborne radioactive material
		Reduction and redirection of ventilation flows in the event that airborne radioactive particulate is detected
	Provide flexibility to allow changes in air quantities and routing necessary to accommodate changes in requirements	System design flexibility to allow changes in air quantities and routing
	Provide safe escape routes for work force	Ventilated escape routes available for all active work areas
	Provide independence between ventilation systems	Compliance with 10 CFR 60.133g Independence of systems Leakage from mining ventilation to waste emplacement ventilation system
Underground closure	Removal of repository structures	Compliance with requirements for decommissioning
	Installation of seals	Compliance with requirements for postclosure seals
	Installation of surface markers	Marker permanence
	Construction of diversion structures or water flow barriers	Construction according to sealing requirements
	Installation of backfill	Filling of all underground openings

^aACGIH = American Conference of Governmental Industrial Hygienists.

^bALARA = as low as reasonably achievable.

Technical background and issue resolution strategy

The requirement of the system guideline to estimate and compare the costs for repository siting, construction, operation, closure, and decommissioning for the various siting options was addressed in the environmental assessment (EA) for the Yucca Mountain site (DOE, 1986b). In that document, a preliminary, total-system life-cycle cost (TSLCC) estimate for a repository at the Yucca Mountain site was presented in Chapter 6 and compared with the TSLCC estimates made for the other nominated sites in Chapter 7. Updated TSLCC estimates for all nominated sites were used in the multiattribute utility analysis that led to recommendation of the three candidate sites for characterization (DOE, 1987d). In both instances, the estimates were developed, using the same methodology for each site, as part of the DOE's annual evaluation of the adequacy of the fee paid to the Nuclear Waste Fund to cover the costs of disposal services (DOE, 1985). These estimates were developed on the basis of the available preconceptual design information for the repository and waste package for each site and do not represent final cost estimates. The TSLCC estimate for the Yucca Mountain site was 8.5 billion 1984 dollars; the range of cost estimates presented in the EAs for the three sites selected for characterization was 8.5 to 12.3 billion dollars. These cost estimates have since been superseded by repository cost estimates prepared for the three recommended sites presented in annual reevaluations of the total system life cycle costs (DOE/RW-0047, 1986). The current TSLCC estimates combine the cost elements in a manner different from that used in the EAs. A detailed comparison of changes in the TSLCC estimates is beyond the scope of the SCP. The uncertainty assigned to these estimates is based on engineering judgment and is plus-or-minus 35 percent of the total cost. This uncertainty, coupled with a 10 to 40 percent contingency built into the estimate, reflects the preliminary nature of the design from which the costs estimates were derived.

The TSLCC estimates presented in the EA and those used in the multiattribute utility analyses were derived from evaluations of the two major cost components of the repository development program:

1. Development and evaluation (D&E) costs, which include costs for all activities, other than final design and construction that are conducted before the start of repository operation (e.g., siting, land acquisition, design development, testing, and regulatory and institutional activities).
2. Construction, operation, closure, and decommissioning (COCD) costs, which include costs for final design, construction, operation, and maintenance of repository facilities; for final design and fabrication of waste packages; and for closure and decommissioning of repository facilities.

Different methods were used to estimate the life cycle costs for each component. The D&E cost component for the Yucca Mountain site was derived from that portion of the total OCRWM Program D&E cost due to development work for the first repository. Cost estimates were developed on the basis of the most recent program budget projections available, the current schedule of program milestones, and a series of assumptions about the conduct of work activities throughout the D&E period. The portion of the first repository

D&E cost attributable to the Yucca Mountain site before site selection, plus all D&E costs allocated to repository development following site selection, were summed to give the D&E costs used in the TSLCC analysis. Note that D&E costs attributed to three candidate sites for activities before site selection would be incurred regardless of which site is ultimately selected for development as a repository.

The COCD component for the Yucca Mountain site was estimated using the REPCOST spreadsheet (DOE, 1985a). This spreadsheet details the costs for repository design (final procurement and construction and Title III) construction, operation (including emplacement, caretaker, and backfill periods), closure, and decommissioning. These costs are accumulated in a multilevel matrix of cost accounts that provides a cost breakdown by repository facilities and related activities for each period in the repository life cycle. The major cost account groupings are

1. Surface facilities.
2. Waste packages.
3. Shafts and ramps.
4. Underground development and operation.

Costs for each account during each phase were estimated from the product of labor, material, or equipment requirements, and the associated unit costs and subsequent buildup factors. Contingency factors of 10 to 40 percent were applied to these estimates, as indicated previously (DOE, 1985a). Costs were summed by account and phase to arrive at the total COCD costs.

To make the higher-level findings required for the related performance issue (Issue 4.1), the DOE will develop a TSLCC estimate for construction, operation (including maintenance of the retrieval option), closure, and decommissioning of a repository at each of the candidate sites that have been characterized and for design and fabrication of the waste packages to be used at each site. In developing the basis for cost estimates and providing for the site selection decision, the impact of site characteristics on the technological requirements and on the complexity of design and operating procedures will be a primary consideration.

For the eventual cost comparisons to be valid, the basis for estimating the TSLCC for each site must be similar, and the degree of uncertainty associated with the various design and operational requirements must be reduced to a reasonable level. To resolve this issue, the DOE intends to rely on refinements of the procedure and model already in use for estimating TSLCC (e.g., DOE/RW-0024, 1985; DOE/RW-0047, 1987a), with TSLCC used as the performance measure. To ensure comparability of information used for each site, the basis for the TSLCC estimate will be the advanced conceptual design (ACD) for each repository and its associated waste package(s), developed in accordance with specified ACD information requirements (DOE, 1987a). The ACD plan contains a physical subsystem structure and code of accounts (PSS-COA) that will be used to establish requirements for the ACD effort, and to estimate costs for the ACD. Additional information requirements from the early stages of license application design (LAD) development may also be considered, as appropriate.

The experience gained from construction of the exploratory shafts and underground testing facility and the results of site characterization activities that provide input to the design process will be relied on to provide an acceptable level of confidence in the bases for and estimates of the costs associated with construction, operation, decommissioning, and closure of a repository at the Yucca Mountain site. By the end of site characterization, the impacts of site characteristics on the major design choices that have a significant effect on cost will have been determined, and there will be adequate information to support a reasonable estimate of costs for comparative evaluation of the available siting alternatives. Since the TSLCC estimates will be based on COCD costs developed for ACD studies, possibly augmented by LAD studies, and on D&E costs estimated from program budget information, no specific information is required from site characterization for the sole purpose of supporting resolution of this issue. Site information that may be needed to support ACD and LAD development is identified under other design issues, such as 1.11, 2.7, 4.2, and 4.4 (Sections 8.3.2.2 through 8.3.2.5).

Repository and waste package cost estimates will be prepared for COCD costs during ACD development. The ACD cost estimates for the Yucca Mountain site will be developed following general DOE cost guidelines that will be applied in estimating costs that are presently scheduled for each site. The specific methods used to develop detailed cost data and buildup factors for the site may vary slightly from those used to develop cost data for the other siting options due to differences in the cost-estimating procedures used by the architect-engineer firms responsible for each design effort. The cost estimates for the Yucca Mountain site will be structured according to a common format to be specified in the DOE cost guidelines. The cost accounts will be based on the physical-subsystem structure provided in the ACD Plan. Costs will be estimated for design, construction, operation, closure, and decommissioning, in a detailed breakdown of cost accounts corresponding to various repository facilities, the waste package, and related activities. The general DOE cost guidelines will specify the cost reporting requirements, assumptions, account definitions, and suggested factors to be used in developing these cost estimates. As the estimates are developed for the Yucca Mountain site, the DOE will monitor the progress through the review process. This will ensure comparability among the projects with regard to the bases used to develop the required cost data. These reviews will identify key differences between candidate sites, ensure that the assumptions made for each are reasonable and consistent, and check for comprehensiveness and conformity in addressing the cost guidelines. This process is expected to lead to comparable estimates of TSLCC for all sites, while allowing the Yucca Mountain site to independently develop its own cost data and the related supporting documentation.

The cost guidelines developed initially for ACD are expected to continue to evolve as the program matures, as a result of site characterization and design studies, so that the final ACD cost guidelines will build upon those currently under development. COCD cost estimates at the time of site selection may provide more detail than is presently envisioned.

Costs for development and evaluation activities for the Yucca Mountain site will be developed in a manner similar to that used to estimate D&E costs for the EAs, as described previously (see DOE/RW-0047, 1987a, for the most recent description of the methodology). Comparable bases for the D&E costs for each project are ensured through the normal DOE schedule review and budget formulation processes. Once determined, these D&E costs will be added to the COCD costs to produce the TSLCC estimates for development of a repository at the Yucca Mountain site and to provide the information needed to support resolution of this issue.

8.2.2.4 Summaries of specific site characterization programs

The site characterization programs are made up of investigations that will provide a general understanding of the Yucca Mountain site and the specific data needed to resolve the performance and design issues. The investigations are organized into 16 site-specific programs. Brief summaries of the site data being obtained and the investigations to be conducted under each program are provided in the following sections.

8.2.2.4.1 Summary of the geohydrology program

The details of the geohydrology characterization program are presented in Section 8.3.1.2. The program is designed to provide an overall understanding of the geohydrology of the Yucca Mountain site, as well as to supply specific geohydrologic information required to resolve the performance and design issues. The overall approach to satisfying the performance and design information requirements is to conduct investigations that will result in a valid geohydrologic model.

Summary of performance and design requirements for geohydrologic information

The purpose of the geohydrologic characterization program is to provide information regarding the geohydrologic characteristics, processes, and conditions necessary to support resolution of the performance and design issues. Figure 8.2-6 provides an overview of the performance and design issues that depend on the geohydrologic characterization program for information, and the geohydrologic investigations planned to acquire the site data.

The primary performance issues relying on geohydrologic data include those for the cumulative release of radionuclides from the mined geologic disposal system (Issue 1.1, Section 8.3.5.13), and the pre-waste-emplacement ground-water travel time (Issue 1.6, Section 8.3.5.12). Compliance with the requirements for waste package containment (Issue 1.4, Section 8.3.5.9) and limiting releases from the engineered barrier system (EBS) (Issue 1.5, Section 8.3.5.10) also depend on a knowledge of the geohydrology. For the waste package, the moisture content of the emplacement environment is one of the critical parameters influencing the predicted performance of the container. For releases from the EBS, estimating the amount of water in the waste package environment is the basis for predicting radionuclide release.

Figure 8.2-6. Interface of the geohydrology program with design and performance issue and other characterization programs.

The geohydrologic characterization program also provides data to resolve Issue 1.3 (Section 8.3.5.15), which addresses the potential for impacts on special sources of ground water.

The design issue relying on geohydrologic data is Issue 4.4 (Section 8.3.2.4), which concerns hazards such as the intersection of ramps or drifts with perched water. These data will be obtained as a part of the geohydrology program but will be evaluated under the preclosure hydrology program (Section 8.3.1.16). Issue 1.4 (Section 8.3.5.9) relies on the geohydrologic characterization program from a design as well as a performance perspective because it addresses features of the waste package design affecting performance of the containment barrier.

In addition, the geohydrologic characterization program will supply data to assist in evaluating the NRC siting criteria (Issue 1.8, Section 8.3.5.17), as well as the higher level findings (Issue 1.9, Section 8.3.5.18) required by DOE in their siting guidelines (10 CFR Part 960).

Approach to satisfy performance and design requirements

The general approach to satisfying the performance and design requirements is to develop a credible geohydrologic model. The geohydrologic model will have three components: the unsaturated zone model, the saturated zone model, and the surface-water model. The unsaturated-zone hydrologic model will be developed only for the near-site vicinity (i.e., site scale), whereas the surface-water and saturated-zone hydrologic models will be developed at both site and regional scales. The geohydrologic model will then be combined with the geochemical model and thermal-mechanical model to produce the site model. Each of these three models will be developed using conceptual and descriptive models as well as numerical models. Components of the numerical models include a complete and accurate description of the geologic and hydrologic framework, initial and boundary conditions, processes at work within the geologic and hydrologic framework, and a hypothesis describing their interrelationships.

Summary of geohydrologic investigations

The geohydrologic investigations that will be conducted to obtain the data necessary to build the geohydrologic model are described in Section 8.3.1.2. Three investigations are planned, focusing on the three hydrologic systems to be characterized. The investigation described in Section 8.3.1.2.1 will develop a description of the regional hydrologic system. Section 8.3.1.2.2 describes studies to investigate the site unsaturated zone system, while the investigation presented in Section 8.3.1.2.3 will provide a description of the saturated zone system at the site. Table 8.2-35 lists the general parameters to be provided by each geohydrologic investigation.

8.2.2.4.2 Summary of the geochemistry program

The details of the geochemistry characterization program are presented in Section 8.3.1.3. The program is designed to provide the information necessary for developing a site geochemical model, as well as to supply specific geochemical information required to address performance and design issues. The overall approach to satisfying the performance and design

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Table 8.2-35. Major parameters provided by investigations in Geohydrology Program 8.3.1.2.

Section number	Investigation	Major parameters
8.3.1.2.1	Description of the regional hydrologic system	Rainfall and temperature Water chemistry Runoff Drainage basin and channel characteristics Debris transport characteristics Hydraulic conductivity Storage coefficients and porosities Isotope ratios Hydraulic heads and gradients — regional Evapotranspiration rates Recharge and discharge locations and rates Regional hydrologic properties Water flux Fracture characteristics
8.3.1.2.2	Description of the unsaturated zone hydrologic system at the site	Effective porosity Fracture and matrix permeabilities Hydraulic conductivity Tortuosity Transmissivity Moisture-retention curves Porosity Dispersivity Diffusion coefficients Hydrochemistry Evapotranspiration rates Flow paths Flow velocities Volumetric flux Infiltration Water potential Matric potential Pneumatic potential Moisture content Saturation profiles

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Table 8.2-35. Major parameters provided by investigations in Geohydrology Program 8.3.1.2 (continued)

Section number	Investigation	Major parameters
8.3.1.2.3	Description of the saturated zone hydrologic system at the site	Hydraulic conductivity Storage coefficient Transmissivity Effective porosity Dispersion coefficient Temperature Hydraulic heads and gradients Water flux Fracture system characteristics

information requirements is to conduct investigations that will evaluate, synthesize, and integrate site and experimental data to show the combined effects of physical, thermal, and chemical processes.

Summary of performance and design requirements for geochemical information

Compliance with the performance and design requirements for a geologic repository will require information about the geochemistry of the Yucca Mountain site. This program provides the geochemical data and data on geochemical processes that are needed to support assessments of site performance and waste package design analyses. Performance assessment calculations of radionuclide transport (Issue 1.1) require specific data about the geochemical behavior of waste elements at the Yucca Mountain site. In addition, the NRC siting criteria addressed by Issue 1.8 include favorable and potentially adverse geochemical conditions that must be evaluated. Figure 8.2-7 graphically displays the performance and design issues requesting geochemical information and the investigations planned to supply this site data.

Approach to satisfy performance and design requirements

As described in Section 8.1.1, a process of performance allocation was used in the performance and design issues to determine the information and data needs required from the geochemistry program. The primary data requested as a result of performance allocation may not be a measurable quantity, and therefore supporting data are necessary to derive the primary information. The studies required to provide the primary and supporting data often involve multiple tests because of the high degree of coupling of the geochemical and physical processes that are the basis for radionuclide retardation. Furthermore, secondary and supporting data may be required to

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Figure 8.2-7. Parameter calls and corresponding model from geochemistry test program.

provide the level of confidence requested by the performance and design issues.

Table 8.2-36 lists the primary parameters provided by the geochemistry program. The parameters listed in the table reflect the primary data required to satisfy the performance or design needs. Data synthesis will be required to identify and quantify the following higher level parameters that are required by the performance and design issues: coupling and retardation factors, distribution coefficients, liquid constrictivity and tortuosity, and hydrodynamic dispersion. These higher-level parameters, in conjunction with other parameters listed in Table 8.2-36, will be used in model validation of coupling factors, source term determination for the waste package, and model calibration and validation for gas-phase transport. The results of these models will be used in determining the effects of climate and human interference on the baseline geochemical conditions, and in determining controls on ground-water composition. The geochemistry program relies upon the investigation described in Section 8.3.1.3.7 (retardation by all processes) to evaluate, synthesize, and integrate the geochemical site and experimental data to show the coupled effects that might not be evident if the geochemical or physical process data were considered separately.

Development of a site geochemical model requires data on liquid constrictivity-tortuosity factors for the rock matrix, fracture networks, fault zone rock mass, and distribution coefficients for radionuclide species for all rock units within the controlled zone. The characterization program addresses this data need by integrating the results of sorption studies with dynamic transport and diffusion studies. Calculations of total system releases (Issue 1.1) require information on the specific discharge field in saturated-zone units and values for hydrodynamic dispersion. This information will be provided by determining the dispersion characteristics for crushed tuff and obtaining hydrodynamic dispersion data for solid rock and fractured tuff. Requests for model validation-coupling factors in the saturated and unsaturated zone units will be satisfied by permeability information from unsaturated tuff column experiments. Solubility limits of chemical species associated with the liquid and gas-phase radionuclides will be used to establish potential source terms for the waste packages. Section 8.3.1.3.5 describes an investigation that will provide dissolved species concentration limits and information on colloid formation and stability will support the source term estimates. Major-ion water chemistry and gas-phase carbon-14 transport in the overburden also provide information for model calibration and validation. The ground-water chemistry model described in Section 8.3.1.3.1, together with gaseous radionuclide transport calculations, provide integrated information to the performance assessment program.

The waste package postclosure design requires information on the composition of the vadose water for particular elements most affecting the waste package stability (Issue 1.10). The ground-water chemistry model being developed in this program will serve as a tool for evaluating present ground-water conditions as a basis for predicting future changes in ground-water chemistry.

The total system performance issue (Issue 1.1) identifies climatic changes and human intrusion scenarios that might increase the flux thus affecting the ground-water chemistry. Information must be provided on the

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Table 8.2-36. Major parameters provided by investigations in Geochemistry Program 8.3.1.3

Section number	Investigation	Major parameters
8.3.1.3.1	Studies to provide the information on water chemistry within the potential emplacement horizon and along potential flow paths	Unsaturated-zone fluid dispersive properties Unsaturated-zone fluid diffusive properties Unsaturated-zone fluid sorptive properties Unsaturated-zone fluid chemistry Unsaturated-zone fluid temperature Unsaturated-zone fluid rock chemistry
8.3.1.3.2	Studies to provide information on mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths.	Rock-unit mineralogy and petrology Fracture-filling mineralogy and physical properties Rock chemistry
8.3.1.3.3	Studies to provide information on stability of minerals and glasses.	Rock-unit mineralogy and petrology Rock chemistry
8.3.1.3.4	Studies to provide information required on radionuclide retardation by sorption processes along flow paths to the accessible environment	Unsaturated-zone fluid sorptive properties Saturated-zone sorptive properties
8.3.1.3.5	Studies to provide the information required on radionuclide retardation by precipitation processes along flow paths to the accessible environment	Unsaturated-zone geochemical properties (solubilities) Saturated-zone geochemical properties (solubilities)
8.3.1.3.6	Studies to provide the information required on radionuclide retardation by dispersive, diffusive and advective transport processes along flow paths to the accessible environment	Saturated-zone geochemical properties Effective diffusivities Major ion chemistry Dispersion characteristics Unsaturated-zone dispersion characteristics

Table 8.2-36. Major parameters provided by investigations in Geochemistry Program 8.3.1.3. (continued)

Section number	Investigation	Major parameters
8.3.1.3.7	Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment	Retardation sensitivity analyses Physical and chemical processes affecting transport Geochemical and geophysical model of Yucca Mountain and integrated geochemical transport calculations Transport models Application determinations of laboratory data to repository transport calculations
8.3.1.3.8	Studies to provide the information required on retardation of gaseous radionuclides along flow paths to the accessible environments	Gaseous radionuclide transport calculations and measurements Physical transport mechanisms and rates Retardation mechanisms and transport with retardation Gas transport measurements

potential magnitude of change in the distribution coefficients based on changing water compositions. The investigation described in Section 8.3.1.3.7 will provide bounding calculations on radionuclide transport using sorption and no sorption. The ground-water chemistry model, the conceptual model of mineral evolution, and data on sorption as a function of solid phase composition will be used in sensitivity analyses to establish the factors controlling water composition.

Summary of the planned geochemical investigations

As shown in Figure 8.2-7, eight investigations are included in the geochemical characterization program. The investigation described in Section 8.3.1.3.1 addresses water chemistry within the potential emplacement horizon and along flow paths to the accessible environment. This investigation will incorporate the existing ground-water chemistry data for the saturated zone and data from the unsaturated zone chemistry activities described in Section 8.3.1.2.2 into the ground-water chemistry model. This model will be used to

better understand factors influencing present ground-water chemistry in order to predict future variations in ground-water chemistry. The investigation described in Section 8.3.1.3.2 addresses mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along flow paths to the accessible environment. Section 8.3.1.3.3 describes studies addressing the stability of minerals and glasses. A conceptual model of mineral and glass evolution at Yucca Mountain will be developed to predict future mineral evolution by natural processes and repository induced thermal loading. Section 8.3.1.3.4 provides the data base on radionuclide retardation by sorption processes along flow paths to the accessible environment. This investigation will evaluate sorption in the far field (beyond the disturbed zone) at Yucca Mountain. Laboratory data will be collected on sorptive behavior and a sorption model (isotherms) will be developed to improve the understanding of the expected sorption at the Yucca Mountain site.

Section 8.3.1.3.5 describes an investigation addressing radionuclide Retardation by precipitation along flow paths to the accessible environment. Solubility measurements and models will be used to provide limits on the concentrations of dissolved waste elements and on natural colloid concentrations under expected site conditions. Section 8.3.1.3.6 addresses radionuclide retardation by dispersive, diffusive, and advective transport processes along the flow paths to the accessible environment. This investigation will determine experimentally the rate of movement and effective retardation of radionuclides by dispersive, diffusive, and advective processes, and will provide support for the applicability of data produced in saturated systems to unsaturated systems. Radionuclide retardation by all processes along flow paths to the accessible environment is addressed in Section 8.3.1.3.7. This investigation uses three-dimensional transport models and other multidimensional process codes to determine, characterize, and quantify the cumulative effects of all significant processes, physical and geochemical, acting on or controlling radionuclide transport at Yucca Mountain. Finally, Section 8.3.1.3.8 addresses retardation of gaseous radionuclides along flow paths to the accessible environment. Potential retardation mechanisms for gaseous radionuclide species will be identified and used to estimate rates of transport.

8.2.2.4.3 Summary of postclosure rock characteristics program

The details of the postclosure rock characteristics program are presented in Section 8.3.1.4. The program is designed to obtain geologic and geophysical site data needed to develop a three-dimensional physical property model, as well as to supply specific data on rock characteristics required by performance and design issues. The overall approach to satisfying the performance and design information requirements is to conduct investigations that will supply the information needed to develop a data base to provide a computer-based representation of the physical properties of the rocks at the site.

Summary of performance and design requirements for rock characteristics information

Compliance with performance and design requirements for a geologic repository will require information about the rock characteristics of the Yucca Mountain site. This information will be used to support assessments of site performance related to ground-water travel time, radionuclide releases to the accessible environment, and the NRC siting criteria (10 CFR 60.122). Design criteria for the underground facility, seals for shafts and boreholes, and waste packages are also evaluated in the context of the natural rock properties of the site. Figure 8.2-8 provides an overview of the performance and design issues that depend on the rock characteristics program for information.

Approach to satisfy performance and design requirements

A summary of the site information requested by performance and design issues is provided in Table 8.2-37. These data needs were derived by applying performance allocation to the performance and design issues described in Sections 8.3.2 through 8.3.5.

The geologic and geophysical site characterization activities provide information needed to develop a three-dimensional physical property model that will relate the geologic framework to the material properties of rocks at the Yucca Mountain site. The data base developed for the model will contain the spatial distribution of parameter values for physical properties within property-dependent rock units. An important function of the computer-based model will be to provide input for numerical computer analyses involving hydrologic, thermal, thermomechanical, and geochemical processes.

To develop the physical property model, four categories of information are necessary: (1) material properties, (2) geometry, (3) assumptions and hypotheses, and (4) initial and boundary conditions. The model will allow predictions of how a physical property changes spatially within and across the boundaries of the model, where the boundaries represent distinct changes in a property. The location of the physical property boundaries will be based on three sources of information: (1) geologic studies, (2) geophysical studies, and (3) the physical property data from core samples. The geologic complexity of the Yucca Mountain site may cause large uncertainties in the variation of the properties between sample locations. Various interpolation methods can be used to estimate the variation in the value of a rock property between sample locations. The ultimate use of specific rock property data determines the precision required in determining the lateral and vertical variability of a particular property at distances away from the sample location. Thus, the nature and number of site sampling activities and characterization studies will be determined by the level of confidence required by the numerical models using the physical properties.

The planned geologic and geophysical studies are intended to identify correlations between the properties of interest that can be directly measured and properties of interest that must be estimated. The results of the geologic studies will therefore be used to calibrate the geophysical data and provide additional sources for correlating parameter information.

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Figure 8.2-8. Interface of the rock characteristics program with design and performance issues and other characterization programs

Table 8.2-37. Major parameters provided by investigations in Postclosure Rock Characteristics Program 8.3.1.4

Section number	Investigation	Major parameters
8.3.1.4.1	Development of an NNWSI Integrated Drilling Program	Development of drilling practices to be followed for site characterization Yearly development of integrated drilling plans for site characterization
8.3.1.4.2	Geologic framework of the Yucca Mountain site	Rock unit contact location and configuration Rock unit lateral and vertical variability Rock unit mineralogy and petrology Rock unit depositional and diagenetic history Fault location, length, and width Fault orientation Fault displacement Fault zone mineralogy and physical properties Fracture orientation Fracture distribution Fracture aperture Fracture length Fracture-filling mineralogy and physical properties
8.3.1.4.3	Development of three-dimensional models of rock characteristics at the repository site	Computer-based three-dimensional physical property model Compiled systematic drilling information Contour maps and cross sections for various site parameters

Summary of planned rock characteristics investigations

As shown in Table 8.2-37, three investigations are planned for the rock characteristics program. The first investigation (Section 8.3.1.4.1) will develop a plan for integrating the NNWSI Project drilling activities for the

entire site characterization program. The second investigation (Section 8.3.1.4.2) will provide primary data on the lateral and vertical variation in structure and stratigraphy in support of design and performance assessment analyses. The third investigation (Section 8.3.1.4.3) will focus on developing a three-dimensional model of the rock characteristics at the Yucca Mountain site. The purpose of this model is to summarize, in a coherent fashion, the geologic, hydrologic, geochemical and thermal mechanical information and to provide a mechanism for transfer of this information to the design and performance assessment issues.

8.2.2.4.4 Summary of the climate site program

The details of the climate characterization program are presented in Section 8.3.1.5. The program is designed to provide the climate information needed to resolve performance and design issues. The overall approach to satisfy the performance and design issues involves building a model that simulates future climate. By using the results of the future-climate model to define the boundary conditions for hydrologic models, the effects of future climate on the hydrologic system can be determined.

Summary of performance and design requirements for climate information

The climate program consists of investigations designed to (1) provide data on past, present, and future climate conditions (Investigation 1.16.1) and (2) determine the effects of climate change on surface hydrology, unsaturated zone hydrology, and saturated zone hydrology (Investigation 1.16.2). Figure 8.2-9 shows the flow of information from the climate program to the performance or design issues requesting the information, as well as the characterization programs relying on climatic data. The climate program will use hydrologic system models developed in the geohydrology program to simulate future hydrologic conditions due to climate change. Thus the geohydrology program also provides information to the climate program.

As shown in Figure 8.2-9, the major performance and design issues requesting climate data are: (1) total system performance (Issue 1.1); (2) NRC siting criteria (Issue 1.8); (3) higher-level findings (Issue 1.9a); (4) prediction of climate over the next 100,000 yr (Issue 1.9b); and (5) postclosure waste package design (Issue 1.10). Postclosure repository design considerations (Issue 1.11, Section 8.3.2.2) and characteristics of seals (Issue 1.12, Section 8.3.3.2) also consider future climatic conditions as design constraints. It has been determined that the climate information needed to satisfy Issue 1.1 will be sufficient to address Issues 1.8, 1.9a, and 1.10, and the other design issues requesting climate information. Additional data and new analytical techniques are necessary to satisfy Issue 1.9b because of the need for predicting expected climatic conditions over the next 100,000 years.

Summary of climatic investigations

The investigations, studies, and activities within the climate program are designed to predict of the effects of future climate change on hydrologic conditions and to estimate the ranges of future climatic conditions to

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Figure 8.2-9. General logic diagram showing ties between climate program and other characterization programs, design issues, and performance issues.

satisfy the performance and design issues. The analysis of paleoclimate and paleoenvironment (Study 8.3.1.5.1.5) is a synthesis activity using data generated by two previous studies and is necessary to assess the long-term variability of paleoclimate, as well as to provide the basis for the estimation of future climatic episodes. This analysis also provides the basis for determining the potential effects of future climatic conditions on hydrologic characteristics. The determination of the nature, probability and timing of future climate scenarios will be derived from a linked global-regional modeling approach, a separate empirical modeling approach, or both (Study 8.3.1.5.1.6). This model will be developed and validated using the paleoclimate and paleoenvironmental information and will be calibrated using present-day meteorological data generated in collaboration with the meteorology program (8.3.1.12).

Section 8.3.1.5.2 describes the investigation to determine the potential effects of future climate change on hydrologic conditions. Paleoclimate and paleoenvironment information established in Section 8.3.1.5.1 will be used in the paleohydrology studies to better understand the Quaternary regional ground-water flow systems. Understanding paleohydrologic and paleoclimate relationships will serve as a basis for predicting hydrologic responses (i.e., changes in infiltration and recharge) initiated by future climate. Hydrologic system models developed in the geohydrology program (8.3.1.2) will be used to determine baseline present hydrologic conditions. Future hydrologic conditions will be modeled on the basis of estimated climate changes. The result will be an estimate of the impact of future climate on the overall hydrologic system.

Table 8.2-38 lists the major parameters to be generated by the climate program. These parameters must be provided at the level of confidence needed for input to design and performance issues.

8.2.2.4.5 Summary of the erosion program

The details of the erosion characterization program are presented in Section 8.3.1.6. The program is designed to provide information on geomorphic processes and conditions at the site needed for design, as well as to supply site-specific erosion data required by the performance issues. The overall approach to satisfying the performance and design information requirements is to conduct investigations that will identify areas of active erosion and deposition at Yucca Mountain and that will quantify these rates for the postclosure period.

Summary of design and characterization requirements

The erosion program will provide the site-specific information regarding geomorphic processes and conditions that is required to satisfy Design Issues 4.4 (preclosure design and technical feasibility, Section 8.3.2.5) and 1.12 (seal characteristics, Section 8.3.3.2), and to provide information to the human interference program (Section 8.3.1.9). Figure 8.2-10 graphically shows the relationship of the design issues and the characterization program requesting information from the erosion program. Issue 4.4 requires data on

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Table 8.2-38. Major parameters provided by investigations in Climate Program 8.3.1.5

Section number	Investigation	Major parameters
8.3.1.5.1	Develop model of future climatic change	<p>Synoptic climate and variations</p> <p>Estimates of past changes in effective moisture and their chronology</p> <p>Estimates of past precipitation, temperature, and evaporation</p> <p>Climatic implications of terrestrial paleoecology</p> <p>Quaternary regional paleo-environment estimate</p> <p>Chronology of paleoclimate/paleoenvironment episodes</p> <p>Soil properties</p> <p>Nature, probability, and timing of future climate scenarios</p>
8.3.1.5.2	Effects of future climate on hydrologic conditions	<p>Characteristics of Eolian deposits</p> <p>Change in unsaturated zone, saturated zone, and surface hydrologic systems due to climate change</p> <p>Characteristics of paleofloods</p> <p>Hydrochemistry of unsaturated zone</p> <p>Characteristics of past discharge</p>

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Table 8.2-38. Major parameters provided by investigations in Climate Program 8.3.1.5 (continued)

Section number	Investigation	Major parameters
		Recharge properties and characteristics
		Properties of hydrogenic deposits

the erosional and depositional processes to identify the most suitable locations for the warning system markers for the repository. Issue 1.12 requires data on bedrock erosion rates that is needed for seal design. The human interference program requires similar information to evaluate the long-term survivability and the future legibility of the markers. As indicated in Figure 8.2-10, these data will be used by Issue 1.1 (total system performance) to aid in assessing the probability for human interference during the 10,000-yr postclosure period by providing information on long-term marker survivability.

Approach to satisfy the design requirements

Because erosion is not believed to pose a hazard to waste isolation at Yucca Mountain, only three field activities are planned. The remaining regulatory requirements will be satisfied through analysis and further evaluation of geomorphic data that will be obtained through investigations in support of this program, the meteorology program (Section 8.3.1.12), and the hydrology program (Section 8.3.1.16). These data will be used to develop topical reports that will address (1) the expected effects of tectonism and climate changes on erosion, (2) the expected effects of erosion on the baseline characteristics at the site, and (3) the siting guidelines of 10 CFR Part 960. These topical reports also will provide the technical data base and analyses needed to address the requirements of 10 CFR Part 60.

Summary of erosion investigations

As shown on Figure 8.2-10, four investigations are planned. Many of the necessary parameters have been obtained and evaluated as part of the ongoing scientific studies at the NTS in support of the weapons testing program. In most instances, data are not site specific, and therefore, not adequate to satisfy the performance and design issues. Studies will be carried out during site characterization to satisfy these remaining data needs. Table 8.2-39 lists the major parameters provided by the erosion program. Existing geomorphic data will be used in conjunction with new data to provide the level of confidence required in these parameters.

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Figure 8.2-10. Relationship between erosion program and investigations.

Table 8.2-39. Major parameters provided by investigations in Erosion Program 8.3.1.6.

Section number	Investigation	Major parameters
8.3.1.6.1	Studies to provide the information needed to determine present locations and rates of erosion	Development of a geomorphic map of Yucca Mountain Analysis of hillslope erosion Analysis of downcutting history of Fortymile Wash
8.3.1.6.2	Studies to provide the information needed to determine the potential effects of future climatic conditions on locations and rates of erosion	Impact of future climatic conditions on locations and rates of erosion
8.3.1.6.3	Studies to provide the information required to determine the potential effects of future tectonic activity on locations and rates of erosion	Effects of future uplift or subsidence and faulting on erosion at Yucca Mountain
8.3.1.6.4	Potential effects of erosion on hydrologic, geochemical, and rock characteristics	Effects of erosion on the baseline conditions at Yucca Mountain

Investigation 8.3.1.6.1 will collect site-specific data on Quaternary erosion and stream incision rates, which will be used to calculate average erosion rates on Yucca Mountain and to develop a history of the downcutting episode(s) of Fortymile Wash. Investigation 8.3.1.6.2 includes studies to assess the potential effects of future climatic changes on locations and rates of erosion. Previously established regional erosion rates suggest that future changes in the climatic regime will not significantly affect upland and hillslope erosion rates. Local erosion data on Yucca Mountain and an evaluation of the relationship of increased runoff in Fortymile Canyon, Fortymile Wash, and their tributaries to localized stream incision rates are needed for Information Need 2.7.1 (Section 8.3.2.3.1). Investigation 8.3.1.6.3 will evaluate the effects of tectonic activity on rates of erosion.

Investigation 8.3.1.6.4 addresses the potential effects of erosion on the baseline hydrologic, geochemical, and rock characteristics at Yucca Mountain. Data obtained from these investigations will be analyzed to provide the information necessary to support the higher-level finding required

by Issue 1.8. These topics will be addressed in a topical report, which will present the discussion supporting termination of the erosion program.

8.2.2.4.6 Summary of the rock dissolution program

Because the findings on rock dissolution made for the environmental assessment (DOE, 1986b) are adequate to meet the requirement for higher-level findings in the siting guidelines, no additional studies are planned for issue resolution. Studies on mineral stability described under the geochemistry program (Section 8.3.1.3) are being conducted to assess geochemical retardation along flow paths to support performance assessment studies for Issue 1.1 (Section 8.3.5.13).

8.2.2.4.7 Summary of the postclosure tectonics site program

The details of the postclosure tectonics program are presented in Section 8.3.1.8. The purpose of the tectonic characterization program is to supply data on the probability and effects of tectonic "initiating events" that could alter existing conditions at Yucca Mountain and potentially have adverse effects on repository performance. Figure 8.2-11 shows the interfaces to the performance and design issues that require information from the tectonic characterization program and the investigations planned to provide the site data.

Summary of performance and design requirements for postclosure tectonics information

Issue 1.1 (Section 8.3.5.13) requires data on the probability and effects of potentially significant tectonic release-scenario classes addressing both anticipated and unanticipated conditions. These data are needed for performance assessment calculations of radionuclide releases to the accessible environment. The tectonic characterization program also supplies data required to perform the analysis to determine the degree to which each of several favorable and potentially adverse conditions listed in 10 CFR 60.122 contributes to or detracts from isolation (Issue 1.8, Section 8.3.5.17). The program also will provide the information needed to make the higher level findings (Issue 1.9, Section 8.3.5.18) required by the DOE in their siting guidelines (10 CFR Part 960). Tectonics information will also be used to accommodate site-specific tectonic conditions in design concepts for the geometry, layout, and emplacement borehole locations of the underground facility (Issue 1.11, Section 8.3.2.2).

Approach to satisfy performance and design requirements

The general approach to satisfying the performance and design requirements is to conduct investigations to provide the additional detail necessary to accurately characterize the effects of tectonic processes operating at or near the site and to measure the rates at which these processes operated during the Quaternary. This information will then be used to provide the

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Figure 8.2-11. Relationships between the postclosure tectonics program, investigations, and performance design issues.

predictions of future rates necessary to satisfy the requirements of the performance and design issues. The tectonic processes that will be evaluated are volcanism, igneous intrusion, faulting, folding, and uplift and subsidence. The tectonics program will estimate the probability of occurrence of significant tectonic events related to these processes during the postclosure time period and evaluate the effects of these events on possible direct releases related to the event, the lifetime of waste packages, and on the possible alteration of hydrologic and geochemical parameters that govern radionuclide transport times and release rates.

A variety of sources of information will be used to evaluate tectonic processes and events including earthquake observations, fault measurements, geologic mapping, drilling, gravity and magnetotelluric surveys, and other geophysical data. Alternative interpretations of the data will be explored and evaluated with respect to implications for repository performance. Multiple interpretations will be refined to the extent necessary to provide the degree of confidence that is specified by the performance and design issues.

Summary of postclosure tectonic investigations

Table 8.2-40 lists the major parameters provided by the investigations and studies to be conducted as part of this program. As shown in Figure 8.2-11, five investigations are planned under this program. The first four investigations are related to the initiating events and their associated data requirements (performance parameters) needed to evaluate the scenarios identified in Issue 1.1. The studies and activities connected with these investigations provide the analysis and assessment of site geologic data necessary to characterize the probability and effects of tectonic initiating events. Because the analysis and interpretation activities for different tectonic initiating events repeatedly call for the same type of data, data gathering activities were grouped separately under a fifth investigation that feeds data as required to the analysis activities associated with the postclosure tectonics program.

8.2.2.4.8 Summary of the human interference program

The details of the human interference program are presented in Section 8.3.1.9. The program is designed to identify, analyze, and evaluate the potential human activities that could adversely affect long-term repository performance, or that could lead to inadvertent intrusion into the repository. Identification, analysis, and evaluation of potential human activities will provide the data required by the design and performance issues. The overall approach to satisfying the performance and design information needs is to identify all credible anthropogenic disruption scenarios, assess their potential consequences, and provide this information as input to a model that will be used to determine total system releases to the accessible environment (Issue 1.1) caused by inadvertent human activities.

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Table 8.2-40. Major parameters provided by investigations in Postclosure Tectonics Program 8.3.1.8.

Section number	Investigation	Major parameters
8.3.1.8.1	Studies to provide information required on direct releases resulting from volcanic activity	Probability of a volcanic eruption penetrating the repository Effects of volcanic eruption penetrating the repository
8.3.1.8.2	Studies to provide information required on rupture of waste packages	Probability of underground displacement
8.3.1.8.3	Studies to provide information required on changes in unsaturated and saturated zone hydrology	Effects of tectonic processes and events on flux rates, on water table elevation, and on local fracture permeability and effective porosity
8.3.1.8.4	Studies to provide information required on changes in rock geochemical properties	Effects of tectonic processes and events on rock geochemical properties
8.3.1.8.5	Studies to provide the general tectonic information required by the analysis and assessment investigations	Characteristics of volcanic features, igneous intrusive features, and folds in Miocene and younger rocks

Summary of performance and design requirements for information related to human interference

The purpose of the human interference characterization program is to provide information regarding the likelihood that the activities of humans in the vicinity of Yucca Mountain over the next 10,000 years will influence the performance of the repository. Information regarding the long-term survivability of the surface marker warning system, the natural resource potential of the site, and the potential effects of future resource exploration or extraction will be provided by the human interference characterization program. Figure 8.2-12 displays the performance and design issues requesting information and the investigations of the human interference program that will provide the information.

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Figure 8.2-12. General logic diagram for the Human Interference Program.

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As shown in Figure 8.2-12, the performance issues that rely on information from the human interference program include the cumulative releases from the repository (Issue 1.1, Section 8.3.5.13), and the demonstration that the site meets the NRC siting criteria (Issue 1.8, Section 8.3.5.17). These issues require information regarding the potential for human interference at the site during the 10,000-yr postclosure period.

The only design issue requesting information from the human interference program is Issue 4.4 (preclosure design and technical feasibility). This issue requests site-specific information on natural processes that could affect the long-term survivability of the surface markers. The data obtained through the human interference program will be used to identify the most suitable locations for the surface markers.

Approach to satisfy performance and design requirements

The general approach to satisfying the performance and design requirements is to conduct investigations that will provide the basis for developing credible human intrusion scenarios. The investigations will provide information about the site and about the survivability of the warning system that can be used to assess the likelihood of occurrence of specific human activities at and near the site. The probability that specific human activities will occur, and the potential influence that such activities might have on repository performance will be determined. These data will provide the information necessary to satisfy the performance and design issue requirements.

Summary of human interference investigations

Table 8.2-41 summarizes the major parameters and the investigations planned for the human interference program. The first investigation (Section 8.3.1.9.1) identified for this program determines all events, both natural and anthropogenic, that could destroy or degrade the surface markers and monuments. Because most anthropogenic factors have been considered and incorporated into the marker design, only three specific data needs are identified, all of which will be provided from other investigations. The magnitudes and locations of fault rupture and seismically induced ground motion (Section 8.3.1.8.2); the rates, magnitudes, and locations of potential igneous activity (Section 8.3.1.8.1); and the potential effects of tectonic activity and future climatic conditions on locations and rates of erosion and deposition (Sections 8.3.1.6.2 and 8.3.1.6.3) will aid in determining the best locations for the surface markers and monuments.

The second investigation (Section 8.3.1.9.2) will identify all resources at the site with current markets, or those that could potentially be marketable in the future. These resources will be described in terms of physical factors such as tonnage and grade. Once resources and reserves are identified, they will be delineated and quantified (Study 8.3.1.9.2.1) and the impact of their presence will be addressed in Studies 8.3.1.9.3.1 and 8.3.1.9.3.2).

Ground water currently is the only commodity classified as a resource in the immediate vicinity of the site. Exploitation of this resource is

Table 8.2-41. Major parameters provided by investigations in Human Interference Program 8.3.1.9

Section number	Investigation	Major parameters
8.3.1.9.1	Studies to provide the information required on natural phenomena and human activities that might degrade surface markers and monuments	<p>Parameter synthesis of tectonic, seismic, and volcanic hazards data for assessing marker survivability</p> <p>Parameter synthesis of geomorphic data for assessing marker survivability</p>
8.3.1.9.2	Studies to provide the information required on present and future value of energy, mineral, land, and ground-water resources	<p>Geochemical assessment of Yucca Mountain in relation to the potential for mineralization</p> <p>Geophysical and geological assessment of Yucca Mountain relative to mineral resources</p> <p>Geothermal resource assessment of Yucca Mountain</p> <p>Mineral and energy resource analog modeling of Yucca Mountain</p> <p>Projected trends in local and regional ground-water development</p> <p>Estimated ground-water withdrawal rates in southern Nevada proximal to Yucca Mountain</p>
8.3.1.9.3	Studies to provide the information required on potential effects of exploiting natural resources on hydrologic, geochemical, and rock characteristics	<p>Data evaluation to support the assessment calculation of the potential for human interference and intrusion</p> <p>Potential effects of resource exploration and extraction on the hydrologic conditions at the site</p> <p>Evaluation of initiating events related to human interference</p>

expected to become economically feasible in the near future. Study 8.3.1.9.2.2 will integrate existing scientific and institutional data with information obtained during characterization of the saturated zone (Section 8.3.1.2.3) to (1) quantify and qualify the ground-water resources proximal to the site, (2) assess the current and future value of the resource, and (3) project the probable rates and locations of ground-water exploitation in the reasonably foreseeable future. These parameters will be considered in calculating the probability for human interference (Section 8.3.1.9.3.1) and in assessing the potential effects of ground-water exploitation on the baseline conditions at the site (Section 8.3.1.9.3.2).

The final investigation (Section 8.3.1.9.3) examines the potential effects of resource extraction on the baseline hydrologic, geochemical, and rock characteristics. The parameters that have been identified are (1) the specific resources determined in Investigation 8.3.1.9.2, (2) the baseline conditions at the site, and (3) the extraction methods that would be used for the specific resources under consideration. The parameters obtained for this investigation will be analyzed and evaluated to determine whether the potential effects of resource exploitation can change the baseline characteristics of the site such that repository performance would be affected.

The second part of Investigation 8.3.1.9.3 will focus on the initiating events of the release scenarios that relate to human activities and their potential effects on long-term repository performance. The parameters defined for this investigation are the initiating events identified in Issue 1.1 (total system performance) that may not be considered sufficiently credible to warrant further consideration because of the improbability of their occurrence. These parameters will be evaluated to establish with a high level of confidence whether they are sufficiently credible or significant to warrant further consideration within Issue 1.1.

8.2.2.4.9 Summary of population density and distribution program

The population density and distribution program is described in Section 8.3.1.10. This program provides references and information to support the resolution of performance and design issues related to preclosure radiological safety. These requirements are derived from 10 CFR Part 20, 10 CFR Part 60, 40 CFR Part 191, and DOE orders. The data requirements necessary to comply with these regulations are addressed in the performance and design issues.

Collection of population density and distribution data is not considered a site characterization activity as defined in the Nuclear Waste Policy Act. Therefore, details for data collection activities are not in this document. However, population density and distribution remains an important component of the program of preclosure radiological safety of members of the general public whether through normal operations or as a result of accident conditions (Issues 2.1 and 2.3, Sections 8.3.5.3 and 8.3.5.5). The data base established through this program will contribute to Issue 2.5 (Section 8.3.5.6), which addresses higher level findings on the qualifying and disqualifying conditions of DOE's siting guideline on population density and distribution (10 CFR 960.5-2-1).

The distribution of future populations in highly populated areas and in unrestricted areas is a significant factor in defining preclosure radiological safety programs. Preparation of a radiological monitoring plan will help to establish the data base required to resolve of performance and design issues related to radiological safety.

8.2.2.4.10 Summary of site ownership site program

The land ownership and mineral rights program is described in Section 8.3.1.11. This program is derived from the requirements of 10 CFR Part 960 and 10 CFR Part 60. The provisions of 10 CFR 60.121 require that

Both the geologic repository operations area and the controlled area shall be located in and on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use.

This provision further requires that (1) such lands shall be held free and clear of all encumbrances, (2) the DOE shall exercise any jurisdiction and control over surface and subsurface estates necessary to prevent adverse human actions that could significantly reduce the repository's ability to achieve isolation, and (3) the DOE shall also have obtained water rights as may be needed to satisfy the requirements of the repository operations area.

The plans and procedures for conducting the land ownership and mineral rights program are not considered site characterization activities as defined by the Nuclear Waste Policy Act (NWPA, 1983). The regulatory requirements just listed are an essential component of the repository program in that they provide for a controlled site, which in part addresses preclosure radiological safety aspects of the program. Thus, performance and design issues concerning radiological dose calculations to the public and workers performed in Issues 2.1, 2.2, 2.3, and 2.7 and discussed in Sections 8.3.5.3 through 8.3.5.5 and 8.3.2.3 can be addressed with the knowledge that actions will be taken to withdraw and control the appropriate portion of land in accordance with applicable regulations. In addition, compliance with these requirements will support Issue 2.5 (Section 8.3.5.6), which addresses higher level findings on the qualifying and disqualifying conditions of the site ownership and control guidelines in 10 CFR 960.

If the Yucca Mountain site is recommended and approved for development as a repository following site characterization, it will be necessary, pursuant to 10 CFR 60.121, for the DOE to withdraw the land that would comprise the repository operations area and controlled area and reserve this land for its use. Such a withdrawal action, under current law, must be made pursuant to applicable implementing regulations. The Federal Land Policy Management Act of 1976 (FLPMA) and the implementing regulations define the data and information required to be provided at the time of application to Congress to support the review of the application for withdrawal. Much of the required data and information will be collected as part of the site characterization activities or other programmatic activities planned by the DOE. A similar requirement to recognize and address withdrawal requirements also exists for additional DOE activities directed at assessing the suitability of the Yucca Mountain site under 10 CFR Part 960 and preparing input

to the environmental impact statement required by the NWA and the National Environmental Policy Act (NEPA, 1970).

8.2.2.4.11 Summary of meteorology site program

The details of the meteorology site program are presented in Section 8.3.1.12. The program is designed to provide a complete understanding of the meteorology of the area, as well as to supply specific information on climatologically average and extreme weather phenomena required by design and performance issues. The overall approach to satisfying the design and performance information requirements is to conduct investigations that will address the preclosure radiological safety aspects of the mined geologic disposal system under normal and accident conditions.

Summary of performance and design requirements for meteorological information

The purpose of the meteorological program is to provide data required to resolve performance and design issues. The types of data requested fall into two categories: (1) data needed in calculating radiological doses resulting from releases from the repository and (2) information required for design of surface facilities. Figure 8.2-13 is a logic diagram summarizing the programs and issues requesting meteorological information.

Approach to satisfy performance and design requirements

As summarized in Figure 8.2-13, the meteorology program establishes (1) regional meteorological conditions (Section 8.3.1.12.1), (2) atmospheric and meteorological phenomena at potential locations of surface facilities (Section 8.3.1.12.2), (3) locations of population centers relative to wind patterns in the general region of the site (Section 8.3.1.12.3), and (4) potential extreme weather phenomena and their recurrence intervals (Section 8.3.1.12.4).

The investigations were created so that a complete understanding of the meteorology of the area, including both climatologically average and extreme phenomena, would be gained. Such an understanding will require looking at data from sites throughout the region and relating and comparing these data to site-specific conditions.

Meteorological data will be used by performance and design issues that assess the preclosure radiological safety aspects of the mined geologic disposal system under normal and accident conditions as shown in Figure 8.2-13. The investigation that deals with population centers relative to wind patterns will be a part of the radiological assessment because wind is the primary transport mechanism by which airborne radionuclides would reach these population centers. Finally, characterization of potential extreme weather phenomena (e.g., tornadoes, hurricanes, extreme wind speeds, temperature and humidity extremes, precipitation extremes, and obstructions to visibility) will provide input to design criteria issues relative to radiological safety. Data collected as part of this program will also provide input to investigations associated with the geohydrology program and will be used, for example, in developing storm trajectories through the area.

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Figure 8.2-13. General logic diagram for meteorology program.

Summary of meteorology investigations

As just described, the investigations planned for the meteorology program fall into two general categories: (1) those concerned with only site-specific data and (2) those associated with regional meteorological conditions. Table 8.2-42 lists the major parameters to be acquired by the meteorology investigations.

To gain an understanding of the regional meteorological conditions, existing data bases will be evaluated and their applicability to Yucca Mountain determined (Investigation 8.3.1.12.1). These data, in combination with data from the site monitoring program will then be assimilated into a data set that represents the regional meteorological conditions. Part of this investigation will also be to coordinate monitoring efforts needed for other issues or programs with the data being collected through the meteorology program.

A site monitoring program consisting of five towers has been implemented at Yucca Mountain. Although this network was initially established to support environmental permitting and licensing activities, the parameters being monitored will be used as input in evaluating preclosure radiological impacts as well. The data being collected will be input to predictive models for dose calculations to ensure that radiological safety is not compromised as a result of meteorological characteristics of the site.

The studies identified for characterizing wind patterns relative to population centers will consist of providing data on and analyses of wind parameters that will be used in conjunction with the population density program identified in Section 8.3.1.10. Together, these results will provide a clear understanding of wind transport patterns relative to population centers and will be used in determining if the patterns would or would not preferentially carry radioactive material released to the air toward these centers.

The existing data bases and technical publications reviewed in characterizing the regional meteorology will also provide data on the extreme weather phenomena that may be experienced at the site. Because extreme weather can affect design and can initiate an accident during repository operation and transportation of waste to the site, the occurrence of such phenomena and their recurrence interval must be determined.

8.2.2.4.12 Summary of offsite installations site program

The offsite installations and operations program is described in Section 8.3.1.13. This program provides technical data required to address preclosure radiological safety requirements for the repository. The investigations derived from these issues address the following topics: (1) the data base necessary to assess the potential offsite accident initiators, (2) possible radioactive releases from other sites that affect the site's ability to comply with radiological requirements, (3) location and adequacy of the transportation access routes, and (4) the agricultural and cultural data required for analysis of the public ingestion-dose pathway.

Table 8.2-42. Major parameters provided by investigations in Meteorology Program 8.3.1.12

Section number	Investigation	Major parameters
8.3.1.12.1	Studies to provide data on regional meteorological conditions	Characterization of meteorological conditions Synthesis of meteorological monitoring data
8.3.1.12.2	Studies to provide data on atmospheric and meteorological phenomena at potential locations of surface facilities	Site meteorological monitoring Data summary for input to dose assessments
8.3.1.12.3	Studies to provide data on the location of population centers relative to wind patterns in the general region of the site	Frequency distribution of wind speed and direction Persistence of wind speed and direction Diurnal wind speed and direction Atmospheric dispersion associated with wind speed and direction
8.3.1.12.4	Studies to provide data on potential extreme weather phenomena and their recurrence intervals	Frequency of severe storms Magnitude and frequency of extreme wind speeds Extremes of temperature and humidity Precipitation extremes and their recurrence intervals Frequency and intensity of fog

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

The offsite installation program requires the identification of all offsite operations that could impact the site. Potential impacts of offsite operations are determined to support the calculation of ingestion doses and exposures to the public and workers for Issues 2.1, 2.2, and 2.3 discussed in Sections 8.3.5.3 through 8.3.5.5.

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The data base established in this program will be used in an evaluation of the higher level findings required for the qualifying condition in the offsite installations technical guideline (10 CFR Part 960), and for the qualifying condition for the preclosure radiological safety system guideline (Section 8.3.5.6).

Approach to satisfy performance and design requirements

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

1. An evaluation of offsite accident initiators, their probabilities and potential impacts, and the parameters required for calculation of public ingestion dose to support Issues 2.1 and 2.3 (Sections 8.3.5.3 and 8.3.5.5).
2. An assessment of releases from all nuclear fuel cycle operations to support Issues 2.3 and 2.5 (Sections 8.3.5.5 and 8.3.5.6).
3. An assessment of the onsite impact of nonrepository-related routine and potential accidental releases of radioactive material to support Item 1 and to support the resolution of Issues 2.3 and 2.5.
4. An evaluation of the adequacy of proposed transportation site access routes to support resolution of Issues 2.3 and 2.5.
5. The collection of agricultural and cultural data to support the calculation of the dose to the public through the ingestion pathway from releases at the Yucca Mountain site and to support resolution of Issues 2.1 and 2.3.

Summary of investigations

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

The investigations identified for nearby industrial, transportation, and military installations and operations (both nuclear and nonnuclear) consist of identifying the nearby site operations, nuclear fuel cycle facilities, and nonnuclear fuel cycle facilities in the area. Once these operations have been identified, the impacts of those facilities will be assessed.

Certain agricultural and cultural data are necessary for assessing radionuclide dose calculations to the public. This information will not be collected as part of this program because this type of data is not considered part of site characterization activities as defined in the Nuclear Waste Policy Act. However, this data is an essential component of the program of

calculating doses to the public through the ingestion dose pathway and will be presented as part of the environmental program planning process within the NNWSI Project.

8.2.2.4.13 Summary of surface characteristics program

The details of the surface characteristics program are presented in Section 8.3.1.14. The program reflects requirements of the DOE, the NRC, and the EPA that the surface facilities, including openings to the underground, must ensure public health and safety, be technically feasible, and have reasonable costs. This program contains three investigations pertinent to preclosure design and performance issues: (1) topography (Section 8.3.1.14.1), (2) soil and bedrock conditions (Section 8.3.1.14.2), and (3) meteorological conditions (Section 8.3.1.14.3).

Summary of performance and design requirements for surface characteristics information

The interfaces between the surface characteristics program, other characterization programs and design and performance issues that require surface characteristics information are presented in Figure 8.2-14. As shown in the figure, surface characteristic information such as topographic contours will be used to locate and design repository surface facilities (Issue 4.4, preclosure design and technical feasibility) and to determine probable flood levels at potential surface facility locations. Topographic contour maps will be used to locate shaft and ramp entrances and other sensitive structures such as waste handling facilities above potential flood levels.

Surface topographic characteristics will also be required for certain underground design and performance studies. Topographic contour maps will be used to determine the usable repository horizon area while maintaining the required amount of overburden (Sections 8.3.5.17 and 8.3.5.18). In addition, in-situ stresses are influenced, in part, by local topography (Sections 8.3.1.4 and 8.3.1.15). Surface characteristics of the alluvial soil and rock at or near the surface influence the location and design of the surface facilities and their costs. This is especially true for sensitive structures, such as the waste handling facilities, which may experience earthquake loading (Section 8.3.1.17). Even for static loading conditions, the soil and rock conditions at the site will influence the selection of the surface facility location and its foundation design. Local meteorological conditions at the site will also impact the location and design of the surface facilities. Meteorological conditions, such as extreme wind or precipitation, must be considered in the design and performance of the surface facilities. These conditions are addressed in the meteorological program (Section 8.3.1.12).

Approach to satisfy performance and design requirements

The general approach to satisfying the performance and design requirements is to obtain and evaluate surface characterization information to determine whether the information is adequate to resolve the performance and design issues. Close collaboration between engineering and geotechnical experts is planned to allow timely development of the repository design. The

Figure 8.2-14. Logic diagram for Program 8.3.1.14, surface characteristics. Roman numerals indicate data flow.

major elements defining the required surface characteristics information include topography, soil and bedrock properties, and meteorologic conditions. The facility designer will use the surface site characteristics data to design surface structures and their foundations, shaft and ramp portals, roads, drainage systems, and flood control structures. These designs will also consider abnormal conditions such as maximum probable floods, high wind loads, and dynamic loading conditions caused by earthquakes and man-induced explosions. To satisfy these requirements, the appropriate surface characteristics information must be obtained.

New investigations are planned for soil and bedrock properties and meteorological conditions but no new studies are needed for topography, because requirements for this investigation have been satisfied. The recommended studies to address the requirements for soil and bedrock properties consist of an exploratory program, laboratory testing program, and a field testing and measurement program. The exploratory program will utilize various methods and techniques to investigate and characterize the subsurface soil and rock strata beneath the reference conceptual site. The laboratory test program will test undisturbed samples (minimal disturbance) obtained from the exploratory program and determine the soil or rock physical and mechanical material properties. The results from the field test and measurement program will further enhance the characterization of the subsurface conditions that may influence or impact surface facilities performance and design.

Summary of surface characteristics investigations

A summary of the information to be provided by the soil and bedrock property investigation is provided in Table 8.2-43. The topography investigation provides no further data because adequate contour maps are available. As previously indicated, any description of studies and activities associated with the meteorological condition investigation will be addressed in the meteorology program (Section 8.3.1.12).

8.2.2.4.14 Summary of thermal and mechanical rock properties program

The thermal and mechanical rock properties program is described in Section 8.3.1.15. Compliance with performance and design criteria for a geologic repository requires information about the rock characteristics of the Yucca Mountain site. This program provides the site information needed on thermal and mechanical rock properties and on ambient stress and temperature conditions required to support assessments of site performance and design criteria for the underground facility, seals, and waste packages.

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

Information requirements of the performance and design issues can be divided into four categories. First, Issues 1.1, 1.12, and 4.4 (Sections 8.3.5.13, 8.3.3.2, and 8.3.2.5) require data on thermal and mechanical properties of the rock for repository design analysis. Second, data on thermal properties of the rock for use in analysis of the disturbed zone are also

Table 8.2-43. Major parameters to be provided by investigations in Surface Characteristics Program 8.3.1.14

Section number	Investigation	Major parameters
8.3.1.14.1	Studies to provide the topographic characteristics of potential locations of surface facilities	Ground surface elevation as a function of geographic position
8.3.1.14.2	Studies to provide soil and rock properties of potential locations of surface facilities	Laboratory tests and material property measurements Physical property and index laboratory tests Mechanical and dynamic laboratory property tests Physical property field tests and characterization measurements Mechanical property field tests Geophysical field measurements

required for Issue 1.6 (Section 8.3.5.12). Third, Issue 2.7 (Section 8.3.2.3) requests information on bulk properties and radon emanation rates for use in analysis of radiologic safety. Finally, data on ambient in situ stress and temperature conditions to serve as initial and boundary conditions for repository design are required for Issues 1.11, 1.12, and 4.4 (Sections 8.3.2.2, 8.3.3.2, and 8.3.2.5). Figure 8.2-15 shows the interfaces between the performance assessment and design issues, and the characterization programs, and the investigations planned to acquire data on thermal and mechanical rock properties.

Approach to satisfy performance and design requirements

Performance allocation has been used to establish performance goals for the design and performance assessment issues requesting information from this program. These performance goals are then used to define the thermal and mechanical data necessary to determine whether the goals are met. In this program characterization goals represent quantitative estimates of the maximum variability in a parameter that can be tolerated without necessitating a change in the existing design. Required confidence levels are a measure of how important it is that the specified limits are met. Both characterization goals and confidence levels have been estimated for performance assessment and design issues based on limited sensitivity studies or on expert judgment. When more than one issue requires a given parameter, the issue that poses the

Figure 8.2-15. Relationship between data acquisition for rock properties and issues requiring the data.

greatest constraint will be used in planning site studies and activities to obtain values for the parameter. A summary of the major parameters provided by this program is presented in Table 8.2-44.

As site characterization proceeds, some site data values may be found to fall outside the specified range for the characterization goal. If this occurs, the portions of the design or of the performance assessment programs affected by these data will be reevaluated to assess the impact. New ranges for these data may be specified, and additional data will be collected if necessary. In addition the possibility exists that not all necessary data have been identified or that the specified ranges are invalid because of the preliminary or nonexistent sensitivity studies. In these instances, additional data may be requested or the specified ranges for a requested parameter may be changed. Either situation might lead to a modification to the site characterization program outlined in Sections 8.3.1.15.1 and 8.3.1.15.2.

Summary of the planned investigations for the thermal and rock properties program

Two investigations and nine studies are planned to collect the required rock characteristics data. The studies consist of those related to laboratory determination of thermal and mechanical properties, to in situ experiments in the exploratory shaft, and to characterization of ambient stress and thermal conditions. Three categories of in situ experiments are planned: (1) experiments related to evaluation of the effects of excavation, (2) mechanical property experiments, and (3) thermomechanical property experiments. Characterization of ambient stress and thermal conditions will include measurements of stress and temperature in new exploratory holes and in the exploratory shaft.

8.2.2.4.15 Summary of the preclosure hydrology program

The details of the preclosure hydrologic characterization program are presented in Section 8.3.1.16. This program is designed to provide the site-specific hydrologic information needed to meet the information requirements of Issue 4.4 (preclosure design and technical feasibility, Section 8.3.2.5), Issue 4.2 (nonradiological health and safety, Section 8.3.2.4), Issue 1.11 (configuration of underground facilities, Section 8.3.2.2), and Issue 1.12 (seal characteristics, Section 8.3.3.2). The overall approach is to obtain data on surface and subsurface hydrologic characteristics that will aid in finalizing the surface and subsurface facility designs.

Summary of design requirements for hydrologic information

The purpose of the preclosure hydrologic characterization program described in Section 8.3.1.16 is to provide the information regarding hydrologic characteristics, processes, and conditions required for repository design. Figure 8.2-16 shows the design issues that depend on the hydrologic characterization program for information, and the investigations that will be performed to satisfy the design requirements.

Table 8.2-44. Major parameters provided by investigations in Thermal and Mechanical Rock Properties Program 8.3.1.15 (Page 1 of 2)

Section number	Investigation	Major parameters
8.3.1.15.1	Studies to provide the required information for spatial distribution of thermal and mechanical properties	<p>Laboratory determination of rock properties characterization of density and porosity</p> <p>Characterization of volumetric heat capacity</p> <p>Characterization of thermal conductivity</p> <p>Thermal expansion testing</p> <p>Compressive mechanical properties of intact rock at baseline conditions</p> <p>Effects of variable environmental conditions on compressive mechanical properties</p> <p>Tensile strength of unit TS_{w2}^a</p> <p>Fracture properties</p> <p>Mechanical properties of fractures at baseline conditions</p> <p>Effects of variable environmental conditions on mechanical properties of fractures</p> <p>Excavation investigations</p> <p>Spatial variability of rockmass deformation</p> <p>Spatial variability of horizontal in situ stress</p> <p>Deformation in tuff caused by excavation of repository-sized rooms</p> <p>Extent of increased fractures</p> <p>Stress changes due to excavations</p> <p>In situ thermomechanical properties</p> <p>Thermal conductivity, heat capacity, and thermal expansion coefficients for TS_{w1}^b and TS_{w2}</p> <p>Deformation modulus</p> <p>Joint wall compressive strength</p> <p>Joint roughness coefficient</p> <p>Measurement of thermally-induced stress</p> <p>Rock-mass deformation</p>

Table 8.2-44. Major parameters provided by investigations in Thermal and Mechanical Rock Properties Program 8.3.1.15 (Page 2 of 2)

Section number	Investigation	Major parameters
8.3.1.15.1 (continued)	Studies to provide the required information for spatial distribution of thermal and mechanical properties (continued)	Estimate of region in which stress state is changed by temperature elevation Rib stress change Ground-support loading and deformation Temperature dependence of measured parameters In situ mechanical properties Plate loading tests Rock-mass strength In situ design verification Evaluation of mining methods Monitoring of ground support systems Monitoring of drift stability Air quality and ventilation requirements
8.3.1.15.2	Studies to provide the required information for spatial distribution of ambient thermal and stress conditions	Anelastic strain recovery in core holes In situ stress Spatial variability of in situ stress Ambient temperature Spatial variability of ambient temperature

^aTsw2 = Topopah Spring welded tuff nonlithophysal unit.

^bTsw1 = Topopah Spring welded tuff lithophysal unit.

The design issues require three types of hydrologic data that will be used in the final design of the surface and subsurface facilities. These data include information on the hazards associated with flooding and debris flows; the location of adequate and alternate water supplies for the construction, operation, and closure of the repository and the surface facilities; and information on the subsurface hydrologic conditions within and above the host horizon. These data will be used to finalize the surface facility design and the shaft and seals designs.

**DESIGN ISSUES
CALLING FOR DATA**

PROGRAM

INVESTIGATIONS

**SUPPORTING
INVESTIGATIONS**

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Figure 8.2-16. Relationship between the preclosure hydrology test program and its investigations.

Approach to satisfy the design requirements

The general approach to satisfying the design requirements is to conduct investigations that will provide values for the specific hydrologic parameters requested. Data regarding the surface hydrologic conditions will be obtained through flood and debris hazard studies and will be used in conjunction with data obtained from regional hydrology investigations (Section 8.3.1.2.1) to determine the values necessary for design. The investigation described in Section 8.3.1.16.2 will evaluate existing water well data and obtain new site-specific data in order to ensure the availability of sufficient water supplies for repository construction and operation. Detailed information on the conditions and characteristics of the unsaturated zone within and above the repository horizon will be obtained and evaluated through the geohydrologic program (Sections 8.3.1.2.1 through 8.3.1.2.3).

Summary of hydrologic investigations

A general list of parameters provided by this program is shown in Table 8.2-45. The site data will be obtained at the level of confidence needed for input to design analyses. For determining the values of parameters that are not readily amenable to measurement or analysis, multiple approaches will be used. More detailed information on the parameters provided by this program is provided in Section 8.3.1.16, and the investigations necessary to satisfy the design requirements are described in detail in Sections 8.3.1.16.1 through 8.3.1.16.3.

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

8.2.2.4.16 Summary of the preclosure tectonics program

The preclosure tectonics program described in Section 8.3.1.17 is intended to provide an understanding of and to characterize the tectonic events that could reasonably impact the operations of structures, systems, or components considered important to safety for the proposed Yucca Mountain repository through the operational phase until permanent closure is achieved. In addition, characterization of tectonic processes and events will be developed for consideration in the design and operation of certain structures, systems, and components required for exercising the retrieval option.

Table 8.2-45. Major parameters provided by investigations in Preclosure Hydrology Program 8.3.1.16

Section	Investigation	Major parameters
8.3.1.16.1	Flood recurrence intervals and levels at potential locations of surface facilities	Surface-water runoff characteristics Surface-water debris transport characteristics
8.3.1.16.2	Location of adequate water supplies	Cost, feasibility, and adequacy of wells J-12 and J-13 for use as alternate water supply Identify primary water supply for the mined geologic disposal system Identify alternate water supply for MGDS Identification and evaluation of effects of ground-water withdrawals on flow system
8.3.1.16.3	Ground-water conditions within and above the potential host rock	Data syntheses: preclosure hydrologic characteristics of the unsaturated zone

Summary of performance and design requirements for preclosure tectonics information

Performance and design issues requiring data from the preclosure tectonics program are indicated in the left half of Figure 8.2-17; the right half of the figure indicates investigations that provide the requested data. The primary requirements come from Issue 4.4, which addresses the preclosure repository design and technical feasibility for repository construction, operation, closure, and decommissioning and is discussed in Section 8.3.2.5. Investigations of technical feasibility that include data requirements from four additional performance and design issues are also noted in the figure. These four issues are repository design criteria for radiological safety (Issue 2.7, Section 8.3.2.3), accidental radiological releases (Issue 2.3, Section 8.3.5.5), waste retrieval ability (Issue 2.4, Section 8.3.5.2), and seal characteristics (Issue 1.12, Section 8.3.3.2). In addition, data are also requested by the postclosure tectonics program (Section 8.3.1.8).

Figure 8.2-17. Logic diagram for the preclosure tectonics site program.

Approach to satisfy performance and design requirements

The approach that has been developed to satisfy performance and design requirements is based on current knowledge and uncertainties about the local tectonic environment, and consideration has been given to state-of-the art capabilities for resolving or bounding the effects of these uncertainties. The performance and design requirements are organized in this program by the type of tectonic event involved (volcanic, faulting, and vibratory ground motion). Two analyses are made for each type of event, one for surface facilities and one for underground facilities.

Both deterministic and probabilistic methods will be used for analyzing the effects of tectonic events during the preclosure period. The deterministic approach will be used to model cause-and-effect mechanisms and to develop particular tectonic event scenarios in greater detail than is typically provided by probabilistic methods. In addition, all final results for volcanic, faulting, and ground-motion events will be evaluated using probabilistic methods to ensure that the full range of identifiable tectonic processes, including uncertainties, is adequately considered and to help identify those processes that are key to parametric characterizations.

Summary of preclosure tectonic investigations

Table 8.2-46 provides a list of the major parameters and principal studies associated with this program. As shown in Figure 8.2-17 the program is divided into four investigations. The first three investigations provide the analysis and assessment of geologic data necessary to satisfy performance and design requirements. Each of these investigations considers a tectonic process that could possibly be significant in the location or design of surface or underground facilities. The data gathering activities that supply the basic geologic field data required by the analysis and assessment investigations are grouped together in the fourth investigation.

8.2.3 ISSUE TRACKING

As described in Section 8.2.1, the performance and design issues were derived from NRC and DOE requirements. The information needs that have been identified under each issue represent the site data and other technical information to be used to support the resolution of the issue. The site programs summarized in Section 8.2.2.4 were structured to acquire the data on present and expected site characteristics, processes, and events needed to develop site descriptions and to support the resolution of the performance and design issues. The general plan for issue tracking and resolution is depicted schematically in Figure 8.2-18. Site information, obtained from tests in the exploratory shaft facility and from surface-based site studies, will be used as required to design a suitable waste package and the surface and underground repository facilities. On the basis of the engineered system designs and the site characteristics and conditions, performance assessment calculations will be made to predict preclosure performance for normal and

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17

Section number	Investigation	Major parameters
8.3.1.17.1	Studies to provide information on volcanic activity that could affect repository design or performance	Ashfall potential Literature survey: Quaternary silicic volcanic centers of the Great Basin Potential ash-fall thickness Particle density and size distribution of ash fall
8.3.1.17.2	Studies to provide information on fault displacement that could affect repository design or performance	Faulting potential at the repository Faulting potential at surface facility locations Potential for displacement on faults intersecting the repository
8.3.1.17.3	Studies to provide required information on vibratory ground motion that could affect repository design or performance	Identification of relevant earthquake sources Characterization of exceptional earthquakes for relevant seismic sources Range of underground nuclear explosion (UNE) sources Determination of maximum UNE sources Determination of ground motion from UNES Empirical models for earthquake ground motion Empirical models for UNES Effects of local site geology on surface and subsurface motions Site effects from ground-motion recordings Site-effects model using wave properties of the local geology Identification of controlling seismic events Characterization of controlling seismic events Ground motion at the site from controlling seismic events Evaluation of earthquake sources Ground-motion probabilities

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17 (continued)

Section number	Investigation	Major parameters
8.3.1.17.4	Preclosure tectonics data collection and analysis	<p>Historical earthquake record</p> <p>Current seismicity</p> <p>Potential for induced seismicity</p> <p>Faulting potential near prospective surface facility locations</p> <p>Identification of Midway Valley trench locations and conduct exploratory trenching</p> <p>Crustal structure and subsurface expression of Quaternary faults crossing the Furnace Creek and Walker Lane zones</p> <p>Evaluation of Quaternary faults within 100 km of Yucca Mountain</p> <p>Evaluation of the Cedar Mountain earthquake of 1933 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site</p> <p>Evaluation of the Bare Mountain fault zone</p> <p>Evaluation of structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures</p> <p>Evaluation of Quaternary faulting proximal to the site within northeast-trending fault zones including Rock Valley, Cane Spring, and Mine Mountain fault systems and the Stagecoach Road fault zone</p> <p>Evaluation of the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area</p> <p>Evaluation of postulated detachment faults in the Beatty-Bare Mountain area</p> <p>Evaluation of the potential relationship of mega-breccia within and south of Crater Flat to detachment faulting</p>

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17 (continued)

Section number	Investigation	Major parameters
8.3.17.4 (continued)	Preclosure tectonics (continued)	<p>Evaluation of postulated detachment faults in the Specter Range and Camp Desert Rock areas</p> <p>Evaluation of the age of detachment faults using radiometric ages</p> <p>Evaluation of Quaternary geology and potential Quaternary faults at Yucca Mountain</p> <p>Evaluation of age and recurrence of movement on suspected and known Quaternary faults</p> <p>Evaluation of subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain</p> <p>Evaluation of intermediate depth (to 2 to 3 km) reflection and refraction methods and plan potential application of these methods within the site area</p> <p>Detailed gravity survey of the site area</p> <p>Detailed aeromagnetic survey of the site area</p> <p>Detailed ground magnetic survey of specific features within the site area</p> <p>Evaluation of surface geoelectric methods and plan potential applications of these methods within the site area</p> <p>Evaluation of methods to detect buried faults using gamma ray measurements, and plan potential application of these methods within the site area</p> <p>Evaluation of thermal infrared methods and plan potential applications of these methods within the site area</p> <p>Evaluation of shallow seismic reflection (Mini-Sosie) methods and if appropriate conduct surveys of selected structures at and proximal to the site area</p>

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17 (continued)

Section number	Investigation	Major parameters
8.3.1.17.4 (continued)	Preclosure tectonics (continued)	<p>Evaluation of present stress field within the site area</p> <p>Evaluation of and test shallow borehole hydrofrac and triaxial strain recovery methods for the determination of in situ stress, and if appropriate, plan potential application of these methods within and proximal to the site</p> <p>Evaluation of published and unpublished data on paleostress orientation at and proximal to the site and assess the relevance of these data to Quaternary tectonics</p> <p>Evaluation of theoretical stress distributions associated with potential tectonic settings (wrench fault, normal fault, detachment fault setting, etc.) of the site</p> <p>Geomorphic evaluation of age and extent of tectonically stable areas at and near Yucca Mountain</p> <p>Evaluation of extent of areas of Quaternary uplift and subsidence at and near Yucca Mountain</p> <p>Evaluation of variations in the nature and intensity of Quaternary faulting within 100 km of Yucca Mountain through morphometric and morphologic analysis</p> <p>Geodetic leveling</p> <p>Relevel base-station network, Yucca Mountain and vicinity</p> <p>Global positioning satellite survey selected base stations, Yucca Mountain and vicinity</p> <p>Analysis of existing releveling data, Yucca Mountain and vicinity</p> <p>Characterization of regional lateral crustal movement</p> <p>Tectonic models and synthesis</p> <p>Evaluation of tectonic processes and tectonic stability at the site</p>

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17 (continued)

Section number	Investigation	Major parameters
	Preclosure tectonics (continued)	Tectonic models Tectonic disruption sequences

accident conditions, and to predict postclosure performance under both nominal (undisturbed) and disturbed conditions. The DOE will use these predictions as a part of the basis for selecting the first repository site according to the process described in 10 CFR Part 960. The repository designs and the performance assessment predictions will also serve as the basis for determinations of compliance with the NRC requirements for permanent disposal of high-level radioactive waste as specified in 10 CFR Part 60.

As shown in Figure 8.2-18, site investigation reports will document the completion of various site activities. These reports will continue to update and extend the data base available for use in repository design and performance assessment activities. When designs and calculations are sufficiently mature, a variety of topical reports, and finally, issue resolution reports will document the preliminary basis upon which the DOE will seek NRC's concurrence with various regulatory and technical requirements. Thus, by acquiring of the site data and other information necessary to support resolution of the performance and design issues, the DOE will systematically establish the information necessary to support demonstrations of compliance with the major technical and regulatory requirements.

An integrated system for monitoring and tracking progress toward issue resolution is under development. The technical basis derived from Section 8.3 provides the list of site activities planned to develop the data base for use in repository and waste package design and performance assessment calculations. Study plans for the site activities will describe the tests and experiments in more detail. Descriptions of repository and waste package design activities that do not require site data will be provided in other documents. These activities will also be monitored through the issue resolution tracking system. As site information and results of design analyses and activities become available, the baseline information will be updated. This process will continue until final designs have been developed and credible performance assessment predictions have been prepared on the basis of those designs. Resolution of those issues that address the DOE's siting guidelines (10 CFR Part 960) will occur when DOE makes a determination that the requirements of these guidelines have been met in support of the site-selection process. Resolution of those issues that address the NRC's

Figure 8.2-18. Schematic diagram showing utilization of site data by performance assessment and design, and finally for preparation of regulatory documents.

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requirements for repository performance and issuance of construction authorization cannot occur until the NRC determines that there is reasonable assurance, at that time, that all requirements are likely to be met.

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Section 8.3

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**PLANNED TESTS, ANALYSES,
AND STUDIES**

Site Characterization Plan

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

Volume IV

January 1988

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

8.3 PLANNED TESTS, ANALYSES, AND STUDIES

This section describes the planned site characterization studies, and the design and performance assessment activities to be conducted during site characterization at the Yucca Mountain site. Additional details on the planned field tests and laboratory tests will be provided in study plans. The current list of study plans with estimated dates for completion is provided in Section 8.5.1.

For the repository, seal, and waste package programs, only those activities requiring site data are described in detail in this document. Additional detail will be provided in appropriate design-related documents. In the case of performance assessment activities, sufficient detail is provided to document the site-data requirements. As described in Sections 8.1 and 8.2, performance allocation was used to identify both design and performance assessment data needs.

Section 8.3.1 presents the site program. It is divided into seventeen subsections (8.3.1.1 through 8.3.1.17) representing the major topical areas for which site data needs have been identified. Section 8.3.2 describes the repository program; the section begins with an overview of the repository program (8.3.2.1), followed by discussions of the issue resolution strategies for four design issues (8.3.2.2--Issue 1.11 on configuration of underground facilities (postclosure); 8.3.2.3--Issue 2.7 covering repository design criteria for radiological safety; 8.3.2.4--Issue 4.2 on nonradiological health and safety of repository workers; and 8.3.2.5--Issue 4.4 covering preclosure design and technical feasibility).

Section 8.3.3 describes the seal program; an overview is provided (8.3.3.1), followed by a discussion of the issue resolution strategy for Issue 1.12, addressing shaft, exploratory, and borehole seal characteristics (8.3.3.2). Section 8.3.4 presents the waste package program; Section 8.3.4.1 provides an overview of the waste package program, and the remaining sections present issue resolution strategies for three of the issues related to waste package design and analyses. Section 8.3.4.2 presents Issue 1.10, which addresses postclosure waste package characteristics; Section 8.3.4.3 addresses preclosure waste package characteristics (Issue 2.6); and Section 8.3.4.4 addresses waste package production technologies (Issue 4.3).

Section 8.3.5 presents the performance assessment program for both pre- and postclosure. The first section (8.3.5.1) is an overview of the preclosure performance assessment strategy. Section 8.3.5.2 addresses Issue 2.4, presenting the issue resolution strategy for the performance objective for waste retrievability. The next three sections (8.3.5.3 through 8.3.5.5) present issue resolution strategies for the issues related to radiological safety requirements for repository workers and the public. Sections 8.3.5.6 and 8.3.5.7 present the issues that cover the requirements for higher level findings on the DOE general siting guidelines for preclosure radiological safety and ease and cost of siting, construction, operation, and closure (Issues 2.5 and 4.1, respectively).

An overview of the postclosure performance assessment strategy is presented in Section 8.3.5.8. Sections 8.3.5.9 and 8.3.5.10 provide issue

resolution strategies for the performance objectives for waste package containment (Issue 1.4) and engineered barrier system performance (Issue 1.5). Section 8.3.5.11 is a discussion of the plans for assessing the performance of the seal system, while Section 8.3.5.12 presents the performance objective for pre-waste-emplacement ground-water travel time (Issue 1.6). Section 8.3.5.13 addresses the issue resolution strategy for the performance objective for the total repository system (Issue 1.1), and Sections 8.3.5.14 and 8.3.5.15 cover the individual protection requirements (Issue 1.2) and the requirement for protection of special sources of ground water (Issue 1.3). Section 8.3.5.16 presents a discussion of the requirements for performance confirmation (Issue 1.7), and Section 8.3.5.17 describes the issue resolution strategy for Issue 1.8, the NRC Siting Criteria. Section 8.3.5.18 addresses the requirement for higher level findings on the DOE general siting guidelines (Issue 1.9). The discussion of the analytical techniques already available and techniques requiring development are provided in the last two sections (8.3.5.19 and 8.3.5.20).

Table 8.3-1 provides an overview of the structure of Section 8.3 showing the order of the specific site programs in Section 8.3.1, and the performance and design issues covered in Sections 8.3.2 through 8.3.5.

Table 8.3-1. Overview of contents of Section 8.3 showing order of presentation of site programs and performance and design issues within major programs

Section 8.3.1 Site Program	Section 8.3.2 Repository Program	Section 8.3.3 Seal Program	Section 8.3.4 Waste Package Program	Section 8.3.5 Performance Assessment Program
8.3.1.2 Geohydrology	8.3.2.2 Configuration of underground facilities (postclosure), Issue 1.11	8.3.3.2 Seal characteristics (postclosure), Issue 1.12 ^a	8.3.4.2 Waste package characteristics (postclosure) Issue 1.10	8.3.5.2 Waste retrievability, Issue 2.4
8.3.1.3 Geochemistry				8.3.5.3 Public radiological exposures--normal conditions, Issue 2.1
8.3.1.4 Rock characteristics	8.3.2.3 Repository design criteria for radiological safety, Issue 2.7		8.3.4.3 Waste package characteristics (preclosure), Issue 2.6	8.3.5.4 Worker radiological safety--normal conditions, Issue 2.2
8.3.1.5 Climatic change				8.3.5.5 Accidental Radiological releases, Issue 2.3
8.3.1.6 Erosion	8.3.2.4 Nonradiological health and safety, Issue 4.2		8.3.4.4 Waste package production technologies, Issue 4.3	8.3.5.6 Higher level findings--preclosure radiological safety, Issue 2.5
8.3.1.7 Dissolution				8.3.5.7 Higher level findings--preclosure system and technical guidelines, Issue 4.1
8.3.1.8 Postclosure tectonics	8.3.2.5 Preclosure design and technical feasibility, Issue 4.4			8.3.5.9 Waste package containment, Issue 1.4
8.3.1.9 Human interference				8.3.5.10 Engineered barrier system release rates, Issue 1.5
8.3.1.10 Population density				8.3.5.12 Ground-water travel time, Issue 1.6
8.3.1.11 Site ownership				8.3.5.13 Total system performance, Issue 1.1
8.3.1.12 Meteorology				8.3.5.14 Individual protection, Issue 1.2
8.3.1.13 Offsite installations				8.3.5.15 Ground-water protection, Issue 1.3
8.3.1.14 Surface characteristics				8.3.5.16 Performance confirmation, Issue 1.7
8.3.1.15 Thermal and mechanical rock properties				8.3.5.17 NRC Siting Criteria, Issue 1.8
8.3.1.16 Hydrology				8.3.5.18 Higher level findings--postclosure system and technical guidelines, Issue 1.9
8.3.1.17 Preclosure tectonics				

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Section 8.3.1

Consultation Draft

SITE PROGRAM

Site Characterization Plan

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

Volume IV

January 1988

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

8.3.1 SITE PROGRAM

This section describes the site characterization investigations currently thought to be necessary to adequately characterize the Yucca Mountain site. The investigations are subdivided into studies and activities. The studies will be described in further detail in study plans; a list of study plans is provided in Section 8.5.1. The site data base developed by the planned studies will be used to meet the requirements specified in the issue resolution strategies for the performance and design issues presented in Sections 8.3.2 through 8.3.5. The site information to be collected in this program will serve as a part of the basis for determining if the regulatory requirements for licensing a geologic repository can be met at the Yucca Mountain site.

The exact locations where the site investigations described in this section will be conducted are tentative. The actual locations will depend on comments received from the U.S. Nuclear Regulatory Commission (NRC), the State of Nevada, and many other commenters. Other items that may influence the actual locations include compliance with applicable Federal and State environmental requirements, access to public or private land needed to conduct the investigation, and cost. Specific boundaries for the Yucca Mountain site have not been determined and site boundaries shown on maps in this document should be considered preliminary and subject to change. It should also be recognized that all schedule and milestone information provided in this section is preliminary and tentative. Section 8.5 describes the assumptions used for estimating milestone completion dates, including the dates assumed for key site-related milestones such as the availability of environmental permits and land access agreements, the beginning of exploratory shaft construction, and the initiation of surface-based testing.

On June 30, 1987, Nevada Governor Richard Bryan signed into law legislation creating the State's 18th county, Bullfrog County. The new county was formed from part of Nye County and comprises a 144 mi² area. Bullfrog County encompasses the Yucca Mountain site and is located on lands administered by the U.S. Air Force, the Bureau of Land Management, and the U.S. Department of Energy. Since the new county has been established recently, the Site Characterization Plan (SCP) has not been revised to reflect the changes, especially county boundaries depicted on various figures. These changes will be incorporated in the final version of the SCP, as necessary.

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Section 8.3.1.1

Consultation Draft

SITE OVERVIEW

Site Characterization Plan

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

Volume IV

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8.3.1.1 Overview of the site program

The site information required to support resolution of the performance and design issues was identified through the use of performance allocation (Sections 8.1 and 8.2). By determining the site features that are important for designing the repository and assessing its performance, performance allocation served as a guide for establishing the scope and content of the site programs described in this section.

This section is organized according to the major topics of investigation within the site program. Some sections tend to have a preclosure or post-closure bias because the primary use of the data is by a performance or design issue with a similar bias. As shown in Table 8.3-1, Section 8.3.1.2 describes the investigations making up the geohydrology program, while Section 8.3.1.3 covers the geochemistry program; Section 8.3.1.4 describes the plans to develop an integrated site characterization drilling program for the NNWSI Project, and the investigations planned to determine the three-dimensional distribution of rock properties at the Yucca Mountain site. Investigations planned to predict the range of future climatic conditions that are possible at the Yucca Mountain site are described in Section 8.3.1.5; Section 8.3.1.6 covers the investigations related to present and future erosion rates at the site, while Section 8.3.1.7 addresses rates of rock dissolution. Section 8.3.1.8 describes the plans for investigation of tectonic processes that operate over the postclosure period, and Section 8.3.1.9 covers the investigations to establish the potential for human interference activities at the site.

Preliminary site-related data needs for radiological safety assessments have been identified and are covered by Sections 8.3.1.10 through 8.3.1.13 (population density and distribution, land ownership and mineral rights, meteorological conditions, and offsite installations). Section 8.3.1.14 describes the investigations necessary to establish the surface characteristics at the site for purposes of repository siting. Investigations addressing data needs for thermal and mechanical rock properties and for ambient stress and temperature conditions are described in Section 8.3.1.15. Section 8.3.1.16 describes the investigations planned to provide information on surface hydrologic conditions and processes. Finally, Section 8.3.1.17 describes the investigations intended to provide site information on the potential for igneous activity, ground motion, and surface faulting at the Yucca Mountain site during the preclosure period.

Site investigations are presented as a number of studies and activities. The studies will be described in further detail in study plans; a list of study plans is provided in Section 8.5.1. All schedule and milestone information provided in this section should be regarded as preliminary and tentative. Section 8.5 describes the assumptions used for estimating milestone completion dates and provides a discussion of recent changes in the overall schedule for the repository program.

Nuclear Waste Policy Act
(Section 113)

Section 8.3.1.2

Consultation Draft

GEOHYDROLOGY

Site Characterization
Plan

Yucca Mountain Site, Nevada Research
and Development Area, Nevada

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8.3.1.2 Overview of the geohydrology program: Description of the present and expected geohydrologic characteristics required by the performance and design issues

The performance issues that require data from this site characterization program are discussed, together with the current strategy that the NNWSI Project intends to use in the conduct of this site characterization program. The investigations and studies to be conducted are identified and discussed with explanations for how these investigations and studies will adequately address requirements of the test program.

The major part of Section 8.3.1.2 summarizes the studies and activities that have been chosen to provide the information required by the characterization investigations, and relates these studies and activities to the performance and design issues. The test program directly relates to various performance requirements identified in 40 CFR Part 191 and 10 CFR Part 60, specifically the following:

40 CFR 191.13(a)

Disposal systems for spent nuclear fuel or high-level or trans-uranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessment, that the cumulative releases of radionuclides to the accessible environment for 10,000 yr after disposal from all significant processes and events, that may affect the disposal system shall:

- (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and
- (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

40 CFR 191.16(b)

Disposal systems for spent nuclear fuel or high-level or trans-uranic radioactive wastes shall be designed to provide a reasonable expectation, that for 1,000 yr after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed:

- (1) Five picocuries per liter of radium-226 and radium-228;
- (2) Fifteen picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or
- (3) The combined concentrations of radionuclides, that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ >4 rems/yr if an individual consumed 2 L/d of drinking water from such a source of ground water.

10 CFR 60.113 (a)(1)(ii)(A)

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 the factors specified in Part 60.113(b) provided that such period shall be not less than 300 yr nor more than 1,000 yr after permanent closure of the geologic repository.

10 CFR 60.113 (a)(1)(ii)(B)

The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000/yr of the inventory of that radionuclide calculated to be present at 1,000 yr following permanent closure, or such 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 <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/yr of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 yr of radioactive decay.

10 CFR 60.113 (a)(2)

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

Regulations 40 CFR 191.13(a) and 10 CFR 60.113(a)(2) are associated with the movement of ground water in the immediate vicinity of the proposed repository. Regulations 40 CFR 191.16(b), 10 CFR 60.113(a)(i)(ii)(A), and 10 CFR 60.113(a)(i)(ii)(B) are associated with the existence of ground water around the repository; in particular, 10 CFR 60.113(a)(i)(ii)(A) and 10 CFR 60.113(a)(i)(ii)(B) directly depend on the emplacement environment, because ground-water moisture is presumed to be the primary mechanism for waste package degradation and for releases from the engineered barrier system.

Each of these regulations is addressed by a specific issue within the NNWSI Project Issues Hierarchy. The respective issues for these regulations are 1.1, 1.3, 1.4, 1.5, and 1.6 (Sections 8.3.5.13, 8.3.5.15, 8.3.5.9, 8.3.5.10, and 8.3.5.12 respectively). The hydrologic information required to satisfy these issues is discussed in Section 8.3.5, and is summarized in the following discussion, where a correlation is made to the data to be collected under the geohydrology program.

In addition to the performance requirements just identified, hydrologic information provided by the geohydrologic test programs is also required to address the favorable conditions identified in 10 CFR 60.122(b) and the potentially adverse conditions of 10 CFR 60.122(c). These conditions are examined under Issue 1.8 (Section 8.3.5.17).

An understanding and a quantitative assessment of the hydrologic conditions at Yucca Mountain are also required to address the higher level findings required by 10 CFR Part 960 for the qualifying conditions on the postclosure system guideline and the disqualifying and qualifying conditions on the technical guidelines for geohydrology, geochemistry, climatic changes, and human interference. An assessment of these findings is addressed under Issue 1.9 (Section 8.3.5.18).

Issue 1.9 also addresses the comparative evaluations required by 10 CFR 960.3-1-5, which is associated with cumulative releases to the accessible environment during 100,000 yr. Once again, the hydrologic system is the primary mechanism by which these releases can occur, and so an understanding of the ground-water and surface-water systems is required to perform these evaluations.

Approach to satisfy performance and design requirements

An understanding of the geohydrologic environment is essential to assessing the suitability of the site because ground water is expected to be the major transport medium of radionuclides to the accessible environment. A potential additional radionuclide transport process is by gaseous-phase flow in the unsaturated zone, which is also addressed by the Geohydrology Program.

The general strategy for carrying out the geohydrology program is to conduct investigations that will result in a complete and accurate description of the pertinent components of the hydrologic system that will reflect an understanding of the hydrologic properties, initial and boundary conditions and processes, and their interrelationships. The results of the geohydrology program will then be combined with the results of other site programs to produce a site model, or complete description of the site.

The geohydrology program consists of the data-collection and evaluation activities that will result in hydrologic models that describe two distinct regimes of the hydrologic system: the unsaturated zone and the saturated zone. Each of these regimes is impacted by the surface-water flow regime, and so a surface-water hydrologic model will also be developed to provide input to the other two hydrologic models. The unsaturated-zone hydrologic model will be developed only at the site scale, whereas the surface-water and saturated-zone hydrologic models will be developed at both site and regional scales. The hydrologic regimes described by these models are those that significantly affect the resolution of hydrologic-related design and performance issues; these regimes, therefore, are the principal subjects of investigation in the geohydrology program.

The geohydrology program is a broad program that includes activities in the disciplines of unsaturated-zone hydrology, saturated-zone hydrology (on both a regional and site scale), and surface-water hydrology. Much of the effort of the geohydrology program will focus on the thick (500 to 750 m) unsaturated zone at the site. This is the environment in which the repository would be constructed; thus, many of the design requirements relate to the unsaturated zone, and this environment is expected to serve as the primary barrier to transport of radionuclides. Despite the extensive investigations planned for the hydrologic characterization of the unsaturated zone, a certain level of uncertainty may still remain as to its effectiveness

as a barrier even after the investigations are completed. This is because detailed understanding of hydrologic processes in thick, arid-region, fractured-rock unsaturated zones is generally poor, and, therefore, various untried and nonstandard approaches must be taken. Consequently, in keeping with the multiple barrier concept, substantial emphasis will also be placed on characterizing the saturated zone.

The saturated zone beneath the site serves as the final portion of the flow path for ground-water flow and transport to the accessible environment. Evaluation of the regional saturated-zone flow system provides knowledge of the boundary conditions at the site; this knowledge is needed to assess accurately the impacts of changes (such as climate) on the flow system beneath the site.

Surface water is expected to be a major source of infiltration to the unsaturated zone and, ultimately, recharge to the saturated zone. Changes in the surface-water flow regime could significantly impact ground-water flow paths and gradients and, thus, radionuclide transport from the site to the accessible environment. In addition, surface-water flooding and debris transport may pose a hazard to repository facilities.

Figure 8.3.1.2-1 is a logic diagram that shows the interface between the geohydrology program and the design and performance issues and other site characterization programs for which the geohydrology program provides information. The diagram shows that the parameters obtained by the geohydrology program will be used in a wide variety of issues and programs in the NNWSI Project.

The logic diagrams of Figures 8.3.1.2-2, -3, and -4 show the relationships between the three hydrologic models (surface-water, unsaturated zone, and saturated-zone) and the geohydrology program. The diagrams expand the hydrologic models to show the models, model components, and common parameter categories used to build that model. The diagrams also show that each hydrologic model consists of numerical models and conceptual/descriptive models, which combine to provide a complete description.

The hydrologic models contain four major components: (1) system geometry, (2) material properties, (3) initial and boundary conditions, and (4) hydrologic hypotheses. In Figures 8.3.1.2-2, 3, and 4 these components are given designations more specific to the particular hydrologic model that they constitute. For each of these hydrologic models, the system geometry is provided by the geologic framework. The material properties include the surface-water hydraulic characteristics (Figure 8.3.1.2-2) the unsaturated hydraulic and gaseous-phase properties zone (Figure 8.3.1.2-3) and saturated-zone hydraulic properties (Figure 8.3.1.2-4). Each of the three hydrologic regimes has its own set of initial and boundary conditions. The first three components together form the basis for developing the numerical models that quantitatively describe various aspects of the hydrologic system. These components also support the fourth component, the hypotheses concerning the conditions, properties, and processes of the particular hydrologic regime being modeled. A consistent set of hypotheses leads to a conceptual model for that hydrologic regime.

Figure 8.3.1.2-1. Interface of the geohydrology program with design and performance issue and other characterization programs.

R.3.1.2-2

Figure 8.3.1.2-2. Logic diagram of the surface-water hydrology component of the geohydrology program.

Figure 8.3.1.2-3. Logic diagram of the unsaturated-zone hydrology component of the geohydrology program.

Figure 8.3.1.2-4. Logic diagram of the saturated-zone hydrology component of the geohydrology program.

Parameters define the geologic framework, hydrologic properties and characteristics, and initial and boundary conditions. Categories of these parameters and their relationships to these model components are shown for each of the hydrologic regimes in Figures 8.3.1.2-2, -3, and -4.

The parameter categories in Figures 8.3.1.2-2, -3, and -4 are tied to Table 8.3.1.2-1, which provides the initial framework for relating (1) the parameter requirements of the design and performance issues and (2) the parameters that will be provided by the geohydrology program to satisfy those requirements. Table 8.3.1.2-1 lists in the two left-hand columns the issues and section numbers that call for information from the geohydrology program. In the two right-hand columns, the table lists the activity parameters that will be obtained in the program in response to those requirements, along with the section numbers where the activities are described that will obtain the parameters. The middle column (parameter category) provides the linkage between the performance and design and the characterization parts of the table; this column also provides the organizational structure upon which the listings of issues and activity parameters are based.

Activity parameters generally are those parameters that will be generated by the field and laboratory testing activities. They represent the most basic measurements that will be used in analyses to characterize the geohydrology of the site. Many of the activity parameters are building blocks to support various aspects of the project. Some, such as hydraulic conductivity, support design and performance issues directly; others, such as drainage-basin areas, primarily provide bases for analyses and evaluations to be conducted within the geohydrology program or within other characterization programs.

In Table 8.3.1.2-1, the activity parameters are grouped according to parameter categories. These categories, including major categories (such as "unsaturated-zone hydrologic properties and conditions") and subcategories (such as transmissive) are topical categories that serve to group similar types of performance and design parameters and match them with groups of similar types of parameters to be obtained during site characterization. Generally, a one-to-one correspondence is not to be expected between a performance parameter and an activity parameter because of the great diversity, volume, and highly specific nature of both types of parameters.

The parameter category serves as a convenient and logical classification scheme that can aid the reader in assessing the appropriateness and completeness of the data collection program. The technical logic for the parameter categories that are applicable to the geohydrology program is reflected in the logic diagrams (Figures 8.3.1.2-2, -3, and -4). In these diagrams, the categories are shown supporting specific model components that make up the various hydrologic models, from which the principal products of the geohydrology program will be derived.

The various geohydrology-related performance and design parameters listed in the performance allocation tables in Sections 8.3.2 through 8.3.5 can readily be matched to the various categories shown in Table 8.3.1.2-1.

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 1 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
METEOROLOGICAL CHARACTERISTICS				
1.12, 2.1, 2.2, 2.3, 4.4	8.3.3.2, 8.3.5.3, 8.3.5.4, 8.3.5.5, 8.3.2.5	Air temperature, maximum and mini- mum daily	8.3.1.2.1.3.3	
		Atmospheric pressure variability	8.3.1.2.1.1.1	
		Atmospheric stability, relation- ship to storms	8.3.1.2.1.1.1	
		Humidity, relative, diurnal and seasonal variability	8.3.1.2.1.1.1	
		Precipitation, monthly and seasonal variability	8.3.1.2.1.1.1	
		Precipitation, quantities and rates	8.3.1.16.1.1	
		Radiation and irradiation, infra- red, diurnal and seasonal variability	8.3.1.2.1.1.1	
		Rainfall, duration	8.3.1.2.1.1.1	
		Rainfall, intensities, durations and frequencies	8.3.1.2.1.3.3	
		Temperature, ground surface	8.3.1.2.1.1.1	
		Wind speed and direction, diurnal, seasonal, and storm-specific variabilities	8.3.1.2.1.1.1	
		Humidity, relative, soil gas	8.3.1.2.2.7.1	
		Temperature, soil	8.3.1.2.2.7.1	
		Water chemistry, precipitation samples	8.3.1.2.1.2.1	
		Rainfall, experimentally induced	8.3.1.2.2.1.3	
		Snowpack, depth and water content	8.3.1.2.1.3.3	

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 2 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
SURFACE-WATER HYDROLOGIC CHARACTERISTICS				
1.12, 4.4 2.1, 2.3	8.3.3.2, 8.3.2.5, 8.3.5.3, 8.3.5.5	Floods and run- off	Flood and runoff, recurrence intervals Floods, character of fluids moved, relative proportions of water, and sediment Floods, peak discharge Runoff, areal extent Runoff, experimentally induced Streamflow, magnitudes, and frequency Runoff, frequencies for different areas Runoff, occurrence, magnitudes and durations at specific sites Runoff, quantity, relationship, to meteorology Streamflow, quantities, duration and rates	8.3.1.16.1.1 8.3.1.16.1.1 8.3.1.16.1.1 8.3.1.2.1.2.1 8.3.1.2.2.1.3 8.3.1.2.1.3.3 8.3.1.2.1.2.1 8.3.1.2.1.2.1 8.3.1.2.1.2.1 8.3.1.16.1.1
1.11, 2.1, 2.2, 2.3, 4.4	8.3.2.2, 8.3.5.3, 8.3.5.4, 8.3.5.5	Drainage-basin and channel characteristics	Drainage-basin altitude range Drainage-basin antecedent moisture quantity and distribution basin area Drainage-basin areal configuration Drainage-basin aspect, geographic orientation	8.3.1.2.1.3.3 8.3.1.2.1.3.3 8.3.1.2.1.3.3 8.3.1.2.1.3.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 3 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
SURFACE-WATER HYDROLOGIC CHARACTERISTICS (continued)				
		Drainage-basin and channel characteristics (continued)	Drainage-basin slope gradient	8.3.1.2.1.3.3
			Drainage-basin vegetative cover, type and density	8.3.1.2.1.3.3
			Drainage channel areal configuration	8.3.1.2.1.3.3
			Drainage channel frictional resistance to flow, Manning's coefficient	8.3.1.2.1.3.3
			Drainage channel slope gradient	8.3.1.2.1.3.3
1.1, 1.12, 2.2	8.3.5.13, 8.3.3.2, 8.3.5.4	Water chemistry	Surface-water chemistry and temperature	8.3.1.2.1.2.1
1.12, 2.3	8.3.3.2, 8.3.5.5	Debris transport	Debris transport, by streamflow physical characteristics	8.3.1.2.1.2.2
			Debris transport, quantity and character during floods	8.3.1.16.1.1
			Debris transport, suspended load	8.3.1.2.1.2.2
			Erosion and deposition, characteristics	8.3.1.2.1.2.2
			Erosion and deposition, quantities	8.3.1.2.1.2.2

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 4 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
1.1, 1.6, 4.4, 1.11, 1.12	8.3.5.13, 8.3.5.12, 8.3.2.5, 8.3.2.2, 8.3.3.2	Transmissive	Effective porosity, bulk, frac- ture/matrix networks	8.3.1.2.2.4.3
			Effective porosity, matrix and fractures, Topopah Spring welded unit	8.3.1.2.2.4.2
			Fracture permeability, anisotropy	8.3.1.2.2.7.1
			Fracture permeability, hydraulic, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4
			Hydraulic conductivity, Ghost Dance fault zone	8.3.1.2.2.6.1
			Hydraulic conductivity, Topopah Spring welded unit	8.3.1.2.2.4.2
			Hydraulic conductivity, perched- water zones	8.3.1.2.2.4.7
			Hydraulic conductivity, subsurface hydrogeologic units	8.3.1.2.2.3.2
			Hydraulic conductivity, surficial hydrogeologic and bedrock units	8.3.1.2.2.1.3
			Permeability, air, profiles in rock units near exploratory shaft	8.3.1.2.2.4.5
			Permeability, bulk, Calico Hills nonwelded unit	8.3.1.2.2.4.6

8.3.1.2-13

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 5 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
		Transmissive (continued)	Permeability, bulk, hydraulic, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4
			Permeability, effective, single fractures	8.3.1.2.2.4.1
			Permeability, in-situ hydraulic, bulk, hydrogeologic units pene- trated by surface-based boreholes	8.3.1.2.2.3.2
			Permeability, in-situ hydraulic, bulk, near Solitario Canyon fault zone	8.3.1.2.2.3.3
			Permeability, in-situ pneumatic, bulk, Solitario Canyon fault zone	8.3.1.2.2.3.3
			Permeability, in-situ pneumatic, bulk, hydrogeologic units pene- trated by surface-based boreholes	8.3.1.2.2.3.2
			Permeability, matrix, hydraulic, subsurface geologic samples	8.3.1.2.2.3.1
			Permeability, pneumatic, bulk, fracture/matrix networks	8.3.1.2.2.4.3
			Permeability, pneumatic, bulk, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 6 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
		Transmissive (continued)	Permeability, pneumatic, bulk, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.7.1
			Permeability, relative, hydraulic, matrix, subsurface geologic samples	8.3.1.2.2.3.1
			Pneumatic conductivity, Ghost Dance fault zone	8.3.1.2.2.6.1
			Pneumatic conductivity, directional and saturation dependence, Topopah Spring welded unit	8.3.1.2.2.4.3
			Pneumatic conductivity, fault zones penetrated by surface-based boreholes	8.3.1.2.2.7.1
			Pneumatic conductivity, fracture networks	8.3.1.2.2.4.2
			Pneumatic permeability, fractured- rock units near exploratory shaft, before and after excavation	8.3.1.2.2.4.4
			Tortuosity, fracture flow paths	8.3.1.2.2.4.1
			Tortuosity, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4
			Tracer concentrations and activi- ties, Ghost Dance fault zone	8.3.1.2.2.6.1
			Transmissivity, perched-water zones	8.3.1.2.2.4.7

Table 8.3.1.2 1. Activity parameters provided by the geohydrology program that support performance and design issues (page 7 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
1.1, 1.6, 4.4	8.3.5.13, 8.3.5.12, 8.3.2.5	Storage	Moisture-retention curves, subsur- face geologic samples	8.3.1.2.2.3.1
			Pore size distribution, matrix, subsurface geologic samples	8.3.1.2.2.3.1
			Porosity, bulk, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4
			Porosity, fracture, effective, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.7.1
			Porosity, matrix, surficial hydro- geologic and bedrock units	8.3.1.2.2.1.1
			Porosity, rock units near explora- tory shaft	8.3.1.2.2.4.5
			Porosity, subsurface geologic samples	8.3.1.2.2.3.1
			Storage coefficient, perched-water zones	8.3.1.2.2.4.7
			1.1, 1.6, 4.4	8.3.5.13, 8.3.5.12, 8.3.2.5
Convective dispersivity, fracture networks	8.3.1.2.2.4.2			
Convective dispersivity, hydrogeo- logic units penetrated by surface-based boreholes	8.3.1.2.2.7.1			

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 8 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
		Dispersive (continued)	Diffusivity, coefficient, Calico Hills nonwelded unit	8.3.1.2.2.4.6
			Dispersion effects, gas phase, Ghost Dance fault zone	8.3.1.2.2.6.1
			Dispersivity, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4
			Dispersivity, fractures	8.3.1.2.2.4.1
			Gaseous diffusion, coefficient, Calico Hills nonwelded unit	8.3.1.2.2.4.6
			Gaseous diffusion, coefficient, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4
			Matrix diffusion, coefficient, fracture networks	8.3.1.2.2.4.2
1.1, 1.4, 1.5, 1.6, 1.12	8.3.5.13, 8.3.5.9, 8.3.5.10, 8.3.5.12, 8.3.3.2	Fluid chemistry and temperature	Carbon-isotope concentrations, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.8.1
			Carbon-isotope concentrations, rock units near exploratory shaft	8.3.1.2.2.4.8
			Gas composition, hydrogeologic units penetrated by surface- based boreholes	8.3.1.2.2.8.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 9 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPERTIES AND CONDITIONS				
		Fluid chemistry and temperature (continued)	Hydrochemistry, Calico Hills non-welded unit	8.3.1.2.2.4.8
			Hydrochemistry, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.8.2
			Hydrochemistry, rock mass near exploratory shaft	8.3.1.2.2.4.8
			Hydrogen and oxygen isotope abundances, rock units near exploratory shaft	8.3.1.2.2.4.8
			Hydrogen and oxygen isotope concentrations, water vapor samples	8.3.1.2.2.8.1
			Pore-gas composition, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.7.1
			Pore-gas composition, rock units near exploratory shaft	8.3.1.2.2.4.8
			Air temperature, boreholes penetrating subsurface hydrogeologic units	8.3.1.2.2.7.1
1.1, 1.5, 1.6, 1.12	8.3.5.13, 8.3.5.10, 8.3.5.12,	Fluid flow	Evapotranspiration rate, from surficial hydrogeologic and bedrock units at site	8.3.1.2.2.1.2

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 10 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
8.3.3.2	Fluid flow (continued)	Evapotranspiration rate under experimental conditions at site	8.3.1.2.2.1.3	
		Flow paths, beneath experimental infiltration plots	8.3.1.2.2.1.3	
		Flow paths, hydrochemical deter- mination, rock units near exploratory shaft	8.3.1.2.2.4.8	
		Flow velocities, air in surface- based boreholes	8.3.1.2.2.7.1	
		Flow velocities, beneath experimen- tal infiltration plots	8.3.1.2.2.1.3	
		Flow velocities, surficial hydro- geologic and bedrock units	8.3.1.2.2.1.2	
		Flux, liquid and gaseous phase, Ghost Dance fault zone	8.3.1.2.2.6.1	
		Flux, volumetric, through fracture/ matrix networks	8.3.1.2.2.4.2	
		Flux, volumetric, through the Topopah Spring welded unit	8.3.1.2.2.4.3	
		Flux, water, beneath experimental infiltration plots	8.3.1.2.2.1.3	
		Infiltration, natural, surficial hydrogeologic and bedrock units	8.3.1.2.2.1.2	
		Infiltration, net, beneath sur- ficial evapotranspiration zone	8.3.1.2.2.1.2	

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 11 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
		UNSATURATED-ZONE HYDROLOGIC PROPERTIES AND CONDITIONS		
		Fluid flow (continued)	Infiltration, rates, saturated and unsaturated, experimentally induced	8.3.1.2.2.1.3
			Travel times, hydrochemical determination; rock units near exploratory shaft	8.3.1.2.2.4.8
			Flow paths (0-18/0-16, D/H), hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.8.2
			Travel times, tritium, carbon-14 and chlorine-36	8.3.1.2.2.8.2
			Water velocity, directional distributions, Topopah Spring welded unit	8.3.1.2.2.4.3
			Water velocity, directional distributions, fracture/matrix networks	8.3.1.2.2.4.2
1.1, 1.6	8.3.5.13, 8.3.5.12	Fluid and thermal potential	Water potential, total, Calico Hills nonwelded unit	8.3.1.2.2.4.6
			Water potential, total, Ghost Dance fault zone	8.3.1.2.2.6.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 12 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
		Fluid and thermal potential (continued)	Matric potential, Ghost Dance fault zone	8.3.1.2.2.6.1
			Matric potential, beneath experi- mental infiltration plots	8.3.1.2.2.1.3
			Matric potential, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4
			Matric potential, in-situ, Soli- tario Canyon, fault zone	8.3.1.2.2.3.3
			Matric potential, in-situ, hydro- geologic units penetrated by surface-based boreholes	8.3.1.2.2.3.2
			Matric potential, subsurface geo- logic samples	8.3.1.2.2.3.1
			Pneumatic potential, Calico Hills nonwelded unit	8.3.1.2.2.4.6
			Pneumatic potential, Solitario Canyon fault zone	8.3.1.2.2.3.3
			Pneumatic potential, fractured-rock units near exploratory shaft	8.3.1.2.2.4.4
			Pneumatic potential, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.3.2

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 13 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPERTIES AND CONDITIONS				
		Fluid and thermal potential (continued)	Pneumatic potential, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.7.1
			Potential fields, ambient, lateral variation near Solitario Canyon fault zone	8.3.1.2.2.3.3
			Pressure-head, profiles, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.3.2
			Temperature, Calico Hills nonwelded unit	8.3.1.2.2.4.6
			Thermal potential, Solitario Canyon fault zone	8.3.1.2.2.3.3
			Temperature, fractured rock units near exploratory shaft	8.3.1.2.2.4.4
			Thermal potential, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.3.2
			Water potential, fracture/matrix networks	8.3.1.2.2.4.2
			Water potential, surficial hydrogeologic and bedrock networks	8.3.1.2.2.1.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 14 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
		Fluid and thermal potential (continued)	Water potential, total, Solitario Canyon fault zone	8.3.1.2.2.3.3
			Water potential, total, Topopah Spring welded unit	8.3.1.2.2.4.3
			Water potential, total, fractured- rock units near exploratory shaft	8.3.1.2.2.4.4
			Water potential, total, hydrogeo- logic units penetrated by sur- face-based boreholes	8.3.1.2.2.3.2
			Water potential, total, perched- water zones	8.3.1.2.2.4.7
			Water potential, total, subsurface geologic samples	8.3.1.2.2.3.1
1.1, 1.6, 4.4, 1.4	8.3.5.13, 8.3.5.12, 8.3.2.5, 8.3.5.9	Moisture conditions	Moisture content, lateral variation in Solitario Canyon fault zone	8.3.1.2.2.3.3
			Moisture content, surficial hydro- geologic and bedrock units	8.3.1.2.2.1.1
			Moisture content, time dependence, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.3.2
			Moisture content, volumetric sub- surface geologic samples	8.3.1.2.2.3.1
			Moisture content, changes in alluvium	8.3.1.2.2.3.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 15 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
Moisture conditions (continued)		Water content, in situ, near exploratory shaft	8.3.1.2.2.4.5	
		Water content, Calico Hills non- welded unit	8.3.1.2.2.4.6	
		Water content, Ghost Dance fault zone	8.3.1.2.2.6.1	
		Water content, Topopah Spring welded unit	8.3.1.2.2.4.3	
		Water content, gravimetric, Solitario Canyon fault zone	8.3.1.2.2.3.3	
		Water content, gravimetric, hydro- geologic units penetrated by surface-based boreholes	8.3.1.2.2.3.2	
		Water content, gravimetric, sub- surface geologic samples	8.3.1.2.2.3.1	
		Water content, surficial hydrogeo- logic and bedrock units	8.3.1.2.2.1.1	
		Water content, unsaturated zone immediately above water table	8.3.1.2.2.3.2	
		Saturation, profiles, hydrogeologic units penetrated by surface-based boreholes	8.3.1.2.2.3.2	

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 16 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
1.1, 1.4, 1.6, 4.4, 1.8, 1.9, 1.5, 4.2	8.3.5.13, 8.3.5.9, 8.3.5.12, 8.3.2.5, 8.3.5.17, 8.3.5.18, 8.3.5.10, 8.3.2.4	Synthesis char- acteristics	Boundary conditions: Dirichlet, Neumann, or mixed Boundary fluxes, boundary poten- tials Chemical composition of pore fluids Flow paths, moisture in unsaturated zone Fluxes, numerical simulation Ground-water travel time, fracture/ matrix networks Ground-water travel time, through Topopah Spring welded unit Hydrogeologic units, definition Hydrologic and thermal properties, component hydrogeologic units Hydrologic processes: single-phase liquid-water or pore-gas flow and storage, or two-phase moisture and pore-gas flow and storage in variably saturated, variably fractured porous media	8.3.1.2.2.9.1 8.3.1.2.2.9.2 8.3.1.2.2.9.1 8.3.1.2.2.10.3 8.3.1.2.2.10.2 8.3.1.2.2.4.2 8.3.1.2.2.4.3 8.3.1.2.2.3.2 8.3.1.2.2.9.2 8.3.1.2.2.9.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 17 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPERTIES AND CONDITIONS				
Synthesis characteristics (continued)		Isotopic composition of pore fluids	8.3.1.2.2.10.2	
		Moisture fluxes, flow paths, and travel times within the unsaturated zone	8.3.1.2.2.10.1	
		Numerical simulation of moisture and pore-gas fluxes	8.3.1.2.2.10.2	
		Prediction of time-dependent moisture and pore-gas flux distributions	8.3.1.2.2.10.3	
		Saturation, liquid water distribution in unsaturated zone	8.3.1.2.2.10.2	
		Solute-transport processes: Liquid- or gas-phase solutes, adsorption, radioactive decay, and chemical reactions, in solution and/or with surrounding rocks	8.3.1.2.2.9.1	
		Spatial distribution of the unsaturated-zone hydrogeologic units and hydraulic properties	8.3.1.2.2.10.1	
		Time-dependent spatial distributions of hydraulic and pneumatic potential	8.3.1.2.2.10.2	

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 18 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS				
		Synthesis char- acteristics (continued)	Time-dependent spatial distribu- tions of liquid-water matric potential and saturation, pore- gas pressure, moisture fluxes, and temperature	8.3.1.2.2.9.2
			Velocities of liquid water and water vapor	8.3.1.2.2.10.3
SATURATED-ZONE HYDRO- LOGIC PROPERTIES AND CONDITIONS				
1.1, 1.6	8.3.5.13, 8.3.5.12	Transmissive	Flow rates, intraborehole	8.3.1.2.3.1.3
			Hydraulic conductivity, tensor of equivalent porous media, multi- ple-well test location	8.3.1.2.3.1.4
			Hydraulic conductivity and trans- missivity, three-dimensional extent, data needs	8.3.1.2.1.3.1
			Hydraulic conductivity, well-test locations throughout the site	8.3.1.2.3.1.6
			Storage coefficient and porosity type, matrix, fracture and fault zones	8.3.1.2.1.3.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 19 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
		UNSATURATED-ZONE HYDROLOGIC PROPER- TIES AND CONDITIONS		
		Transmissive (continued)	Transmissive character, fault zones, Solitario Canyon	8.3.1.2.3.1.1
			Transmissivity, bulk, estimates at multiple-well test location	8.3.1.2.3.1.3
			Effective porosity, bulk, estimates from earth-tide analysis of water levels	8.3.1.2.3.1.3
			Effective porosity, single-well and multiple-well tracer test locations	8.3.1.2.3.1.5
			Effective porosity, well-test loca- tions throughout the site	8.3.1.2.3.1.6
1.1, 1.6	8.3.5.13, 8.3.5.12	Storage	Specific storage, well-test loca- tions throughout the site	8.3.1.2.3.1.6
			Storage coefficient, estimate from water-level fluctuations	8.3.1.2.3.1.2
			Storage coefficient, stratigraphic variations at multiple-well location	8.3.1.2.3.1.4
1.1, 1.6	8.3.5.13, 8.3.5.12	Dispersive	Dispersion coefficients, single- well and multiple-well tracer test locations	8.3.1.2.3.1.7

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 20 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
SATURATED-ZONE HYDRO- LOGIC PROPERTIES AND CONDITIONS				
		Dispersive (continued)	Dispersion coefficients, well- test locations throughout the site	8.3.1.2.3.1.8
1.1, 1.6	8.3.5.13, 8.3.5.12	Ground-water chemistry	Chemical concentrations, regional ground water	8.3.1.2.1.3.5
			Chemical concentrations, site ground water	8.3.1.2.3.2.2
			Ionic balance, ground water at the site	8.3.1.2.3.2.2
			Isotope ratios, ground water at the site	8.3.1.2.3.2.2
			Isotope ratios, stable, at the site	8.3.1.2.3.2.2
			Isotope ratios, stable, regional ground water	8.3.1.2.1.3.5
			Radioisotope activities, regional ground water	8.3.1.2.1.3.5
			Radioisotope activities, upper saturated-zone ground water	8.3.1.2.3.2.2
			Specific electrical conductance, regional ground water	8.3.1.2.1.3.5
			Water chemistry and age, with depth near Fortymile Wash	8.3.1.2.1.3.3
			Ground-water temperature, existing or needed at site	8.3.1.2.3.2.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 21 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
SATURATED-ZONE HYDRO-LOGIC PROPERTIES AND CONDITIONS (continued)				
1.1, 1.6	8.3.5.13, 8.3.5.12	Ground-water chemistry (continued)	Ground-water temperature, regional	8.3.1.2.1.3.5
			Ground-water temperature, upper saturated zone	8.3.1.2.3.2.2
			Heat flow, regional	8.3.1.2.1.3.2
		Ground-water potential	Hydraulic gradient, near Solitario Canyon	8.3.1.2.3.1.1
			Hydraulic gradient, regional	8.3.1.2.1.3.2
			Hydraulic gradient, site vicinity	8.3.1.2.3.1.2
			Hydraulic head, distribution, regional	8.3.1.2.1.3.2
			Hydraulic head, for evapotranspiration determinations	8.3.1.2.1.3.4
		Ground-water flow	Discharge, locations and rates	8.3.1.2.1.3.1
			Evapotranspiration, rates and spatial distribution, discharge areas	8.3.1.2.1.3.4
Hydraulic boundaries and conduits, scale of well tests and type of flow	8.3.1.2.3.1.3			
Recharge, locations and rates, region	8.3.1.2.1.3.1			
Recharge, locations, and rates, near Fortymile Wash	8.3.1.2.1.3.3			

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 22 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
SATURATED-ZONE HYDRO- LOGIC PROPERTIES AND CONDITIONS (continued)				
1.1, 1.6, 1.8, 1.9, 1.3	8.3.5.13, 8.3.5.12, 8.3.5.17, 8.3.5.18, 8.3.5.15	Synthesis character- istics	Aquifer heterogeneity and spatial distribution	8.3.1.2.3.1.4
			Dispersion coefficients of fracture networks	8.3.1.2.3.3.2
			Effective porosities of fracture networks	8.3.1.2.3.3.2
			Effective porosities, concepts in site flow model	8.3.1.2.3.3.1
			Flow paths	8.3.1.2.3.3.3
			Fluxes, calculated by site flow model	8.3.1.2.3.3.3
			Geophysical logs, regional studies	8.3.1.2.1.3.2
			Hydraulic conductivities, fracture networks	8.3.1.2.3.3.2
			Hydraulic conductivities, used in site flow model	8.3.1.2.3.3.1
			Hydraulic gradient, used in regional three-dimensional model	8.3.1.2.1.4.4
			Hydraulic gradient, used in sub- regional cross-section model	8.3.1.2.1.4.3
			Hydraulic gradient, used in sub- regional two-dimensional areal model	8.3.1.2.1.4.2

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 23 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
		SATURATED-ZONE HYDRO- LOGIC PROPERTIES AND CONDITIONS (continued)		
			Hydraulic gradients, concepts in regional flow models	8.3.1.2.1.4.1
			Hydraulic gradients, concepts in site flow model	8.3.1.2.3.3.1
			Hydrologic properties of the saturated-zone rock units, concepts in regional model	8.3.1.2.1.4.1
			Hydrologic properties of the saturated-zone rock units, regional cross-section model	8.3.1.2.1.4.3
			Hydrologic properties of the saturated-zone rock units, regional flow model	8.3.1.2.1.4.2
			Recharge and discharge, assumptions for regional three-dimensional model	8.3.1.2.1.4.4
			Recharge and discharge, assumptions for subregional cross-section areal model	8.3.1.2.1.4.3
			Recharge and discharge, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Recharges and discharges, regional conceptual flow model	8.3.1.2.1.4.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 24 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
SATURATED-ZONE HYDRO- LOGIC PROPERTIES AND CONDITIONS (continued)				
		Synthesis char- acteristics (continued)	Spatial distribution of hydraulic conductivity, concepts in regional flow model	8.3.1.2.1.4.1
			Spatial distribution of hydraulic conductivity, regional cross- sectional model	8.3.1.2.1.4.3
			Spatial distribution of hydraulic conductivity, regional two-dimen- sional areal model	8.3.1.2.1.4.2
			Spatial distribution of hydrogeo- logical units and hydraulic properties, site conceptual model	8.3.1.2.3.3.1
			Storage coefficients, fracture networks	8.3.1.2.3.3.2
			Storage properties, concepts in site flow model	8.3.1.2.3.3.1
			Water chemistry, site conceptual model	8.3.1.2.3.3.1
			Water flux, calculated by regional three-dimensional flow model	8.3.1.2.1.4.4
			Water flux, calculated by sub- regional two-dimensional areal model	8.3.1.2.1.4.2

Table 8.3.1.2 1. Activity parameters provided by the geohydrology program that support performance and design issues (page 25 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
ROCK-UNIT CHARACTERISTICS				
1.1, 1.6, 1.11, 1.12, 4.4	8.3.5.13, 8.3.5.12, 8.3.2.2, 8.3.3.2, 8.3.2.5	Thickness; loca- tion and con- figuration of contacts	Contact altitude, hydrogeologic units	8.3.1.2.2.3.2
		Distribution; lateral and vertical variability	Thickness, soil and alluvium	8.3.1.2.2.1.1
			Density, grain and bulk	8.3.1.2.2.1.1
			Density, grain and bulk	8.3.1.2.2.3.1
			Geophysical properties, hydro- geologic units at the site	8.3.1.2.3.1.2
			Physical characteristics, hydro- geologic units and structural features	8.3.1.2.3.1.2
			Soil texture	8.3.1.2.2.1.1
			Surficial deposits, type and distribution, drainage basin	8.3.1.2.1.3.3
			Surficial deposits, type and distribution, drainage channels	8.3.1.2.1.3.3
1.1, 4.4	8.3.5.13, 8.3.2.5	Mineralogy and petrology	Clay mineralogy	8.3.1.2.2.1.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 26 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
FRACTURE CHARACTERISTICS				
1.1, 1.6, 1.11, 1.12, 4.4	8.3.5.13, 8.3.5.12, 8.3.2.2, 8.3.3.2, 8.3.2.5	Fracture dis- tribution	Fracture and fracture-set spacing and density	8.3.1.2.2.4.3
			Fracture characteristics	8.3.1.2.2.4.4
			Fracture characteristics	8.3.1.2.2.4.5
			Fracture characteristics	8.3.1.2.2.4.6
			Fracture characteristics	8.3.1.2.2.6.1
			Fracture characteristics, inferred from hydraulic tests	8.3.1.2.3.1.4
			Fracture density	8.3.1.2.2.1.1
			Fracture distribution	8.3.1.2.2.3.2
			Fracture distribution	8.3.1.2.2.3.3
			Fracture spacing	8.3.1.2.2.3.2
			Fracture spacing	8.3.1.2.2.3.3
			Fracture spacing	8.3.1.2.2.4.2
			Fracture-system characteristics, inferred from hydraulic and tracer tests	8.3.1.2.3.1.6
			Fracture-system characteristics, inferred from tracer tests	8.3.1.2.3.1.5
1.6, 1.11, 4.4	8.3.5.12,, 8.3.2.2, 8.3.2.5	Geometry	Fracture aperture	8.3.1.2.2.4.2
			Fracture aperture, roughness and contact area	8.3.1.2.2.4.1
			Fracture and fracture-set length and connectiveness	8.3.1.2.2.4.3

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 27 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
FRACTURE CHARACTERISTICS (continued)				
		Geometry	Fracture connectiveness	8.3.1.2.2.3.3
			Fracture connectiveness	8.3.1.2.2.4.2
			Fracture orientation	8.3.1.2.2.1.1
			Fracture orientation	8.3.1.2.2.3.2
			Fracture orientation	8.3.1.2.2.3.3
			Fracture orientation	8.3.1.2.2.4.2
		Mineralogy and petrology of fracture fillings	Fracture characteristics including mineralization and alteration	8.3.1.2.2.6.1
FAULT CHARACTERISTICS				
1.1, 1.6, 1.11, 4.4	8.3.5.13, 8.3.5.12, 8.3.2.2, 8.3.2.5	Location	Fault-zone structural controls	8.3.1.2.2.7.1
1.1, 1.6, 1.11, 4.4	8.3.5.13, 8.3.5.12, 8.3.2.2, 8.3.2.5	Geometry	Orientation and extent, Solitario Canyon fault zone	8.3.1.2.3.1.1
			Fault-zone effective width	8.3.1.2.2.3.3

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 28 of 28)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program ^a	
Issue	SCP section		Activity parameter	SCP activity
FAULT CHARACTERISTICS (continued)				
4.4	8.3.2.5	Mineralogy and petrology pro- perties of fault zones	Fault zone characteristics, including mineralization and alteration	8.3.1.2.2.6.1

^aCharacterization parameters and associated testing bases will be developed from activity parameters under each parameter category. See text for explanation.

In particular, the supporting performance parameters used in resolving Issue 1.6 (ground-water travel time), as listed in Table 8.3.5.12-2, provide a close match to the activity parameters and their categories in Table 8.3.1.2-1.

As the process of integration of the geohydrology program with the design and performance issues matures, Table 8.3.1.2-1 will be modified in subsequent progress reports to include characterization parameters and associated testing bases. A characterization parameter is a parameter obtained by a characterization program that has a logical, direct tie to a performance or design parameter and for which a testing basis can be defined. Most characterization parameters will be developed from some combination of activity parameters; i.e., they will be the products of data reduction, test analyses, and modeling. An example would be unsaturated-zone flux, which will be derived from the analysis of many activity parameters obtained from a wide variety of tests.

Characterization parameters commonly will be expressed as functions of space and/or time and will be shown on maps, graphs, tables, or other formats that provide a means of synthesizing the information into a form that is usable to help resolve design and performance issues. Thus, even an activity parameter that seemingly directly supports performance and design analyses (such as saturated hydraulic conductivity) will require some analyses, to provide the appropriate spatial distribution to meet performance and design needs.

In the modifications of Table 8.3.1.2-1 that will be included in SCP progress reports, a testing basis will be included for each characterization parameter. A testing basis consists of some means of expressing the goals, confidence levels, and accuracy that is (or is expected to be) associated with each characterization parameter, in order to provide satisfactory input to the appropriate performance or design parameter requirements. For discussions of the terms "goal" and "confidence," as used in this context, see the description of performance allocation in Section 8.1.2.

The specific means of expressing the testing basis of a characterization parameter are currently being developed. For example, consider that the distribution of saturated hydraulic conductivity of the rock mass in the unsaturated zone below the repository horizon is designated as a characterization parameter. The distribution of this characterization parameter could be shown on a map. The testing basis could be that some statistical measure, such as the mean, of the values of each map unit be known to a specified degree of accuracy. If knowledge of this parameter were highly important in resolving a performance issue, such as ground-water travel time, the needed level of confidence for the accuracy of the map units would be high. Based on the current state of knowledge of the distribution of this parameter, the current level of confidence probably would be low.

In addition to supporting design and performance analyses, the activity parameters included in Table 8.3.1.2-1 are needed (1) to test hypotheses that support conceptual models, and (2) as input to hydrologic numerical models. A common requirement for all the parameters is that sufficient confidence can

be placed in their values and in the understanding of their interrelationships that they can be used with confidence for the purpose intended. Therefore, a principal strategy of the geohydrology program is to use approaches that minimize uncertainty in the values of the parameters and in the understanding of their interrelationships, within the constraints of available resources. Some degree of uncertainty is inevitable because parameters vary in space and time, measurements contain errors, and hydrologic processes are slow and difficult to measure. But, as described in the following paragraphs, the strategy of the geohydrology program is to increase confidence by using multiple approaches to parameter determination, by testing hypotheses, and by developing valid models.

Confidence in the information is increased by applying multiple approaches for determining parameters not readily amenable to measurement or analysis. Table 8.3.1.2-1 shows that many parameters listed are being generated by more than one activity. For example, infiltration, needed as a boundary condition for evaluating deeper percolation, is being assessed through monitoring of natural infiltration, characterizing hydrologic properties or surficial materials, and conducting various controlled infiltration tests. The combined effect of these investigations will be to produce reasonable confidence in the spatial distribution of infiltration rate.

Another way in which the use of multiple approaches increases confidence in the results is to measure a parameter at different scales. For example, various tests are designed to measure unsaturated fracture hydraulic conductivity at various scales, from the conductivity of a single fracture to that of an increasingly more-extensive fracture network. The results will increase confidence that an understanding has been gained of the relationship between hydraulic conductivity and fracture characteristics, and that the appropriate scale has been selected for modeling.

A major advantage to using multiple approaches for determining parameters is that, in general, reliance is not placed only on one test to determine a value for a given parameter. Because some of the tests planned for site characterization are nonstandard, the possibility that one or more tests may fail in completely achieving the desired objectives is recognized. The use of multiple approaches for determining parameter values increases confidence that the failure or the partial failure of one or more tests will not severely inhibit the ability of the characterization activities in providing the information required by the performance and design issues. In addition, prototype testing of many aspects of tests planned for site characterization, especially those related to characterization of the unsaturated zone, will be performed to increase confidence that test objectives will be achieved.

The testing and refinement of hydrologic hypotheses provide a logical and systematic approach to improving our understanding of how the geohydrologic system functions. The result is an improved conceptual model which, in turn, leads to increased confidence in the hydrologic models and ultimately in the geohydrologic model. As shown in Figures 8.3.1.2-2, 3, and 4, the refinement of conceptual models also helps guide and modify the investigative program, including parameter determination. In turn, results of the program provide a basis for updating and revising the hypotheses. The net effect is a program that is efficiently directed toward the goals of the overall project and improved confidence in the outcomes.

The hypothesis components shown in Figures 8.3.1.2-2, 3, and 4 are tied to Table 8.3.1.2-2, which lists current hypotheses for each of the hydrologic regimes. Also shown in Table 8.3.1.2-2 are the number designations and objectives and approaches of the activities that are directly involved in testing these hypotheses. The surface-water hydrology hypotheses deal principally with the runoff and debris-transport characteristics in the Yucca Mountain area. The unsaturated-zone hydrology hypotheses describe the manner in which water and gases move through the unsaturated zone, including the directions and paths in which flow occurs. The saturated-zone hydrology hypotheses relate to the nature of flow, including sources and mechanisms of recharge and discharge, and also addresses the origins of various observed hydrologic features. The parameters associated with each activity in Table 8.3.1.2-2 are listed later in this section under the descriptions of the respective investigations.

In conducting preliminary performance and design analyses, certain assumptions must be made regarding parameter values and hydrologic processes and conditions. These preliminary analyses may include assumptions involving parameters such as flow paths, velocities, fluxes, gradients, conductivities, anisotropies, boundary conditions, and structural and stratigraphic controls on saturated and unsaturated flow. Concepts that may affect these aspects of the hydrologic system include the potential for lateral flow and capillary barriers in the unsaturated zone, the conditions under which matrix and fracture flow occur, and the development of perched water systems. The ongoing process of hypothesis testing helps to increase confidence that the assumptions made in preliminary analyses are reasonable and based on current investigative results.

The successful development of calibrated numerical models of the hydrologic flow systems increases confidence that the hydrogeologic framework, the distribution of input parameters, and the nature of initial and boundary conditions are appropriate for use in performance and design analyses. Such models can be used as tools to improve understanding of the functioning of the flow system, to test hypotheses, and to further guide data collection. Many of the specific parameters listed in Table 8.3.1.2-1, while not required directly for resolving performance and design issues, are required to accomplish satisfactory hydrologic modeling, which in turn increases confidence in the accuracy of the values of those parameters that are required for performance and design purposes.

Hydrologic modeling produces the velocity field essential for defining flow paths and computing ground-water travel time. Such modeling requires sufficiently detailed knowledge of the hydrogeologic framework and the three-dimensional distribution of potential values and conductivity properties. Since model input data cannot be known explicitly everywhere throughout the modeled area, the input parameters must be expressed as statistical distribution functions. Calibration of the model to observed conditions (generally, heads measured at specific points) increases confidence that the modeled distribution of parameters is an accurate representation of actual conditions. Numerical models will be used as a principal approach to assess whether the data collected to describe the present and expected geohydrologic characteristics provide the information required by the performance and design issues. Complete validation of the flow models is not possible because of the long times for which numerical predictions must be calculated.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (1 of 17)

Hypothesis description	Activity	Activity objective
SURFACE-WATER HYDROLOGIC HYPOTHESES		
Surface-water runoff occurs erratically in the Yucca Mountain area. Runoff does not happen with predictable regularity, and the magnitudes of streamflow vary greatly from storm to storm and year to year.	8.3.1.2.1.2.1	To evaluate streamflow characteristics in the Yucca Mountain region. The approach will be to collect, analyze, and interpret streamflow data from selected drainages and sites to provide a realistic data base from which the best possible predictions of future streamflow can be made.
One of the major components of ground-water recharge in the Yucca Mountain area is that which is derived from infiltration of streamflow along the channel of Fortymile Wash. The location, amount, and timing of the infiltration potential of this major regional stream system can be better understood and quantified by precipitation-runoff modeling of the Fortymile Wash drainage basin.	8.3.1.2.1.3.3	To evaluate runoff characteristics of of Fortymile Wash in order to calibrate precipitation-runoff models. The approach will be to collect, analyze, and interpret precipitation, streamflow, snowpack, and air temperature data in the Fortymile Wash drainage basin.
The deficient streamflow data base of Yucca Mountain and vicinity can be measurably lengthened and improved by examining evidence of previous erosion and sediment deposition throughout the area by prehistoric floods.	8.3.1.5.2.1.1	To identify and evaluate the magnitudes and timing of prehistoric floods, by collecting evidence of past erosion of the landscape and stratigraphic evidence of prehistoric sediment deposition by these floods.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (2 of 17)

Hypothesis description	Activity	Activity objective
SURFACE-WATER HYDROLOGIC HYPOTHESES (continued)		
Intensive streamflows from ephemeral drainages of the Yucca Mountain area commonly mobilize large quantities of debris of varying particle sizes. The resultant streamflow fluid contains sediment debris of sufficient quantities and characteristics to be seriously hazardous to the activities and works of man.	8.3.1.2.1.2.2	To evaluate the potential for debris transport in order to assess, reduce, and/or mitigate, the potential hazards posed by this natural hydrologic process. The approach will be to collect, analyze, and interpret data on the movement of large amounts of debris by severe surface runoff.
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES		
Moisture enters the unsaturated-zone system as net infiltration below the plant-root zone and occurs principally as liquid-water flow in fractures of the surficial Tiva Canyon welded unit (TCw), with subsequent uptake into matrix of the TCw unit. At sufficiently low infiltration rates, all of the water entering the TCw unit is drawn into the matrix before the full thickness of unit is traversed; at sufficiently high infiltration rates, flow occurs through fractures across the full thickness of the TCw unit.	8.3.1.2.2.1.2	To determine present-day natural net infiltration rates near the surface of Yucca Mountain, and to determine natural moisture profiles and liquid water flow paths in the surficial units. Approaches include (1) neutron moisture logging, (2) monitoring control plots, (3) tritium profiling, and (4) water budget studies.
	8.3.1.2.2.1.3	To determine liquid-water flow paths, spatial variability of infiltration rates, and development of perched water under controlled field conditions. Models relating flow paths to infiltration rates are to be developed and calibrated/validated as part of Activity 8.3.1.2.2.1.2.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (3 of 17)

Hypothesis description	Activity	Activity objective
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
	8.3.1.2.2.2.1	To assist in quantitative evaluation of infiltration rates, using isotopic measurements of soil and tuff samples.
Unsaturated lateral flow can occur at the contact between the TCw and Paintbrush non-welded (PTn) units, depending on the flux magnitude and the permeability contrast across the contact.	8.3.1.2.2.4.4	To evaluate the potential for lateral movement of water along hydrogeologic contacts, using tests of radial boreholes in the exploratory shaft.
	8.3.1.2.2.6.1	To develop a plan to (1) determine conditions that lead to formation of a perched water zone, (2) evaluate lateral diversion of percolation, and (3) evaluate flux in the Ghost Dance fault. Various field testing approaches will be evaluated.
Lateral flow can occur within the PTn unit, because of intercalation of layers with contrasting hydraulic properties within the dipping PTn unit.	8.3.1.2.2.4.4	To evaluate the potential for lateral movement of water within dipping units, using tests of radial boreholes in the exploratory shaft.
Flow in the Topopah Spring welded unit (TSw) is vertical and occurs under steady-state conditions. Flow is primarily in the matrix when the flux is less than some value related to the saturated matrix hydraulic conductivity, and flow is primarily in the fractures at fluxes higher than that value.	8.3.1.2.2.3.2	To determine the distribution of potential and hydraulic properties in the TSw unit, using tests of surface-based vertical boreholes.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (4 of 17)

Hypothesis description	Activity	Activity objective
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
	8.3.1.2.2.4.1	To evaluate conditions under which liquid-water movement in fractures occurs and the characteristics of that movement. The approach will be to conduct laboratory tests of intact fractures taken from the exploratory shaft facility. This information will also be used in calibrating larger-scale field tests that investigate water movement in the rock mass.
	8.3.1.2.2.4.2	To determine the hydrologic conditions that control the occurrence of fracture and matrix flow in a rock mass containing a network of intersecting fractures. The approach will be to conduct controlled in situ infiltration tests in the exploratory shaft facility.
	8.3.1.2.2.4.8	To determine the flow directions, fluxes, and travel times of liquid water using isotope geochemistry techniques. The approach will be to analyze water samples from fractures and matrix in the exploratory shaft facility.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (5 of 17)

Hypothesis description	Activity	Activity objective
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
Unsaturated lateral flow can occur at the contact between the TSw and Calico Hills (CHn) units, depending on the flux magnitude and the permeability contrast of the materials across of the contact.	8.3.1.2.2.8.2	To determine the flow directions, fluxes, and travel times of liquid water using isotope geochemistry techniques. The approach will be to analyze water samples from fractures and matrix in cores taken during drilling of surface-based boreholes.
	8.3.1.2.2.4.4	To evaluate the potential for lateral movement of water along hydrogeologic contacts, using tests of radial boreholes in the exploratory shaft.
Flow in Calico Hills zeolitic (CHnz) and Calico Hills vitric (CHnv) units, is predominantly vertical through the matrix, although a lateral component can occur parallel to the bedding of the CHnv unit. Water continues vertically downward through the CHn unit to the water table, either directly (where the water table transects the CHn unit) or through the underlying unsaturated Crater Flat (CFu) unit (where the CHn unit lies totally above the water table).	8.3.1.2.2.4.4	To detect vertical movement of liquid water and evaluate the potential for lateral movement, using tests of radial boreholes in the exploratory shaft.
	8.3.1.2.2.4.6	To determine the hydrogeologic properties and conditions within the CHn unit, using tests of lateral and vertical boreholes penetrating the CHn unit in the exploratory shaft facility.

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Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (6 of 17)

Hypothesis description	Activity	Activity objective
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
	8.3.1.2.2.3.2	To determine the distribution of potential and hydraulic properties in the CHn unit, using tests of surface-based vertical boreholes.
The nearly vertically oriented fault zones and their associated fractures can be highly effective pathways for vertical liquid-water flow at high flux rates, especially in the competent TCw and TSw units. Under some conditions, faults can impede lateral flow and thus produce perched-water bodies where the faults intercept significant lateral flow.	8.3.1.2.2.3.3	To examine the extent of fracturing, brecciation, and gouge development associated with the Solitario Canyon fault and evaluate the hydrogeologic significance of the fault on water movement, by sampling and testing surface-based lateral boreholes that cross the fault.
	8.3.1.2.2.6.1	To determine if perched water exists at or near the contact between the TSw and the CHn units and to investigate the permeability of the Ghost Dance fault in the TSw and CHn units. The approach will be to sample and test lateral and vertical boreholes penetrating the TSw and CHn units and the Ghost Dance fault in the exploratory shaft facility.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (7 of 17)

Hypothesis description	Activity	Activity objective
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
	8.3.1.2.2.4.7	To determine the occurrence of perched water zones and determine the implications of the existence of such zones on flux and flow paths. The approach will be to observe, sample, and test perched water zones if encountered in the exploratory shaft.
	8.3.1.2.2.6.1	To develop a plan to (1) determine conditions that lead to formation of a perched water zone, (2) evaluate lateral diversion of percolation, and (3) evaluate flux in the Ghost Dance fault. Various field testing approaches will be evaluated.
Temperature-driven or barometrically-driven moisture flow can occur as water vapor, especially within the interconnected fractures of the TSw unit.	8.3.1.2.2.3.1	To determine in situ gaseous-phase travel times and mechanisms by conducting pneumatic tests in surface-based vertical boreholes.
	8.3.1.2.3.1.4	To determine if the fractured media can be represented as an anisotropic porous media, or if a fracture-network model is more appropriate, based on results of multiple well interference tests.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (8 of 17)

Hypothesis description	Activity	Activity objective
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
	8.3.1.2.3.1.5	To evaluate aquifer properties estimated by porous-media techniques versus those estimated by fracture-network modeling, based on conservative tracer tests in the C-holes.
	8.3.1.2.3.1.6	To determine flux characteristics throughout the site, based on conservative tracer tests in the C-holes.
	8.3.1.2.3.3.2	To simulate ground-water flow and conservative-solute transport in a discrete-fracture network, based on the development of an appropriate model.
	8.3.1.2.2.4.3	To determine bulk efficiency of the fractured TSw unit to transmit water vapor. The approach will be to conduct bulk permeability tests in the exploratory shaft facility.
	8.3.1.2.2.4.4	To detect vertical movement of water in both liquid and vapor phases, using tests of radial boreholes in the exploratory shaft.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (9 of 17)

Hypothesis description	Activity	Activity objective
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
	8.3.1.2.2.8.1	To understand the nature of the gas transport processes within the unsaturated zone and to provide independent evidence of flow directions and fluxes of gas. The approach will be to analyze gas samples taken from radial boreholes in the exploratory shaft.
	8.3.1.2.2.3.2	To evaluate the magnitudes, directions and pathways for gaseous-phase components in the unsaturated zone. The approach will be to sample, test, and monitor surface-based vertical boreholes and to model vapor fluxes and gas transport.
	8.3.1.2.2.7.1	To investigate gas transport mechanisms and provide evidence of gas flow directions, fluxes, and travel times. The approach will be to analyze gas and water-vapor samples taken from surface-based vertical boreholes.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (10 of 17)

Hypothesis description	Activity	Activity objective
UNSATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
Moisture flow within the deep unsaturated units at Yucca Mountain occurs effectively under steady-state conditions. Significant liquid-water flow within the fractures occurs only as near-surface, transient, non-equilibrium events that are followed by eventual uptake by the rock matrix of water descending through the fractures. Liquid-water potentials in the fractures and the matrix are in equilibrium at depth.	8.3.1.2.2.3.2	To (1) determine the potential field in order to evaluate the degree of uniformity of water potentials and (2) monitor temporal changes in unsaturated-zone hydrologic conditions. The approach will be to test and monitor surface-based vertical boreholes.
SATURATED-ZONE HYDROLOGIC HYPOTHESES		
<p>The nature of ground-water flow in the saturated zone is as follows:</p> <p>Ground water flow occurs principally in fractures; flow through unfractured rock is of secondary importance.</p> <p>Hydraulic characteristics vary areally as a result of variations in fracture characteristics. South and east of Yucca Mountain, faults are common, generally interconnected, and serve as</p>	8.3.1.2.3.1.3	To characterize type of flow (linear, radial, fracture, matrix, or any combination of these); to determine the magnitudes and directions of flow components at the site; and to evaluate the influence of structural and lithologic controls on these components. The approach will be to evaluate previously completed hydraulic-stress tests at the C-holes.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (11 of 17)

Hypothesis description	Activity	Activity objective
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SATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)

principal pathways for flow. In areas where faulting is less frequent, faults generally are not interconnected, and flow is controlled by smaller-scale fracturing;

Although ground-water flow is principally through fractures, the system can be simulated by analogy to porous media, and where hydraulic conductivity and effective porosity of unfractured rock are small, but not negligible, a double-porosity model can approximately represent the in situ system;

At the site, the tuff ground-water flow system behaves as a single, thick aquifer, with negligible vertical variations in hydraulic aquifer properties and seepage velocity. Flow is controlled by structural features, such as faults and joints; these dip steeply, are not related to stratigraphy, and effectively eliminate vertical hydraulic gradients.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (12 of 17)

Hypothesis description	Activity	Activity objective
SATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
The chemical and isotopic character of ground water can be used to infer likely sources and mechanisms of recharge and likely flow paths.	8.3.1.2.1.3.5	To evaluate the evolution of ground-water composition along regional flow paths, based on analyses of water samples from wells, springs, and surface-water sites in the region.
	8.3.1.2.3.2.1	To compile and evaluate existing hydrochemical data at the site and in the region.
	8.3.1.2.3.2.2	To evaluate the ground-water chemistry in the upper 100 m of the saturated zone, based on analyses of samples from the water-table holes at and near the site.
The spatial distribution and population and compositional variations of secondary minerals in faults and fractures in the rocks are the result of rock-water interactions, and reflect present and past ground-water chemistries and hydrologic conditions.	8.3.1.2.3.2.1	To compile and evaluate existing hydrochemical data at the site and in the region.
	8.3.1.2.3.2.2	To evaluate the ground-water chemistry in the upper 100 m of the saturated zone, based on analyses of samples from the water-table holes at and near the site.
	8.3.1.3.2.1.1	To determine the petrologic variability within the devitrified Topopah Spring Member at Yucca Mountain and to define the stratigraphic distribution of variability.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (13 of 17)

Hypothesis description	Activity	Activity objective
SATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
	8.3.1.3.2.1.2	To determine the three-dimensional distribution and the total abundance of all major rock-matrix minerals within the host rock and extending to the boundary of the accessible environment.
	8.3.1.3.2.1.3	To determine the distributions of minerals within fractures at Yucca Mountain, within all significant rock masses that might provide transport pathways with some component of fracture flow.
	8.3.1.3.3.1	To determine the hydrothermal nature of deep-seated alteration through the investigation of mineral assemblages.
	8.3.1.3.3.2.1	To predict the rates of possible transformation of silica polymorphs in Yucca Mountain and the effect such transformations would have on aqueous silica activity.
	8.3.1.3.3.2.2	To determine end-member free energies from solubility measurements.
	8.3.1.3.3.2.3	To provide descriptions of the thermodynamics of the clinoptilolite/heulandite and analcime solid solutions.

Table 8.3.1.2 2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (14 of 17)

Hypothesis description	Activity	Activity objective
SATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
	8.3.1.3.3.3	To develop a conceptual model to explain the observed distributions of minerals in Yucca Mountain.
	8.3.1.4.2.1.1	To determine the spatial distribution, history, and lithology of stratigraphic units within the Paintbrush Tuff, rhyolite of Calico Hills, Crater Flat tuff and perhaps older volcanic rocks within the site area.
Recharge to the regional ground-water flow system occurs as (1) throughflow from the Timber Mountain region, (2) vertical infiltration from Fortymile Wash, (3) throughflow from western Amargosa Desert, (4) throughflow from the Ash Meadows springline, (5) possible upward leakage from underlying Paleozoic units, and (6) minor amounts as downward leakage from the overlying unsaturated zone. Among these, vertical infiltration from Fortymile Wash is the largest component and most directly affects water-table conditions at the site.	8.3.1.2.1.3.2	To define the regional potentiometric surface to estimate ground-water flow directions and hydraulic gradients. The approach will be to identify previously unknown or unmeasured wells and springs and collect water-level data from them; to assemble existing records; and to drill new water-table holes.
	8.3.1.2.1.3.3	To evaluate the significance of streamflow infiltration through the channel bottom of Fortymile Wash as a major source of recharge near Yucca Mountain. The approach will be to conduct infiltration studies along the channel of Fortymile

Table 8.3.1.2 2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (15 of 17)

Hypothesis description	Activity	Activity objective
SATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
		Wash; do rainfall-runoff modeling; and analyze moisture samples obtained from drillholes.
	8.3.1.2.1.3.5	To evaluate the evolution of ground-water composition and variations along regional flow paths, based on analyses of water samples from wells, springs, and surface water sites in the region.
	8.3.1.2.1.4.4	To simulate the regional ground-water flow system using a quasi-three-dimensional model.
	8.3.1.2.2.1.2	To evaluate present-day infiltration processes and net-infiltration rates beneath stream channels at Yucca Mountain. The results can be applied to conditions at Fortymile Wash.
	8.3.1.2.2.1.3	To characterize the range and spatial variability of infiltration rates, flow velocities, and flow pathways in approximately the upper 15 ft of both consolidated and unconsolidated surficial materials, using ponding studies at Yucca

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (16 of 17)

Hypothesis description	Activity	Activity objective
SATURATED-ZONE HYDROLOGIC HYPOTHESES (continued)		
		Mountain. The results can be applied to conditions at Fortymile Wash.
Discharge from the regional flow system occurs as evapotranspiration in the Amargosa Desert and as springs in Death Valley. Simulations of the regional flow system are particularly sensitive to these components of flow. Spring discharge is relatively well known, but improved estimates of evapotranspiration rates and distributions are needed to simulate the regional flow system accurately.	8.3.1.2.1.3.2	To define the regional potentiometric surface, in order to estimate ground-water flow directions and hydraulic gradients, and to establish depths to water in discharge areas. The approach will be to identify previously unknown wells or springs and collect water-levels from them; to assemble existing records; and to drill new water-table holes.
	8.3.1.2.1.3.4	To estimate evapotranspiration (ET) through the Amargosa Desert, by measuring ET at selected sites in the Amargosa Desert and relating ET and depth to water.
Steep hydraulic gradients north and west of the site are caused by the Solitario Canyon fault to the west and low-permeability rocks or faults to the north.	8.3.1.2.1.3.2	To define the regional potentiometric surface, in order to estimate ground-water flow directions and hydraulic gradients. The approach will be to identify previously unknown or unmeasured wells and springs, and collect water-level data from them; to assemble existing records; and to drill new water-table holes.

Table 8.3.1.2-2. Hypotheses of the geohydrologic conceptual models and relationship to site characterization plan (SCP) activity objectives (17 of 17)

Hypothesis description	Activity	Activity objective
SATURATED-ZONE HYDROLOGIC PROPERTIES (continued)		
	8.3.1.2.1.4.4	To test concepts of ground-water flow by using a regional three-dimensional model.
	8.3.1.2.3.1.1	To determine nature of Solitario Canyon fault and if it is a barrier to eastward movement of ground water, by drilling and testing boreholes on either side of the fault.
	8.3.1.2.3.1.2	To determine the causes of water-level fluctuations at the site by evaluating the character and magnitude of fluctuations.

Partial validation of the models will be accomplished through a combination of peer review and comparison of model predictions with laboratory experiments, field experiments, and natural analogs. Successful application of any of these methods will increase confidence that the encoded mathematical model adequately describes the physical processes of the flow system.

Interrelationships of geohydrology investigations

Three investigations are identified for the geohydrology program, namely

<u>Investigation</u>	<u>Subject</u>
8.3.1.2.1	Description of the regional hydrologic system
8.3.1.2.2	Description of the unsaturated-zone hydrologic system at the site
8.3.1.2.3	Description of the saturated-zone hydrologic system at the site

This program will develop an understanding of the present and expected geohydrologic characteristics of each of the saturated and unsaturated flow regimes, and of the gaseous and water-vapor flow process.

The regional hydrologic flow system surrounding Yucca Mountain (Investigation 8.3.1.2.1) must be understood to define the following: (1) the boundary conditions (present and expected) for the site unsaturated and saturated zone ground-water models (Information Needs 1.1.4 (Section 8.3.5.13.4), 1.6.2 (Section 8.3.5.12.2), and Investigations 8.3.1.2.2 and 8.3.1.2.3) and (2) the hydrogeologic setting in which the site occurs.

The hydrogeologic conditions and processes of the unsaturated and saturated zone must be understood to develop models of the current and potential future flow paths and fluxes (Investigations 8.3.1.2.2 and 8.3.1.2.3), and to calculate ground-water travel time (Information Needs 1.1.4 and 1.6.2). The hydrologic characteristics to be obtained in the studies of Investigations 8.3.1.2.2 and 8.3.1.2.3 will be complemented by the data from studies of water chemistry (Investigation 8.3.1.3.1), geologic stratigraphy and structure (Investigation 8.3.1.4.1), and paleohydrology (Investigation 8.3.1.5.2).

Changes to the ground-water flow system due to potential climate changes, erosion, tectonic activity, and human interference will be evaluated in Investigations 8.3.1.5.2, 8.3.1.6.4, 8.3.1.8.2, and 8.3.1.9.3, respectively, using models developed in Investigations 8.3.1.2.1, 8.3.1.2.2, 8.3.1.2.3, and 8.3.1.5.2. Temperature and other data collected under this work will be assessed for its resource potential in Section 8.3.1.9.2.1.3 and for its tectonic implications on volcanism in Section 8.3.1.8.5.2.3.

As a means of estimating the future conditions, baseline studies of the regional hydrologic conditions will be performed (Investigation 8.3.1.2.1). Paleohydrologic investigations in Investigation 8.3.1.5.2 will provide information about the Quaternary hydrology at Yucca Mountain.

Summary of studies

Saturated zone. Site characterization of the ground-water system within the saturated zone focuses on determining the boundary conditions imposed by structure, recharge, and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of hydrostratigraphic units. Studies have been developed to characterize the regional meteorology, surface-water runoff, and ground-water flow system. The resulting description of the boundary conditions, hydraulic gradients, and aquifer properties will form the basis for synthesis and modeling activities that will conclude with calculations of flow paths, fluxes, and velocities within the saturated zone.

Precipitation is the original source of all water fluxes. Therefore, sufficient data must be collected throughout the region to characterize present-day precipitation as a function of topographic setting and storm track. Data on rainfall intensity and duration will be collected to provide input to rainfall-runoff models and for infiltration studies. Modern meteorological conditions, together with long-term indirect climatic records, will also form a basis for deducing paleoconditions and predicting future conditions.

Knowledge of flood hazards and the relationships of streamflow to ground-water recharge is essential to properly understand the regional hydrologic system. The specific data needs of flood-hazard prediction and an acceptable understanding of the quantities and processes of ground-water recharge require the collection of adequate streamflow data. The needed data cannot be attained through simulation technology or by transfer from other nearby or distant areas; therefore, a program to measure land-surface runoff (streamflow) and to assess the relationships between precipitation and runoff has been implemented to describe adequately the regional hydrologic system. The study of floods and associated debris movement will also provide the data required to relate modern flood processes and occurrences to those of the past and, thus, provide some of the needed perspective to compare and relate the effects of paleoclimates to those of the present climate.

Adequate statistical characterization of the geometry of hydrostratigraphic units and their hydraulic conductivity, storativity, dispersivity, and porosity requires that a sufficient number and distribution of boreholes be drilled to determine these properties. Results of production surveys, combined with hydraulic-test results, have failed to identify definitive hydrostratigraphic units. Instead, the results indicate that discrete production zones associated with fractures in one well may be connected to fractures occurring in overlying or underlying stratigraphic units in other wells. The hydrologic significance of intervening bedded units is not known. If pervasive fracturing crosses stratigraphic boundaries and accounts for orders of magnitude greater hydraulic conductivity than does the matrix, the effect of dipping beds on ground-water flow paths may be insignificant. Additional well tests are needed to determine three-dimensional relationships among stratigraphy, fracture connectivity, and bulk aquifer properties.

Recharge and discharge quantities and locations will be investigated to provide the boundary conditions required for modeling. The location of present and paleodischarge points will be sought by defining the regional head distribution from observations of wells, mines, and springs, and by

using field reconnaissance and remote sensing tools. Whereas regional discharges have been quantified in the past, additional studies will improve the quantifications. Activities in the discharge areas will characterize controls and locations of present and former discharge sites, as well as estimate fluxes. Evidence of recharge to the regional ground-water flow system by infiltration of Fortymile Wash streamflow will also be sought through field experiments and infiltration modeling.

Regional ground-water flow models will then be used to provide (1) a synthesis of the available hydrogeologic data, (2) direction for additional data collection, and (3) estimates of ground-water flow paths, fluxes, and velocities. In addition, the regional models will provide tools for analyzing the possible effects of changes in future stresses to the hydrologic system such as increased recharge resulting from future climatic changes, potential increased withdrawal of ground water, and changes in hydrogeologic properties resulting from tectonic events.

Unsaturated zone. For the purpose of site characterization investigations, the unsaturated-zone system at Yucca Mountain has been divided into the infiltration boundary and the percolation region. Each component of the system will be studied using multidisciplinary approaches (i.e., hydraulic, pneumatic, and gaseous and aqueous-phase hydrochemical studies) to describe the spatial and temporal distributions of the flux and travel times within this system. On this basis, four data collection studies have been developed: (1) the characterization of infiltration, (2) percolation, (3) gaseous-phase movement, and (4) hydrochemistry. A fifth study, flow and transport modeling, is designed to simulate the natural system so that data needs for the final simulations could be identified early in the site characterization phase, and also to enable evaluation of the sensitivity of the flux and travel-time calculations to certain site characteristics that may not readily be determined. Finally, a sixth study is designed to develop a conceptual model for the unsaturated zone from which the testing programs can be designed and modified. This conceptual model will be modified and eventually will lead into the integration of the information acquired in the first five studies to provide a sufficient understanding of the unsaturated zone at Yucca Mountain.

The infiltration boundary, or the surficial units, at Yucca Mountain is one of the most important boundaries that needs to be characterized. Through this boundary, water and air can enter, and gases and water vapor can escape the unsaturated zone directly above the repository. The infiltration study will be targeted at characterizing this upper boundary of the unsaturated zone system. Its goal will be to determine the present day net infiltration rates. These data are needed as input into the system flow model.

The goal of the percolation study will be to provide an understanding of the spatial distribution of the present-day fluxes within the unsaturated zone system. These values are not only required for the site system model but are essential for the performance assessment modeling. The salient conditions to be characterized in the percolation zone are the hydraulic and pneumatic potential gradients that extend from the land surface to the water table (which is 500 to 750 m below the surface at Yucca Mountain). Saturation and matric potential may vary discontinuously from stratum to stratum.

The characterization of flow in Yucca Mountain must include, for all hydrostratigraphic units, the determination of flux distribution under a variety of conditions. Since flux is difficult to measure adequately at either the infiltration boundary or the water table, it must be deduced from the potential distribution and the conductive properties of the system, or by other indirect means. From the viewpoint of isolation, the most significant findings will be to predict the transport of radionuclides from the repository, 335 to 585 m beneath the surface of Yucca Mountain, to the water table, about 165 m below the repository. The hydraulic-properties data that will be used for flux calculation will be collected in the surface-based and exploratory shaft drilling and testing program.

Gas flow in the unsaturated zone has an important hydrologic role as well as that of providing a mechanism for transport of gaseous radionuclides to the accessible environment. Whereas the coexisting matrix and fracture pore systems greatly complicate computations of total-system behavior under present or future fluxes, the existence of the large-aperture fractures provides not only drainability in the unsaturated zone but also large relative gas permeability. Consequently, natural gas-phase fluxes are driven through the mountain by seasonal atmospheric density differences between the slopes and the summit, and by geothermal heat within. Vapor discharges from the air filled fracture system may offset the infiltration of rain and snowmelt because of convective and diffusive vapor transport out of the mountain. By desaturating the matrix, perhaps below free-drained residual saturation, increased moisture tension aids in damping infiltration pulses that may be channeled in the fractures or faults. It is important to be able to quantify the vapor flux because it may be in a direction opposite of the liquid flux.

Activities addressing this phenomenon include all those yielding air conductivities from packer tests with gas injection in boreholes, cross-hole air flow, and gas tracer tests. A study has been specifically designed to define the gaseous flux distribution.

Essential corroboration of ground-water velocities and the transport of dissolved chemicals and gases will be sought through isotopic-dating of the fluids and gases found in the pores at various depths. A thorough understanding and evaluation of all factors influencing the hydrochemistry of the natural flow system will be needed because such knowledge provides the only potential means for assessing rates of water movement independent of the hydrologic deduction process, as well as a means of discriminating between hydrologic processes that would otherwise remain hypothetical. In addition to its contributions to the assessment of ground-water travel time, hydrochemistry provides information relevant to the characterization of gas transport, to the assessment of paleohydrologic conditions, to geochemical relationships, and to contamination by exploration activities.

Flow behavior in the unsaturated zone of Yucca Mountain involves complex interactions that are amenable to solution with the aid of numerical modeling. A great depth of understanding is required to predict the transport of solutes and gases in a sequence of dipping pyroclastic units that have variable granularity, degree of welding and alteration, porosity, and fracturing. How these variables interact is essential knowledge for attaining a correct solution; however, the interactions are very complex. For example, variable saturation relates to variable relative conductivity and anisotropy in

hydrostratigraphic units whose fluxes relate to complex distributions of hydraulic and pneumatic potential between ill-defined boundaries with internal discontinuities. The general approach that is being used to solve this problem is to (1) refine the existing concepts of the phenomena of unsaturated, sometimes transient, flow of fluids and constituents in double-porosity layered media; (2) construct detailed digital models that spatially and temporally integrate the processes, incorporating boundary conditions, physical properties, and parameters; (3) compute fluxes, potentials, concentrations and missing data that can be verified by field tests and observations; and (4) establish consistency with all relevant verifiable knowledge. Since the environment of field tests seldom isolates one phenomenon from all others, models will be used as working tools on many levels. Ultimately, two- and three-dimensional models of Yucca Mountain will be constructed that integrate the whole system as a means of assessing combined effects of heat, water, and gas flow for modern, ancient, and future conditions. The conceptual model and verification steps will be cycled until the results are scientifically defensible.

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

8.3.1.2.1 Investigation: Studies to provide a description of the regional hydrologic system

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

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

<u>SCP section</u>	<u>Subject</u>
3.1	Description of surface hydrology
3.2.1.1	Ongoing and future studies of flood and debris hazards potential
3.4	Chemical composition of adjacent watercourses
3.5	Points of ground-water discharge
3.6.1	Hydrogeologic units
3.6.2	Relationship among hydrogeologic units
3.6.3	Potentiometric levels

<u>SCP section</u>	<u>Subject</u>
3.6.4	Hydraulic characteristics of principal hydrogeologic units
3.7.1	Identification of recharge and discharge areas
3.7.2	Principal ground-water flow paths
3.7.3	Isotopic and regional hydrochemistry
3.10.1	Summary of significant results (regional hydrology)
3.10.3	Identification of investigations (regional hydrology)

Parameters

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

1. Meteorologic characteristics. Spatial and temporal variability of atmospheric temperature, pressure, wind, and precipitation.
2. Surface water characteristics. Spatial and temporal variability of runoff and debris movement.
3. Ground-water characteristics. Spatial distribution of the physical and hydraulic properties of the rock units in the saturated zone and the areal distribution of flux.

Other site activities that provide information that support the determination of the previous parameters include the following:

<u>Activity</u>	<u>Subject</u>
8.3.1.5.2.1.1	Regional paleoflood evaluation
8.3.1.5.2.1.3	Evaluation of past discharge areas
8.3.1.16.1.1.1	Site flood and debris hazards studies

Purpose and objectives of the investigation

The objective of this investigation is to develop a conceptual model of the regional hydrologic system to assist in assessing the site's suitability to contain and isolate waste. A consistent regional model of ground-water flow will be constructed, so that reliable boundary conditions can be assigned to the more critical site area embedded within the regional model. To do so, fluxes and hydraulic heads at boundaries of the regional system are required, as well as regional transmissivities. Sensitivity analyses pertaining to these variables are needed to prioritize additional data collection.

Technical rationale for the investigation

Numerous hydrogeologic investigations that have been conducted during the last few decades in and around the NTS have provided a broad understanding of the regional hydrogeologic framework (for example, Winograd and Thordarson, 1975). Existing data have been used in developing preliminary two-dimensional flow models of this system. As a result of evaluations of the data base and of these models, certain additional data have been identified as needed to satisfy the investigation on the regional hydrologic system, as described in Section 8.3.1.2.1.1. Potential additional data needs will be identified and prioritized based on sensitivity analyses using a flow model. As a result, some additional activities may later be proposed to fill significant gaps in the data base. But no new major program of data collection, beyond that described in this plan, is expected to be needed to describe the regional ground-water flow system sufficiently to this satisfy investigation.

Within the hydrogeologic study area (Figure 8.3.1.2-5) regional hydrogeologic data delineate an elongate ground-water subbasin crossing several topographic divides from Pahute Mesa 145 km (90 mi) south to the Amargosa Desert and Death Valley. The Yucca Mountain area, midway between the high- and low-potential ends, lies near the western boundary of the subbasin. Because of the great depths to the water table in the northern half of the subbasin, potentiometric data are limited. However, in the southern half of the subbasin, depths to ground water are less, and more potentiometric data are available.

Aquifer properties have been measured in many deep drillholes over the course of 30 yr of hydrogeologic work on the NTS (Winograd and Thordarson, 1975). Many uncertainties remain, limiting the accuracy available for site-specific applications. The hydraulic properties of the hydrogeologic units vary greatly within the hydrogeologic study area. These units include tuffaceous, carbonate, and alluvial aquifers, as well as clastic and crystalline aquitards. These aquitards act as major barriers to ground-water flow and have a major impact on regional ground-water flow direction and magnitude. In addition, faults within the area may act either as barriers or conduits to ground-water flow, which may, in part, explain anomalously steep gradients found in certain locations.

Regional ground-water modeling to date has included regional heterogeneities of various hydrogeologic units. Major assumptions inherent in regional models pertain to the location and magnitude of recharge and discharge boundary conditions and regional transmissivities. Recharge estimates across model boundaries are often crude resulting from lack of sufficient hydraulic gradient and transmissivity data; however, prioritization of data collection may be facilitated through sensitivity analyses using regional flow models. The task is to prioritize data collection and reduce the potential range of key model variable values. Regional ground-water flow models provide valuable synthesis of available hydrogeologic data as well as estimates of ground-water flow paths, fluxes, and velocities; these models are also useful for directing additional data collection. Regional models also provide tools for analyzing the possible effects of changes in future stresses to the hydrologic system such as increased

Figure 8.3.1.2-5: Location of regional and subregional modeling areas, with generalized ground-water flow directions and generalized geology (modified from Waddell, 1982).

recharge resulting from future climatic changes, potential increased withdrawal of ground water, and changes in hydrogeologic properties resulting from tectonic events.

Records of existing precipitation gages at the Nevada Test Site (NTS) and surrounding region will be used to characterize regional precipitation patterns. Additional precipitation gages will be established to support infiltration studies (Section 8.3.1.2.2.2) and rainfall-runoff modeling (Section 8.3.1.2.1.4.3). These activities require detailed knowledge of rainfall events, to relate precipitation to observations of infiltration and runoff. The additional gages will be systematically incorporated into the existing monitoring system to form an integrated regional gaging network (Section 8.3.1.12.1). Although the records that will be obtained from these new gages will be too short to serve in themselves as a basis for characterizing regional precipitation, the records are expected to contribute to an improved understanding of regional precipitation patterns.

There are no perennially flowing streams on or near Yucca Mountain or at the adjacent NTS. As a result, very few streamflow data have been collected within a radius of tens of miles from Yucca Mountain. Knowledge of flood hazards and the relationships of streamflow to ground-water recharge is essential to properly understanding the regional hydrologic system. The specific data needs of flood-hazard prediction and an acceptable understanding of the quantities and processes of ground-water recharge require the collection of adequate streamflow data. The needed data cannot be attained through simulation technology or by transfer from other nearby or distant areas. Therefore, a program to measure land-surface runoff (streamflow) and to assess the relationships between precipitation and runoff is essential to adequately describe the regional hydrologic system.

The study of floods and associated debris movement will relate modern flood processes and occurrences to those of the past, and thus provide some of the needed perspective to compare and relate the effects of paleoclimates to those of the present climate. There are two investigative strategies as follows:

1. Present-day floods will be documented by measurements of the peak magnitudes of flood flows in selected channels. These peak flows will then be correlated with precipitation and weather conditions, and evaluated with respect to qualitative and quantitative assessments of any severe debris movements caused by and associated with the intense flows.
2. Prehistoric floods will also be investigated through the identification and interpretation of their land-surface scars and deposits.

It is recognized that short-term records of floods in arid regions, such as will be obtained in these studies, cannot be used in detailed quantitative evaluations of the potential for major floods. The documentation of modern floods and associated debris transport will be used principally in a qualitative manner to improve understanding of the relationship between climate and flooding. An assessment of extreme flooding and debris transport will be conducted principally on the basis of paleoflood evaluations.

Fortymile Wash, the major surface drainage following the axis of the ground-water subbasin, is a principal subject for surface-water investigations. It is a focus of attention because it may prove to be a major source of recharge, and may thus affect the movement and accumulation of ground water at the repository site near Yucca Mountain. Neutron-probe measurements will be made and soil water samples will be collected in the bed of the wash to characterize relationships between infiltration and runoff, and to investigate if preferential recharge takes place along possible faults. Ground-water flow rates may be deduced through the use of conservative tracers and interpretations of water chemistry. Evidence of recharge to the regional ground-water flow system by infiltration of Fortymile Wash streamflow will be sought. Infiltration modeling is planned. Infiltration, percolation, and recharge studies described in Investigation 8.3.1.2.3 will also contribute quantitative measures of the regional input fluxes.

8.3.1.2.1.1 Study: Characterization of the meteorology for regional hydrology

The objectives of this study are (1) to characterize the area surrounding Yucca mountain in terms of precipitation and its relationship to surface runoff, with particular emphasis on the Fortymile Wash drainage basin, and (2) to provide input into the rainfall-runoff model development effort. One activity is planned to collect the data required to satisfy these objectives.

8.3.1.2.1.1.1 Activity: Precipitation and meteorological monitoring

Objectives

The objective of this study is to provide site-specific information on storm precipitation at, and near, the network streamflow-measurement sites.

Parameters

The parameters for this study are as follows:

1. Precipitation amounts.
 - a. Rainfall intensity and duration.
 - b. Monthly and seasonal precipitation variability.
2. Surface temperature.
3. Atmospheric pressure and pressure variability.
4. Relative humidity and diurnal humidity cycles and seasonal variability.
5. Incoming and outgoing short-wave radiation and its diurnal and seasonal variability.

6. Wind speed and direction and diurnal, seasonal, and storm-specific variability.
7. Atmospheric stability and its relationship to storm events.

Description

Runoff and streamflow at and around Yucca Mountain and the NTS are almost always direct responses to precipitation, mainly rainfall. Although the National Weather Service (NWS) has operated a precipitation gage network at the NTS since late 1957, the precipitation-gage network was not designed for, and is not ideally suited to, the development of rainfall-runoff relations. Systematic streamflow measurements were started in 1983, and since that time a network of precipitation gages was installed, which is growing and evolving (Figure 8.3.1.2-6 and Table 8.3.1.2-3). This network is providing an understanding of the relations between localized rainfall and the runoff. In addition, precipitation data from the NWS network complements and supplements the precipitation measurements collected in tandem with the streamflow records.

The precipitation measurement network being operated as part of the streamflow measurement program currently (late 1986) consists of 2 continuously recording, tipping-bucket rain gages and 14 nonrecording plastic rain gages. One of the recording gages is located in upper Fortymile Wash at the site of a recording streamflow gage near Pahute, Rainier, and Buckboard mesas (Station 2 in Figure 8.3.1.2-6); the other is located atop a small ridge (Exile Hill) at the base of the east-facing slope of Yucca Mountain, in the general area of proposed nuclear waste storage facilities (Station 5 in Figure 8.3.1.2-6). These two gages provide general calibration data on rainfall intensities and durations for comparisons with the cumulative-precipitation data for specific and select storms that are obtained from the plastic rain gages. Most of the plastic gages are located at sites of streamflow-measurement network sites; thus, the cumulative precipitation trapped by the plastic gages gives some sense of rainfall quantities in specific drainages that promote streamflows of varying magnitudes. They were located at the stream-measurement sites for logistic efficiency in operation and maintenance. Five of the plastic gages are located at sites without streamflow gages. These precipitation gages were located in places where supplementary rainfall information is needed to fill data gaps between other networks and collection sites. The precipitation data collected by plastic rain gages are not as accurate as those obtained by more sophisticated gages. Also, the data collected by the plastic gages must be recorded quickly, following a storm, before evaporation depletes the precipitation collected by the gages. Because of these limitations, such precipitation data will only be supplementary to those collected by the more formal precipitation-measurement network. These supplementary data will provide added detail to improve interpretations of the areal distribution of precipitation that causes runoff.

An upgrading and expansion of the currently operating network is planned to provide a better accounting of precipitation occurring in the area surrounding Yucca Mountain. A plan to develop an integrated precipitation network is discussed in Section 8.3.1.12.1. The network will be of sufficient

Figure 8.3.1.2-6. Regional precipitation and streamflow stations (numbers correspond to those shown in Table 8.3.1.2-3).

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Table 8.3.1.2-3. Regional precipitation and streamflow stations
(see Figure 8.3.1.2-6 for locations)

Map #	Location	Gage type	Nevada State coordinates	
			North	East
1	Amargosa River near Beatty	CSG ^a	780,900	472,880
2	Unnamed Tributary to Fortymile Wash North Rattlesnake Ridge	RRG ^b RSG ^c	865,620	616,670
3	Fortymile Wash at Narrows	PRG ^d RSG	778,010	583,580
4	Yucca Wash	PRG CSG	770,320	579,750
5	Exile Hill	RRG	764,990	569,340
6	North Fork Coyote Wash	PRG	766,120	563,030
7	Drillhole (Sever) Wash	PRG CSG	753,630	578,750
8	Fortymile Wash at well J-13	PRG RSG	749,400	577,890
9	Dune Wash	PRG CSG	743,770	575,700
10	Fortymile Wash near Highway 95	PRG RSG	699,320	568,200
11	Topopah Wash	PRG CSG	736,070	602,410
12	Cane Springs Wash Tributary	PRG CSG	749,390	667,300
13	Skull Mountain Pass on Jackass Flats Highway	PRG	723,750	627,060
14	Rock Valley on Jackass Flats Highway	PRG	704,400	651,830
15	Rock Valley at Highway 95	PRG	683,380	604,810
16	Amargosa River Tributary near Mercury	PRG CSG	659,900	666,890

Table 8.3.1.2-3. Regional precipitation and streamflow stations
(see Figure 8.3.1.2-6 for locations) (continued)

Map #	Location	Gage type	Nevada State coordinates	
			North	East
17	Amargosa River Tributary #1 near Johnnie	CSG	622,800	664,360
18	Amargosa River Tributary #2 near Johnnie	CSG	614,160	674,320
19	Indian Springs Valley Tributary near Indian Springs	CSG	661,500	432,950
20	Stockade Pass	PRG	878,700	635,610

^aCSG = crest-stage stream gage.

^bRRG = recording rain gage (tipping bucket).

^cRSR = recording stream gage.

^dPRG = plastic rain gage.

density to characterize and track storm movement and intensity within the regional study area. The network will be of greater density within the site boundaries to provide input to the infiltration studies for use in water budget calculations (Activity 8.3.1.2.2.1.2). Meteorologic data will also be collected at network stations that are located within the boundaries of the site to provide input to the gas-phase circulation study (Activity 8.3.1.2.2.7.1) as well as the infiltration studies (Activity 8.3.1.2.2.1.2). The amount and timing of rainfall will be related to the amount and timing of runoff. The information collected under this study will be correlated with that discussed in Section 8.3.1.12 (meteorology). Findings from this study will be used in conjunction with those of paleoflood studies (Activity 8.3.1.5.2.1.1) to help provide a basis for future flood predictions (Activity 8.3.1.5.2.2.1).

The precipitation data collected as a part of this study will span only a short-term duration compared with the length of time nuclear waste will be stored. These relatively short-term data can probably be statistically correlated with regional precipitation data spanning a longer (but also relatively short) time (Section 8.3.1.12.1). Both regional and site-specific data will be correlated with paleoclimatic data (Section 8.3.1.5.2.2). Overall worth of the short-term, site-specific data will depend on the quality and quantity of data obtained and on the range of variability of the data compared with the long-term range of natural variability of the climatic system. Techniques of data analysis and interpretation will depend on the analytical technology available at the time of analysis and on the quality,

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quantity, and characteristics of the available data of that time; techniques will also depend on the quality and quantity of regional data and paleo-climatic data available for comparisons and correlations.

Methods and technical procedures

The method and technical procedure for Activity 8.3.1.2.1.1.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Operate precipitation gages	HP-43, RO	Method of installation and operation of non-recording rain gage	15 Nov 84

8.3.1.2.1.2 Study: Characterization of runoff and streamflow

The objectives of this study are to (1) collect basic data on surface-water runoff at, and peripherally to, Yucca Mountain and its hydrologic flow system; (2) use the streamflow data to describe the runoff characteristics of the area and assess the response of runoff to precipitation; (3) assess the potential for flood hazards and related fluvial-debris hazards to the NNWSI Project; and (4) provide basic data and interpretations of surface-water runoff to investigations that evaluate the amounts and processes of ground-water recharge at Yucca Mountain and surrounding areas.

Two activities are planned to provide the knowledge required to satisfy the objectives stated previously: (1) collect and interpret streamflow data within the regional hydrologic study area, and (2) document movement of debris initiated or perpetuated by the direct or indirect processes of surface-water runoff when and where the debris movement constitutes a hazard or significantly alters the geomorphic landscape.

8.3.1.2.1.2.1 Activity: Surface-water runoff monitoring

Objectives

The objectives of this activity are as follows:

1. To develop needed basic data on the characteristics, magnitudes, frequencies, and timing of surface-water runoff to develop an understanding of the relationships between specific runoff events and the characteristics of the storms and associated precipitation.

2. To develop a streamflow data base adequate to provide the necessary calibration data for precipitation-runoff modeling efforts for the regional study area.

Parameters

The parameters of the activity are

1. Occurrences of runoff.
2. Areal extent of runoff.
3. Frequencies and runoff recurrence in specific and general areas.
4. Magnitudes of streamflow at specific sites.
5. Durations of individual runoff events.
6. Quantities of runoff at specific sites.
7. Relations of runoff to weather conditions.

Description

Streamflow data will be collected to document surface-water runoff, both quantitatively and qualitatively, in selected streams of the Yucca Mountain area and the NTS. Two stream gage networks currently exist: one for the regional study area and one for the site. These two networks satisfy a variety of NNWSI Project needs. A dense network is required on site to provide detailed data for the unsaturated-zone infiltration studies (Section 8.3.1.2.2.1.2). A broader network is required in the regional study area to develop an understanding of the relationships between specific runoff events and the characteristics of the storms and associated precipitation. These two networks will complement each other in providing a comprehensive understanding of the surface-water regime for input into the conceptual model.

Application of the streamflow data generally will be restricted to the specific purposes described. The short duration of the records that will be obtained probably will preclude development of meaningful long-term runoff characteristics. Long-term records were checked from gaging stations in a broad region around the Yucca Mountain area to evaluate their usefulness in correlating with the Yucca Mountain data. No records that were useful and appropriate for this purpose were found.

Surface-water runoff studies, in general, document the occurrences of runoff by measuring streamflow, when it occurs, at selected sites. A network of streamflow-measurement sites has been established for the regional study area and locations of the sites are shown in Figure 8.3.1.2-6 and Table 8.3.1.2-3. At many of the regional network sites, measurements consist of only a determination of the peak magnitude of streamflow and accompanying stream stage (height) at that specific site; however, at several sites along the Fortymile Wash, the stage of streamflow in the channel is continuously monitored. This continuous record of stream stage will be mathematically converted into a continuous record of the rate of streamflow past the site.

Currently, four continuous stream stage gages are operating:

1. One in an unnamed 4-mi² tributary to the headwaters of Fortymile Wash near Rattlesnake Ridge.

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2. One at a relatively narrow channel constriction of Fortymile Wash (hereafter referred to as the narrows), a short distance upstream from the mouth of Yucca Wash. At this site, flow from the integrated upstream drainage of about 250 mi² of Fortymile Wash is monitored; a video cassette recorder is also installed at this site to furnish a visual record of streamflow to compare experimentally with the continuous record of stream stage.
3. One in Fortymile Wash, downstream from the Yucca Mountain road crossing, near well J-13. In addition to the runoff passing the narrows site upstream, that passing this site also includes inflow from Yucca Wash (about 17 mi²) and much of the runoff from Yucca Mountain that enters Fortymile Wash from the Drillhole-Sever Wash drainage (about 16 mi²).
4. One downstream on Fortymile Wash near Highway 95 and Lathrop Wells. This streamflow record shows losses or gains in flow downstream from the gage upstream near well J-13, and thus, may indicate the potential for streamflow in the wash to recharge the ground-water system along its alluvial pathway.

These continuously recording stream gages are visited approximately each month for maintenance, and, also, as soon as possible, following each runoff event.

The addition of another continuously recording stream gage is planned for the regional network. This gage will be installed near Beatty, Nevada, in either the Amargosa River or Beatty Wash and will record runoff and flood flows from the northwestern part of Pahute Mesa. This drainage, which is similar in size to the Fortymile Wash drainage, is currently not being monitored, and monitoring will provide valuable input to the evaluation of the rainfall-runoff relationship of the Yucca Mountain area.

Scour chains have been installed at the narrows, well J-13, and Highway 95 (Lathrop Wells) gaging sites. Scour chains are vertically suspended lengths of chains buried in an individual vertical pit excavated in the alluvial streambed along a line perpendicular to the direction of streamflow. About a half dozen of these chains, spaced about 5 to 10 ft apart along the cross-channel lineament, are buried at each gaging site. They were vertically suspended in the pits dug in the streambed and were buried in the vertically extended position. Because of their flexibility, any scour of the streambed during periods of streamflow will deform the upper segment of the chains to a nonvertical position to the depth of streambed scour. Documentation of the levels of deformation of the individual chains along the channel cross section will generally define the cross-sectional depth and shape of scour for a specific runoff event. The depth and degree of scour will provide a sense of the degree of reliability of the recorded stream stage to depict the varying cross-sectional area of streamflow during the runoff event.

In addition to the established network of continuous streamflow-measurement sites, peak magnitudes of streamflows will be selectively measured in drainages that do not contain network sites, and at nonnetwork

sites in drainages that contain network sites. These miscellaneous measurements will be made, as deemed necessary, to characterize specific runoff events in, or peripheral to, the regional study area. They also will permit a more efficient expansion of the markedly deficient streamflow data base for the general area. These miscellaneous measurements are expected to add important data regarding intensive runoff events that are needed to assess the potential for severe runoff that might occur throughout the area or region under prevailing climatic conditions. This regional peak stream gage network currently (late 1986) includes ten crest-stage gages. Locations are shown in Figure 3-3. These gages record only the peak stage of any specific runoff event and do not record any data on rising or receding stages below the peak, the timing of runoff, or the duration of runoff.

Half of these crest-stage gages are part of a statewide network of crest-stage gages that have been operated since the 1960s. Thus, they make up the only historic streamflow data base for the area immediately surrounding and including the Yucca Mountain area and the NTS. These five incorporated sites are outside of the proposed Yucca Mountain regional study area but are relatively nearby. This historic core network has, thus far, been supplemented by five additional crest-stage gage sites located closer to Yucca Mountain. The crest-stage gage network is visited periodically, generally monthly, in concert with operational visits to the continuously recording gages. They are also visited as soon as possible during or following runoff events. Thus, the occurrences of flow events and runoff peaks recorded by the crest-stage gage component of the stream gage network can be correlated with data from the continuously recording gages.

This regional streamflow network is not of an adequate areal density, or of a needed level of detail, to satisfy the specific requirements of accounting for all streamflow in the many small drainages in the site area that is proposed for waste storage. The more detailed and continuous site data are needed to understand the full range of responses of the varying terrain of Yucca Mountain to varying ranges and characteristics of precipitation. The streamflow component of the hydrologic cycle needs to be quantitatively defined for the specific geographical area that will encompass proposed waste storage facilities. This definition is necessary to allow a meaningful quantitative assessment of infiltration of precipitation to the unsaturated ground-water zone (Activity 8.3.1.2.2.1.2, natural infiltration monitoring). To satisfy this need, streamflow will be measured and surface runoff will be documented at about two dozen selected sites on Yucca Mountain drainages (Figure 8.3.1.2-7 and Table 8.3.1.2-4). These streamflow measurement sites will be instrumented with continuously recording stream stage gages at flumes calibrated to mathematically relate stream stages to streamflow rates. In this manner, streamflow will be continuously documented at the measurement sites. The sites were selected to provide streamflow data for a variety of different size drainages of variable aspects and widely scattered locations on Yucca Mountain.

Continuously recording precipitation gages are also planned for each of the streamflow sites to provide geographically specific data on rainfall for the drainages of interest (Activity 8.3.1.2.1.1.1, regional precipitation monitoring). Site-specific precipitation data will be used in conjunction with the regional precipitation data to define quantitative relations between rainfall and runoff for the selected drainages. Fluvial suspended-sediment

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Figure 8.3.1.2-7. Site precipitation, streamflow, and proposed weather stations (refer to Table 8.3.1.2-4 for precipitation and streamflow location descriptions).

Table 8.3.1.2-4. Site precipitation and streamflow stations
(see Figure 8.3.1.2-7 for locations)

Map #	Location	Gage type	Nevada State coordinates	
			North	East
S1	Wren Wash--below UE-25 UZN#98, just below lower confluence	TBD ^a	767,900	562,250
S2	Wren Wash--above UE-25 UZN#26, just below upper confluence	TBD	768,890	560,450
S3	Wren Wash--above USW UZ-N70, near top of drainage	TBD	769,450	559,830
S4	Drill Hole Wash--just above USW UZ-N46	TBD	772,250	559,700
S5	Drill Hole Wash--just below UE-25 UZN#18	TBD	766,350	565,240
S6	Coyote Wash--north fork, 100 ft downstream from trench	TBD	766,300	562,500
S7	Coyote Wash--south fork, just upstream from USW UZ-N42	TBD	765,650	562,700
S8	Coyote Wash--south fork, just below crest of Yucca Mountain	TBD	766,150	559,675
S9	Pagany Wash--just below UE-25 UZN#12	TBD	768,550	566,800
S10	Pagany Wash--just above UE-25 UZN#10	TBD	770,050	564,650
S11	Split Wash--500 ft above UE-25 UZN#19	TBD	763,910	564,125
S12	H-4 Canyon--1,000 ft above USW H-4	TBD	762,275	563,150
S13	WT-2 Canyon--just below USW UZ-7	TBD	760,850	563,000
S14	WT-2 Canyon--north fork, just below USW UZ-N73	TBD	760,950	559,010
S15	Ghost Dance Wash--north fork, west of QTec deposit	TBD	758,700	559,600
S16	Ghost Dance Wash--south central Fork, lower part	TBD	757,480	560,375

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Table 8.3.1.2-4. Site precipitation and streamflow stations
(See Figure 8.3.1.2-7 for locations) (continued)

Map #	Location	Gage type	Nevada State coordinates	
			North	East
S17	Abandon Wash--just below Ghost Dance fault trench	TBD	755,050	560,500
S18	Drainage south of USW UZ13--just below USW UZ-N33	TBD	750,300	559,350
S19	Solitario Canyon--near USW UZ N35	TBD	754,525	556,875
S20	Solitario Canyon--Canyon Mouth near USW WT-7	TBD	755,300	554,225
S21	Solitario Canyon--mid-part of Canyon just above USW H-6 road	TBD	762,750	556,190
S22	Solitario Canyon--upper part of canyon--due west of Wren Wash	TBD	768,780	557,725
S23	Solitario Canyon--unnamed tributary between USW UZ-N81 and USW UZ-N79	TBD	757,675	566,000
S24	Solitario Canyon--unnamed tributary just above USW UZ-N36	TBD	765,800	557,775
P1	Yucca Crest--north end	TBD	772,100	558,670
P2	Yucca Crest--near top of Split Wash	TBD	763,920	559,300
P3	Yucca Crest--near USW H-3	TBD	756,540	558,450
P4	Yucca Crest--near USW G-3	TBD	765,780	558,480

^aTBD = to be determined.

These data will also be useful to planned future rainfall-runoff modeling studies of Fortymile Wash (Activity 8.3.1.2.1.3.3, Fortymile Wash recharge study).

monitoring is also planned for about six of the measurement sites. These measurements will provide data regarding the magnitudes and temporal distributions of the relative proportions of water and sediment in the streamflow mixtures. The sediment data are needed to improve accuracy when assessing the true water-volume component of the streamflow mixtures. This detailed site streamflow data will be useful in the study of regional runoff and streamflow and to related activities investigating flood hazards and associated fluvial-debris hazards (Activity 8.3.1.16.1.1.1, site flood and debris hazards studies).

Because runoff is ephemeral, erratic, unpredictable, and generally of short duration in and around the Yucca Mountain area, direct measurements of streamflow using standard USGS current meter-measuring techniques are precluded. Almost all measurements at both network and miscellaneous sites must be made using indirect measurement techniques after the runoff has occurred. Although these indirect techniques are made according to accepted standard USGS practices, they are generally acknowledged to be less accurate than normal current meter measurements made during stable streamflow conditions. They, nonetheless, provide extremely valuable data, at a reasonable cost, for an area where quantitative and qualitative streamflow data are practically nonexistent.

Indirect measurements of peak flows also are made following runoff events in drainages, or at sites, where no continuous stream stage recorders or crest-stage gages are located. Sites for these miscellaneous measurements are selected as targets of opportunity when a field reconnaissance of recent runoff suggests that these normally unmonitored drainages have experienced runoff of a character that requires measurements to adequately characterize storm-runoff relations. The data thus collected supplement and complement data collected systematically and periodically throughout the formal streamflow-measurement network. Often, the spotty nature of desert flooding results in significant or severe runoff in the area that only marginally affects streams that are instrumented with continuously recording gages or crest-stage gages. At these times, the supplementary data are critical in characterizing the magnitude and extent of local runoff and flooding that might otherwise be overlooked or undeveloped. Because the locations and numbers of miscellaneous measurement sites vary greatly from storm to storm and from year to year, none of the sites are shown in Figure 8.3.1.2-6. The locations of miscellaneous-measurement sites will be shown in periodic progress and summary reports of this investigation to properly document the data collected during specific time intervals during the study.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.2.1 are given in the following table.

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Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Operate continuous stream stage recorder	HP-45, RO	Method of installation, operation, and inspection of recording streamflow gage using the bubblegage STACOM manometer system	14 Aug 84
Measure and analyze stream discharge	HP-40, RO	Method for determination of peak discharge by the slope-conveyance	14 Aug 84
Measure streamflow using flumes	TBD ^a	TBD	TBD
Measure fluvial-sediment transport	TBD	TBD	TBD
Measure crest stage using gages	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.2.2 Activity: Transport of debris by severe runoff

Objectives

The objective of this activity is to document, both quantitatively and qualitatively, the characteristics of debris transported by intense surface runoff.

Parameters

The parameters of this activity are

1. Quantities of erosion and deposition.
2. Characteristics of erosion and deposition.
3. Physical characteristics of debris transport by streamflow.

Description

If field investigations of runoff suggest that the debris movement would constitute a serious hazard to nuclear waste storage activities, data will be collected to document intense and rapid movement of debris by surface runoff. The documentation will include qualitative and quantitative (when feasible and practical) assessments of the characteristics of erosion, transport, and deposition of debris by surface runoff. These data will be collected in the Yucca Mountain area and peripheral areas important to understanding hazardous (severe and intensive) debris transport at the proposed nuclear waste storage area. The information thus obtained will increase knowledge on severe erosion and depositional processes currently active on the landscape, and the part these processes play in present-day fluvial-debris hazards.

Times, locations, areal extent, and depths of severe erosion and deposition caused by intense runoff will be noted, measured, or estimated, if possible, where erosion scars or deposits are prominent. Direct and indirect measurements will be used to quantify or describe (1) the amount of channel or hillslope erosion that was caused by a given flood at a specific site or sites, (2) the sediment deposit(s) that were created by the erosion and transport of debris, and (3) the physical characteristics of the debris that was eroded, transported, and deposited by flooding. Direct measurements of the transport of sediment during periods of hazardous movement will probably not be possible. Land-surface photography, areal photography, and remote sensing will be used in the post-fact analyses of the debris movement during major runoff events whenever possible and feasible. Scars and deposits resulting from known recent flash floods will be used to develop measurement and estimation techniques. When severe sediment transport takes place, the causes and knowledge of the processes of movement will be sought. These causes and processes will be related to specific storm and runoff characteristics if, and when, possible.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.2.1.2.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Measurement of channel or hillslope erosion from floods	TBD ^a	TBD	TBD
Measurement of sediment deposition	TBD	TBD	TBD

Method	Technical procedure		
	Number	Title	Date
Measurement of physical characteristics of eroded debris	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.3 Study: Characterization of the regional ground-water flow system

The objectives of this study are (1) to further define the distribution of hydraulic properties of the regional ground-water flow system and (2) to use hydrologic, hydrochemical, and heat-flow data to determine the magnitude and direction of ground-water flow.

Five activities are planned to collect the data required to satisfy this objective: (1) an assessment of regional hydrogeologic data needs in the saturated zone, (2) regional potentiometric level studies, (3) a Fortymile Wash recharge study, (4) evapotranspiration studies, and (5) regional hydrochemical tests and analyses.

8.3.1.2.1.3.1 Activity: Assessment of the regional hydrogeologic data needs in the saturated zone

Objectives

The objective of this activity is to prioritize data needs for use in the regional ground-water flow description.

Parameters

The parameters of this activity are

1. Distribution of hydraulic conductivity, transmissivity, storage coefficient, and porosity type (matrix, fracture).
2. Location and rate of recharge and discharge.

Description

A hierarchy of priorities will be assigned to data requirements for the description of regional ground-water flow description of the saturated zone. A two-dimensional ground-water flow model (Czarnecki and Waddell, 1984) will be updated to evaluate the adequacy of regional ground-water data and to

guide future data collection. While enough data currently exist to construct models of regional ground-water flow, sufficient uncertainty in initial and boundary conditions exists to reduce the certainty of model results. By prioritizing model variables as to their effects on key model-calculated results (such as ground-water flow-path directions and gradients), data collection may be focused to minimize uncertainties in these key variables.

Sensitivity analyses will be performed using a two-dimensional digital, finite-element model of ground-water flow to prioritize the effects of key model variables, such as hydraulic conductivity, transmissivity, storage coefficient, porosity, and locations and rates of recharge and discharge. For example, little is known about the potentially steep hydraulic gradient between the Amargosa Desert and the Furnace Creek Ranch discharge area in Death Valley, or the hydrologic properties of the fault zone that causes the spring line at Ash Meadows. The sensitivity of hydrologic properties of these and other areas will be evaluated using the modeling approach.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.3.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS--)		
Two-dimensional finite-element model parameter sensitivity analyses	TBD ^a	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.3.2 Activity: Regional potentiometric level studies

Objectives

The objective of this activity is to establish potentiometric data within the regional flow system in order to reliably estimate ground-water flow directions and hydraulic gradients.

Parameters

The parameters of this activity are

1. Hydraulic head.
2. Hydraulic gradient.

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3. Heat flow.
4. Transmissivity.

Description

A general field reconnaissance will be conducted to locate previously unknown or unobserved wells, springs, and mine shafts that may yield information about regional ground-water levels. In addition, searches will be made for agencies, local residents, and well drillers that are likely to have well records or water-level information. Where possible, depth-to-water measurements will be obtained in these previously unknown or unobserved wells. Depth to water and total well depth will be determined by means of a measuring tape, or a sensor, that is lowered into the hole on a logging cable that goes over a sheave with a counter. In addition, where possible, geophysical logs similar to those for new water-table holes (described in the following paragraph) will be run.

Because Crater Flat lacks water levels needed for modeling of that area, two new water-table holes, USW WT-21 and USW WT-22, will be drilled to collect additional water-level data (Figure 8.3.1.2-8). Other proposed water-table holes shown in Figure 8.3.1.2-8 are considered under Activity 8.3.1.2.3.1.2 (Site potentiometric-level evaluation). Additional wells will be drilled if determined to be needed in Activity 8.3.1.2.1.3.2. USW WT-21 will be located 1.5 km southwest of USW H-6 and drilled to a probable depth of about 549 m. USW WT-22 will be located in northern Crater Flat and drilled to a probable depth of about 396 m. Both holes will be drilled using the air-foam method and completed similarly to previously drilled water-table holes. They will have diameters of about 22 cm. The drilling of these holes will be integrated and coordinated with the overall drilling program as outlined in Section 8.3.1.4.1.

In support of objectives that are not necessarily part of these potentiometric-level studies, the newly drilled water-table holes will be geophysically surveyed to attain all the logs that are typically run in the unsaturated zone holes drilled in support of the NNWSI Project. Such logging programs include a gyroscopic survey (for vertical deviation) and logs used in support of structural and stratigraphic analyses, such as vibroseis and optical television surveys, and dielectric, gamma-ray spectrum, caliper, fluid density, electric, density, and epithermal neutron logs. In addition, magnetometer or other logs may be made.

After downhole geophysical logs are completed in each hole, a small-capacity pump will be hung in the hole on tubing, and the pump will be operated for about a week to obtain water samples for chemical and isotopic analyses. The pump will be removed and the tubing reinstalled to enable measurements of the water levels.

Depth-to-water measurements will be obtained by means of a measuring tape, or a sensor, that is lowered into the hole on a logging cable that goes over a sheave with a counter. The water-level depth will be converted to altitude when combined with the surveyed altitude of land surface. For newly drilled water-table holes, water levels may also be monitored continuously by means of a semipermanently installed downhole pressure transducer that is connected to recording equipment at the surface. These holes will be added

Figure 8.3.1.2-8. Location of existing and proposed water-table holes.

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to the existing water-level monitoring network of about 25 holes located in the vicinity of Yucca Mountain. If determined applicable, corrections will be made to account for factors that could affect hydraulic head, such as relative density differences.

Although it is recognized that these boreholes will not be ideally constructed for heat-flow calculations, some useful heat-flow information can be obtained from them. Therefore, where feasible, temperature logs and thermal-conductivity measurements or estimates will be made in newly drilled holes and newly located existing holes, and heat flow will be calculated. Various methodologies, such as the silica geothermometer method of Swanberg and Morgan (1978), will be considered. The results will be integrated with ongoing heat-flow analyses to supplement potentiometric data in interpreting regional ground-water flow directions and hydraulic gradients.

A mining company is drilling boreholes in the Amargosa Desert as a part of its exploration programs. This commercial company has agreed to allow (1) installation of piezometers in their holes for NNWSI Project data collection, and (2) borehole geophysical logging of these holes. Some piezometers and piezometer nests have been installed to measure water levels in areas adjacent to the Yucca Mountain site to provide data for regional hydrologic studies. Additional piezometers will be installed if additional holes are made available to the Project. General areas where these boreholes will be located are shown in Figure 3-1. Standard geophysical logs--resistivity, caliper, gamma-gamma, and neutron-density--will be run in these boreholes to provide data on stratigraphy, lithology, porosity, and permeability of the host rock. Borehole cuttings, collected at 10-ft intervals from these holes by the mining company, will be provided for analysis of (1) lithology, (2) grain size, (3) bulk density, (4) porosity, (5) permeability and hydraulic conductivity, (6) environment of deposition, and (7) effective saturated thickness. Instrumentation of each of these holes with two piezometers will provide deep and near-surface potentiometric data for determining vertical hydraulic head distribution. Water samples will be obtained from these piezometers for hydrochemical analyses.

Water-level recovery will be monitored after sampling to determine estimates of transmissivity. Downhole temperature will be measured at selected intervals to estimate the vertical component of ground-water flow. Regional ground-water flow rates and velocities may then be estimated from transmissivity, hydraulic conductivity, porosity, effective saturated thickness, and hydraulic gradient.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.3.2 are given in the following table.

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Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Field reconnaissance of wells, springs and/or mine shafts and well record reviews	HP-25, R0	Methods for measuring water levels using the dodge logging van	20 July 84
	HP-01, R0	Methods for determining water level	11 Jan 82
	HP-26, R0	Method for calibrating water-level measurement equipment using the reference steel tape	14 Aug 85
Drilling and completion of water-table holes	HP-23, R1 TBD ^a	Collection and field analysis of saturated zone ground-water samples	4 Nov 83
Water level measurement and long-term monitoring	HP-25, R0	Methods for measuring water levels using the Dodge logging van	20 July 84
Geophysical and borehole video surveys	HP-02, R0	Acoustic televiewer investigations	14 Aug 84
	HP-50, R0	Method for neutron scatter and gamma ray attenuation logging using the USGS logging van	15 Nov 84
	GPP-17, R0	Magnetometer borehole logging operations	27 May 86
Water sampling for chemical and isotopic analyses	TBD	TBD	TBD
Hydraulic testing by drawdown-recovery methods	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.3.3 Activity: Fortymile Wash recharge study

Objectives

The objective of this activity is to determine to what extent (quantitatively, if feasible) that Fortymile Wash has been a source of recharge to the saturated zone under present and past conditions.

Parameters

The parameters of this activity are

1. Times, magnitudes, recurrence frequencies, and volumes of streamflow.
2. Times, rates, and volumes of precipitation.
3. Maximum and minimum daily temperatures.
4. Depth and water content of snowpack.
5. Location and rates of recharge, past and present, in Fortymile Wash.
6. Type and density of vegetative cover.

Description

Ground-water modeling of the saturated ground-water flow system has supported the inference that the Fortymile Wash drainage channel may be an important zone of regional ground-water recharge (Czarnecki and Waddell, 1984). Modeling studies have also indicated that the position of the water table beneath Yucca Mountain may be sensitive to the rate of recharge flux through Fortymile Wash (Czarnecki, 1985). If so, ground-water levels beneath the proposed Yucca Mountain nuclear waste storage areas may be strongly influenced by the percolation of streamflow into and through the bed of the wash. Other smaller washes at and near Yucca Mountain are also being evaluated for their recharge potential (Activity 8.3.1.2.2.1.2). Infiltration studies along the channel of Fortymile Wash will address this potential for streamflow to act as a recharge mechanism. Rainfall-runoff modeling of the wash, upstream from Yucca Mountain, will characterize the relationships between precipitation and runoff in various segments of the Fortymile Wash drainage basin. Actual streamflow and precipitation data will be needed to calibrate the rainfall-runoff modeling exercises. If the data thus obtained allow a reasonably good calibration of the model, or models, the models' capabilities to accurately predict changes in runoff related to future changes in climate will be enhanced. The use of measured data are essential to a realistic calibration of rainfall-runoff models if these models are to provide acceptable predictions of streamflow for precipitation that varies in today's climate and with changing climatic conditions.

Hydrologic characteristics of Fortymile Wash drainage basin will be determined and subbasins will be selected for precipitation and streamflow measurements. After the number and locations of data-collection sites have been determined, streamflow gages will be installed to continuously record

stream stages. Precipitation gages will also be installed to continuously record precipitation. Maximum and minimum daily temperatures will be recorded at select sites. These stations, if needed, will supplement the streamflow and precipitation data that are currently being collected in Fortymile Wash as part of Activity 8.3.1.2.1.2.1 (surface-water runoff monitoring). Stream stages, precipitation, and temperatures will probably be continuously transmitted to a data-assembling and storage site. Snowpack accumulation and dissipation will be monitored automatically by snowpillows and manually at designated snowcourses. Snowpillow data will probably be relayed on a real-time basis. (A snowpillow consists of an inflated elastomeric bladder connected to a pressure transducer in such a way that the weight of snow falling on the bladder may be determined by changes in pressure within the bladder.)

The infiltration rate will be estimated by measuring the streamflow losses and monitoring the moisture pulses. Devices, such as neutron moisture tubes, will be installed at key locations in and across the channel of Fortymile Wash. The completed depths will be below 10 m, the maximum depth where significant evapotranspiration occurs. The devices will be monitored during infiltration events with a frequency that will ensure adequate observation of the movement of moisture pulses through the shallow unsaturated zone. The results of these measurements will be used to estimate the infiltration locations and rates.

Three drillholes (UE-25 FM#1, #2, and #3) will be drilled into the saturated zone to obtain unsaturated-zone moisture samples and saturated-zone water samples to determine the recharge history. Drillhole UE-25 FM #1 will be located in a wash that is 1.2 km east of UE-25 WT#15 (Figure 8.3.1.2-9). This drillhole will have a total depth of approximately 427 m. Drillhole UE-25 FM#2 will be located in a wash that is at the crossing of the main road to Yucca Mountain and will have a total depth of approximately 381 m (1,250 ft). Drillhole UE-25 FM#3 will be located south of well J-12 and will have a total depth of approximately 290 m.

Moisture measurements will be obtained in each of these holes by coring selected intervals within the unsaturated zone. Water samples will be obtained near the top of the saturated zone in each hole and about 91 m deeper, which is near the bottom of each hole. Samples will also be collected if perched water is encountered. Each of the three drillholes will be used for infiltration experiments. These experiments will be similar to those planned for the unsaturated zone, where an infiltration pond will be constructed around the drillhole casing. Periodic or continuous moisture content measurements will be made in the drillhole casing at selected locations, as water infiltrates downward from land surface. Results from these infiltration experiments will be used with results from Studies 8.3.1.2.1.1 and 8.3.1.2.1.2 to estimate annual average estimates of recharge occurring along Fortymile Wash for use in the regional and site models of ground-water flow.

All samples will be sent to the laboratory for chemical and isotope analyses. The isotope analyses will include determination of the oxygen-18, deuterium, carbon-13, carbon-14, and tritium content. The precipitation, surface water, and ground-water sample analyses will be compared and interpreted in terms of probable sources and flow paths in the Fortymile Wash

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Figure 8.3.1.2-9. Location of existing and proposed drillholes for the Fortymile Wash recharge study.

drainage. The results of other investigations from which ground-water movement or the paleoenvironment may be inferred, such as studies of zeolite facies Section 8.3.1.3.2.2), will be used in conjunction with hydrologic interpretations based on these surface and subsurface chemical analyses to determine the recharge history.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.3.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Streamflow measurement	HP-44, RO	Field procedures for crest-stage gage installation and inspection	15 Nov 84
	HP-45, RO	Method of installation, operation, and inspection of recording stream-flow gage using the bubble-gage STACOM manometer system	14 Aug 84
Neutron moisture tubes and lysimeter monitoring	HP-62, RO	Method for measuring subsurface moisture	16 Mar 87
Precipitation and surface-water runoff sampling	TBD ^a	TBD	TBD
Borehole drilling and coring	TBD	REECO drilling procedures	TBD
Soil moisture measurement	HP-28, RO	Laboratory procedures for the determination of moisture retention curve on rock core	15 May 85
	HP-32, RO	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85

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Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Ground-water sampling	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
Chemical and isotopic analysis of water samples	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82
Chemical and isotopic analyses of water samples	HP-11, R0	Methods for determination of radioactive substances in water	18 Aug 82
Fortymile Wash recharge analyses	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.3.4 Activity: Evapotranspiration studies

Objectives

The objective of this activity is to estimate ground-water discharge by evapotranspiration in the Amargosa Desert, in order to provide boundary-condition data for the regional ground-water flow model.

Parameters

The parameters of this activity are

1. Evapotranspiration rates and spatial distribution.
2. Hydraulic head and distribution with depth.
3. Depth to water table.

Description

A data requirement of the two-dimensional regional ground-water flow model is to specify the distribution and rate of ground-water discharge. Ground-water discharge occurs primarily as evapotranspiration, evaporation, and spring discharge within the regional ground-water flow system. The two principal discharge areas in the flow system are Franklin Lake Playa and the

Furnace Creek Ranch area (Figure 8.3.1.2-10). Estimates of spring discharge and evapotranspiration (Section 3.5) have been made for these areas (Walker and Eakin, 1963; Hunt et al., 1966; Winograd and Thordarson, 1975; Miller, 1977). The spring discharge measurements are considered reliable, but estimates of evapotranspiration at Franklin Lake Playa do not conclusively yield annual-average volumetric discharge fluxes because the area over which evapotranspiration occurs is not adequately defined. The need for these estimates stems from the sensitivity analyses performed by Czarnecki and Waddell (1984).

Upgradient from Franklin Lake Playa in the Amargosa Desert, depths to the water table increase; at water-table depths greater than some critical value, ground-water discharge by evapotranspiration does not occur. This activity includes (1) defining the area of ground-water discharge by evapotranspiration, by delineating the critical depth to the water table and (2) estimating the amount of ground-water discharge by evapotranspiration, by measuring evapotranspiration rate and relating it to depth to water table.

In the area of ground-water discharge by evapotranspiration, an upward hydraulic gradient is expected to occur in the saturated zone; elsewhere, the gradient is expected to be downward or lateral. To determine whether an upward gradient exists, a nest of piezometers will be installed at each of several sites with various depths to the water table; variations in head with depth will be measured at each site. One of the sites will be where the water table is at least 30 m below land surface, where it can confidently be assumed that no ground-water discharge by evapotranspiration occurs. From the gradient information obtained from the piezometers, approximate values of the critical depth to water for ground-water discharge to occur will be evaluated.

At each piezometer site, evapotranspiration will be measured using the Eddy-correlation technique (Weeks et al., 1985) and the Bowen ratio technique (Stannard, 1985). These measurements will help to establish the relationship of evapotranspiration to depth to water in areas where ground-water discharge by evapotranspiration occurs, and to establish the baseline evapotranspiration in areas where the discharge is only from moisture in unsaturated surficial soils.

It is recognized that the value for the critical depth to the water table probably is not a constant but depends on various factors (besides depth to water) that influence evapotranspiration rates, such as soil texture and plant type and density. These factors will be considered in locating the piezometer and evapotranspiration-measurement sites and in evaluating the test results.

Once values for the critical depth to water have been established, additional piezometers will be constructed to map the water table and to delineate the critical depth. Depths to water may also be determined by using either resistivity or seismic refraction surveying, with resolution to within a meter. A total of up to 30 shallow piezometers will be constructed to depths of 3 to 30 m below the water table.

Figure 8.3.1.2-10. Subregional ground-water flow study area showing principal discharge areas at Furnace Creek Ranch and Franklin Lake Playa (Czarnecki and Waddell, 1984).

Ground-water discharge by evapotranspiration will be estimated from the relationship established between the depth to water and evapotranspiration, taking into account the baseline evapotranspiration, within the areas of ground-water discharge.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.2.1.3.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Eddy-correlation techniques	TBD ^a	TBD	TBD
Bowen ratio techniques	TBD	TBD	TBD
Phreatophyte mapping	TBD	TBD	TBD
Test drilling	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.3.5 Activity: Regional hydrochemical tests and analyses

Objectives

The objectives of this activity are to

1. Describe regional spatial variations in ground-water chemistry in the saturated zone.
2. Describe the evolution of ground-water composition and compositional variations along regional ground-water flow paths.

Parameters

The parameters of this activity are

1. Chemical concentrations.
2. Temperature.
3. pH.
4. Specific electrical conductance.
5. Stable-isotopes and stable-isotope ratios.
6. Radioisotope activity.

Description

Water samples will be collected from wells, springs, and surface-water sites as they are identified or become available. Pumping of wells or piezometers will also allow estimating hydraulic conductivity by monitoring the recovery of water levels. Samples will be analyzed for standard ionic composition; carbon-14 and tritium; stable isotopes of carbon, hydrogen, oxygen, and sulfur; and other inorganic constituents, as needed. The usefulness and applicability uranium-series disequilibrium analyses will be evaluated; if determined to be appropriate, these analyses will also be done. The analytical data will be combined with extant data and their interpretations (Claassen, 1985; Benson et al., 1983; Winograd and Thordarson, 1975; Naff, 1973; Walker and Eakin, 1963) to describe the spatial compositional variations in regional ground-water chemistry.

This information, together with existing geohydrologic information describing the saturated flow system, will be used to estimate ground-water flux and to investigate the relative significances of flow-system geometry, water rock interactions, and geohydrologic processes with respect to spatial variations in ground-water chemistry. Analyses of stable isotopes of carbon, oxygen, hydrogen, and sulfur will provide insight as to the evolution and movement of ground waters and will aid in comparisons of individual water samples to establish evidence of possible flow paths. Hydrochemical modeling using the complete hydrochemistry of samples (as well as geologic, petrologic, and mineralogic data) will be performed to account for the spatial distribution and variation of ground waters in the regional flow system, and to provide supporting evidence for possible flow paths and mixing mechanisms consistent with the conceptual models of ground-water flow. The bulk data may be used by Investigation 8.3.1.3.1 in its development of a ground-water chemistry model. Furthermore, Investigation 8.3.1.3.3 may also use the bulk data, if appropriate, when the Pahute Mesa area is studied.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.3.5 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Sample collection and field analysis	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-49, R0	Method for using hand-held glass thermometers	14 Aug 84

Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Chemical and isotopic analysis	HP-08, RO	Methods for determina- tion of inorganic substances in water	6 Aug 82
	HP-11, RO	Methods for determi- nation of radio- active substances in water	18 June 82
	HP-127, RO	Carbon-14 dating by tandem accelerator mass spectrometer	TBD ^a

^aTBD = to be determined.

8.3.1.2.1.4 Study: Regional hydrologic system synthesis and modeling

The objectives of this study are (1) to synthesize the available data into a model and make a qualitative analysis of how the system is functioning and (2) to represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive flow model. Four activities are planned to analyze and integrate the data in order to satisfy these objectives: (1) conceptualization of regional hydrologic flow models, (2) subregional two-dimensional areal hydrologic modeling, (3) subregional two-dimensional cross-sectional hydrologic modeling, and (4) regional three-dimensional hydrologic modeling.

Results from these modeling activities are not intended to directly estimate ground-water travel time from the repository to the accessible environment. Rather, the modeling results will be used as a basis for specifying boundary conditions for more detailed models of ground-water flow at the site.

8.3.1.2.1.4.1 Activity: Conceptualization of regional hydrologic flow models

Objectives

The objectives of this activity are

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1. To synthesize the available data into a model and make a qualitative analysis of how the regional hydrologic system functions.
2. To outline the flow system boundaries, hydrogeologic units, structural controls, and other hydrogeologic features pertaining to the regional ground-water flow system.

Parameters

The parameters of this activity are

1. Spatial distribution of hydraulic conductivity.
2. Hydraulic gradient.
3. Water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated-zone rock units.

Description

All reliable data (hydrologic, geologic, and geophysical) and reasonable interpretations of it will be assimilated into a description of the regional flow system. This description will include the physical and hydraulic characteristics of the rock units and structural features, as well as the likely ways that the flow system operates within this framework. The data will contain information obtained from the published literature and site characterization activities. This conceptual description of the flow system will be used to update a regional ground-water flow model originally developed by Waddell (1982). This updated model will be used as the baseline condition for regional ground-water flow at the site.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.4.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Analyses and interpretation of regional flow system	TBD ^a	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.4.2 Activity: Subregional two-dimensional areal hydrologic modeling

Objectives

The objective of this activity is to improve estimates of regional ground-water flow, by updating an existing two-dimensional, subregional, parameter-estimation model through the incorporation of additional hydrogeologic data.

Parameters

The parameters of this activity are

1. Spatial distribution of hydraulic conductivity.
2. Hydraulic gradient.
3. Water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated zone rock units.

Description

A subregional model of two-dimensional ground-water flow has been developed by Czarnecki and Waddell (1984) for estimating ground-water flow. Since the development of the model, numerous additional studies and data-collection activities have occurred and are planned in and around the modeled area (Figure 8.3.1.2-10). Additional drillholes have been and will be constructed in the study area yielding potentiometric data and hydraulic properties. Potentiometric data will be used, in part, as a basis for model calibration and as an indicator of variations in hydraulic properties, based on variations in hydraulic gradients.

Geophysical studies have produced and will provide additional information regarding stratigraphic and structural features in and around the site. Of particular utility is seismic refraction work that will be used to define the location, type, and distribution of structural and stratigraphic units that may affect ground-water flow. Although hydraulic properties in the vertical dimension are lumped, when used in the areal two-dimensional ground-water flow model, information such as effective saturated thickness can be combined with model ground-water flux estimates to yield estimates of ground-water travel times. Additional data in the third dimension also aid in the development of three-dimensional models of ground-water flow (Section 8.3.1.2.1.4.4). Other geophysical studies that will produce results for consideration of incorporation into the model include the following: (1) resistivity surveys, (2) gravity surveys, (3) magnetic surveys, (4) seismic reflection surveys, and (5) borehole geophysical surveys (Section 8.3.1.4.2.1.2). All these various activities have the potential for providing additional data on the distribution, type, and properties of stratigraphic and structural units, for use in the subregional ground-water flow model. Results from these various activities will be reviewed as they become available, and incorporated into the model as appropriate.

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Additional hydrogeologic data will be provided from the analyses of drillhole cuttings from exploration boreholes constructed in the Amargosa Desert by a commercial mining company (Section 8.3.1.2.1.3). These analyses will provide further knowledge of the areal and vertical distributions of hydraulic conductivity, porosity, bulk density, lithology, and stratigraphy. Additional estimates of hydraulic conductivity will be provided by monitoring the recovery of water levels in wells and piezometers after they have been pumped for hydrochemical samples (Section 8.3.1.2.1.3.5). The need for additional information on the distribution of hydrogeologic properties will be determined as part of a regional data-needs assessment (Section 8.3.1.2.1.3.1).

Annual average estimates of evapotranspiration are being made at Franklin Lake playa, based on measurements made at various times throughout the year. These estimates (Section 8.3.1.2.1.3.4) will be used in the two-dimensional subregional model as one of the discharge boundary conditions. Sensitivity analyses (Czarnecki and Waddell, 1984) have indicated that the flow system is sensitive to evapotranspiration, and that the flow model would be improved by refining these values. In addition, recharge estimates made at Fortymile Wash will be used in the model; other refinements in recharge estimates throughout the study area will also be used.

Hydrochemical studies at site and regional scales will provide additional data to be considered as part of the ground-water flow modeling activities (Sections 8.3.1.2.1.3.5 and 8.3.1.2.3.2.2). Hydrochemical analyses will be used to help define the flow paths of ground water through various lithologies, to account for the evolution of various water chemistries and ages. This hydrochemical perspective will be used as a partial basis for conceptual models of ground-water flow.

The finite-element computer program to be used in the simulations of this study is FEMOD. FEMOD has been verified against numerous analytical test cases and has been validated in field applications (Czarnecki, 1985), and comparisons against other models.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.4.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Parameter estimation and finite-element modeling	TBD ^a	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.4.3 Activity: Subregional two-dimensional cross-sectional hydrologic modeling

Objectives

The objective of this activity is to estimate the ground-water flow direction and magnitude along a potential flow path through the repository block to the accessible environment, and extending into the region, to help establish hydrologic boundary conditions at the boundary of the accessible environment.

Parameters

The parameters of this activity are

1. Spatial distribution of hydraulic conductivity.
2. Hydraulic gradient.
3. Water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated zone rock units.

Description

A two-dimensional, steady-state, cross-sectional model of ground-water flow in the saturated zone will be constructed along a potential flow line through Yucca Mountain (Figure 8.3.1.2-11). The model will be constructed to evaluate the vertical component of flux in the saturated zone and to examine the importance of potential structural features (such as fault-zone barriers) on the ground-water flowpath. Sensitivity analyses will be performed (1) to evaluate the effect of saturated thickness distribution on flux direction and magnitude, and (2) to evaluate the effect of recharge from the unsaturated zone. Results from this model may be used, in conjunction with other models and studies that are designed to estimate effective porosity at the site, as a basis for estimating ground-water travel time from the site to the accessible environment. Because the model will be used principally to identify in a qualitative sense the significance of vertical flow components, a highly simplified representation of the section will be used, with each layer being modeled as isotropic with respect to hydraulic properties.

The cross-sectional line shown in Figure 8.3.1.2-11 is based on a potential flow path estimated by Czarnecki and Waddell (1984) using a two-dimensional areal ground-water flow model. One of the basic assumptions made in using the areal model was that ground-water flow was strictly horizontal. By modeling along a cross section, this assumption can be tested, particularly from the repository block to the accessible environment. If the vertical component is minor (as is suggested by current potentiometric data), then the two-dimensional areal modeling approach may be valid instead of using a fully three-dimensional model. A vertical component of ground-water flow would also lengthen the flow path in the zone of saturation, although it would not necessarily increase travel time.

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Figure 8.3.1.2-11. Location of the flow line for the subregional two-dimensional cross section of hydrologic model (modified from Czarnecki and Waddell, 1984).

The cross-sectional ground-water flow model would be documented, verified, and validated per requirements in the standard operating procedure in force at the time of implementation. The code that will be used and specific plans for verification and validation have not yet been developed.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.4.3 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Finite-element modeling along a two-dimensional vertical cross section	TBD ^a	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.4.4 Activity: Regional three-dimensional hydrologic modeling

Objectives

The objectives of this activity are to

1. Develop a quasi-three-dimensional ground-water flow model of the saturated zone of the Yucca Mountain region.
2. Use the regional model to improve concepts of ground-water flow and to estimate the distribution of hydrologic properties where they are not well known.
3. Improve the regional model simulation through incorporation of new hydrologic data and information as it becomes available from other studies.
4. Use the regional model to test the impacts of possible future tectonic activity and climatic changes on the saturated hydrologic system.

Parameters

The parameters of this activity are

1. Spatial distribution of transmissivity.
2. Hydraulic gradient.

3. Water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated zone rock units.

Description

A numerical, quasi-three-dimensional ground-water flow model of the saturated zone of the Yucca Mountain region will be constructed and calibrated. Initially, the model will contain two layers that simulate horizontal flow in each of two major hydrogeologic units in the study area: (1) a combination of the Plio-Pleistocene deposits and the Miocene volcanic rocks and (2) the Paleozoic carbonate rocks. In areas where one of these units is missing, only a single layer will be used in the model. Vertical flow between the two hydrogeologic units will be simulated by a leakance layer in the model. The leakance layer will represent the composite effects of upper and lower layer thicknesses, vertical hydraulic conductivities, and any low-permeability zones present. The technical basis for using the leakance layer in the quasi-three-dimensional model is discussed in McDonald and Harbaugh (1984). With the existing data base, use of more than two layers to represent the regional ground-water-flow system is not expected to be justified because of a sparsity of data on the three-dimensional hydrogeologic properties of the system. This quasi-three-dimensional (or layered) simulation of the saturated zone is needed because of the differences in hydraulic properties between the two major hydrogeologic units and the differences in potentiometric head (50 to 60 ft, 16 to 20 m) between the two units. These differences in hydraulic properties and potentiometric head could not be simulated with a single-layered, two-dimensional model.

The USGS modular three-dimensional finite difference ground-water flow model (McDonald and Harbaugh, 1984) is the model that will be used to simulate the ground-water flow system in the Yucca Mountain region. The USGS three-dimensional model allows ground-water flow simulations both in two and three dimensions and, therefore, provides considerable flexibility for simulating complex geohydrologic systems.

The model will be constructed using hydrogeologic data from previous studies of the Yucca Mountain and Nevada Test Site areas. Data will be compiled from previous drilling programs, geologic reports, well-scheduling efforts, the regional and site characterization studies (8.3.1.2.1.3 and 8.3.1.5.2.1.3), the USGS Great Basin Regional-Aquifer System Analysis (Sun, 1986), and the USGS WATSTORE data base. Remote sensing studies (Activity 8.3.1.5.2.1.3) will provide information on possible ground-water flow paths from recharge to discharge areas. Initial model simulations will use the transmissivity distributions, recharge, and boundary conditions described by Waddell (1982) and Czarnecki and Waddell (1984) for a previously constructed two-dimensional ground-water flow model of the study region. Leakage from the unsaturated zone will be simulated as areal recharge to the saturated zone in upland areas, which have wetter and cooler climatic conditions, and in lowland areas, such as Fortymile Wash, where periodic surface runoff is believed to be a source of recharge. Where arid conditions prevail, leakage from the unsaturated zone is considered negligible on a regional scale and available data do not justify simulation. However, model simulations of the

saturated zone at the site scale in the immediate vicinity of Yucca Mountain (Study 8.3.1.2.3.3) will consider leakage from the unsaturated zone.

Virtually no information exists regarding vertical hydraulic conductivity of the hydrogeologic units. An extensive testing program to determine values for this parameter probably is not warranted. The units will be modeled as isotropic with respect to hydraulic properties, and sensitivity analysis will be conducted to evaluate the impacts of this assumption.

The model will be calibrated for steady conditions based on water-level data contained in Winograd and Thordarson (1975), Waddell (1982), and Czarnecki and Waddell (1984), and collected from Activities 8.3.1.2.1.3.2 and 8.3.1.2.3.1.2. Model calibration will consist of successive adjustment of hydraulic properties (transmissivity, recharge, and vertical leakage) within reasonable ranges to minimize the difference between observed and simulated potentiometric head. The most significant adjustments are expected to be for transmissivity in the vicinity of the steep-gradient area northeast of the proposed repository site and for recharge along Fortymile Wash. As an ongoing activity, the model will be updated and recalibrated using data from the regional and site characterization studies and other geological studies. As the data base improves, an attempt may be made to improve the regional simulation by adding several additional layers (such as the saturated alluvium) to the model in order to simulate flow in the saturated zone in more detail as more hydrogeologic data become available.

As a part of other activities (8.3.1.5.2.2.3 and 8.3.1.8.3.1.2), the regional quasi-three-dimensional ground-water flow model will be used to test the impacts of possible future ground-water developments, tectonic activity, and climatic changes on the saturated hydrologic system. Future movement along faults in the vicinity of Yucca Mountain could change hydraulic properties so as to either impede or enhance ground-water flow. The impact of such changes will be evaluated using the model. Future climate in the study area could be considerably wetter than the present climate and produce corresponding greater amounts of ground-water recharge. Increased recharge will be simulated using the model to predict the impact on ground-water levels under the site of the proposed repository at Yucca Mountain.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.4.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date

(NWM-USGS-)

Construction and calibration of quasi-three-dimensional ground-water-flow model

Not needed--planning activity

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Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Documentation of calibrated regional groundwater flow model	TBD ^a	TBD	TBD
Simulation of impact of future tectonic activity and climatic changes	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.1.5 Application of results

The information derived from the studies and activities of the plans described previously will be used in the following areas of site characterization, repository design, and performance assessment:

<u>SCP section</u>	<u>Subject</u>
8.3.1.2.3	Description of the saturated zone hydrologic system at the site
8.3.1.6.1	Present locations and rates of surface erosion
8.3.1.14.3	Local meteorological conditions at potential locations of surface facilities
8.3.1.16.1	Flood recurrence intervals and levels at potential locations of surface facilities
8.3.1.16.2	Location of adequate water supplies

8.3.1.2.1.6 Schedules and milestones

This investigation contains four studies: 8.3.1.2.1.1 (characterization of the meteorology for regional hydrology), 8.3.1.2.1.2 (characterization of runoff and streamflow), 8.3.1.2.1.3 (characterization of the regional groundwater flow system), and 8.3.1.2.1.4 (regional hydrologic system synthesis and modeling). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from the implementation of the approved study plans to the issuance of final products

associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

Study 8.3.1.2.1.4 is an out-year study. Precipitation data from Study 8.3.1.2.1.1 will be used in Studies 8.3.1.2.2.1 and 8.3.1.2.2.7 to help characterize the unsaturated zone. Further, this precipitation data will be correlated with regional and paleoclimatic data from Investigations 8.3.1.5.2 and 8.3.1.12.1. Streamflow data from Study 8.3.1.2.1.2 will be used in unsaturated zone infiltration studies (8.3.1.2.2.1) and site flood and debris hazard studies (8.3.1.2.1.3 will be combined with other data from which ground-water movement or paleoenvironment may be inferred, such as studies of zeolite facies (8.3.1.3.2.2) to determine recharge history. Development of the hydrologic models within Study 8.3.1.2.1.4 may require additional geophysical data from Studies 8.3.1.2.3.2. Calibration of these models requires the use of data collected under Studies 8.3.1.2.1.3 and 8.3.1.2.3.1. The quasi-three-dimensional model developed in Study 8.3.1.2.1.4 will be used in Studies 8.3.1.5.2.2 and 8.3.1.8.3.1 to test the impacts of future ground-water developments, tectonic activity, and climatic changes on the saturated hydrologic system.

The study numbers and titles corresponding to each timeline are shown on the left of the preceding figure. The points on the timelines represent

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major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces among studies. The data input and output at the interfaces are shown by circles.

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

<u>Point number</u>	<u>Description</u>
1	Issue first yearly report on precipitation and meteorological monitoring data.
2	Yearly precipitation to Studies 8.3.1.2.2.1 and 8.3.1.2.2.7.
3	Issue final yearly report on precipitation and meteorological monitoring data.
4	Milestone Z230. Report available on the characterization of the meteorology for Yucca Mountain regional hydrology.
5	Issue first yearly report on streamflow, debris flow, and precipitation.
6	Yearly streamflow data to Studies 8.3.1.2.2.1 (UZ infiltration) and 8.3.1.16.1.1 (site flood and debris hazard studies).
7	Quantitative relations between rainfall and runoff (from Studies 8.3.1.2.1.1 and 8.3.1.2.1.2) will be used for completion of Milestone P892.
8	Issue final yearly report on streamflow, debris flow, and precipitation data.
9	Milestone Z494. Report available on the characterization of runoff and streamflow for Yucca Mountain and vicinity.
10	Milestone Z242. Report available on the results of the assessment of the regional hydrogeologic data needs in the saturated zone.
11	Milestone P927. Report available on ground-water discharge at Franklin Lake.
12	Milestone M378. Report/map available on the regional potentiometric surface.
13	Hydrogeologic data gathered under Study 8.3.1.2.1.3 will supplement development of the models in Study 8.3.1.2.1.4.
14	Milestone P695. Report available on ground-water recharge at Fortymile Wash.

<u>Point number</u>	<u>Description</u>
15	Milestone P892. Report available on ground-water recharge at Fortymile Wash.
16	Milestone Z254. Report available on regional ground-water chemistry.
17	Milestone Q044. Report available on the characterization of the Yucca Mountain regional hydrologic system. This report summarizes results of both Studies 8.3.1.2.1.3 and 8.3.1.2.1.4.
18	Milestone Z243. Report available on the two-dimensional cross-sectional ground-water flow model.
19	Milestone P890. Report available on regional ground-water flow model.
20	Milestone P797. Report available on the refinement of sub-regional two-dimensional areal ground-water flow model.
21	Milestone Z491. Report available on the refinement of the regional three-dimensional ground-water flow model. This model will be used in Studies 8.3.1.5.2.2 and 8.3.1.8.3.1 to test the impacts of possible future ground-water developments, tectonic activity, and climatic changes on the saturated hydrologic system. Additional hydrogeologic data gathered under Study 8.3.1.2.1.3 will supplement the development of this model.
22	Three-dimensional model to Studies 8.3.1.5.2.2 and 8.3.1.8.3.1 to test impacts of future ground-water developments, tectonic activity, and climate changes on the saturated hydrologic system.

8.3.1.2.2 Investigation: Studies to provide a description of the unsaturated zone hydrologic system at the site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the data chapters summarize existing data relevant to this investigation:

<u>SCP section</u>	<u>Subject</u>
3.9.2.1	Hydraulic characteristics of the unsaturated zone
3.9.3.1	Accessible environment and credible pathways

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<u>SCP section</u>	<u>Subject</u>
3.9.4	Ground-water velocity and travel time
3.9.5	Hydrochemical confirmation of ground-water behavior
3.10.1	Summary of significant results (unsaturated zone hydrology)
3.10.2	Relation to design (unsaturated zone hydrology)
3.10.3	Identification of investigations (unsaturated zone hydrology)

Parameters

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

1. Infiltration characteristics, spatial distribution of the physical and hydraulic properties of the surficial hydrogeologic units at Yucca Mountain.
2. Unsaturated zone percolation characteristics, spatial distribution of the physical and hydraulic properties of the repository host rock and surrounding hydrogeologic units.
3. Unsaturated zone gas-phase movement characteristics, gas-phase (pneumatic) properties of the repository host rock and surrounding units.
4. Unsaturated zone hydrochemical characteristics, spatial and temporal variation of the gas and water quality in the repository host rock and surrounding units.
5. Velocities, fluxes, and travel times of water and gases in the unsaturated zone.

Other site studies that supply information that support the determination of the above parameters include the following:

<u>Study</u>	<u>Subject</u>
8.3.1.2.1.1	Characterization of the regional meteorology (precipitation patterns)
8.3.1.2.1.2	Characterization of the regional surface water (runoff component of the precipitation)
8.3.1.2.1.4	Characterization of the regional ground-water flow system (Fortymile Wash ground-water recharge to the site unsaturated zone)

<u>Study</u>	<u>Subject</u>
8.3.1.4.2.1	Characterization of the vertical and lateral distribution of stratigraphic units within the site area (site hydrogeologic units)
8.3.1.4.2.2	Characterization of site structural features (site fractures and hydrogeologic units)
8.3.1.4.2.2	Exploratory shaft facility geological studies (site lithostratigraphy and structure that would lead to hydrogeologic unit definitions)
8.3.1.5.2.1	Characterization of the Quaternary regional hydrology (site unsaturated zone water age and analog recharge chemistry)
8.3.1.5.2.2	Characterization of the future regional hydrology due to climate changes (future site unsaturated zone flow)
8.3.1.6.4.1	Evaluation of impact of future erosion on hydrologic characteristics at Yucca Mountain and vicinity (future site unsaturated zone flow)
8.3.1.8.3.1	Characterization of the future regional hydrology due to igneous and tectonic activity (future site unsaturated zone flow)

Purpose and objectives of the investigation

The objective of this investigation is to develop a model of the unsaturated-zone hydrologic system at Yucca Mountain that will assist in assessing the suitability of the site to contain and isolate waste. Developing this model requires an understanding of the manner in which water and gases move through the unsaturated zone, including the directions, paths, and rates in which flow occurs. This information will be provided through studies of the characterization of infiltration, percolation, gaseous-phase movement, and hydrochemistry. Flow and transport modeling designed to simulate the natural system will provide sensitivity analyses to help prioritize additional data collection.

Technical rationale for the investigation

In this introduction, the rationale for organization of the studies in this information need is discussed and a logic for integration of the studies and activities is presented. There are six major studies planned to be conducted under this investigation: (1) characterization of unsaturated zone infiltration, (2) characterization of percolation in the unsaturated zone, (3) characterization of gaseous-phase movement in the unsaturated zone, (4) characterization of the unsaturated zone hydrochemistry, (5) unsaturated zone flow modeling and transport modeling, and (6) analysis and integration of the unsaturated zone system. Of these, there are four data collection studies that have specific objectives, and although each will have modeling as part of the test design and data analysis, there will be no system

modeling associated with each study. Prototype test activities will be conducted in support of the unsaturated-zone site characterization investigation. These activities will not be part of site characterization but will be performed to develop specific procedures/methods or instrumentation/equipment that will be used in characterizing Yucca Mountain. All prototype activities referenced in the subsequent discussion of the unsaturated-zone investigation plans will not be conducted at the Yucca Mountain site nor will they use samples from Yucca Mountain.

The infiltration study is targeted at characterizing the upper boundary of the unsaturated zone system. Present day net infiltrations into this boundary and estimates of the bounds on the future net infiltration rates are needed as an input for the system flow model. The goal of the percolation study is to provide an understanding of the spatial distribution of the present day fluxes within the unsaturated zone system. These values are not only input for the site system model but also are essential for the performance assessment modeling. The percolation study also will provide the material property and potential distribution values that will be needed for the system modeling. All four data collection studies are designed to reduce the uncertainties in the characteristics of site properties in the two-phase flow model developed for the unsaturated zone and in the information required to identify disruptive scenarios and to quantify their likelihood.

One of the features of Yucca Mountain that permits consideration of a repository in the unsaturated zone is the very deep water table, generally about 500 to 750 m below land surface (Robison, 1984). As proposed, the repository would be constructed in the lower part of a densely welded fractured tuff, the Topopah Spring Member of the Paintbrush Tuff. These rocks appear to have geomechanical properties that permit the construction of stable openings and geochemical and thermal properties that are suitable for storage of waste (Johnstone et al., 1984). In addition, these rocks have fracture densities and apertures (Scott et al., 1983) that probably facilitate large, episodic increases of flux while maintaining unsaturated conditions. Accordingly, a waste container and underground facility probably can be designed to enhance water drainage through the surrounding rocks. Capillarity is expected to cause percolating water to bypass openings such as drifts and canister holes, so that only minimal water contact is made with the waste containers (Roseboom, 1983).

At the Yucca Mountain site, the unsaturated zone could be a natural barrier to radionuclide migration that would add to the barriers that exist in the saturated zone system. The first component of the unsaturated zone barrier is the very slow ambient flux of water that occurs at Yucca Mountain. Next, a sequence of nonwelded porous tuffs that overlies the Topopah Spring Member probably form a natural capillary barrier to retard the entrance of water into the fractured tuffs. A similar sequence of nonwelded tuffs underlies the Topopah Spring Member. These underlying nonwelded tuffs locally contain sorptive zeolites and clays that could be an additional barrier to the downward transport of radionuclides from a repository to the water table.

Although the general conditions just described probably exist, details of the hydrologic processes, conditions, and properties in the unsaturated zone are unknown. These details need to be known to characterize the site properly. The current lack of knowledge is the result of (1) lack of data,

because of the newness of the focus on the unsaturated zone, (2) inadequacy of the general state of understanding of the physics of flow in thick, fractured-rock unsaturated zones in arid environments, and (3) lack of well-established techniques for testing and evaluating the hydrology of such unsaturated zones. To develop the information and understanding needed to assess the suitability of the unsaturated zone at Yucca Mountain within the time frame imposed by the national site-selection effort, an efficient and focused investigative program needs to be conducted, and preliminary results need to be obtained early in the program.

The phenomena of unsaturated flow have been studied extensively for application to agricultural soil conditions (e.g., Schilfgaard, 1974; Hagan et al., 1967; Childs, 1957; and Hillel, 1982); however, this is not true for the lithified fractured porous media of Yucca Mountain. In all hard rock settings, predictions of fluid-flow behavior depends on the correct applications of fracture hydrology, a topic no more than 25 yr in development. The state of the knowledge of unsaturated flow in fractured media is even less advanced. Confidence in isolation of waste at Yucca Mountain depends upon the verity of present concepts of flow through such media, and, therefore, the unsaturated-zone activities of the site characterization plan are necessarily directed at solving the problems associated with the fundamentals of liquid and gas flow.

For this purpose, the unsaturated zone system at Yucca Mountain was divided into the infiltration boundary and the percolation region. Each component of the system will be studied by multidisciplinary approaches (i.e., hydraulic, pneumatic, and gaseous and aqueous-phase hydrochemical studies) to describe the spatial and temporal distributions of the flux and travel times within this system. On this basis, four major studies have been developed: (1) characterization of infiltration, (2) percolation, (3) gaseous phase movement, and (4) hydrochemistry. A fifth study, the flow and transport modeling, is designed to simulate the natural system so that data needs for the final simulations could be identified early in the site characterization phase, and also enable evaluation of the sensitivity of the flux and travel time calculations to certain site characteristics that may not readily be determined. Finally, the sixth study is designed to develop a conceptual model for the unsaturated zone on the basis of which the testing programs can be designed and modified. This conceptual model will be modified and eventually will lead into the integration of the information acquired in the first five studies to provide a sufficient understanding of the unsaturated zone at Yucca Mountain.

The infiltration boundary, or the surficial units, at Yucca Mountain is one of the most important boundaries that need to be characterized. Through this boundary water and air can enter and gases and water vapor can escape the unsaturated zone where the repository is prepared to be located.

The net infiltration at Yucca Mountain is now imprecisely estimated from regional water balance studies and other sources (Sections 3.9.3.3 and 3.9.3.4); improved estimates will be obtained by monitoring the natural infiltration process and simulating a variety of infiltration conditions in a controlled manner. Physical properties and distribution of surficial soils, rocks and vegetation influencing infiltration will be determined by field sampling studies and mapping techniques. Drill core and cuttings, plus

neutron probe use, will provide lithologic and structural data, and especially the distribution of moisture and effective permeability. Geophysical tools will enhance the coverage of inaccessible units and their properties. About 100 neutron access holes will be drilled and monitored to permit the calculation of flux and to characterize natural infiltration events from the propagation of moisture fronts under a variety of conditions. Analysis of stable isotopes, tritium, chlorine-36, fluorocarbons, and carbon dioxide content from waters extracted from cores will provide independent estimates of infiltration rates. To understand the effects of rainfall intensity and duration outside the present natural range, artificial tests on several soil plots will be run using simulated rainfall and ponding, while monitoring transient and steady water movements in the underlying units. Dye and chemical tracers will be used. Numerical modeling will be intrinsic to these tests, facilitating not only the design and operation but also the interpretation of results and the extrapolation to hypothetical future conditions, which will serve as the boundary flux conditions for models of the entire unsaturated zone.

The unsaturated zone at Yucca Mountain consists of a gently dipping sequence of fine-grained ash-flow tuffs, mostly welded and fractured, with some ash-flow and air-fall, nonwelded, sparsely fractured tuffs that are vitric in some parts and zeolitized in others. The definition of the physical properties and spatial distribution of the different media within the unsaturated zone is the subject of much of the testing (Studies 8.3.1.2.2.3 through 8.3.1.2.2.6) because all modeling and synthesis work require these data. The thickness, lateral extent, inhomogeneities, and geophysical properties of all hydrostratigraphic units, as well as the distribution of fractures and faults and their effective apertures, orientations, and interconnectedness, are being studied as part of the surface-based and exploratory shaft drilling and testing programs.

Salient conditions to be characterized in any thick unsaturated zone are the hydraulic and pneumatic potential gradient that extend from the land surface to the water table (500 to 750 m at Yucca Mountain). Saturation and matric potential may vary discontinuously from stratum to stratum. The characterization of flow in Yucca Mountain must include, for all hydrostratigraphic units, the determination of flux distribution under a variety of present and future conditions. Since flux is difficult to measure adequately at either the infiltration boundary or the water table, it must be deduced from the potential distribution and the conductive properties of the system, or by other indirect means. From the viewpoint of isolation, the most significant findings will be to predict the transport of radionuclides from the repository, 335 to 585 m beneath the surface of Yucca Mountain, to the water table about 165 m below the repository. The hydraulic properties data that will be used for flux calculation will be collected in the surface-based and exploratory shaft drilling and testing program (Studies 8.3.1.2.2.3 through 8.3.1.2.2.6).

Gas flow in the unsaturated zone has an important hydrologic role, as well as providing a potential mechanism for transport of radionuclides to the accessible environment. Whereas the coexisting matrix and fracture pore systems greatly complicate computations of total-system behavior under present or future fluxes, the existence of the large-aperture fractures not only provides drainability in the unsaturated zone but also provides large

relative gas permeability. Consequently, there are natural gas-phase fluxes through Yucca Mountain driven by seasonal atmospheric density differences between the slopes and the summit and by geothermal heat within. Vapor discharges from the air-filled fracture system may offset the infiltration of rain and snowmelt because of convective and diffusive vapor transport out of the mountain. By desaturating the matrix, perhaps below free-drained residual saturation, increased moisture tension aids in damping infiltration pulses that may be channeled in the fractures or faults. It is important to be able to quantify the vapor flux because it may be in a direction opposite to the liquid flux. Activities addressing this phenomenon include all those yielding air conductivities from packer tests with gas injection in boreholes, cross-hole air flow and gas tracer tests. Activities specifically designed to define the gaseous flux distribution include the gas-phase circulation study (Activity 8.3.1.2.2.7.1), the Solitario Canyon horizontal borehole study (Activity 8.3.1.2.2.3.3), and the simulation of the natural hydrologic system (Activity 8.3.1.2.2.9.2).

The hydraulic and pneumatic testing described under this investigation will provide a basis for estimating the distribution of flux through the unsaturated zone. To compute travel times from the flux estimates, a good understanding of the effective porosity is required. Presently, there are very few methods that can provide the effective porosity, and these are discussed under appropriate activities; however, the effective porosity measurements are for small volumes of rock. The environmental tracers method is one of the techniques available for large-scale effective porosity measurements. The stable and radioactive environmental isotopes such as carbon-14, chlorine-36, and tritium will be used in this technique. Integration of the percolation information with that of the hydrochemical data will provide a basis for travel time calculations and future hydrologic condition predictions. The process for providing parameters required by ground-water travel time (Issue 1.6) is depicted in Figure 8.3.1.2-12.

Essential corroboration of ground-water velocities and the transport of dissolved chemicals and gases will be sought through age dating of the fluids and gases found in the pores at various depths. A thorough understanding and evaluation of all factors influencing the hydrochemistry of the natural flow system will be needed, because the knowledge provides the only potential means for assessing rates of water movement independent of the hydrologic deduction process, as well as a means of discriminating between hydrologic processes that would otherwise remain hypothetical. In addition to its contributions to ground-water travel time, hydrochemistry provides information relevant to the characterization of gas transport, to the assessment of paleohydrologic conditions, to geochemical relationships, and to contamination by exploration activities. In the gaseous-phase and aqueous-phase investigations (Activities 8.3.1.2.2.8.1 and 8.3.1.2.2.8.2), analyses to support the various test programs include not only a suite of inorganic components but also certain organics, including freon-11 and -12 which serve as tracers; lithium and bromine used to tag drillwater; SF₆ used to tag drilling-air; and carbon-14 dioxide, chlorine-36, methane, ³H₂O, HDO and the oxygen-18 to oxygen-16 ratio, all natural or man-made tracers. Large numbers of gas and water samples will be analyzed. These data will be used to characterize (1) waste container environment at the repository and (2) the environment under which sorption and solubility of waste elements will occur along flow paths in the unsaturated zone.

Figure 8.3.1.2-12. Process for providing parameters required by Issue 1.6 (pre-waste-emplacement travel-time).

Flow behavior in the unsaturated zone of Yucca Mountain involves complex interactions that are amenable to solution only with the aid of numerical modeling. A great depth of understanding is required to predict the transport of solutes and gases in a sequence of dipping pyroclastic units that have variable granularity, degree of welding and alteration, porosity, and fracturing. How these variables interact is essential knowledge for attaining a correct solution; however, the interactions are very complex. For example, variable saturation relates to variable relative conductivity and anisotropy in hydrostratigraphic units whose fluxes relate to complex distributions of hydraulic and pneumatic potential between ill-defined boundaries with internal discontinuities. The general approach that is being used to solve this problem is to (1) refine the existing concepts of the phenomena of unsaturated, sometimes transient, flow of fluids and constituents in double-porosity layered media; (2) construct detailed digital models that spatially and temporally integrate the processes, incorporating boundary conditions, physical properties, and parameters; (3) compute fluxes, potentials, concentrations, and missing data that can be verified by field tests and observations; and (4) establish consistency with all verifiable knowledge. Since the environment of field tests seldom isolates one phenomenon from all others, models are working tools on many levels. Ultimately, two- and three-dimensional models of Yucca Mountain will be constructed that integrate the whole system as a means of assessing coupled effects of heat, water, and gas flow for modern, ancient, and future conditions. The conceptual model and verification steps must be cycled until the whole reaches a scientifically defensible result, answering the information needs of the NNWSI Project. The flow and transport modeling described in this issue, for both the saturated and unsaturated zones, will be coordinated with modeling efforts in Performance Issues 1.1 through 1.6 (Section 8.3.5).

Certain interrelationships between fluxes, gradients, and properties can only be elucidated by modeling. A unique attribute of the welded tuffs is that they are traversed by a system of fractures with apertures at least one order of magnitude greater than the matrix pore diameters (Klavetter and Peters, 1986). In these rocks, effective bulk hydraulic conductivity (matrix plus fracture hydraulic conductivity at a given matric potential) increases rapidly through several orders of magnitude as saturation increases and potential increases. It will be attempted to demonstrate, with data from piezometers below the water table and from thermocouple psychrometers above the water table, that an abrupt change of vertical hydraulic gradient (near-unity to near-zero) occurs when saturation and conductivity abruptly change. A highly transmissive saturated zone may prove insensitive to changes of recharge, minimizing predicted changes of the water-table level.

Flow model calibration and validation will require redundant data, such as hydrochemistry is expected to provide; otherwise, imprecise measurements of matric potential may produce distributions of hydraulic properties and boundary conditions that are not internally consistent. The reason is that relative bulk conductivity is very sensitive to matric potential. In general, fracture and fault systems have very low porosity but very high conductivity relative to the matrix (up to 4 orders of magnitude difference) (Davis and DeWiest, 1966; Snow, 1969); thus, flux can be greatly enhanced by small increases of saturation. Fluxes characteristic of different climates may be modeled, perhaps within the range of present observational precision. It will be necessary to refine measurement methods to give meaning to such

behavior as the penetration of episodic, secular, or pluvial infiltrations in a double-porosity model. Young fracture water may bypass older matrix water, depending on fracture coatings present.

Hydrochemical data will be vital to the verification of the concepts of flow in this unsaturated medium. The mechanisms will be examined and modeled in connection with underground tests in which infiltration will be induced artificially at various rates. Whereas fracture system flow channeling may occur readily in the uppermost unit, the Tiva Canyon welded tuff, models and in situ tests may suggest that fractures are less significant in the Paintbrush and Calico Hills nonwelded tuffs, so that matrix imbibition damps out infiltration pulses.

The Ghost Dance fault also requires conceptual modeling and field verification, especially in connection with any horizons that could divert infiltration to such a feature. Because phenomena of unsaturated, double-porosity, two-phase flow have not been studied previously in the detail needed by the NNWSI Project, much research, testing, and fracture-model simulation are planned. These plans include fracture-matrix interactions such as matrix diffusion, matrix flow controlled by fractures as capillary barriers or conduits according to their saturation and geometry, hydrodynamic dispersion during fracture system flow, fault zone conduction and interaction with perched water zones, and the bulk relative conductivities of the several hydrostratigraphic units, with hysteresis and perhaps effects of air entrapment. Other subjects of model investigations include transport properties of sorbed and nonsorbed species, for liquid and gas flow, soil-rock interactions during shallow infiltration; conditions for development of lateral flow and perched water zones; and capillary barrier effects caused by lithologic boundaries.

Gas-phase flux and potential distributions will be calculated from two-dimensional and three-dimensional modeling that incorporates fracture system anisotropic conductivity and saturation relationships, plus gas storativity of fracture and matrix pore systems, for all units above the water table. Flow will be driven by atmospheric pressures and temperatures, varying daily and seasonally, and also by the ambient geothermal gradient. A data-gathering program is designed to provide input to such models as well as to verify derived quantities.

When the phenomenologic components of the system have matured sufficiently to permit reasonable synthesis, a three-dimensional coupled heat and two-phase moisture flow model will be constructed for the existing natural, pre-waste-emplacement system. The model must incorporate appropriate external and internal boundary conditions and material properties. This model will serve as a baseline description of the natural hydrologic and transport processes, and, additionally, will be used to model past and future natural conditions. Such a model requires interactive complexity to accomplish such objectives as (1) assess the importance and effects of topographic and structural boundaries; (2) assess the relative roles of vapor and liquid transport; (3) describe the gas-phase and liquid-phase transport of such tracers as tritium, deuterium, carbon-14 and others introduced by man; (4) establish limiting conditions for lateral flow, perched water and structural drainage; and (5) establish consistency of fluxes with temporal and spatial variations of boundary conditions.

The heat released by the waste is recognized to have a significant effect on repository behavior and will have to be evaluated. The thrust of the work described here is to understand hydraulic and transport behavior of the natural system, unaffected by the repository or the emplaced waste; analysis of thermal effects is discussed in Sections 8.3.5.12.4.1 and 8.3.5.13.3.1.

8.3.1.2.2.1 Study: Characterization of unsaturated-zone infiltration

The objectives of the unsaturated-zone infiltration study are (1) to determine the effective hydraulic conductivity, storage properties, and transport properties as functions of moisture content or potential, and (2) to determine the present and estimate the future spatial distribution of infiltration rate over the repository block. Four activities are planned to collect the data that are required to satisfy these objectives: analysis of matrix hydrologic properties in the laboratory, evaluation of natural infiltration, characterization of hydrologic properties of surficial materials, and studies of artificial infiltration.

8.3.1.2.2.1.1 Activity: Characterization of hydrologic properties of surficial materials

Objectives

The objective of this activity is to characterize the infiltration-related hydrologic properties and conditions of the surficial soils and rocks covering Yucca Mountain.

Parameters

The parameters of this activity are

1. Infiltration rates.
2. Runoff rates.
3. Porosity.
4. Density.
5. Water content.
6. Water potential.
7. Clay mineralogy.
8. Soil texture.
9. Soil and alluvium thickness.
10. Fracture density and fracture orientation.

Description

Methods designed to characterize the hydrologic properties of surficial materials include sampling, testing, and mapping; remote sensing; nuclear borehole geophysical logging; shallow surface seismic exploration; and geotomography studies. The main purpose of these tests is to help characterize the infiltration-related hydrologic properties of the surficial

materials of Yucca Mountain. Hydrologic property data from these and other tests described in this report will be analyzed using statistical and geostatistical methods to help delineate surficial hydrogeologic units. Representative hydrologic-property data from surficial hydrogeologic units will then be used by others to model infiltration processes on Yucca Mountain.

Units that are defined on the basis of shallow infiltration processes in the upper 1 ft of surficial material are called infiltration-runoff units. Units that are defined to characterize net infiltration processes at depths below 1 ft are termed surficial hydrogeologic units. The relationship between surface infiltration and net infiltration is described in artificial infiltration studies (Activity 8.3.1.2.2.1.3).

Some of the methods described in this section are divided into a prototype component and a site characterization component. The prototype component is designed to determine how equipment and methods must be adapted to be used successfully on Yucca Mountain during site characterization.

Sampling, testing, and mapping methods will be used to help develop an unconsolidated surficial-materials map of Yucca Mountain delineating units with common shallow infiltration and runoff properties. These units will aid in modeling runoff and shallow infiltration as a function of precipitation. A 1:12,000-scale geologic map of the surficial materials covering Yucca Mountain will be produced (Activity 8.3.1.5.1.4.3). These surficial geologic units are expected to be a satisfactory base and starting point for developing units with common infiltration and runoff properties. The new units will be called infiltration-runoff surficial units.

Preliminary studies will be conducted on an adjoining canyon and ridge test area on Yucca Mountain to select the most appropriate infiltration-related hydrologic property measurements to make on desert-mountain surficial materials, to test state-of-the-art measurement techniques on these materials, and to determine a sampling program necessary to characterize infiltration-runoff units. These studies also will determine if surficial geologic units can serve as a basis, or starting point, for defining infiltration-runoff units.

A preliminary surficial geologic unit map will be developed for the surficial materials covering the canyon-ridge test area. Surficial materials will be classified mainly on the basis of geomorphic processes and characteristics. Geomorphic processes and characteristics include both pedologic and hydrologic factors. Samples of surficial materials will be collected from each map unit; and hydrologic properties, conditions, and related characteristics will be measured. Hydrologic properties measured in the laboratory will include texture, density, water content, and water potential. Clay mineralogy will be determined on selected samples. Density and water-content measurements will also be made in the field. Related characteristics include soil thickness, slope, and aspect.

Geostatistics will be used to determine the spatial relationship between measurements and to determine if additional measurements are required beyond the boundaries of surficial geologic units. Areas with similar hydrologic properties will be defined, and the boundaries of these areas will be compared with the boundaries of surficial geologic map units. This analysis

will permit the determination of the geologic map units, or portions thereof, that will be useful in defining infiltration-runoff units.

The preliminary definitions of infiltration-runoff units developed in these preliminary studies will be evaluated and refined by conducting double-ring infiltrometer tests in this same canyon-ridge test area (artificial infiltration Activity 8.3.1.2.2.1.3). Furthermore, the feasibility of using remote sensing techniques to aid in the mapping of infiltration-runoff units will be evaluated, as described below. When optimum methods are identified for mapping infiltration-runoff units, these methods will be used to produce a map of infiltration-runoff units for the surface of Yucca Mountain.

Remote sensing methods will be used to help define infiltration-runoff units and the changes in water content that may occur within these units as a result of variations in precipitation and other meteorological parameters. Preliminary tests will be conducted on the canyon-ridge test area of Yucca Mountain to determine the feasibility of correlating remote sensing imagery data with hydrologic properties (infiltration-runoff units) and conditions of surficial soils and rocks. Potentially useful infrared, visible, thermal, and radar remote sensing data from this ridge system will be analyzed and map units with statistically different spectral characteristics will be identified. Infiltration-runoff units in the canyon ridge system defined by the sampling, testing, and mapping methods will be compared with map units defined by common spectral characteristics. Spectral characteristics that correlate well with infiltration-runoff units in this canyon-ridge system will be identified for possible use in the site characterization mapping of rainfall runoff units. The determination of acceptable levels of correlation will be determined. In addition, thermal and radar remote sensing data will be collected before and after precipitation events over a 1-yr period in this canyon ridge system. These data will be analyzed to determine if they can be used to describe changes that occur in the water contents of the surficial materials as a function of precipitation, and other meteorological parameters that may affect these water contents.

If the spectral characteristics of any of the various remote sensing imagery correlate well with previously mapped infiltration-runoff units and/or hydrologic conditions in the canyon-ridge test area, these remote sensing imagery and associated spectral characteristics will be used throughout the site. Remote sensing methods will be incorporated with the sampling, testing, and mapping methods and the double-ring infiltrometry methods described under the artificial infiltration studies (Activity 8.3.1.2.2.1.3). Finally, if thermal or radar remote sensing methods prove successful in monitoring moisture changes in the surficial materials covering the canyon-ridge test area, the methods will also be used to monitor moisture changes on the entire surface of Yucca Mountain.

Borehole nuclear geophysical logging methods will be used (1) to develop reliable laboratory field and calibration procedures that can be used for selected borehole geophysical logging tools (including hand-held neutron moisture meters used in neutron access hole logging); (2) to determine density and porosity profiles in near-surface boreholes using gamma-gamma density, neutron moisture and neutron porosity logging methods; and (3) to complement the neutron moisture logging program by independently obtaining

water-content profiles in neutron access holes and other near surface boreholes using neutron porosity methods. The scope of this logging program is limited to measuring the hydrologic or hydrologically related parameters of moisture content, porosity, and density. This logging program complements density and porosity data obtained from core samples and will provide the only source of these data in regions of boreholes where cores are not collected. The program is not intended to generate a complete suite of borehole geophysical logs that would yield electrical, magnetic, or spectroscopic data.

Prototype borehole nuclear logging has been conducted to develop optimum methods for calibrating the logging tools in the laboratory, and preliminary tests have been conducted in the field. Neither standard field calibration pits nor laboratory calibration facilities of any type for tuffaceous rock existed before the beginning of these tests.

Three permanent laboratory calibration simulation tanks that simulate borehole conditions around 5-in. inner diameter casing have been successfully constructed during prototype tests. Each tank has a significantly different water content, a slightly different dry bulk density, and a similar chemical composition. All geophysical logging tools have been successfully calibrated in these tanks. Based on these prototype tests, quality assurance Level I procedures have been written for the construction of additional simulators. These additional simulators will permit a more complete calibration of nuclear logging tools over a wider range of densities and water contents. Furthermore, these tanks will help resolve the effects of large differences in dry bulk density on neutron moisture tool response.

Preliminary field calibration tests have been successfully conducted in cased and uncased sections of alluvium and nonwelded tuffs. However, testing is required in cased and uncased sections of welded tuff to determine under what conditions (if any) field calibrations can be successfully conducted. Tests are also planned to determine if multidetector compensated neutron porosity and gamma-gamma tools improve calibration curves, especially in welded sections of tuff penetrated by the hole. Field calibrations in cased nonwelded sections of boreholes compare favorably with laboratory calibrations previously described. These field calibrations have also resulted in progress in determining optimum tool and decentralizer design, logging rates, and time constants for various rock types.

When these laboratory prototype tests and preliminary field tests are successfully completed, all near-surface boreholes including neutron access holes, shallow core instrument holes, and artificial infiltration monitoring holes will be logged at least once with the gamma-gamma density, neutron porosity, and neutron moisture analog recording borehole logging tools. These logs will be in addition to neutron moisture meter logging described under natural infiltration studies (Activity 8.3.1.2.2.1.2). Volumetric water content and wet bulk density profiles will be generated directly from calibration curves. Dry bulk density and porosity profiles will be calculated from these measured profiles. These continuous profile data will be used together with core data to determine the vertical spatial variation of the physical and hydrologic properties measured. These vertical profile data measured in a number of boreholes will also be useful in determining the

horizontal spatial variability between boreholes using geostatistical techniques. The spatial variability data will be used to help define surficial hydrogeologic units.

Shallow surface seismic methods will be used to (1) help define the fracture densities and orientations in surficial bedrock units covering Yucca Mountain and (2) determine depth to bedrock beneath alluvium-filled canyons dissecting Yucca Mountain.

Shallow seismic techniques utilizing small energy sources will be used to characterize the seismic velocities of surficial rock units. Information about rock matrix density, fracture density, and fracture orientation in some instances can be inferred from seismic velocities (e.g., Crampin et al., 1980). These properties, together with the thickness of various surficial layers, are important factors that affect the flow of water in these surficial materials. In this study, they will be treated as hydrologic properties.

Prototype shallow surface seismic studies will be conducted off Yucca Mountain to determine optimum methods that apply to determining the thickness of alluvium in canyons on Yucca Mountain during site characterization. All prototype work concerned with determining the alluvium-bedrock contact will be carried out in areas where depth-to-bedrock is clearly defined by boreholes. Seismic lines will be run parallel, perpendicular, and at an approximate 45-degree angle to the major axis of shallow canyons where bedrock depths are accurately known from borehole data. Interpretative as well as field methods will be developed in this study.

Seismic fracture studies will be conducted on surficial bedrock units covering Yucca Mountain to determine the fracture properties of these units. Fracture data from the bedrock units will be analyzed together with the hydrologic characteristics of the overlying soils to help define surficial hydrogeologic units. Seismic studies will also be conducted to determine the thickness of alluvium in canyons and/or portions of canyons not containing boreholes. Maps of bedrock depth in canyons will be generated.

Surface seismic methods previously described are relatively inexpensive and easy to conduct but are inherently low-resolution techniques and are not expected to yield detailed fracture geometry data. Recent advances in high-resolution geophysics (Ramirez and Daily, 1985), however, suggest that the geotomography method, when coupled with infiltration experiments, has the potential to characterize both detailed fracture geometry and possibly the hydraulic properties of fracture systems.

In theory, geotomography has the potential to produce an image or a cross-sectional picture of the subsurface distribution of the electrical conductivity and the dielectric constant between boreholes. Electrical conductivity is related to fluid salinity and mineralogy, and the dielectric constant is proportional to water content. Therefore, if a saline tracer is added to water infiltrating into rock, it may be possible to monitor both the changes in water content and the movement of the saline tracer.

Prototype geotomography studies will be conducted off Yucca Mountain in conjunction with several prototype artificial infiltration studies (Activity

8.3.1.2.2.1.3) to evaluate the potential of using geotomography during site characterization to evaluate the properties of the near-surface fracture regime and to monitor infiltrating waters in the surficial rocks covering Yucca Mountain. Artificial infiltration tests will include as many as three ponding prototype tests and two large-plot rainfall simulation (LPRS) prototype tests. Ponding tests will involve ponding water at the ground surface and monitoring the saturated (or near-saturated) wetting front that advances downward and the drainage that occurs after ponding is stopped. LPRS tests will mainly involve monitoring unsaturated wetting front advancement resulting from the application of artificial rainfall. Both ponding and LPRS prototype test plots will be located in areas that contain the range of fracture properties expected at Yucca Mountain.

Prototype tests will be conducted first in relatively homogeneous alluvium containing no fractures to test equipment and to produce baseline images of wetting and drying of the profile during infiltration experiments. Similar tests will then be conducted on fractured rock with simple fracture patterns at the ground surface. Finally, tests will be conducted on fractured rock with a high degree of heterogeneity. Dye tracers will be used during the last infiltration test at each site to stain the mineral surfaces of flow pathways. All sites will be excavated and flow pathways mapped to verify the geotomography images.

If prototype test results indicate that geotomography methods can be successfully used to characterize the fracture geometry and hydrologic properties of fracture systems beneath artificial infiltration plots, these methods will be used in site characterization studies. It is planned to use geotomography methods on the majority of ponding and LPRS plots proposed for artificial infiltration studies (Activity 8.3.1.2.2.1.3).

Methods and technical procedures

The methods and procedures for Activity 8.3.1.2.2.1.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS)			
Sampling, testing, and mapping studies	TBD ^a	Site characterization sampling, testing and mapping studies	TBD
Remote sensing studies	TBD	Site characterization remote sensing studies	TBD
Borehole nuclear-geophysical logging studies	TBD	Site characterization borehole nuclear geophysical logging studies and calibration procedures	TBD

Method	Technical procedure		
	Number	Title	Date
Shallow surface-seismic survey studies	TBD	Shallow surface-seismic site characterization studies	TBD
Geotomography studies	TBD	Site characterization geotomography studies	TBD

^aTBD = to be determined.

8.3.1.2.2.1.2 Activity: Evaluation of natural infiltration

Objectives

The objective of this activity is to characterize present-day infiltration processes and net-infiltration rates in the surficial soils and rocks covering Yucca Mountain.

Parameters

The parameters of this activity are

1. Infiltration rates.
2. Net infiltration rates.
3. Flow velocities.
4. Precipitation.
5. Runoff.
6. Evapotranspiration.

Description

The main purpose of the natural infiltration studies is to characterize the upper flux boundary condition for Yucca Mountain under present-day climatic conditions. This upper boundary condition is required to model flow through the thick unsaturated zone beneath Yucca Mountain. The determination of this boundary condition will be accomplished by four major studies. Neutron access hole studies will monitor natural infiltration in approximately 100 neutron access holes located with the intent of sampling the range in expected surficial hydrologic properties and conditions on Yucca Mountain. Artificial infiltration control plot studies will be monitoring natural infiltration beneath as many as 25 small and 12 large rainfall-simulation control plots located in major hydrogeologic-surficial units. Tritium profiling studies will determine flow velocities averaged over approximately the last 30 yr by analyzing bomb-produced tritium concentrations in core obtained from representative neutron access holes. Consideration will be given to profiling of gaseous as well as liquid tritium, because movement of tritium

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in the vapor phase could affect infiltration analyses. Water budget studies will calculate net infiltration by mass balance methods.

Some of the studies in the following description have been divided into prototype and site-characterization components. The prototype component is designed to determine how methods and equipment must be adapted to be applied successfully at Yucca Mountain during site characterization. These prototype studies will be conducted at locations off Yucca Mountain. All prototype work has been completed for neutron access hole studies. Prototype work has not begun on water budget or artificial infiltration control plot studies.

Neutron moisture logging techniques are currently being used in 74 neutron access holes to monitor natural infiltration. The locations of these 74 holes and 24 additional proposed holes are shown in Figures 8.3.1.2-13a, 8.3.1.2-13b, and 8.3.1.2-13c. Water-content profiles in these holes can be obtained from neutron moisture logging data and appropriate calibration data. Differences between water-content profiles from consecutive logging dates is an indication that water movement is occurring, at least in the vicinity of the borehole. Changes in water profiles are indicative of nonsteady state flow processes that typically result from high-intensity and short-duration precipitation events (thunderstorms) that yield surface runoff.

Steady state flow processes by definition do not result in water content changes and therefore cannot be monitored by neutron moisture logging methods. Steady state or approximately steady state flow processes may exist during and for a short period after long-duration and low-intensity winter rainfall where constant-head (or -flux) boundary conditions have the potential to develop. These conditions may also be approximated during the slow melting of a winter snowfall. Steady state flow conditions will be purposely generated during some artificial infiltration studies (Activity 8.3.1.2.2.1.3). The potential importance of steady state flow during natural infiltration processes will be further evaluated after the completion of these artificial infiltration tests.

Water flow velocities can be estimated from tritium concentration versus depth profiles obtained by conducting tritium analyses on core samples collected from unsaturated-zone boreholes. The maximum depth reached by elevated bomb-produced tritium concentrations is estimated from the profiles. Tritium concentrations greater than approximately ten tritium units are considered to be elevated above natural background levels. This depth is then divided by the time elapsed from the midpoint in the period of above-ground atmospheric testing (approximately 30 yr). This quotient is an estimate of flow velocity over the last 30 yr. The analyses could be affected by perturbations caused by movement of tritium in the vapor phase, and so profiling of gaseous tritium will be considered as well.

Boreholes selected for initial tritium concentration profiling studies are located in rock units thought to cover the range in surficial hydrologic properties found on Yucca Mountain. When the initial program of tritium analyses is completed, the data will be analyzed to determine additional boreholes that should be tested for tritium content. The flow-velocity data will be subjected to geostatistical analyses where possible. These spatial variability results, when combined with other hydrologic property data, should be useful in determining additional holes that should be tested.

Figure 8.3.1.2-13a. Neutron access hole locations. See Figures 8.3.1.2-13b and -13c for inserts No. 1 and 2, respectively.

Figure 8.3.1.2-13b. Insert 1 to Figure 8.3.1.2-13a, neutron access hole locations.

Figure 8.3.1.2-13c. Insert 2 to Figure 8.3.1.2-13a, neutron access hole locations.

These results should also be helpful in defining surficial hydrogeologic units.

Natural infiltration will also be monitored in the control plots associated with both small- and large-plot rainfall simulation sites. Prototype and site-characterization studies planned for these control plots along with associated test plots are described in more detail under artificial infiltration studies (Activity 8.3.1.2.2.1.3). Natural infiltration will be monitored with several nuclear logging techniques from monitoring holes located on the edges of the control plots (and test plots), and with a variety of water content and water potential probes and sensors installed in different horizontal planes beneath the plots. Control plots will be located at different sites to cover the range in expected infiltration capacities within each surficial hydrogeologic unit. Natural infiltration will then be monitored beneath as many as 25 small- and 12 large-plot rainfall simulator control plots for the duration of site characterization studies on Yucca Mountain.

Water budget studies will be conducted to (1) evaluate the potential of using water budget techniques as a tool to estimate infiltration in different surficial materials covering Yucca Mountain under different climatic conditions and (2) if these methods show potential, to apply these techniques to monitor infiltration from both natural and artificial precipitation events. The water budget studies will be used to supplement direct measurements of infiltration.

The simplest form of the mass-balance water budget equation used to estimate infiltration is

$$\text{Infiltration} = \text{Precipitation} - \text{Runoff} - \text{Evapotranspiration}$$

Unfortunately, the combined error from precipitation, runoff, and evapotranspiration measurements may be equal to or larger than infiltration values in desert climates. Evapotranspiration can be calculated from meteorological and soils data as well as from evapotranspiration simulators to varying degrees of accuracy depending on climatic, soil, and vegetation conditions. However, the error in the calculations and measurements of evapotranspiration alone may be as large or larger than the low natural infiltration rates expected for Yucca Mountain.

A similar problem exists in the evaluation of infiltration rates, which are typically a small component of the overall mass-balance equation. For this reason, infiltration values will be measured directly. Evaluation of infiltration values from the mass-balance equation will be done only for confirmatory purposes.

Because of the problems expected with applying mass-balance methods to infiltration problems on Yucca Mountain, a preliminary prototype study will first be conducted to evaluate the suitability of using this approach for different surficial materials under both natural and artificial rainfall conditions. An analysis of the source and magnitude of errors of measurement will be made in these preliminary studies. Attempts will be made to determine the conditions under which the errors of measurement are significantly less than infiltration values. These conditions may occur only during and

after artificial rainfall simulations of precipitation events having higher intensity, frequency, and duration than is encountered in a typical year under present-day climatic conditions. The problem of defining the relationship between natural and artificial rainfall will also be addressed. This problem is discussed in further detail under the artificial infiltration studies (Activity 8.3.1.2.2.1.3).

Methods and technical procedures

The methods and procedures for Activity 8.3.1.2.2.1.2 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Neutron access holes studies	HP-62, R1	Method for measuring subsurface moisture content using a neutron moisture meter	16 Mar 87
	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, NTS	30 Mar 87
	HP-55, R1	Hydrologic laboratory testing of core and drill cutting samples from unsaturated-zone test holes	9 Sep 85
	HP-133, R0	Handling and storage of core at the unsaturated zone testing laboratory	TBD ^a
Tritium profiling studies	TBD	Tritium profiling methods	TBD
Water budget studies	TBD	Site characterization water budget studies	TBD
Artificial infiltration control-plot studies	TBD	Site characterization artificial infiltration control-plot studies	TBD

^aTBD = to be determined.

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8.3.1.2.2.1.3 Activity: Evaluation of artificial infiltration

Objectives

The objectives of this activity are

1. To characterize the range and spatial variability of infiltration rates in approximately the upper foot of unconsolidated surficial material using double-ring infiltrometer studies.
2. To characterize the range and spatial variability of infiltration rates, flow velocities, and flow pathways in approximately the upper 15 ft of both consolidated and unconsolidated surficial materials using ponding studies.
3. To characterize the complex relationship between rainfall, thickness of soil, and development of perched water tables in approximately the upper 3 ft of unconsolidated surficial material using small-plot rainfall simulation tests.
4. To characterize the relationship between precipitation, runoff, infiltration, and evaporation, in approximately the upper 15 ft, on at least one site, in each hydrogeologic surficial unit using large-plot rainfall simulation tests.

Parameters

The parameters of this activity are

1. Rainfall.
2. Evapotranspiration.
3. Runoff.
4. Saturated and unsaturated infiltration rates.
5. Water fluxes.
6. Flow velocities.
7. Flow pathways.

Description

Artificial infiltration tests will be conducted on the surficial materials covering Yucca Mountain to characterize near-surface water movement. Water fluxes, flow velocities, and flow pathways will be characterized in the major hydrogeologic surficial units under present-day and simulated wetter climatic conditions. The main purpose of these tests is to determine the upper flux boundary conditions for Yucca Mountain under simulated wetter climatic conditions. A series of four different types of artificial infiltration studies is proposed in this plan: double-ring infiltrometer studies, ponding studies, small-plot rainfall simulation studies (SPRS), and large plot rainfall simulation studies (LPRS). Beginning with the double-ring infiltrometer studies, each type of study increases in complexity and builds on the results of previous studies.

Some of these studies will consist of prototype and site characterization components. Prototype studies, to be conducted off Yucca Mountain,

will be limited in scale and will be designed to determine how methods and equipment must be adapted to be applied to the surficial materials on Yucca Mountain during site characterization.

Double-ring infiltrometry measurements will be used in this study to characterize infiltration rates in approximately the upper foot of unconsolidated surficial materials covering Yucca Mountain. The characterization of surficial infiltration rates over Yucca Mountain is important for several reasons. The infiltration rate, relative to the rate of rainfall or snowmelt, determines how much water will enter surficial materials and how much will run off. The relationship between snowmelt or precipitation rate and surface runoff is of critical importance in modeling the effect of wetter climatic conditions on the unsaturated-zone hydrology of Yucca Mountain. In addition, surficial infiltration rates may, in some instances, be low enough to be the limiting factor that controls infiltration to deeper zones. In these instances, measurements of surficial infiltration rates can be used to estimate net infiltration rates. The term infiltration rate is defined here as the infiltration flux resulting when water, at atmospheric pressure, is made freely available to the unconsolidated material surface.

If infiltration-runoff units defined from double-ring infiltrometry measurements correlate well with units previously determined from (1) mapping activities involving field and laboratory hydrologic property measurements (Activity 8.3.1.2.2.1.2, characterization of hydrologic properties of surficial materials), and (2) remote-sensing data-collection activities, then site-characterization mapping procedures will rely mainly on these previously used methods and only a limited number of double-ring infiltrometry measurements will be used. If the correlation is poor, double-ring infiltrometer measurements will be used extensively to define infiltration-runoff units over Yucca Mountain. The infiltration-runoff units will be used to help model shallow infiltration and runoff from possible future precipitation events.

Ponding tests will use existing neutron access holes; however, additional boreholes will be drilled at ponding sites if prototype geotomography tests (Activity 8.3.1.2.2.1.1) are successful. Impoundments will be built around selected neutron access holes to permit the ponding or flooding of surficial units. Monitoring the water-level changes in the impoundment gives an estimate of the maximum intake or infiltration rate into the surficial unit. Tracking the wetting-front advancement via neutron moisture logging, geotomography, or other geophysical logging methods will give an estimate of flow velocities and an indication of the relative importance of fracture and matrix flow. Following changes in the water content profile during drainage can provide an estimate of hydraulic conductivity as a function of formation water content (Libardi et al., 1980).

An organic dye tracer that will adsorb on mineral surfaces to a limited extent will also be added to the ponded water to define pathways. After ponding experiments are completed, several sites covering the range of infiltration rates for each hydrogeologic unit will be excavated and flow pathways mapped by following the colored dye tracer. The tracer dye will be selected to be as conservative as possible, and yet to absorb enough on mineral surfaces to be readily visible or detectable. The area beneath some highly fractured ponding sites may be excavated to depths as great as 25 ft. This will require a mining operation to reach these depths. After mapping of the

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flow pathways is completed, the large holes will be backfilled with mixtures of muck and bentonite. No more than six 25-ft deep excavations are estimated to be required. All other excavations will be shallow enough so that they can be completed with surface excavation equipment.

In this study, ponding tests that measure infiltration rates over approximately the upper 15 ft of unconsolidated surficial materials will be conducted at the same location as double-ring infiltrometry measurements. If shallow infiltration rates measured by double-ring infiltrometry methods correlate well with net infiltration rates determined by ponding methods in a particular area; double-ring infiltrometry data will be used to describe the spatial variation of net infiltration over that particular area.

Over 80 percent of the bedrock above the valley floor on Yucca Mountain is estimated to be covered by a layer of unconsolidated rock or soil ranging in thickness from less than 1 in. to 5 ft or more. Depending on the thickness of this layer, its porosity, and the size of a precipitation event, the unconsolidated material can theoretically act as a storage zone and prevent infiltration into the underlying fractured bedrock. In this situation, unconsolidated layers act as capillary barriers. However, if rainfall occurs for a long (as yet undetermined) period of time, perched water conditions are likely to develop at the bedrock-unconsolidated material contact. The positive pressure heads in this perched water zone can cause flow into any large open fractures in the bedrock. Field data are required from each hydrogeologic unit to determine the complex relations between rainfall, thickness and properties of unconsolidated rock or soil, and the development of perched water tables. Small-plot rainfall simulation (SPRS) studies will be conducted to collect this needed data. The main purpose of SPRS tests is to determine these relationships in the upper 3 ft of surficial material covering Yucca Mountain. The SPRS studies are ideally suited for studying infiltration through shallow, layered systems. In the relatively unlayered alluvium deposits found in valleys, SPRS tests will be used to define unsaturated hydraulic conductivity functions and flow parameters in the upper 3 ft.

A control plot will also be located adjacent to each SPRS test plot in an equivalent hydrogeologic setting. Note that it may be very difficult to find an equivalent setting in fractured rock, even in adjacent areas. SPRS control plots will be instrumented similarly to SPRS test plots, but they will not receive artificial rainfall. The control plot will be used to monitor infiltration and runoff from natural rainfall. These control plots are described more fully under natural infiltration activities (Activity 8.3.1.2.2.1.2).

The instruments to be used in the program include various moisture and water potential sensors, vacuum samplers for unsaturated-zone water, and surface runoff flumes. Control plots will be instrumented identically to test plots, except that vacuum ground-water samplers will be omitted. Artificial rainfall of different intensities and durations will be applied to the SPRS test plots. This artificial rainfall will contain conservative ground-water dye tracers to help monitor the movement of infiltrating waters. Wetting-front advancement will be monitored by moisture and water-potential sensors, by ground-water tracers, and by geophysical logging techniques. These monitoring techniques will also yield data on fluxes and flow velocities.

Results from double-ring infiltrometry, ponding, and other data collection programs should facilitate the combination of similar hydrogeologic surficial map units and help locate the SPRS plots. Ponding tests are expected to show that the thickness, texture, and porosity of unconsolidated soil are important factors in governing net-infiltration rates. In some instances, soil hydrologic properties may be more important than the properties of the underlying bedrock. SPRS plots will be located adjacent to ponding sites in order to characterize in more detail the infiltration process occurring in the upper 3 ft of unconsolidated surficial material and bedrock in the vicinity of the ponding site. Care will be taken to locate all SPRS plots in positions that are equivalent in every way to the nearby ponding plots. In addition, SPRS plots will be located in such a way as to ensure that the water content of the rock beneath the SPRS plots has not been disturbed by the ponding tests.

After completion of SPRS tests, more complex large-plot rainfall simulations (LPRS) will be carried out on at least one site from each hydrogeologic unit to measure rainfall, infiltration, runoff, and evapotranspiration under simulated wetter climatic conditions. LPRS tests are better suited for studying these processes than SPRS tests because larger areas and deeper depths can be studied. Factors affecting the development of perched water tables will also be examined. After the artificial rainfall application is stopped, and the profile is sufficiently wet, the drainage of that profile will be monitored. A comparison of drainage data with profile wetting data will yield an estimate of hydraulic conductivity as a function of water content.

LPRS control plots will be located adjacent to each LPRS test plot in an equivalent hydrologic environment. Artificial rainfall will not be applied to the control plots. Infiltration-runoff data from control plots during natural rainfall, compared with infiltration-runoff data from LPRS plots during simulated rainfall, will help establish the relationship between natural and simulated rainfall. The LPRS control plots are also important components of the natural infiltration monitoring program.

Both control and test LPRS plots will be instrumented similarly to the SPRS plots discussed previously. These instruments plus various geophysical logging techniques will be used to monitor moisture movement beneath these plots in response to both natural and artificial rainfall.

Parameters will also be measured at each site for water budget calculations of infiltration. Meteorological data will be collected at each site for evapotranspiration calculations. Runoff and sediment yield as a function of rainfall will be determined by monitoring flumes. The meteorologic and runoff data will be collected as part of Studies 8.3.1.2.1.1 and 8.3.1.2.1.2.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.1.3 are given in the following table.

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Method	Technical procedure		Date
	Number	Title	
(NWM-USGS-)			
Double-ring infiltrometer studies	TBD ^a	Site characterization double-ring infiltrometer studies	TBD
Ponding studies	TBD	Site characterization ponding studies	TBD
	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated zone boreholes at the well-site, NTS	3 Mar 87
Small-plot rainfall simulation studies	TBD	Site characterization small-plot rainfall simulation studies	TBD
	HP-55, R1	Hydrologic laboratory testing of core and drill-cutting samples unsaturated zone test holes	9 Sep 85
Large-plot rainfall simulation studies	TBD	Site characterization large-plot rainfall simulation studies	TBD
	HP-133, R0	Handling and storage of core at the unsaturated zone test laboratory	TBD

^aTBD = to be determined.

8.3.1.2.2.2 Study: Water movement tracer tests using chloride and chlorine-36 measurements of percolation at Yucca Mountain

The objective of this study is to obtain information derived from isotopic measurements of soil and tuff samples collected from Yucca Mountain that is pertinent for assessing the performance of a nuclear waste repository. Measurements of chlorine isotopic distributions will help characterize

the percolation of precipitation into the unsaturated zone. The chlorine-36 in the unsaturated zone occurs from atmospheric fallout of chlorine-36 produced by cosmic-ray secondaries reacting with argon-40 and, to a lesser extent, with argon-36 and as global fallout from high-yield nuclear weapons tests conducted at the Pacific Proving Grounds between 1952 and 1963. When chloride ions at the surface are washed underground by precipitation, the radioactive decay of the chlorine-36 in the chloride can be used to time the rate of water movement. The chlorine-36 half-life of 301,000 yr permits the detection of water movement in the range of approximately 50,000 to 2 million years. These data are part of the input for developing numerical models of ground-water flow at this site.

Measurements of technetium-99, when combined with some of the chlorine isotopic distributions, will provide data about the in situ sorption characteristics of technetium. The in situ data will be correlated with laboratory measurements of technetium sorption to help assess the reliability of using sorption data from laboratory experiments in modeling radionuclide transport under field conditions.

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

Objectives

The purpose of this activity is to help quantify the amount of percolation from precipitation into the unsaturated zone at Yucca Mountain. The data will be used as part of the input to characterize the movement of water through the unsaturated zone at Yucca Mountain.

Parameters

Data needed is for the following parameters:

1. Precipitation measurements.
2. Dry chloride fallout.
3. Fracture morphology in Paintbrush Tuff.
4. Site hydrology and hydrochemistry.

Data has been gathered for the following parameters:

1. Depth of each sample from the surface.
2. Chloride in soil and tuff samples.
3. Chlorine-36 to chlorine ratios in soil and tuff samples.
4. Chlorine-35 to chlorine-37 ratios in soil and tuff samples.

Description

Previous work in this subactivity has resulted in the measurement of chlorine-36 as a function of depth in soils from two locations at Yucca Mountain. The data permitted the calculation of infiltration during the past quarter century at one location, trench YW-6. - The small quantity of chlorine-36 observed at the second location, the exploratory shaft site in Coyote

Wash, indicated that recent hydrologic activity carried the chlorine-36 either laterally or downward. Chloride analyses of samples from greater depths at the exploratory shaft site will be performed to characterize the extent to which recent water movements can be traced by chlorine-36. Sampling depths in the exploratory shaft will be determined using stratigraphic information from USW G-4. Care will be taken in determining the possible chloride contribution from the shaft construction (e.g., blasting and well J-13 water).

Additional chloride measurements will be performed on samples to be collected after a survey of Yucca Mountain to determine areas of active percolation (Activity 8.3.1.2.2.1.2). These measurements will define the areal and part of the vertical distribution of chloride and its isotopes. Measurements of tuff samples will elucidate meteoric chloride movement into the tuff. These data will aid in estimating the effect of the tuff matrix in retarding the migration of water and solutes in the more permeable fracture zones.

All the data collected in this activity will be used to develop numerical models to estimate the effective infiltration rate at Yucca Mountain.

Methods and technical procedures

Chloride analyses of soil samples will be performed by standard leaching and titrimetric procedures. Chloride analyses of tuff samples require a fusion technique. Isotopic analyses of chloride samples will be performed with conventional mass spectrometric techniques to determine chlorine-35 to chlorine-37 ratios and with tandem accelerator mass spectrometric techniques to measure chlorine-36 to chlorine ratios.

8.3.1.2.2.3 Study: Characterization of percolation in the unsaturated zone--surface-based study

The objectives of the surface-based unsaturated zone percolation study are to (1) determine the present in situ hydrologic properties of the unsaturated zone hydrogeologic units and structural features, (2) determine the present vertical and lateral variation of percolation flux through the hydrogeologic units and structural features, (3) investigate the relationships between present flux and past climatic conditions, and (4) determine the effective hydraulic conductivity, storage properties, and transport properties as functions of moisture content or potential. Three activities are planned to collect the data that are required to satisfy these objectives. The planned activities are (1) matrix hydrologic properties testing, (2) site vertical borehole studies, and (3) Solitario Canyon horizontal borehole study.

In the matrix hydrologic properties laboratory analysis, a variety of standard laboratory tests will be conducted in support of hydrologic studies: matric suction and moisture content, moisture retention, porosity, density, and the effective conductivity moisture characteristics for air and water. Tests will be run on core, cuttings, and excavated blocks collected during drilling and mining. Prototype tests to determine optimum methods of sample

handling and to develop and evaluate various testing methods for matrix hydraulic property acquisition will be performed. The objective is to characterize ambient matrix properties for all penetrated hydrogeologic units, and to provide the data necessary for modeling past and future hydrologic conditions as well as to serve the many ongoing activities. A data base will be built to provide statistics of measurement errors and populations important to the definition of cumulative distribution functions of travel time and contaminant breakthrough. Samples to be tested will be obtained from the exploratory shaft, from surface-based boreholes described in this investigation, and from other surface-based boreholes.

In the site vertical borehole studies, 17 vertical holes are planned to provide information on hydrologic characteristics of the unsaturated tuffs across the site. Immediately following drilling, packer nitrogen-injection tests will be run in each vertical borehole (except two) to determine gas-phase permeabilities of the rock mass. Cross-hole pneumatic tests will be run in two cluster sets of boreholes. The hydraulic properties such as permeabilities to air and water will be determined using packer-injection tests in single and cross-hole configurations. By deducting matrix (laboratory) permeabilities, fracture permeabilities will be derived from bulk (in situ) permeabilities. Aperture distributions and spacings estimated from fracture permeability distributions will permit computations of bulk conductivity as a function of matrix suction. Gas tracer diffusion studies will be undertaken at one borehole cluster set. Samples will be collected from the boreholes to be tested to determine hydrologic properties and their variation across the site. The determination of the in situ potential field across the site will be attempted by installing instrumentation within each borehole and monitoring them for 3 to 5 yr. It is recognized that drilling the borehole may initially disturb the in situ conditions and that time will be required for conditions to reequilibrate. Prototype tests are being performed to evaluate the capabilities and limitations of the instrumentation to be used in the extended monitoring time period and to evaluate whether in situ conditions will return within the monitoring period. Numerical analyses will also be used to predict how long the disturbed region around the boreholes will take to return to its in situ condition. The objectives and design of the boreholes will be evaluated after completion of these prototype tests and analyses. If these tests prove feasible, a definition of the in situ potential field will provide the initial condition of in situ pressure head distribution across the site that is called for by Issue 1.1 and 1.6 (Section 8.3.5).

Lateral variations in permeability will be determined in part by drilling a horizontal borehole into the west side of the repository block, where the Solitario Canyon slope and fault zone provide different infiltration and gas-flow conditions than the rest of the block. By penetrating about 100 m of the steep fault zone within the fractured Topopah Springs welded tuff, the borehole will facilitate measurement of fault zone permeability to air (packer tests within the zone) and transverse permeability (packer-to-packer across the fault). The distribution of moisture as a function of depth under the slope, together with core properties and air permeabilities will be used to define the boundary conditions for modeling.

No natural perched water has been observed in holes drilled in Yucca Mountain. However, circulating drilling fluid that was lost in hole USW G-1 was observed in USW UZ-1, 335 m distant. This occurrence suggests that there

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is the potential for perched water to form and move laterally under certain conditions. Therefore, in the event that other seeps are discovered in any excavation, the perched-water test has been developed to measure flows and to sample the water for chemical composition and age determination. Hydraulic properties of any perched zones located will be determined, and instruments will be installed to monitor pressure or potential. A possible horizon for perched water conditions may exist above a capillary barrier in the Paintbrush nonwelded or bedded tuff. Though it is not presently evident, perched water might contribute to the diversion of higher fluxes if pluvial climatic conditions were to return. Prototype testing will be performed in G-tunnel to develop instrumentation and test procedures.

8.3.1.2.2.3.1 Activity: Matrix hydrologic properties testing

Objectives

The objectives of this activity are

1. To characterize the flux-related matrix hydrologic properties of major unsaturated zone hydrogeologic units through laboratory testing of geologic samples obtained from surface based boreholes and excavations and boreholes from the exploratory shaft (ES-1).
2. To use statistical and geostatistical methods to calculate, with known certainties, the values of flux-related matrix hydrologic properties within large volumes of rock beneath Yucca Mountain.

Parameters

The parameters of this activity are

1. Porosity.
2. Density.
3. Permeability.
4. Relative permeability.
5. Moisture retention.
6. Matric potential.
7. Water potential.
8. Water content.
9. Water storage capacity.
10. Fluid flux.

Description

This investigation is designed to develop a comprehensive matrix-property data base to be used in calculation of matrix flux within the unsaturated zone of Yucca Mountain under both present and possible future climatic conditions. To accomplish this, matrix hydrologic properties will be measured on geologic samples collected from the coring of surface-based boreholes (Activity 8.3.1.2.2.3.2 and Program 8.3.1.4), and from excavations and boreholes in ES-1. Matrix hydrologic property measurements will be conducted on consolidated geologic rock samples only. The sampling program

from this activity will be coordinated with the sampling program activity described in Investigation 8.3.1.4.1. Measurements will not be made on unconsolidated geologic samples (drive-core samples) of alluvium-colluvium whose matrix properties can be easily disturbed during sampling. The collection and handling of samples and measures taken to minimize the alteration of sample matrix hydrologic properties from in situ conditions is discussed in detail by Hammermeister et al. (1985).

Prototype tests will be conducted to determine optimum methods of collecting, dividing, coring, preserving, transporting, and storing large rock samples from exploratory shaft excavations. These tests will also determine (1) the minimum sample dimensions that will be required for the large rock samples to be obtained from exploratory shaft excavations, and (2) the minimum sample dimensions of large rock samples required to obtain 2.56-in. outer diameter core. These cores are required for matrix hydrologic property tests and the extraction of water for geochemical analyses. Air rotary coring procedures will be developed to obtain core from large rock samples with minimally disturbed water content.

A summary of all existing and planned surface-based unsaturated zone boreholes that have or will yield geologic core samples suitable for matrix hydrologic property testing is given in Table 8.3.1.2-5. This table does not yet include the boreholes planned under Issue 8.3.1.4 because specific information on those holes has not been developed. The information will be included when available. Total numbers of samples available for matrix hydrologic property testing is given in Table 8.3.1.2-6 for all existing and currently planned boreholes. For planned unsaturated zone boreholes, this same information is estimated. Unsaturated boreholes include shallow core and instrument holes (200 to 500 ft deep), deep core and instrument holes (1,000 to 2,000 ft deep), neutron access holes (20 to 100 ft deep), and artificial recharge monitoring holes (5 to 35 ft in depth). In all unsaturated boreholes, the depth interval between core samples designated for matrix hydrologic property tests in continuously cored portions of tuff is approximately 2.5 ft.

Classical statistics and property testing methods will be used to determine the number and locations of the geologic samples to be tested for matrix hydrologic properties for each surface-based borehole. Sufficient samples will be collected to permit assessment of the combined effects of inherent random and spatial variation among samples and the experimental error of measurement. The random and spatial variation in matrix properties will be estimated both in the vertical directions and in lateral direction parallel to the dip of the units.

Initially, the vertical spatial variation in matrix properties will be estimated by intensive sampling of a few surface-based reference boreholes. Preliminary tests on samples from these reference holes will be conducted to characterize the vertical structure of the spatial variability using values of matrix hydrologic properties in the vertical direction as accurately as possible. The analysis of data from these tests will then be used to determine testing frequency in all other surface-based boreholes. The testing frequency of the holes described here will be coordinated with the holes planned under Issue 8.3.1.4.

Table 8.3.1.2-5. Borehole information and estimates of numbers of core samples available for permeability related tests (page 1 of 2)

Borehole	Comple- tion date	Non- to partially welded and bedded tuff units			Moderately to densely welded tuff units	
		Total depth (ft)	Continuously cored inter- vals (ft)	Number of samples available	Depth interval between "spot cores" (ft)	Number of samples available
SHALLOW CORED AND INSTRUMENTED HOLES						
UE25 UZ#4	9/84	366.5	275.8	83	10	8
UE25 UZ#5	10/84	363.0	264.0	94	10	2
USW UZ-7	1/85	207.0	81.0	31	10 to Continuous	10
USW UZ-13	3/85	430.1	57.0	21	10	18
USW UZ-6s	5/85	519.0	85.0	18	20	21
USW UZ-8	- ^a	350.0	80.0	30	10	25
USW UZ-11	-	500.0	20.0	10	10	40
DEEP CORED AND INSTRUMENTED HOLES						
UE-25 UZ#9	-	2,000.0	85.0	30	10	75
UE-25UZ UZ#9a	-	1,500.0	85.0	30	10	50
UE-25UZ UZ#9b	-	1,500.0	85.0	30	10	50
USW UZ-10	-	1,500.0	80.0	25	10	50
USW UZ-2	-	1,500.0	90.0	35	10	50
USW UZ-3	-	1,400.0	90.0	35	10	50
NEUTRON ACCESS HOLES						
UE25 UZN#10	12/85	99.0	99.0	16	-	-
USW UZ-N24	2/86	75.0	51.0	21	10	2
USW UZ-N46	1/86	99.0	99.0	30	-	-
USW UZ-N47	1/86	86.4	17.4	7	intermittent	2
USW UZ-N98	2/86	75.0	49.0	15	-	-
USW UZ-N11	-	50.0	-	-	5	10
USW UZ-N15	-	50.0	-	-	5	10
UE25 UZN#16	-	50.0	-	-	5	10
USW UZ-N17	-	50.0	50.0	20	-	-
USW UZ-N27	-	50.0	-	-	5	10
USW UZ-N31	-	50.0	-	-	5	10
USW UZ-N32	-	50.0	-	-	5	10
USW UZ-N33	-	50.0	-	-	5	10
USW UZ-N34	-	50.0	-	-	5	10

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Table 8.3.1.2-5. Borehole information and estimates of numbers of core samples available for permeability related tests (page 2 of 2)

Borehole	Comple- tion date	Non- to partially welded and bedded tuff units		Number of samples available	Moderately to densely welded tuff units	
		Total depth (ft)	Continuously cored inter- vals (ft)		Depth interval between "spot cores" (ft)	Number of samples available
USW UZ-N35	-	50.0	-	-	5	10
USW UZ-N36	-	50.0	-	-	5	10
USW UZ-N37	-	50.0	-	-	5	10
USW UZ-N38	-	50.0	-	-	5	10
USW UZ-N39	-	50.0	-	-	5	10
USW UZ-N53	-	50.0	-	-	5	10
USW UZ-N54	-	50.0	-	-	5	10
USW UZ-N55	-	50.0	-	-	5	10
USW UZ-N57	-	50.0	-	-	5	10
USW UZ-N58	-	50.0	50.0	20	-	-
USW UZ-N61	-	50.0	-	-	5	10
USW UZ-N63	-	50.0	-	-	5	10
SMALL-PLOT ARTIFICIAL INFILTRATION MONITORING HOLE						
SPRS-1 --	-	5.0	0-5	48	-	-
SPRS-24	-	-	-	-	-	-
SPRS-25 --	-	5.0	-	-	2.5	198
SPRS-100	-	-	-	-	-	-
LARGE-PLOT ARTIFICIAL INFILTRATION MONITORING HOLE						
LPRS-1 --	-	35.0	0-35	700	-	-
LPRS-50	-	-	-	-	-	-
LPRS-50 --	-	35.0	-	-	2.5	980
LPRS-120	-	-	-	-	-	-
TOTAL				748		1,178

^a - = not available

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Table 8.3.1.2 6. Estimated number of unsaturated zone core samples available for matrix-hydrologic property testing

Borehole symbol	Purpose of hole	Number of hole	Estimated number of core samples originally available ^a	Estimated number of core samples available for matrix hydrologic property tests ^b
UZ	Unsaturated zone hydrology studies	334	3,270	3,270
A	Initial geologic stratigraphy and structure study	5	849	636
B	Initial saturated zone hydrology study	1	420	316
C	Saturated zone tracer studies	3	150	112
G	Geologic stratigraphy and structure studies	5	3,259	2,444
H	Saturated zone hydrology study	6	323	242
	TOTAL		8,271	7,020

^aOne core sample was assumed to be obtained for every 2.5 ft of continuous core. If a core interval was less than 2.5 ft long, 1 sample was assumed to be originally available.

^b100 percent of original samples of unsaturated zone holes was assumed to be available for matrix property testing; 75 percent of original samples from all other holes was estimated to be currently available for testing.

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Regions where reference boreholes show statistically similar matrix hydrogeologic properties will be defined as preliminary hydrogeologic units. These preliminary hydrogeologic units are expected to encompass lithostratigraphic units or subunits. This expected relationship between hydrologic properties and lithostratigraphic units will greatly facilitate the identification of boundaries of preliminary hydrogeologic units. However, if the analysis of matrix hydrologic property data indicates that no such relationship exists, preliminary surficial hydrogeologic units will be defined independently of lithostratigraphic units.

During the vertical excavation of ES-1, single blast rounds will deepen the 12-ft (3.66-m) diameter shaft by approximately 1 m. Many large pieces of rock will be collected during the mucking operation following each blast round. The number of large rock samples will exceed the number predicted to be necessary to estimate the matrix properties. The predicted number of required measurements will be based on geostatistical models of matrix properties in preliminary hydrogeologic units in surface-based boreholes. Not every large rock sample from every blast round should be needed to estimate matrix properties. A sufficient number of samples must be available, however, for testing from every blast round if it is determined that intensive testing is required. After a preliminary subsurface hydrogeologic unit has been penetrated, several blast rounds will be selected as references. Matrix property tests will be conducted on a large number of samples from these blast rounds. This reference blast round data will be used to calculate the number of tests required to estimate the matrix hydrologic properties for each preliminary subsurface hydrogeologic unit. The approach used to determine the number of required matrix hydrologic properties in horizontal excavations will be essentially the same as that for the vertical shaft. The effect of blasting on the matrix hydrologic properties will be determined in the prototype blasting effects test and will be factored into the analyses.

The horizontal spatial variation in subsurface matrix properties will be examined on a small scale during the excavation of the 12-ft (3.66-m) diameter vertical shaft, on a larger scale (several hundred feet) during the excavation of alcoves and drilling of radial boreholes, and up to 2,000 ft (606 m) in drifts to major structural features. Lateral spatial variability on any scale larger than 2,000 ft (606 m) will be estimated from the surfaced-based boreholes over Yucca Mountain. The opportunity to collect a virtually unlimited number of geologic samples during excavation will mean that sample availability will not be a constraint on the number of samples tested, permitting improved estimates of the experimental error for the various testing methods. The large number of samples will also permit improvement in the accuracy of geostatistical models.

The vertical and lateral spatial variability of matrix hydrologic properties in approximately the upper 30 ft (9 m) of surficial rocks covering Yucca Mountain will be estimated from core samples obtained from 220 shallow artificial infiltration boreholes and selected neutron access holes. To make these estimates in both surface and subsurface regions some assumptions must be made about the structure of the variability in the measured properties. This uncertainty may be accounted for in geostatistical models that estimate spatial functions. Methods for geostatistics, such as kriging, will be used

to interpolate between measured data points using fitted spatial distributions. Stochastic models will then be used to simulate possible structure of matrix hydrologic properties for large volumes of rock.

These statistical methods will permit the definition of both surface and subsurface hydrogeologic units for site characterization purposes. These hydrogeologic units will replace the preliminary hydrogeologic units described previously. The surface and subsurface hydrogeologic units are expected to encompass at least some adjacent lithostratigraphic units as defined by Scott and Bonk (1984). The new hydrogeologic unit boundaries, however, may not conform to lithostratigraphic unit boundaries or the boundaries of the hydrogeologic units proposed earlier by Montazer and Wilson (1984) from limited matrix and fracture property data.

Before matrix hydrologic property testing on geologic samples for site characterization begins, preliminary prototype work is required to develop and evaluate various testing methods to ensure that the resulting matrix hydrologic property data is of the highest possible quality. Matrix property tests will be conducted to (1) determine the most suitable established methods for measuring permeability, relative permeability, and moisture retention relationships; (2) develop new or adapt existing methods for measuring hydrologic properties when existing methods are not appropriate or do not exist; and (3) compare appropriate established methods with new methods to determine optimum procedures for various tuffaceous rocks at Yucca Mountain.

The development and evaluation of new methodology is desirable for several reasons. Proven methods to measure parameters such as water and matric potential on consolidated rock core samples do not exist. In addition, many of the established methods for measuring moisture retention and relative permeability have limitations and disadvantages that make it difficult to apply these methods to the wide range of tuffaceous rocks found at Yucca Mountain. Finally, the potentially large number of tests to be conducted, and their high cost, require that new multipurpose methods that would yield more than one type of data be evaluated. If a new method proves successful, it will be compared with other methods that measure the same property to select the most appropriate method of measurement. The preliminary testing will be used to determine which of the various methods under consideration is the most practical and will yield the most satisfactory results.

Drilling and coring methods used in most unsaturated-zone boreholes produce core samples with water contents, and in some instances water potentials, that are similar to those in the formation rock surrounding the borehole (Hammermeister et al., 1985). In these instances, the determination of water potentials and/or matric potentials of core samples would permit the characterization of these potentials in the formation rock. Knowledge of the distribution of these potentials in unsaturated zone formations is necessary to characterize liquid flow processes in these regions. Unfortunately, methods and equipment to measure both water and matric potentials have been developed for field agricultural soils or plant materials and not for consolidated rock core samples. Preliminary testing is required to determine if existing methods and equipment can be adapted for this purpose. Work will be conducted to attempt adaptation of tensiometer-transducer (Watson, 1965) and heat-dissipation probe (Phrene et al., 1971) techniques, permitting the

measurement of matric potentials on rock cores. Tests have been successfully conducted to adapt a Richards thermocouple psychrometer technique (Richards and Ogata, 1958) and commercially available equipment (Decagon Devices, Pullman, Washington) to reproducibly measure water potentials on samples of rock core and, in some instances, samples of drill cuttings.

Fluid permeability tests to be compared will include air permeability, Klinkenberg air permeability at different overburden pressures, specific water permeability, and oil permeability. The relationship between these different fluid permeabilities is discussed by Amyx et al. (1960). Although water is the primary fluid of interest, air permeability is being evaluated because it is the quickest and least expensive method. Klinkenberg air permeability and oil permeability have been included to characterize the deviation of air and water from ideal fluid behavior.

Established methods that will be evaluated to determine moisture retention curves include pressure plate (Rose and Bruce, 1949), centrifuge (Hassler and Brunner, 1945), and mercury porosimetry (American Petroleum Institute RP-40) techniques. A variation of the established pressure plate method, called the submersible pressure plate method (Constantz and Herkelrath, 1984), will be evaluated to determine if this method and equipment can be modified for use on various types of tuffaceous rock core from Yucca Mountain. A psychrometer method (Peters et al., 1984), which uses a Richards thermocouple psychrometer in conjunction with microwave drying techniques, is also being evaluated. Additional tests will be conducted to determine if the gas-drive relative permeability method can be modified to also collect moisture retention data without significant evaporation. Significant amounts of time and money will be saved if this dual purpose gas-drive technique proves to be a reliable method. Finally, methods suitable for characterizing moisture retention hysteresis effects will also be identified.

Both steady state and nonsteady state relative permeability methods will also be evaluated. Steady state methods include a centrifuge method (Nimmo et al., 1987) and an evaporation method (Constantz, 1982) for water relative permeability measurements and the Hassler method (Hassler, 1944) for both water and gas relative permeability measurements. Nonsteady state methods for water relative permeability measurements include a centrifuge method (Van Spronsen, 1982), a gas-drive method (Owens et al., 1956), and a pressure plate outflow method (Passioura, 1976). Accurate measurements of relative permeability will be made using steady state methods in the region of 100 percent water saturation (e.g., approximately 80 to 100 percent) on various core with a range of permeabilities. These accurate measurements will then be used to evaluate the same portion (extrapolated or measured) of relative permeability curves obtained from less accurate nonsteady state methods.

In addition to these direct measurements of relative permeability, various indirect methods of calculating relative permeability from moisture retention data (Muallem, 1976) will be evaluated. Finally, tests will be conducted to determine if the nonsteady state centrifuge method can be modified to produce both moisture retention and relative permeability data at the same time.

After the matrix property measurements have been completed and the hydrogeologic units determined, three-dimensional models will be developed

using geostatistical techniques. The boundaries of the hydrogeologic units will be defined so that each unit contains a set of matrix hydrologic properties judged sufficiently different from adjacent hydrogeologic units. Stochastic models will be used to simulate possible heterogeneities for each hydrogeologic unit. Enough simulations will be run so that confidence levels can be set for the occurrence of heterogeneities. The simulations will provide the initial and boundary conditions and the necessary matrix properties that will be used in large scale hydrologic modeling of Yucca Mountain.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.3.1 are given in the following table:

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Gravimetric water content	HP-55, RO	Hydrologic laboratory testing of core and drill cutting samples from unsaturated zone test holes	9 Sep 85
Volumetric water content	HNMTL-	TBD ^a	TBD
Bulk density	HNMTL-	TBD	TBD
Grain density	HNMTL-	TBD	TBD
Porosity	HNMTL-	TBD	TBD
Matric potential			
tensiometer-transducer	HP-	TBD	TBD
heat-dissipation probes	HP-	TBD	TBD
Water potential	HP-55, RO	Hydrologic laboratory testing of core and drill cutting samples from unsaturated zone test holes	9 Sep 85
Saturated permeability			
Liquid and gas	HNMTL-	TBD	TBD
Klinkenberg	HNMTL-	TBD	TBD

Method	Technical procedure		Date
	Number	Title	
Moisture retention curves submersible pressure plate	HP-28, RO	Laboratory procedures for the determination of moisture retention curves on rock core	15 May 85
USGS additional procedures	USGS-	TBD	TBD
HNMTL additional procedures	HNMTL-	TBD	TBD
Relative permeability			
USGS procedures	USGS-	TBD	TBD
HNMTL procedures	HNMTL-	TBD	TBD
Calculation of relative permeability	USGS-	TBD	TBD

^aTBD = to be determined.

8.3.1.2.2.3.2 Activity: Site vertical borehole studies

Objectives

The objectives of this activity are

1. To define the potential field.
2. To determine the in situ bulk permeability characteristics of the unsaturated media within the proposed repository host rock and surrounding units at Yucca Mountain, Nevada.

Parameters

The parameters of this activity are

1. Gravimetric moisture content (ambient/matrix/laboratory).
2. Volumetric moisture content (ambient/matrix/laboratory).
3. Matric potential (ambient/matrix and bulk/laboratory and in situ).
4. Water potential (ambient/bulk/in situ).

5. Thermal potential (ambient/in situ).
6. Pneumatic potential (ambient/in situ).
7. Matrix permeability as a function of saturation and matric potential (laboratory).
8. Matrix pore size distribution (laboratory).
9. Grain density (laboratory).
10. Bulk density (laboratory).
11. Total porosity (matrix/laboratory).
12. Effective porosity (matrix/laboratory).
13. Bulk permeability (pneumatic/in situ).
14. Bulk permeability (hydraulic/in situ).
15. Fracture frequency, orientation, spacing, and distribution.
16. Depths to hydrogeologic contacts.
17. Definition of hydrogeologic units.
18. Saturation profiles.
19. Pressure head profiles.

Thermal and mechanical properties will be measured as described in the activities under Studies 8.3.1.15.1.1 through 8.3.1.15.1.6.

Description

This investigation is confined to that area of Yucca Mountain immediately overlying and adjacent to the primary repository boundary (Figure 8.3.1.2-14). Vertically, the study area extends from the near surface of Yucca Mountain to the underlying water table. This subactivity involves dry drilling and coring of 17 vertical boreholes ranging in depth from 60 to 610 m. Nine of the proposed boreholes will range in depth from 60 to 150 m and will terminate above the proposed repository horizon. The remaining eight boreholes will be drilled to depths ranging from 365 to 610 m and will penetrate the unsaturated zone below the proposed repository horizon. Construction details applicable to each of the proposed boreholes are shown in Table 8.3.1.2-7.

An additional (eighteenth) borehole, may be required to support the vertical seismic profiling (VSP) investigation. Present plans are to install the downhole geophones in USW UZ-6 as part of the instrumentation program for that borehole. If this is not feasible, an additional borehole will be required.

Figure 8.3.1.2-14. Map of existing and proposed unsaturated-zone borehole locations.

Table 8.3.1.2-7. Summary of construction details of vertical boreholes (page 1 of 3)

Borehole designation	Status	Drilling method	Total depth (m)	Bit Diameter (mm)	Depth interval (m)	Casing inside diameter (mm)	Casing depth interval (m)	Stratigraphic unit at total depth	Comments
USW UZ-1	Completed (07/31/83)	Reverse vacuum	387.1	1219 914 610 444 381 235	0-12.6 12.6-29.6 29.6-30.8 30.8-385.6 385.6-386.8 386.8-387.1	1041	0-12.0	Topopah Spring Member of Paintbrush Tuff	Drilling terminated because of large volume of water.
USW UZ-2	Planned	ODEX/ reverse vacuum	+460	≤445	- ^a	-	-	Tuffaceous beds of Calico Hills	Approximately 60 m west of USW UZ-6, paired w/ USW UZ-3 for cross-hole testing.
USW UZ-3	Planned	ODEX/ reverse vacuum	+430	≤445	-	-	-	Tuffaceous beds of Calico Hills	Approximately 60 m west of USW UZ-6, paired w/ USW UZ-2 for cross-hole testing.
UE-25 UZ#4	Completed (10/10/84)	ODEX/ cored	111.9	153 108	0-68.9 68.9-111.9	127	0-17.7	TOPOPAH SPRING Member of Paintbrush Tuff	PAIRED W/ UE-25 UZ#5 to investigate flux in and near a drainage.
UE-25 UZ#5	Completed (11/19/84)	Reverse vacuum	111.3	153	0 111.3	127	0- 5.2	Topopah Spring Member of Paintbrush Tuff	Paired w/ UE-25 UZ#4 to investigate flux in and near a drainage.
USW UZ-6	Completed (09/26/84)	Reverse vacuum	575.2	762 610 445	0-12.2 12.2-103.9 103.9-575.2	660 483	0-12.2 0-98.6	Prow Pass Member of Crater Flat Tuff	Drilling terminated because of over-run of drilling time and excessive breakage of drillstring.
USW UZ-6s	Completed (09/09/85)	ODEX	158.2	216 102	0-150.9 150.9-158.2	178	0- 0.9	Topopah Spring Member of Paintbrush Tuff	Drilled to complete sampling that drilling problems precluded in USW UZ-6.

Table 8.3.1.2-7. Summary of construction details of vertical boreholes (page 2 of 3)

Borehole designation	Status	Drilling method	Total depth (m)	Bit Diameter (mm)	Depth interval (m)	Casing inside diameter (mm)	Casing depth interval (m)	Stratigraphic unit at total depth	Comments
USW UZ-7	Completed (01/22/85)	ODEX	63.1	152	0-63.1	127	0-6.1	Topopah Spring Member of Paintbrush Tuff	Designed along with USW UZ-8 to straddle Ghost Dance fault.
USW UZ-8	Incomplete (10/86)	ODEX	*107	216	-	-	-	Topopah Spring Member of Paintbrush Tuff	Designed along with USW UZ-7 to straddle Ghost Dance fault.
UE-25 UZ#9	Planned	ODEX reverse/ vacuum	*610	≤445	-	-	-	Tuffaceous beds of Calico Hills	Part of three-hole cluster for cross-hole testing.
UE-25 UZ#9a	Planned	ODEX reverse/ vacuum	*460	≤445	-	-	-	Tuffaceous beds of Calico Hills	Part of three-hole cluster for cross-hole testing.
UE-25 UZ#9b	Planned	ODEX reverse/ vacuum	*460	≤445	-	-	-	Tuffaceous beds of Calico Hills	Part of three-hole cluster for cross-hole testing.
USW UZ-10	Planned	ODEX reverse/ vacuum	*460	≤445	-	-	-	Tuffaceous beds of Calico Hills	
USW UZ-11	Planned	ODEX	*122	216	-	-	-	Topopah Spring Member of Paintbrush Tuff	In Solitario Canyon; straddles Solitario Canyon fault.
USW UZ-12	Planned	ODEX	*122	216	-	-	-	Topopah Spring Member of Paintbrush Tuff	In Solitario Canyon; straddles Solitario Canyon fault.

Table 8.3.1.2-7. Summary of construction details of vertical boreholes (page 3 of 3)

Borehole designation	Status	Drilling method	Total depth (m)	Bit Diameter (mm)	Depth interval (m)	Casing inside diameter (mm)	Casing depth interval (m)	Stratigraphic unit at total depth	Comments
USW UZ-13	Completed (04/18/85)	ODEX/ cored	131.1	152 102	0-125.0 125.0-131.1	127	0-100.6	Topopah Spring Member of Paintbrush Tuff	
USW UZ-14	Planned	ODEX	*122	216	-	-	-	Topopah Spring Member of Paintbrush Tuff	Near USW UZ-1; needed to complete sampling. May need to drill deeper.

^a- denotes not applicable.

Other surface-based boreholes are planned to obtain information on rock characteristics at the site. These boreholes are described in Section 8.3.1.4. The samples obtained from those boreholes will be used to determine, among other things, stratigraphy, thermal properties, mechanical properties, and hydrologic properties at the site.

For the boreholes described here, the ODEX drilling method will be used to the maximum extent possible. Reverse air-vacuum drilling may be required for attainment of the deeper depths. Depending on the drilling method used to achieve the targeted depths, borehole diameters will range from 15 to 25 cm for ODEX and up to 45 cm for reverse air vacuum. Drive core, rotary core, and cuttings will be taken throughout the drilling operation. In alluvium, 2-ft (0.6-m) core will be taken at 5-ft (1.5-m) intervals. In the densely welded tuff, rotary core will be taken for 1 ft (0.3 m) at 10-ft (3.0-m) intervals. In the non-to-partially welded tuff, rotary core will be taken continuously wherever possible.

An onsite lithologic log will be developed to guide the drilling operations and to determine when core samples should be taken outside of the normal sampling schedule. An onsite laboratory analysis of cutting samples will also be conducted to determine gravimetric moisture content. All other samples, core and cuttings, with the exception of those used for later lithologic analysis, will be capped, taped, and waxed to inhibit evaporation. These samples will be sent to a laboratory for determination of ambient volumetric moisture content and matric potential and for determination of other physical and hydrologic rock properties as identified on the parameter listing for this section. These samples will be tested under the matrix hydrology properties laboratory analyses investigation described under Activity 8.3.1.2.2.3.1.

Borehole geophysical logs will be run in each borehole, either during a pause in drilling or following completion of drilling. A listing of these logs is given in Table 8.3.1.2-8. Radial (side scan viewing) and axial (forward viewing) oriented television video camera logs of each borehole will also be run. These will be used for mapping fracture orientations, distributions, and densities.

Two deep boreholes, one at or near the USW UZ-6 complex, and the other at the UE-25 UZ#9 complex (Figure 8.3.1.2-15), will be instrumented with a string of permanently emplaced, oriented, three-component geophones located at 7.3 m intervals. These geophones will be used in a vertical seismic profiling (VSP) investigation across the central portion of Yucca Mountain. The VSP technique is being used in this investigation to provide three-dimensional information on the lateral and vertical extent of fracturing within each hydrogeologic unit over a contiguous volume of rock mass much larger than that available to single isolated boreholes. The test volume includes the Ghost Dance fault structure. The VSP technique will also be used for discrimination of geologic units and stratigraphic correlation purposes.

Immediately following drilling (or during a pause in drilling), packer nitrogen-injection tests will be run in each of the vertical boreholes except USW UZ-1 and USW UZ-6 to determine gas permeabilities of the combined fracture and rock matrix system. Multiple test zones will be selected for each

Table 8.3.1.2-8. Status of drillhole logging activities in the unsaturated zone^{a,b}

Drillhole designation	Status	Depth (m)	Dia-meter (cm)	Lith. and geol.	Tele-vision	Cali-per	Den-sity gam. gam.	Epit. neut. poro.	Seis-mic vel.	Dielec-tric	Gamma ray	Spec-tral gam.	TV frac-ture	Dir-ect. surv.	Temper-ature	Induc-tion	Neut. moist meter	Neut. scat.	Neut. or gam. att.	Fld.
USW UZ-1	c	386.8	44.4	c	c	c	c	c	-	c	c	c	-	c	-	c	-	-	-	-
USW UZ-2	p	457.2	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	-	p	-	-
USW UZ-3	p	426.7	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	-	p	-	-
UE25 UZ#4	c	111.9	15.2	c	c	p	p	p	p	p	p	p	p	p	p	p	c	p	-	-
UE25 UZ#5	c	111.3	15.2	c	c	p	p	p	p	p	p	p	p	p	p	p	c	p	-	-
USW UZ-6	c	575.2	44.4	c	c	c	c	c	c	c	c	c	-	c	c	c	-	p	-	c
USW UZ-6s	c	158.2	21.6	c	c	p	p	p	p	p	p	p	p	p	p	p	c	p	-	-
USW UZ-7	c	63.1	15.2	c	p	p	p	p	p	p	p	p	p	p	p	p	c	p	-	-
USW UZ-8	i	106.7	15.2	i	p	p	p	p	p	p	p	p	p	p	p	p	p	p	-	-
UE-25 UZ#9	p	609.6	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	p*	p	p	-
UE-25 UZ#9a	p	457.2	44.5	p	p	p	p	p	p	p	p*	p*	p	p	p	p	p*	p	p	-
UE-25 UZ#9b	p	457.2	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	p*	p	p	-
USW UZ-10	p	457.2	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	p*	p	-	-
USW UZ-11	p	121.9	21.6	p	p	p	p	p	p	p	p	p	p	p	p	p	p*	p	-	-
USW UZ-12	p	121.9	21.6	p	p	p	p	p	p	p	p	p	p	p	p	p	p*	p	-	-
USW UZ-13	c	131.1	15.2	c	c	p	p	p	p	p	p	p	p	p	p	p	p	p	-	-
USW UZ-14	p	121.9	21.6	p	p	p	p	p	p	p	p	p	p	p	p	p	p*	p	-	-

^a c = completed; i = incomplete; p = planned; p* = not done because final borehole diameter is too large to effectively run the designated geophysical log; - = not available; the planned log needs to be run early in the drilling of the drillhole while there is a smaller diameter pilot drillhole.

^b Lith. and geol. = lithologic and geologic; gam. gam. = gamma gamma; Epit. neut. poro. = epithermal neutron porosity; vel. = velocity; surv. = survey; Neut. moist meter = neutron moisture meter; scat. = scatter; att. = attenuation; and Fld. = formation density log.

Figure 8.3.1.2-15. Map depicting location of gas tracer diffusion and vertical seismic profiling testing programs.

hydrogeologic unit. These zones will be tested with a straddle packer system consisting of a variable length injection interval, and two sensing sections equipped with thermocouple psychrometers (or another humidity sensor), thermocouples, and pressure transducers. The flow rate and injection pressure of the gas (nitrogen) will be monitored until steady state conditions (i.e., pressure measured in the sensing sections remains essentially constant) are achieved. The same procedure will be carried out at higher flow rates and pressures for each tested interval. Widths of tested intervals will be varied to test effects of heterogeneity and fracturing within a given section of rock mass.

Cross-hole pneumatic testing will be undertaken in the two cluster sets of boreholes (USW UZ-6 and UE-25 UZ#9 complexes). Monitoring will be conducted in both the injection borehole and the satellite observation boreholes using straddle packer systems. Tests will be run until steady state conditions are achieved. Multiple intervals will be tested to assess the influence of fracturing on bulk rock mass permeabilities. Cross-hole pneumatic testing will be prototyped in G-tunnel and test procedures will be developed.

Gas tracer diffusion studies will be undertaken at the UE-25 UZ#9 borehole complex. These tests are designed to (1) measure in situ gaseous phase travel times through an unsaturated fractured rock system, (2) measure contaminant transport and pneumatic properties of the medium, and (3) establish whether diffusion or convection is the dominant gaseous transport mechanism. Testing will take place after the boreholes have been stemmed and instrumented. Gas samples will be taken periodically from tested intervals in the observation boreholes equipped with sampling tubes. Tracer breakthrough curves will be constructed from the gas analyses data. Interpretation of test results will be based on analyses of borehole logs, matrix hydrologic and physical properties data, pneumatic testing, and information obtained from the gaseous phase movement study.

Downhole sensors, consisting of pressure transducers, thermocouple psychrometers, heat dissipation probes, and thermal sensors will be installed in each of the 17 vertical boreholes. These will be monitored for an extended period of time (estimated at from 3 to 5 yr). Monitoring will be accomplished using a fully automated, computer activated and controlled, integrated data acquisition system (IDAS). The downhole sensors will be used to measure (in situ) pneumatic potential, water potential, matric potential, and thermal potential. In contrast to laboratory measurements, downhole sensors will measure these parameters for the combined rock matrix and fracture system. In addition to these instruments, each borehole will be provided with tubing to permit recovery of in situ pore gases and water vapor for hydrochemical analyses as part of the hydrochemical characterization study.

It is recognized that drilling of the borehole will disturb in situ conditions in the rock mass adjacent to the borehole. Numerical analyses are being done to estimate the time required for the rock mass to return to a condition close to its original in situ hydrologic condition. The drilling method to be used to drill the boreholes was chosen to minimize the in situ disturbance of the hydrologic system. It is not known at this time if in situ conditions will return within the time period allotted for monitoring (3 to 5 years). The objectives and extent of this part of the surface-based

borehole investigations study will be evaluated at the completion of the cross-hole prototype testing and the numerical analyses. Prototype testing will also investigate the capabilities and limitations of the instrumentation to be used in the long-term monitoring of the hydrologic characteristics.

It is also recognized that nitrogen pressure injection testing in the borehole before in situ instrumentation and monitoring could impact on the objectives of long-term monitoring by driving moisture away from the near field environment of the downhole instrumentation cavities. The probable magnitude of this effect on pre-injection equilibrium conditions will need to be evaluated for proper interpretation of the long-term monitoring data. Pre-injection baseline information, relevant to this concern, will be collected before nitrogen injection testing. This information consists of laboratory measurements of moisture content and matric potential from core and cuttings and geophysical logging records correlated with these data. Estimates of the time needed to reestablish pre-injection equilibrium conditions will be developed from numerical modeling and from tests in existing, open boreholes. The latter testing program will use packers to monitor selected borehole intervals before injection testing and following injection testing. Different lithologic rock types with varying fracture densities will be tested in this manner. The nature of the impact on long-term monitoring objectives will depend on whether or not vapor-phase equilibrium or liquid-phase equilibrium will need to be reestablished to represent the pre-injection hydrologic state of the affected rock mass.

Following the monitoring phase, the gas sampling access tubes will be used to inject water into each of the isolated, downhole instrument stations. These tests will be conducted to measure in situ saturated hydraulic conductivities. Constant-head injection tests will run until steady state flow conditions can be achieved.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.3.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Borehole drilling and coring	TBD ^a	REECo borehole drilling and coring pro-	TBD
	TBD	REECo casing extraction procedure (ODEX system)	TBD
	TBD	Verification of borehole wall cleaning procedure	TBD

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Method	Technical procedure		
	Number	Title	Date
Drill-bit cuttings and core sampling, lithologic analysis, hydrologic measurements	HP-12, R	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, Nevada Test Site (NTS)	30 Mar 87
	HP-74, RO	Use of the Stabil-Therm miniature batch oven	28 Oct 85
	HP-32, RO	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-73, RO	Calibration and use of the Sartorius electronic top loader (balance) Model 1507 MPS	19 Mar 85
	HP-13, RO	Collection and field analysis of unsaturated zone ground-water samples	29 Aug 83
Drill-bit cuttings and core laboratory analysis	GPP-08, RO	Permeability measurements of rock samples at high pressures and temperatures	1 Nov 84
	GPP-10, RO	Rock property analysis of Yucca Mountain core samples	16 Jan 85
	HP-55, RO	Hydrologic laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sep 85

Method	Technical procedure		
	Number	Title	Date
	HP-18, R0 (to be revised)	Frequency of equipment calibration for unsaturated zone testing, NTS	20 July 84
	HP-28, R0	Laboratory procedures for the determination of moisture-retention curved of rock core	15 May 84
	TBD	Determination of effective porosity from core samples	TBD
	TBD	Determination of grain density from core samples	TBD
	TBD	Determination of bulk density from core samples	TBD
	TBD	Determination of thermal conductivity from core samples	TBD
	TBD	Determination of resistivity from core samples	TBD
	TBD	Determination of sonic velocity from core samples	TBD
	TBD	Determination of heat capacity from core samples	TBD
Borehole geophysical surveys	HP-62, R1	Method for measuring subsurface moisture content using a neutron moisture meter	16 Mar 87
	HP-18, R0 (to be revised)	Frequency of equipment calibration for unsaturated zone testing, Nevada Test Site	20 July 84

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Method	Technical procedure		Date
	Number	Title	
Borehole logging of lithology and geology	HP-50, RO	Method for neutron scatter and gamma ray attenuation logging using the USGS logging van (I-139055)	15 Nov 84
	GP-10, RO (to be revised)	Borehole video fracture logging	12 Apr 85
	TBD	Frequency and method of calibration of noncommercial logging tools for unsaturated zone testing, Nevada Test Site	TBD
	TBD (F&S)	Fenix and Scisson (F&S) frequency and method of depth calibration of commercial logging tools for unsaturated zone	TBD
	TBD	Frequency and method of depth calibration of noncommercial logging tools for unsaturated zone testing, Nevada Test Site	TBD
	TBD	F&S obtaining original digital or video tape of drillhole using proper speed, depth, and illumination, making copy of the original digital or videotape of drill hole	TBD
	TBD	Lithologic examination and analysis of bit-cuttings and core samples	TBD
	GP-11, RO	Logging fractures in core	15 May 85

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Method	Technical procedure		Date
	Number	Title	
	GP-10, RO (to be revised)	Borehole video fracture logging	12 Apr 85
In situ pneumatic testing	TBD	Pressure sensor and sensor lead calibration	TBD
	TBD	Temperature sensor and sensor lead calibration	TBD
	TBD	Humidity sensor and sensor lead calibration	TBD
	TBD	Mass flow meter calibration and use	TBD
	TBD	Data logger internal voltmeter calibration	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Straddle packer system leak detection	TBD
	TBD	Straddle packer system placement procedure	TBD
	TBD	Single-hole gas injection test procedure	TBD
	TBD	Pressure pulse gas injection test procedure	TBD
	TBD	Cross-hole gas injection test procedure	TBD
	TBD	Flow test data identification, shipping, handling and archiving	TBD
Water injection test	TBD	In situ recalibration of pressure sensor	TBD

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Method	Technical procedure		
	Number	Title	Date
	TBD	In situ recalibration of temperature sensor	TBD
	TBD	Pressure sensor and sensor lead calibration	TBD
	TBD	Temperature sensor and sensor lead calibration	TBD
	TBD	Water flow meter calibration	TBD
	TBD	Data logger internal voltmeter calibration	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Single-hole water injection test procedure	TBD
	TBD	Flow-test data identification, shipping, handling and archiving	TBD
	TBD	Procedure for determining excursion rates from permeation devices	TBD
Laboratory tracer studies	MDP-01, RO	Identification, handling, storage and disposition of drillhole core and samples	TBD
	TBD	Procedure for conducting tracer compatibility tests	TBD
	TBD	Procedure for conducting sorption tests on geologic and stemming materials	TBD

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Method	Technical procedure		Date
	Number	Title	
Field tracer test	TBD	Procedure for conducting sorption tests on tubing and stemming instruments	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Procedure for introducing tracer into test interval	TBD
	HP-56, R0 (to be revised)	General procedure for soil gas sampling from unsaturated zone test hole	15 Nov 84
Stemming and in situ instrumentation	TBD	Gas chromatograph calibration	TBD
	HP-17, R0	Method of calibration and testing for the operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-15, R0	Methods for calibrating heat-dissipation sensors for measuring in-situ matric potential within porous media	9 July 84
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84
	TBD	Field procedure for in situ calibration of pressure transducer	TBD

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Method	Technical procedure		
	Number	Title	Date
	TBD	Field procedure for in situ evaluation of thermocouple psychrometers sensor performance	TBD
	TBD	Field procedure for stemming and instrumenting vertical boreholes	TBD
	TBD	Field procedure for stemming and instrumenting horizontal boreholes	TBD
	TBD	Field procedure for logging stemmed borehole	TBD
	TBD	Field procedure for connection of sensor leads and initializing data acquisition system	TBD
	HP-19, RO	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone (UZ) at the NTS	20 July 84
	TBD	Preliminary probe installation and stemming plan for UZ test holes, NTS	TBD
	TBD	Preliminary plan for final checkout and acceptance of instrumentation packages and emplacement into UZ test holes, NTS	TBD
Vertical seismic profiling	TBD	Field procedure for installation of geophone cable array in test holes	TBD

Method	Technical procedure		Date
	Number	Title	
	TBD	Field procedure for continuity testing of geophone cable array prior to and during borehole installation	TBD
	TBD	Field procedure for layout of energy source locations	TBD
	TBD	Field procedure for seismic data acquisition (vertical seismic profiling)	TBD
	TBD	Procedure for data archiving, copying, vertical seismic profiling	TBD
In situ monitoring, data collection, transmission, storage and retrieval--IDAS system	HP-132; RO (in preparation)	Method for stabilizing air temperature inside instrument shelter used for monitoring downhole sensors	TBD
	HP-133, RO (in preparation)	Design of an alarm and warning feedback subsystems used for monitoring messages transmitted by the instrumentation/data acquisition system	TBD
	HP-134; RO (in preparation)	For operation of Hewlett Packard 3497A, 3495 data acquisition/control units, 3498A extension unit, and 3457A multi-meter used to monitor downhole sensors	TBD

Method	Technical procedure		Date
	Number	Title	
	HP-135, RO (in pre- paration)	Procedure for developing data acquisition, tel- emetry, and communica- tions software to access data from remote field sites	TBD

^aTBD = to be determined.

8.3.1.2.2.3.3 Activity: Solitario Canyon horizontal borehole study

Objectives

The objectives of this activity are

1. To examine, on a local and limited scale, the extent of fracturing, brecciation, and gouge development associated with the Solitario Canyon fault.
2. To evaluate, locally, the hydrogeologic significance of fault-related features on water movement within the Solitario Canyon fault zone.
3. To evaluate, based on the findings developed under the first two objectives, whether additional information is needed to characterize adequately hydrologic boundary conditions along the Solitario Canyon fault zone, should the results indicate potentially adverse effects on repository performance.

Parameters

The parameters of this activity are

1. Gravimetric moisture content (ambient/matrix/laboratory).
2. Volumetric moisture content (ambient/matrix/laboratory).
3. Matric potential (ambient/matrix and bulk/laboratory and in situ).
4. Water potential (ambient/bulk/in situ).
5. Thermal potential (ambient/in situ).
6. Pneumatic potential (ambient/in situ).

7. Matrix permeability as a function of saturation and matric potential (laboratory).
8. Matrix pore size distribution.
9. Grain density (laboratory).
10. Bulk density (laboratory).
11. Total porosity (laboratory).
12. Effective porosity (laboratory).
13. Bulk permeability (pneumatic/in situ).
14. Bulk permeability (hydraulic/in situ).
15. Fracture frequency, orientation, spacing, distribution, interconnectedness.
16. Effective width of fault zone.
17. Lateral variation in moisture content.
18. Lateral variations in ambient potential field.

Description

One horizontal borehole is planned for this activity. Its exact location has not yet been determined. A detailed site reconnaissance survey will be required to select an appropriate site. From preliminary analysis of existing geologic maps, it is likely that the selected site will be near the northwestern part of Yucca Mountain (Figure 8.3.1.2-15). The horizontal borehole will be sited to penetrate the Solitario Canyon fault structure at a point where the fault plane (zone) is bounded by blocks of the Topopah Spring welded tuff on both sides. Additional siting consideration will be given to minimizing the length of the borehole but only to the extent that minimization will not compromise the overall objectives of this investigation. It is recognized that the hydraulic properties of the fault zone may vary from unit to unit, but the principal investigative effort will be focused on the Topopah Spring unit because it is the proposed repository host rock.

It is anticipated that the total length of the borehole could be as much as 300 m, depending on final site selection. The borehole will be dry cored and drilled with air to preserve the ambient moisture content of recovered core and cuttings and of the in situ rock mass. The borehole will be drilled at a 2 to 3 degrees inclination downward to a depth at least sufficient to penetrate undisturbed (unfaulted) Topopah Spring tuff. A slight downward deviation of the borehole is preferred to aid in the containment and sampling of perched water should it be encountered during drilling. Core will be scribed during drilling to permit orientation of fracture surfaces. The site geologist will log the structural features onsite shipment of core and cuttings to the laboratory for further testing of matrix hydrologic and physical (parameter listing) properties. Oriented television video camera

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surveys will be run in the borehole following construction and removal of casing. Geophysical logs of the borehole will be obtained during a pause in drilling or upon completion of drilling.

Gas permeability will be measured by injection of nitrogen gas beyond a single packer set every 3 m as drilling proceeds to obtain a continuous permeability profile. Following drilling and casing removal, testing using a single-hole straddle packer configuration will be conducted to the extent that borehole conditions will permit.

Following pneumatic testing, the borehole will be stemmed and instrumented to measure temperature, pressure, matric potential, and water potential. Gas sampling tubes will be provided to permit recovery of pore gas and water vapor for periodic analyses of isotopic, tracer, and gaseous phase chemical composition.

After recovery from the pneumatic testing, water will be injected into the borehole using the gas sampling tubes. These tests will be conducted to measure in situ saturated hydraulic conductivities.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.2.2.3.3 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Borehole drilling and coring	TBD ^a	REECo borehole drilling and coring procedure	TBD
	TBD	REECo casing extraction procedure (ODEX System)	TBD
	TBD	Verification of borehole wall cleaning procedure	TBD
Drill-bit cuttings and core sampling, onsite lithologic analysis and hydrologic measurements	HP-12; R1 (under revision)	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, NTS	30 Mar 87
	HP-74; R0	Use of the Stabil-Therm miniature batch oven	28 Oct 85

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Method	Technical procedure		
	Number	Title	Date
Drill-bit cuttings and core laboratory analysis	HP-32, RO	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-73, RO	Calibration and use of the Sartorius electronic toploader (balance) Model 1507 MPS	29 Mar 85
	HP-13, RO	Collection and field analysis of unsaturated zone ground-water samples	29 Aug 83
	GPP-08, RO	Permeability measurements of rock samples at high pressures and temperatures	1 Nov 84
	GPP-10, RO	Rock property analysis of Yucca Mountain core samples	16 Jan 85
	HP-55, RO	Hydrologic laboratory testing of core and drill-cutting samples from unsaturated zone test holes	9 Sep 85
	HP-18, RO	Frequency of equipment calibration for unsaturated zone testing, Nevada Test Site	20 July 84
	HP-28, RO	Laboratory procedures for the determination of moisture retention curves of rock core	15 May 85
	TBD	Determination of effective porosity from core samples	TBD

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Method	Technical procedure		Date
	Number	Title	
	TBD	Determination of grain density from core samples	TBD
	TBD	Determination of bulk density from core samples	TBD
	TBD	Determination of thermal conductivity from core samples	TBD
	TBD	Determination of resistivity from core samples	TBD
	TBD	Determination of sonic velocity from core samples	TBD
	TBD	Determination of heat capacity from core samples	TBD
Borehole geophysical surveys	HP-62, R1	Method for measuring subsurface moisture content using a neutron moisture meter	16 Mar 87
	HP-18, R0	Frequency of equipment calibration for unsaturated zone testing, Nevada Test Site	20 July 84
	HP-50, R0	Method for neutron scatter and gamma ray attenuation logging using the USGS logging van (I-139055)	15 Nov 84
	GP-10, R0	Borehole video fracture logging	12 Apr 85

Method	Technical procedure		
	Number	Title	Date
	TBD	Frequency and method of calibration of noncommercial logging tools for unsaturated zone testing, Nevada Test Site (NTS)	TBD
	TBD (F&S)	Fenix and Scisson (F&S) frequency and method of depth calibration of commercial logging tools for unsaturated zone testing, Nevada Test Site (NTS)	TBD
	TBD	Frequency and method of depth calibration of noncommercial logging tools for unsaturated zone testing, Nevada Test Site	TBD
	TBD	F&S obtaining original digital or videotape of drillhole using proper speed, depth, and illumination, making copy of the original digital or videotape of drillhole	TBD
Borehole logging of lithology and geology	TBD	Lithologic examination and analysis of bit-cuttings and core samples	TBD
	TBD	Core scribing techniques	TBD
	GP-11, RO	Logging fractures in core	15 May 85
	GP-10, RO (to be revised)	Borehole video fracture logging	12 Apr 85
In situ pneumatic testing	TBD	Pressure sensor and sensor lead calibration	TBD

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Method	Technical procedure		Date
	Number	Title	
	TBD	Temperature sensor and sensor lead calibration	TBD
	TBD	Humidity sensor and sensor lead calibration	TBD
	TBD	Mass flow meter calibration and use	TBD
	TBD	Data logger internal voltmeter calibration	TBD
	TBD	Data acquisition system operation check	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Straddle packer system detection	TBD
	TBD	Straddle packer system placement procedure	TBD
	TBD	Single-hole gas injection test procedure	TBD
	TBD	Pressure pulse gas injection test procedure	TBD
	TBD	Flow test data identification, shipping, handling, and archiving	TBD
Water-injection test	TBD	In situ recalibration of pressure sensor	TBD
	TBD	In situ recalibration of temperature sensor	TBD
	TBD	Pressure sensor and sensor lead calibration	TBD
	TBD	Temperature sensor and sensor lead calibration	TBD
	TBD	Water flow meter calibration	TBD

Method	Technical procedure		
	Number	Title	Date
	TBD	Data logger internal voltmeter calibration	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Procedure for deter- mining test location	TBD
	TBD	Single-hole water injec- tion test procedure	TBD
	TBD	Flow-test data identifi- cation, shipping, hand- ling and archiving	TBD
Stemming and in situ instrumentation	HP-17, R0	Method of calibration and testing for oper- ation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-15, R0	Method of calibrating heat-dissipating sensors for measuring in situ matric poten- tial within porous media	9 July 84
	HP-14, R1	Method for calibrating peltier-type thermo- couple psychrometers for measuring water potential of partially saturated media	9 July 84
	TBD	Field procedure for in situ evaluation of thermocouple psychro- meter sensor performance	TBD
	TBD	Field procedure for stem- ming and instrumenting horizontal boreholes	TBD
	TBD	Field procedure for logging stemmed borehole	TBD

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Method	Technical procedure		
	Number	Title	Date
	TBD	Field procedure for connection of sensor leads and initializing data acquisition system	TBD
	HP-19, RO	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at the NTS	20 July 84
	TBD	Preliminary probe installation and stemming plan for unsaturated zone test holes, NTS	TBD
	TBD	Preliminary plan for final checkout and acceptance of instrumentation packages and emplacement into unsaturated zone test holes, NTS	TBD
In situ monitoring, data collection, transmission, storage and retrieval-IDAS system	HP-132, RO (in preparation)	Method for stabilizing air temperature inside instrument shelter used for monitoring downhole sensors	TBD
	HP-133, RO (in preparation)	Design of an alarm and warning feedback subsystem used for monitoring messages transmitted by the instrumentation/data acquisition system	TBD
	HP-134, RO (in preparation)	For operation of Hewlett Packard 3497A, 3495 data acquisition/control units, 3498A extension unit, and 3457A multimeter used to monitor downhole sensors	TBD

Method	Technical procedure		Date
	Number	Title	
	HP-135, RO (in pre- paration)	Procedure for developing data acquisition, tele- metry, and communications software to access data from field sites	TBD

^aTBD = to be determined.

8.3.1.2.2.4 Study: Characterization of Yucca Mountain percolation in the unsaturated zone--exploratory shaft facility study

This study consists of eight individual sets of hydrologic tests that will be conducted in the exploratory shaft facility (ESF), including in the exploratory shaft itself and in rooms and drifts associated with the various breakout levels (see Section 8.4.2). The ultimate purposes of the ESF hydrologic tests are to (1) supplement and complement the surface-based hydrologic information needed to characterize the Yucca Mountain site and (2) provide information for analyzing fluid flow and the potential for radionuclide transport through unsaturated tuff. The integrated results from the ESF hydrologic tests will be combined with data from the surface-based studies to provide an overall understanding of the unsaturated-zone hydrologic system.

The design of the ESF hydrologic tests is principally based on the initial conceptual unsaturated-zone hydrologic model for the site (Montazer and Wilson, 1984). These tests are different from those being conducted as part of the surface-based investigations, in that the ESF tests are designed to provide phenomenologic information about water flow through unsaturated fractured tuffs, in addition to providing basic hydrogeologic data.

The ESF test data will include hydrologic information that is not readily obtainable from the surface-based boreholes, by providing a testing environment that is suitable for three-dimensional characterization of the rock mass. Large volumes of rock will be studied in situ, and experiments will be designed to provide information in various directions. Lateral variations will be studied through horizontal drifts and boreholes and by careful mapping of large areas of underground rock exposure. Excavation of the shaft will produce large volumes of rock that can be used for determination of water chemistry and for laboratory analyses of rock/hydraulic properties. In addition, a relatively good representation of fracture orientation, distribution, and continuity will be available in the walls of the excavations. Therefore, correlation between hydrologic and geologic information will be made with a higher level of confidence. Samples of rock containing intact fractures will be obtained from various locations within the underground openings. Results of hydraulic tests on such samples are expected to be representative of in situ conditions. Infiltration tests will be conducted in

a rock mass that is not disturbed by weathering and is thus representative of the repository host rock. Large-scale bulk permeability tests are possible only in an underground environment.

In addition to providing data that could not be readily or adequately obtained from surface-based boreholes, the ESF will be the source of a large amount of supplementary hydrologic data. In order to obtain from a surface-based program the types and amounts of data comparable to those that will be produced from the shaft, many deep, instrumented, unsaturated-zone boreholes in close proximity to each other would be required.

The planned ESF tests described in this study are the (1) intact fracture test, (2) water flow and chemical transport through fracture networks in variably saturated welded tuff test, (3) bulk permeability test, (4) radial boreholes test, (5) excavation effects test, (6) Calico Hills test, (7) perched water test, and (8) hydrochemistry tests. These ESF tests are described in detail in the following activities. Plans for these have been evolving as reviews have been conducted and the exploratory shaft facility (ESF) designs have been modified. The activity descriptions in the SCP represent the plans as they existed at some point in time; they do not necessarily represent current thinking exactly, nor are they necessarily fully consistent with ESF designs presented elsewhere in this document (Section 8.4.2). Revisions of these activities that reflect updated versions of the tests will be included in progress reports of this document.

The intact fracture test will evaluate the conductive properties of individual fractures to assess the in situ behavior of fracture systems. Matric potentials, moisture content, and the characteristic conductivity relationships will be measured in the laboratory. Properties of single fractures selected for testing require undisturbed sampling, to be accomplished by overcoring a tensioned rock-bolt set in a hole normal to each candidate fracture. Fracture specimens, instrumented with low-voltage displacement transducers to register aperture changes, will be tested with radial flow of air and water at different stress levels and with differing fracture saturations. By injecting a conservative tracer and observing breakthrough concentrations, measures of single-fracture dispersivity and retardation by matrix diffusion will be obtained. Details of flow channelization on a single fracture surface will be observed by dye-tracing and film registration. Discrete fracture computer modeling will assist the work of establishing porous media equivalent properties. Because many aspects of this test are not standard, prototype testing will be performed to develop testing techniques and evaluate the limitations and usefulness of the resulting data.

Conceptual and model work on double-porosity media will be included in several activities, especially the infiltration test (Activity 8.3.1.2.2.4.2). The properties of individual fractures in this environment are fundamental to developing valid concepts of flow. The test of water flow and chemical transport is a basic investigation of properties of the Topopah Spring welded tuff at the repository horizon, aimed at resolving the contributions of fracture and matrix flow under varying artificial infiltration rates. Tracer-tagged water will be trickled uniformly on a sand bed on the floor of a drift underlain by fractured rock instrumented with a number of boreholes. Logging, fracture mapping, and nitrogen-injection packer tests will characterize the

conduit system, along with laboratory tests of the matrix permeability. This in situ test will provide well-controlled boundary conditions (flux and gradient) on a scale that may be judged representative of the formation fracture system. The lowest measurable rate will include some fracture flow, thus applied fluxes representing various climatic conditions and the measured potentials will define the characteristic variation of fracture system hydraulic conductivity versus potential, a property required for travel time and transport calculations. This test is an opportunity to define conditions for the initiation of significant fracture flow and the propagation of infiltration pulses via fractures. The test requires knowledge of the rate of matrix uptake through fracture walls, under a range of antecedent moisture conditions in the matrix.

The relationship between effective permeability for air and for water will be investigated, so the numerous packer air tests in boreholes can be interpreted for hydraulic conductivities. Hysteresis will be investigated, if possible, by reversing the sequence of steady state fluxes applied. Anisotropy and the dip of the beds may result in lateral flow components. Consideration of steady state potential distributions across the various units for different fluxes suggests that above the contacts of units of different characteristics, gradients other than unity prevail, and since the beds dip 5° to 10° east, the gradient can have small lateral components, aligned with or against the dip direction. A fundamental understanding of tracer velocity and effective porosity, the convective dispersion tensor and matrix diffusion can also be obtained from the test, since the fracture system geometry will be well described. Numerical modeling will be required at several stages. Tracer tests will be conducted in a cluster of vertical holes, with the objective of determining the dispersion properties of the medium by gas injection and sampling. Single-well and multiple-well configurations will be used. After several years of gas-phase monitoring at these test holes, the gas-sampling tubes will be used to inject water in a series of tests to determine saturated hydraulic conductivity and aqueous dispersive properties.

Dispersivity may be predicted by digital modeling of the medium. Because of the fractured and low-matrix permeability environment in which this test is to be conducted, this test will be prototyped on a large scale and various pretest numerical analyses will be performed to evaluate test feasibility. Because water movement in unsaturated welded tuff matrix is expected to be very slow, only small changes in hydrologic characteristics may be detectable on the time-scale available in which to perform this experiment. Prototype instrumentation to be used to monitor hydrologic characteristics will also be developed. After prototype testing and numerical analyses have been performed, the most effective approach to performing the test as a site characterization activity will be evaluated.

The bulk permeability test is designed to measure air flow to and from a closed chamber of 10 by 10 by 50 ft (3 by 3 by 15 m) dimensions to obtain the average conductivity of a much larger mass surrounding the chamber that contains a large number of different fracture conduits. If the distribution of fracture apertures, spacings, and orientations were known from independent single-fracture or packer tests, it would be possible to compute the volume required to include a sufficiently large number of conduits so that the bulk

permeability provides a representative average within a specified tolerance. Lack of confidence in the application of this approach arises because the discharge within individual fractures depends on the cube of the apertures, whereas the bulk depends on some ill-defined continuity, homogeneity, and interconnectivity within the system. A larger fracture, perhaps a fault, may be encountered as the volume increases. Because the population of fracture discharges may become unbounded, modeling must incorporate as discrete features all conduit sizes outside the range sampled for a bulk system. The application of continuum theory to discontinuous properties is thought to require definition of a representative elementary volume (REV), below which discrete models of individual conduits must be used, and above which continuum average properties are justifiable within large-scale boundaries, such as faults, excluded from the sample.

For the bulk permeability test, after suitably detailed fracture mapping and borehole logging is done, an arrangement of boreholes is to be drilled along the principal permeability axes. To measure the size effects, cross-hole packer tests at increasing scales are to be run to determine the volume yielding values asymptotic to the chamber test value. The bulk air conductivity values will be directly applicable to the analysis of room, repository, or larger-scale gas-phase flow and transport models, and with minor modifications, for analysis of saturated flow at similar scales since the larger fracture openings will dominate the bulk air and saturated water conductivities. But the full range of effective hydraulic conductivities and scale effects require water testing. For that purpose, the many drillholes in the bulk permeability test arrangement will be packer-tested with water after all air testing is completed. Steady state testing at a range of saturations will not be possible but an estimate of the REV can be obtained because it is probably measured by small multiples of fracture spacing when flow through the matrix is interrupted by many no-flow air gaps and channelled through numerous fracture surface contacts and wedge-outs where saturation makes them conductive for cross and parallel flow.

As with the previous test, the innovative nature of this experiment is recognized and prototype testing will be performed. The results of this test are expected to provide valuable information on scale effects on hydrologic characteristics. As well as prototyping instrumentation and experimental techniques, technical procedures will be developed and analysis techniques to interpret the resulting data will be evaluated. The results of these activities will support evaluation of the experiment for use in site characterization activities.

The radial boreholes in the radial boreholes test will be the principal means of eliminating the bias of vertical holes that are incapable of characterizing rocks dominated by near-vertical fractures. In this test, radial boreholes will be drilled in the exploratory shaft at 8 depth horizons. Orientation of the boreholes in each set will be determined by analyzing fracture orientation data, and an attempt will be made to drill parallel to the minimum and maximum directional permeability axes. Core will be logged to describe the physical characteristics of the rock. In situ hydraulic testing and long-term monitoring will be conducted to (1) detect vertical movement of water, in both vapor and liquid forms, (2) evaluate the potential for lateral movement of water along the hydrogeologic contacts, (3) estimate tortuosity and effective porosity of the drained pore spaces of the hydrogeologic units,

(4) determine the effective vertical permeability to air of the various hydrogeologic units, and (5) evaluate the effects of excavation of the shaft on the hydrologic properties of the hydrogeologic units. Prototype testing will be performed in support of this test to evaluate cross-hole and pneumatic testing and to develop instrumentation and techniques required to measure hydrologic characteristics in welded tuff.

The excavation effects on permeability will be related to stress changes in the excavation effects test. Tests will be completed in the nonwelded Paintbrush Tuff and in the Topopah Spring welded tuff. The conceptual design of this test is based on the assumption that excavation of ES-1 will cause opening or closure of fractures at various locations in the vicinity of the shaft. These deformations will modify the hydrologic properties and conditions of the rock mass, which will be detectable by measurements made at various times during shaft construction. Orientation of the fractures with respect to the shaft is important in determining the type of modification that might occur. As planned, these tests will be conducted in 27 vertical and angled boreholes drilled in radial arrangements in the floors of each of the two breakout rooms. Permeabilities will be measured by packer-injection testing of nine of the 27 boreholes. Neutron logging will be used to measure moisture content. Directional deformations will be measured in the other 18 boreholes by installation of deformation and load measuring devices. Quantitative evaluation of stress-dependent conductivity will be made, so that future loading effects can be modeled.

Hydrologic properties of the unsaturated Calico Hills tuff are critical to the calculation of radionuclide travel time and transport between the repository and the water table; thus a breakout from the exploratory shaft and numerous vertical drillholes into the Calico Hills are planned. The main purposes of the Calico Hills tests are to investigate whether water moves through the nonwelded units by matrix or fracture flow, whether the Ghost Dance fault is continuously conductive across the nonwelded unit, how perched water may develop in or above the zone, and lastly, what is the potential for retardation of radionuclides moving in fractures by sorption and matrix diffusion. One vertical hole drilled from the lower breakout room in the Topopah Spring tuff to about 15 m below the top of the Calico Hills tuff will mainly monitor construction damage relating conductivity changes due to the excavation. A second vertical hole, drilled about 140 m deep from the Calico Hills breakout will penetrate the water table and provide samples, potentials, conductivities, and instrumental records of that important interval. Lateral boreholes will be drilled for the purposes of monitoring construction effects and to investigate the structure of the Ghost Dance fault within the Calico Hills nonwelded unit. Cross-hole hydraulic and tracer tests will be conducted in the fault zone between the Calico Hills hole and a hole cutting the fault at the lower breakout level. Four sets of holes drilled radially to the shaft in the Calico Hills zone will also provide structural and cross-hole hydrologic data. All holes will be optically and geophysically logged and packer tested with gas; standard laboratory tests of matrix properties will be done so that the nature of relative matrix and fracture permeabilities can be determined. Tracer tests are to establish effective porosities of matrix (laboratory) and fracture (field) systems, as well as to measure retardation factors, especially in the very sorptive zeolitized tuffs.

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

Objectives

The objective of this activity is to evaluate fluid-flow and chemical-transport properties of single relatively undisturbed fractures as a function of stress.

Parameters

The parameters of this activity are

1. Effective permeabilities to air and water as functions of saturation, water potential, and normal stress.
2. Dispersivity of fractures.
3. Flow-path tortuosity in fractures.
4. Fracture aperture roughness and contact area.

Description

Photographs of all exposed surfaces in the exploratory shaft, main underground drifts, and the major breakout horizons will be taken. Mapping will vary in extent throughout these areas. Individual fractures, joint sets, and fracture networks will be mapped in areas where samples may be collected for the laboratory intact fracture tests. The photographic survey will be included as a part of the mapping process to provide a convenient, permanent record of the exposed fracture trace patterns and an additional source for comparison with the fracture maps. Three-dimensional projections of individual fractures will be determined from two-dimensional fracture maps and fracture orientation data. Suitable fracture sampling locations will be determined from the three-dimensional projections. Fillings and pieces of intact fractures will be collected and analyzed. The results are expected to allow determination of which fractures are induced and which are natural.

For the radial flow studies, a bolting and overcoring method will be used to obtain samples containing fractures that are approximately parallel to the mined surface. These samples are collected by first drilling a pilot hole perpendicular to the fracture; the fracture is then secured by a rock bolt, which holds the fracture together during core extraction, minimizing damage to the fracture plane. The sample is overcored and broken off with a core shovel. Prototype testing will be performed to develop the bolting and overcoring techniques and associated technical procedures. Approximately five fracture samples will be collected from each of four general areas where drift-wall mapping has indicated there are suitable locations for coring. The four units to be sampled are: the Tiva Canyon, Pah Canyon, and Topopah Spring members of the Paintbrush stratigraphic unit, and the Calico Hills stratigraphic unit. The pilot hole will be approximately (0.75 in.) 1.9 cm in diameter and will be drilled 5.9 in. (15 cm) beyond the fracture.

Intact fractures that are parallel to the axis of the extracted cores will also be collected in approximately the same numbers from the same areas for use in the axial flow studies. These samples will be obtained by first drilling two NX-sized boreholes, which are relatively parallel to the fracture and are diametrically opposed to each other on the periphery of where the overcore will be drilled. The fracture will then be overcored (with the NX boreholes on the periphery of the overcore cut). Circumferential clamps will be placed around the overcore (placing the union of the clamp in one of the NX boreholes, so that it can be tightened) starting at the farthest end of the overcore with each subsequent clamp closer to the mined surface. Before the core is broken off with a coring shovel, plaster is placed across the fracture aperture. Any change in the plaster (i.e., cracking when the overcore is broken) would indicate that the fracture had been disturbed.

Onsite and offsite laboratory determinations will be made of the hydraulic properties of the rock matrix in the same borehole that the intact-fracture sample is collected from. Gravimetric water content analyses will be performed locally to insure water content does not change as a result of handling, shipment, or exposure to air. The matrix parameters to be determined offsite include matric potential (via psychrometry and tensiometry), water content (volumetric), bulk density (liquid displacement), water potential (Richard's psychrometer), liquid and gas permeability (steady state), relative permeability (diffusivity), and porosity (Boyle's Law using helium and/or mercury intrusion). The samples for testing will be collected from portions of the overcore that break off when a core shovel is used to separate the intact fracture sample from the remaining overcore, from core previous to actual sample collected, and from material remaining after the core is trimmed to fit the confining vessel.

Laboratory injection tests will evaluate two-phase flow properties, particularly the permeability to both water and air at varying stages of saturation. The tests will be conducted under constant loading conditions by monitoring transient outflow of both air and water phases during injection of either fluid. Tests will be conducted on approximately four intact fracture samples from each of the four hydrologic units to be sampled.

Tracer injection laboratory tests will be used to evaluate the role of the rock matrix in retarding the diffusion of solutes. Tracers will be injected into the intact fracture samples and their concentrations will be monitored over space and time. The data collected will be used to construct breakthrough curves. These curves will be used to determine if contaminant diffusion into the matrix from the fractures could occur and to what extent. Dispersivity tests will be conducted on approximately four intact fracture samples from each of the aforementioned units. Tracers may also be used in the fluid- and air-injection laboratory tests to distinguish between sample and injected fluids.

Flow channelization in the fracture plane of three or four intact-fracture samples will be quantitatively and qualitatively described in laboratory tests by recording the amount of fluid introduced over time and observing the movement of dye-tagged water across the plane of a fracture. Fracture-plane roughness, which is an important factor in characterizing flow-channelization, will be determined before fracture closure by inserting a pliable polymer film between the fracture walls. Impressions in the film

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will be traced and used to calculate contact area and the distribution of contact points. In addition, a low melting point metal injection technique developed by L. J. Pynak-Nolte, N.G.W. Cook, L. R. Myer, and P.A. Witherspoon (Lawrence Berkeley Laboratory), in which metal is used to obtain a cast of the flow channels, may also be used to determine the topography of the flow channels between the contact points. The core will be taken apart at the conclusion of the test and photographs taken of the fracture plane to record the fluid movement pattern.

Because of the innovative techniques to be used in this activity, prototype testing will be performed before initiation of this activity to develop methods and procedures. In particular, the laboratory injection tests to evaluate fracture two-phase flow properties, the tracer injection tests, and the flow channelization tests will be prototyped.

Stress permeability tests will be conducted in the laboratory by injecting liquids and gases into the sample under varying simulated stress conditions using a triaxial compression cell and a loading frame apparatus. Flow rates of injected liquids and gases will be held constant to indicate how permeability is affected by stress-induced aperture variations. Flow rate, vertical displacement, and water pressure will be measured at each loading step up to the maximum and then every unloading step back to zero. Testing will be performed on three or four intact fracture samples.

A computer model of fluid flow in discrete fractures will be used to design and predict the results of the intact fracture tests for planning purposes. The codes will determine the conditions necessary for optimizing the test procedures. The results of the laboratory tests will then be used to calibrate models used in subsequent larger-scale tests (infiltration and bulk permeability tests) where fracture-flow properties will also be studied.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.1 are given in the following table:

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Fracture mapping and analysis	MDP-01, RO	Identification, handling, storage, and disposition of drill-hole core and samples	15 Oct 81
	GP-02, RO	Subsurface investigations	1 Mar 83
	GP-05, RO	Geologic support activities	1 Mar 83

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Method	Technical procedure		Date
	Number	Title	
Fracture sampling by bolting and overcoring method	TBD ^a	Geochemical procedures (LANL)	
	TBD	Mapping fractures on drift and breakout surface procedure	TBD
	TBD	Photographing fractures on drift and breakout surface procedure	TBD
	TBD	Fracture sampling by bolting and overcoring procedure	TBD
	GP-11, RO	Logging fractures in core	15 May 85
Fracture sampling by clamping and over- coring method	TBD	Procedures for handling and shipment of intact fracture core samples	TBD
	TBD	Fracture sampling by clamping and over- coring procedure	TBD
	GP-11, RO	Logging fractures in core	15 May 85
	TBD	Procedures for handling and shipment of intact fracture core samples	TBD
Onsite laboratory hydraulic properties testing of core	HP-32, RO	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-55, RO	Hydrologic laboratory testing of core and drilling-cutting samples from unsatur- ated zone test holes	9 Sept 85

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Method	Technical procedure		Date
	Number	Title	
Offsite laboratory hydraulic properties testing of core	HP-73, RO	Calibration and use of the Sartorius Electronic Toploader (Balance) Model 1507 MPS	29 Mar 85
	HP-74, RO	Use of the Stabil-Therm miniature batch oven	28 Oct 82
	HP-69, RO (draft)	Construction and operation simple tensiometers	TBD
	HP-123, RO (draft)	Development of tensio- meter-transducer equip- ment and techniques for measuring the matric potential of minimally disturbed core from Yucca Mountain	TBD
	HP-95, RO (draft)	Tensiometer calibration	TBD
	ASTM D1188-71	Determination of volu- metric water content using liquid displace- ment procedure	TBD
	HP-55, RO	Hydrologic laboratory testing of core and drilling-cutting samples from unsaturated zone test holes	9 Sep 85
	ASTM D1188-71	Bulk density determi- nation using liquid displacement procedure	TBD
	HP-30, RO	Calibration and opera- tion procedure for Quantachrome stereo- pycnometer Model SPY-2 USGS petrophysics laboratory Denver, CO	15 May 85

Method	Technical procedure		
	Number	Title	Date
	API RP-27	Determination of saturated liquid and gas permeability procedure (steady state)	TBD
	Passioura, 1976	Determination of relative permeability (diffusivity) procedure	TBD
	HP-47, RO	Method of operating Micrometric series 910 mercury penetration porosimeter USGS petrophysics laboratory, Denver, CO	14 Aug 84
Fluid (water/air) injection laboratory tests	TBD	Laboratory procedure for determining effective permeability by fluid-displacement tests under constant loading: steady state (+transient) air-injection method	TBD
	TBD	Laboratory preparation of intact fracture samples for triaxial compression cells in a loading frame apparatus and stress-strain instrumentation	TBD
	TBD	Laboratory procedure for determining effective permeability by fluid displacement tests under constant loading: steady state and transient, water-injection method	TBD
	TBD	Laboratory procedure for operation of flow meter apparatus for gas injection in intact fracture samples	TBD

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Method	Technical procedure		Date
	Number	Title	
Stress permeability tests	TBD	Laboratory procedure for operation of flow meter apparatus for liquid injection in intact fracture samples	TBD
	TBD	Laboratory calibration of linear variable differential transformers	TBD
	TBD	Laboratory calibration of pressure transducers for loading frame apparatus	TBD
	TBD	Laboratory calibration of strain gages for loading frame apparatus	TBD
	TBD	Laboratory procedure for operation of triaxial compression cell in a loading frame apparatus	TBD
	TBD	Laboratory procedure for preparation and installation of automated data acquisition system (DAS)	TBD
	TBD	Procedure for analyzing data collected from DAS	TBD
	TBD	Laboratory procedure for determining stress-permeability relations using a loading frame apparatus	TBD
	TBD	Laboratory preparation of intact fracture samples for triaxial compression cells in a loading frame apparatus and stress-strain instrumentation	TBD

Method	Technical procedure		Date
	Number	Title	
	TBD	Laboratory procedure for operation of flow meter apparatus for gas injection in intact fracture samples	TBD
	TBD	Laboratory procedure for operation of flow meter apparatus for liquid injection in intact fracture samples	TBD
	TBD	Laboratory calibration of linear variable differential transformers	TBD
	TBD	Laboratory calibration of pressure transducers for loading frame apparatus	TBD
	TBD	Laboratory calibration of strain gages for loading frame apparatus	TBD
	HP-14, R1	Method for calibrating Peltier type thermocouple psychrometers for measuring water potentials of partially saturated media	9 July 84
	HP-69, R0 (draft)	Construction and operation of simple tensiometers	TBD
	HP-123, R0 (draft)	Development of tensiometer-transducer equipment and techniques for measuring the matric potential of minimally disturbed core from Yucca Mountain	TBD
	HP-95, R0 (draft)	Tensiometer calibration	TBD

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Method	Technical procedure		Date
	Number	Title	
Tracer-injection (dispersivity) laboratory tests	TBD	Laboratory procedure for monitoring water content of core samples using electrical resistivity techniques	TBD
	TBD	Laboratory procedure for monitoring tracers (ionic/radioactive) in core fluids	TBD
	TBD	Laboratory procedure for using a triaxial compression cell in a loading frame apparatus	TBD
	TBD	Laboratory procedure for preparation and installation of automated DAS	TBD
	TBD	Laboratory procedure for operation of automated DAS	TBD
	TBD	Analysis of data collected from DAS procedure	TBD
	TBD	Laboratory procedure for tracer injection (dispersivity) in intact fracture sample with constant loading	TBD
	TBD	Laboratory procedure for operation of flow meter apparatus for liquid injection in intact fracture samples	TBD

Method	Technical procedure		Date
	Number	Title	
	HP-14, R1	Method for calibrating Peltier type thermocouple psychrometers for measuring water potentials of partially saturated media	9 July 84
	HP-69, R0 (draft)	Construction and operation of simple tensiometers	TBD
	HP-123, R0 (draft)	Development of tensiometer transducer equipment and techniques for measuring the matric potential of minimally disturbed core from Yucca Mountain	TBD
	HP-95, R0 (draft)	Tensiometer calibration	TBD
	TBD	Laboratory procedure for sampling injected fluids in outflow from an intact fracture sample in a loading frame	TBD
	TBD	Laboratory procedure for determination of breakthrough curves of tracer concentration in intact fracture samples	TBD
	TBD	Procedure for calculating dispersivity from breakthrough curves	TBD
	TBD	Preparation and installation of automated laboratory data acquisition system	TBD

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Method	Technical procedure		Date
	Number	Title	
Flow channelization laboratory tests	TBD	Operation of automated laboratory data acquisition system	TBD
	TBD	Analysis of data collected from data acquisition system	TBD
	TBD	Laboratory procedure for characterizing flow channelization in intact fracture samples: photographic methods	TBD
	TBD	Laboratory procedure for characterizing flow-channelization in intact fracture samples: fluorescent dye penetration method	TBD
	TBD	Laboratory procedure for using a simple mounting frame to control fracture aperture	TBD
	TBD	Laboratory method for characterizing flow channelization in intact fracture samples: impressionable polymer film method	TBD
	TBD	Preparation and installation of automated laboratory data acquisition system	TBD
	TBD	Operation of automated laboratory data acquisition system	TBD
	TBD	Analysis of data collected from data acquisition system	TBD

Method	Technical procedure		Date
	Number	Title	
Intact fracture test modeling	TBD	Computer for single, variably saturated fractures	TBD
	TBD	Procedure for calibrating a computer flow model for discrete, variably saturated fractures	TBD

^aTBD = to be determined.

8.3.1.2.2.4.2 Activity: Infiltration tests in the exploratory shaft facility

Objectives

The objective of this activity is to determine the hydrologic conditions that control the occurrence of fracture and matrix flow.

Parameters

The parameters of this activity are

1. Unsaturated hydraulic conductivities to air and water as functions of water saturation and matrix potential (including the determinations of critical saturation).
2. Effective porosities of matrix and fractures.
3. Total or hydraulic potential.
4. Volumetric flux and travel time through the rock mass.
5. Directional water velocity distributions.
6. Convective dispersion and matrix diffusion coefficients.
7. Fracture spacings, orientations, connectivity, and apertures.

Description

A test room will be excavated on the lower breakout horizon of the exploratory shaft for the purpose of conducting the infiltration tests. Individual fractures, joint sets, and fracture networks will be mapped along

the exposed surfaces of the infiltration test room, as part of the geologic mapping project (Activity 8.3.1.4.2.2.4). Photographs of the test room surfaces will also be taken to provide a record of the fracture trace patterns and add an additional source for comparison with the fracture maps. Fracture orientations and three-dimensional projections will be determined from the mapping and photographic data.

The walls, floor, ceiling, and all other exposed surfaces of the test room will be covered with an impermeable lining. The purpose of the lining is to prevent evaporation from surfaces of the room; such evaporation would complicate the analysis of the test. The mode of lining installation and its effectiveness will be determined during prototype testing. A ventilation door will then be installed near the entrance to the room. This door will be completely sealed on all sides and around inlet and outlet ventilation ducts. Instrumentation will be installed to monitor air pressure, temperature, and relative humidity of both incoming and outgoing ventilation.

A sand bed and flow tank apparatus will be installed on the floor of the test room to provide a medium for controlled and uniform rates of infiltration. The sand bed will consist of a framed-in box filled with well-sorted sand, an array of heat dissipation probes, tensiometers, thermocouple psychrometers and a trickler system.

Twelve horizontal boreholes (5 to 6 cm in diameter, 8 to 10 m in depth) will be drilled in three rows beneath the test room level using air-drilling techniques (Figure 8.3.1.2-16). The boreholes in the lower two rows will be oriented in fan-like patterns with angles that will be determined from the results of fracture mapping. Four vertical holes (5 to 6 cm diameter, 5 m depths) will be drilled with air in the floor of the test room and cased with steel. Cores will be obtained for onsite determination of fracture geometry parameters, moisture content, and matric potential. Coring methods that maximize core retrieval will be selected.

All boreholes will be surveyed for fracture locations using standard downhole geophysical methods including caliper, gamma, neutron, and resistivity. In addition, television logs, and perhaps cross-hole geotomography methods will be used, where applicable. The core from all horizontal and vertical cores will also be logged in detail for fracture locations and geometric parameters (i.e., fracture spacing, orientation, aperture roughness). When fractures are identified, their location, strike, and dip will be measured and recorded. When available, other features will be determined such as length of trace, surface roughness (of fracture walls), fill materials, degree of weathering, mineralized coatings, and aperture.

Onsite laboratory determinations will be made of the hydraulic properties of the rock matrix in the core sample (Activity 8.3.1.2.2.3.1, matrix hydrologic properties laboratory analyses). The analyses will be performed locally in order to minimize the disturbance of those properties by handling, shipment, and exposure to air. The parameters to be measured include moisture content (gravimetric and volumetric), moisture retention, water and matric potential (via psychrometric heat-dissipation sensing), grain density, porosity, and bulk density. From these measurements, hydraulic conductivities and relative permeabilities will be calculated.

(a) VERTICAL CROSS SECTION

(b) PLAN VIEW

Figure 8.3.1.2-16: Conceptual design of the infiltration test.

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Samples of core from all the boreholes will be collected for tracer injection tests in the laboratory. A conservative or nonreactive tracer will be injected into a rock sample under steady state flow conditions. Tracer concentrations will then be monitored over time and distance traveled using lysimeters. Breakthrough curves (concentration versus time) that allow for the effects of mechanical dispersion or molecular diffusion will be determined from the data.

Air-injection packer tests (using nitrogen gas) will be performed in all horizontal and vertical boreholes. Packer spacing will be designed to isolate discrete fractures or fracture zones, as determined from drift wall mapping and borehole logging. A straddle packer system, consisting of packers, pressure transducers, thermocouple psychrometers, and temperature thermocouples, will be installed in each hole. After packer inflation, nitrogen will be injected until steady state conditions are reached. The packer tests will provide additional information on the geometry and conductivity of fractures. This information will then be used in refining a preliminary computer model of the test set up. Such a productive model will consist of a code capable of simulating variably saturated flow in nonhomogeneous and nonisotropic rock with discrete fractures using the finite element approximation method. The particular code to be used is currently being developed.

To monitor both short- and long-term infiltration (a few days or less as opposed to a period of months), boreholes will be divided into two groups. Boreholes drilled on the left side of the long axis of the test room will be instrumented for long-term monitoring of temperature, air pressure, relative humidity, water potential, and tracer concentration. Boreholes on the right side will be used to monitor in situ tracer detection, packer tests, and to log moisture content and temperature. This arrangement will allow for test monitoring on each side without disturbance of the flow regime and permits a greater variety of instruments to be used. The exact types of instruments, tracers, and methods for in situ tracer detection will be determined during prototype testing.

The infiltration testing will consist of trickling tracer-tagged water into the sand bed and monitoring tracer concentration in the boreholes as the fluid passes through the fractured rock mass beneath the test bed. A suitable tracer will be selected during prototype testing. A constant water flux will be maintained and infiltration will proceed until steady state conditions are reached or, at least, approached with some degree of certainty. It is recognized that the time required to induce large changes over the tested volume of tuff matrix may be quite long because of the very low permeability of the tuff matrix. Prototype testing and numerical simulations will determine the likelihood of achieving steady state conditions in the rock mass and whether changes will need to be made in the test design if steady state conditions cannot be achieved or approached. This activity may be further modified when the prototype testing and numerical simulations have been completed. Then, a tracer will be applied to the sand bed and its movement will be predicted by computer modeling for a predetermined length of time. Increasing the infiltration rate in increments will be continued until fracture flow is initiated. The flow tank apparatus will control the flow of water and tracer through the trickler system. Different sized tanks, each instrumented with differential pressure transducers and flow meters, will be

used to provide a range of flow rates. The system will be designed to automatically adjust the flow rate based on signals from the sand bed instruments, flow meters, or both. The local data acquisition system will control these feedback mechanisms, as well as provide for long-term monitoring of flow rates and water potential distributions. Fracture flow will be assumed to have occurred when discrete fractures in the middle row of boreholes show significant differences in water potential from that in the matrix.

Three-dimensional, variably saturated transport computer models will be used to predict the test outcome for test design purposes, and following comparison and calibration with actual test results, estimate and characterize the anisotropy of various hydrologic parameters for the same volume of rock. Two basic types of models will be used: (1) those incorporating discrete fractures and (2) those using the continuum or dual-porosity approach. Both models may be used to predict hydrologic responses and parameters in larger volumes of rock given the outcome of the infiltration test. The models will also be used in concert with simulations and data from other exploratory shaft tests (i.e., intact fracture and bulk permeability tests) to define the representative elementary volume (REV).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.2 are given in the following table:

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Test room location and excavation	TBD ^a	USGS geological procedure for mapping fractures in underground drifts and test rooms	TBD
Borehole drilling and coring	TBD	Reynolds Electrical and Engineering Company (REECo) dry drilling and coring procedure—horizontal and vertical holes	TBD
	TBD	Borehole cleaning and verification technique	TBD
	TBD	Permeability tensor determination for borehole location	TBD

CONSULTATION DRAFT

Method	Technical procedure		Date
	Number	Title	
Sampling, lithologic examination, and hydrologic analysis of bit-cutting and core samples	MDP-01, RO	Identification, handling, storage, and disposition of drill-hole core and samples	15 Oct 81
	GP-05, RO	Geologic support activities	1 Mar 83
	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, NTS	30 Mar 87
	HP-18, RO (to be revised)	Frequency of equipment calibration for unsaturated zone testing, Nevada Test Site (NTS)	20 July 84
	HP-28, RO	Laboratory procedures the determination of moisture retention curves on rock core	15 May 85
	HP-32, RO	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-55, RO	Hydrologic laboratory testing of core and drilling-cutting samples from unsaturated zone test holes	9 Sep 85
	HP-73, RO	Calibration and use of the Sartorius electronic top loader (Balance) Model 1507 MPS	29 Mar 85
	HP-74, RO	Use of the Stabil-Therm miniature batch oven	28 Oct 85

CONSULTATION DRAFT

Method	Technical procedure		
	Number	Title	Date
	HP-123, RO	Development of tensio-meter-transducer equipment and techniques for measuring the matric potential of minimally disturbed core from Yucca Mountain	TBD
	HP-131, RO	Method for handling and transporting unsaturated core for hydrochemical analysis	TBD
Borehole video surveys	TBD	Fenix & Scisson (F&S) borehole video and logging survey procedure-horizontal and vertical holes	TBD
	TBD	Borehole video fracture logging in horizontal holes	TBD
	GP-10, RO	Borehole video fracture logging (vertical holes)	TBD
Borehole geophysical surveys and logging	TBD	F&S geophysical logging procedure for horizontal and vertical holes	TBD
	TBD	Procedure for determining porosity from compensated-density logging	TBD
	TBD	Procedure for determining moisture content profiles from induction logging	TBD
	TBD	Procedure for determining formation boundaries from spectra-gamma logging	TBD

CONSULTATION DRAFT

Method	Technical procedure		Date
	Number	Title	
In situ pneumatic testing	TBD	Procedure for determining moisture content profiles from dielectric logging	TBD
	TBD	Method for measuring moisture content using a neutron moisture meter in horizontal holes	TBD
	TBD	Neutron moisture meter calibration for horizontal holes	TBD
	HP-62, R1	Method for measuring subsurface moisture content using a neutron moisture meter	16 Mar 87
	HP-96, R0	Neutron moisture meter calibration (vertical holes)	TBD
	HP-122, R0	Development of borehole geophysical laboratory calibration methods	TBD
	HP-17, R0	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84
	TBD	Laboratory procedure for calibration of thermal sensors	TBD

CONSULTATION DRAFT

Method	Technical procedure		Date
	Number	Title	
	TBD	Laboratory procedure for mass flow meter calibration	TBD
	TBD	Laboratory procedure for data logger internal voltmeter	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Straddle packer system leak detection	TBD
	TBD	Straddle packer system placement procedure	TBD
	TBD	Single-hole gas injection test procedure	TBD
	TBD	Pressure pulse gas-injection test procedure	TBD
	TBD	Flow test data identification, shipping, handling and archiving	TBD
Cross-hole pneumatic testing	HP-17, R0	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84

CONSULTATION DRAFT

Method	Technical procedure		
	Number	Title	Date
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Mass flow meter calibration and use	TBD
	TBD	Data logger internal voltmeter calibration	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Straddle packer system leak detection	TBD
	TBD	Straddle packer system placement procedure	TBD
	TBD	Cross-hole gas injection test procedure	TBD
	TBD	Procedure for introducing gas tracers into test interval	TBD
	HP-56, RO	General procedure for soil sampling in unsaturated zone test holes	15 Nov 84
	TBD	Gas sample analysis	TBD
	TBD	Field procedure for in situ calibration of pressure transducers	
Test room preparation	HP-18, RO	Frequency of equipment calibration for unsaturated zone testing, Nevada Test Site	20 July 84

Method	Technical procedure		
	Number	Title	Date
	HP-48, RO	Method for calibrating hand-held glass thermometers	14 Aug 84
	HP-49, RO	Method for using hand-held glass thermometers	14 Aug 84
	TBD	Method for calibrating barometers for ambient air pressure monitoring in underground test rooms	TBD
	TBD	Procedure for monitoring ambient air pressure in underground test rooms using barometers	TBD
	TBD	Method for calibrating thermocouple psychrometers for relative humidity monitoring in underground test rooms	TBD
	TBD	Procedure for monitoring relative humidity in underground test rooms using thermocouple psychrometers	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Underground test room monitoring data identification, shipping, handling, and archiving	TBD
Infiltration installation	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84

CONSULTATION DRAFT

Method	Technical procedure		Date
	Number	Title	
	HP-15, R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 July 84
	HP-17, R0	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-18, R0	Frequency of equipment calibration for unsaturated zone testing, NTS	20 July 84
	HP-19, R0	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at NTS	20 July 84
	HP-69, R0	Construction and operation of simple tensiometers	TBD
	HP-70, R0	Psychrometer calibration	TBD
	HP-95, R0	Tensiometer calibration	TBD
	TBD	Operation of thermocouple psychrometers in an infiltrometer sand bed	TBD
	TBD	Operation of heat-dissipation sensors in an infiltrometer sand bed	TBD

CONSULTATION DRAFT

Method	Technical procedure		
	Number	Title	Date
	TBD	Operation of pressure transducer tensiometers in an infiltrometer sand bed	TBD
	TBD	Method for constructing and instrumenting an infiltrometer sand bed	TBD
	TBD	Method for installing and instrumenting an infiltrometer flow tank apparatus	TBD
	TBD	Method for operating an infiltrometer for use in an underground test room	TBD
	TBD	Method for injecting conservative and reactive tracers through an infiltrometer	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Infiltrometer data identification, shipping, handling, and archiving	TBD
Test hole instrumentation and monitoring	HP-13, R0	Collection and field analysis of unsaturated zone groundwater samples	29 Aug 83
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84

CONSULTATION DRAFT

Method	Technical procedure		Date
	Number	Title	
	HP-15, R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 July 84
	HP-17, RO	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 July 84
	HP-18, RO (to be revised)	Frequency of equipment calibration for unsaturated zone testing, NTS	20 July 84
	HP-19, RO	Method for identification, transports and handling of instrumentation packages and equipment for field testing in the unsaturated zone at NTS	20 July 84
	HP-69, RO	Construction and operation of simple tensiometers	TBD
	HP-70, RO	Psychrometer calibration	TBD
	HP-95, RO	Tensiometer calibration	TBD
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Field procedure for in situ calibration of pressure transducers	TBD

Method	Technical procedure		Date
	Number	Title	
	TBD	Field procedure for in situ evaluation of thermocouple sensor performance	TBD
	TBD	Field procedure for stemming and instrumenting horizontal boreholes	TBD
	TBD	Field procedure for connection of sensor leads and initiali- zation of data acquisition system	TBD
	TBD	Preliminary probe installation and stemming plan for infiltration test boreholes	TBD
	TBD	Preliminary plan for final checkout and acceptance of instru- mentation packages and emplacement into infiltration test holes	TBD
	TBD	Procedures for in situ measuring and moni- toring of tracer con- centrations in boreholes	TBD
	TBD	Procedure for monitoring moisture content and movement using gamma- gamma probes in hori- zontal and vertical holes	TBD

CONSULTATION DRAFT

Method	Technical procedure		Date
	Number	Title	
	TBD	Procedure for determining moisture-content profiles from gamma-gamma logging	TBD
	TBD	Procedure for monitoring moisture content and movement using a neutron moisture meter in horizontal hole	TBD
	HP-62, R1	Method for measuring subsurface moisture content using a neutron moisture meter	16 Mar 87
	TBD	Procedure for monitoring moisture content and movement using time domain reflectometry	TBD
	TBD	Procedure for monitoring moisture content and movement using geotomography	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Test hole data identification, shipping, handling, and archiving	TBD
Infiltration test method	TBD	Method for conducting an underground infiltration test using an infiltrometer and borehole monitoring network	TBD

^aTBD = to be determined.

8.3.1.2.2.4.3 Activity: Bulk-permeability test in the exploratory shaft facility

Objectives

The objectives of this activity are

1. To determine a large scale permeability value that is representative of the Topopah Spring welded unit.
2. To determine a large scale effective porosity value that is representative of the Topopah Spring welded unit.
3. To evaluate the scale effects for the medium.
4. To determine the effects on permeability by the process of excavation of a horizontal drift.

Parameters

The parameters of this activity are

1. Unsaturated hydraulic conductivities relative to air and water as a function of saturation and matric potential.
2. Water content of matrix and rock mass.
3. Effective porosity of matrix and fractures (including pore-size distribution of matrix).
4. Hydraulic potential of matrix and rock mass.
5. Volumetric flux and travel time through the rock mass.
6. Directional water velocity distributions
7. Fracture and fracture-set lengths, densities, spacings, orientations, connectivities, and apertures
8. Air permeability before and after excavation.

Description

The bulk permeability test will be conducted in a sequence of three stages consisting of (1) detailed fracture mapping on exposed rock surfaces within the exploratory shaft (ES-1) and lower breakout rooms, (2) preliminary assessment of the fluid transport properties of the Topopah Spring welded unit by using air-injection techniques within horizontal boreholes, and (3) excavation of and experimentation within a specially constructed, pneumatically isolated testing chamber. These stages will proceed sequentially, with the final design of each succeeding stage being based on the results and analysis of each preceding stage. This test is not standard. As described later, prototype testing of various components of this activity are planned. This activity will be further evaluated at the completion of the prototype testing.

CONSULTATION DRAFT

The analysis techniques to interpret the resulting data are also being evaluated.

Individual fractures, joint sets, and fracture networks will be mapped using standard survey procedures along the exposed surfaces of the exploratory shaft (ES-1) and lower breakout rooms. The fracture mapping will include (1) the measurement of individual fracture orientations, lengths, and apertures; (2) the identification of prevalent fracture sets; (3) the determination of fracture densities and spacing with sampling bias removed; and (4) the assessment of fracture and fracture-set interconnectivities. Sufficient fracture data will be collected on rock surfaces of varying orientations and locations to determine the three-dimensional geometry and properties of the extant fracture systems at the repository target horizon. Prototype testing is planned to identify the most appropriate methods for accomplishing this task. The resulting fracture network will be used to (1) locate the test room in an area that is devoid of any major discontinuities and (2) determine the orientations of the primary permeability axes so that the test room can be oriented parallel to one of them. This fracture mapping will be done as part of Activity 8.3.1.4.2.2.4 (geologic mapping of the exploratory shaft walls and drifts).

In addition to the detailed fracture mapping, rock-matrix lithology and hydrologic properties will be determined for sample sets collected within the drifts excavated at the lower breakout level. These data are required in order to evaluate fully the independent contributions of the rock matrix and the fractures to the overall composite rock mass hydrologic properties of the Topopah Spring welded unit at the repository target horizon. Samples will be collected for mineralogical, petrographic, and hydraulic properties studies. The physical properties that will be determined include pore geometry, welding, grain density, bulk density, and porosity. The hydraulic properties that will be determined include the moisture content (gravimetric and volumetric), water potential, matric potential, and moisture retention. This work will be done as part of Activity 8.3.1.2.2.3.1 (matrix hydrologic properties laboratory analyses).

Following the acquisition, analysis, and evaluation of the fracture characteristics and the rock-matrix hydrologic property data, a site within the lower breakout zone will be chosen for the testing chamber. The chamber will be located (1) in a rock mass of effectively homogeneous composition and properties so as to be unaffected by transecting faults or the presence of abrupt lithologic discontinuities, (2) where it can be oriented preferentially with respect to the directions of the principal axes of fracture-set anisotropy, and (3) so that the experiments performed within it remain unaffected by the other activities that will be occurring at the lower breakout level. Modeling and prototype testing will be used to approximate the minimum distance that will be required to avoid interference with adjacent activities. Proper orientation of the room may require excavation of an access drift 30 to 45 m in length.

A horizontal exploratory borehole will be air-cored parallel to the planned longitudinal wall of the test chamber (Figure 8.3.1.2-17) and evaluated to further determine the site's suitability. The evaluation will be based on (1) logging the core, (2) laboratory testing of the core, and (3) running geophysical surveys in the hole. Air-drilling methods will be

Figure 8.3.1.2-17. Layout of the bulk permeability test showing locations of the exploratory holes.

used to minimize the disturbance of the natural hydrologic conditions. Prototype testing is planned to develop procedures for the dry-coring and drilling of this and additional boreholes. The exploratory borehole will be 12 ft (3.6 m) away from the wall of the room, 3 ft (1 m) above the floor, and approximately 100 to 200 ft (30 to 60 m) long. Core will be logged in detail for fracture locations and geometrical orientations. When fractures are identified, their strike, dip, surface roughness, fill materials, degree of weathering, mineralized coatings, and apertures will be determined. The borehole walls will also be surveyed for fracture locations with a recording television camera, a deviatometer, geophysical loggers (caliper, gamma, neutron, and resistivity), and possibly cross-hole tomography methods. This information will be used to determine whether the test room siting criteria listed previously can be met. If conditions prove unsatisfactory throughout the entire length of the exploratory borehole, a second location will be chosen and evaluated as before. If both locations prove only partially satisfactory, the site that seems to be more suitable will be selected.

After selection of the site, two additional exploratory test holes will be air cored parallel to the first exploratory borehole. If an access drift is deemed necessary, these two later test holes may be drilled from an alcove constructed from the access drift to reduce the length of the drill holes. These test holes will be drilled at 4 and 8 ft (1.2 and 2.4 m) away from the wall of the room. The one at 8 ft (2.4-m) distance will be drilled 8 ft (2.4 m) above the floor, and the one at 4 ft (1.2 m) will be drilled 4 ft (1.2 m) above the floor. Both test holes will be geophysically surveyed, and the core logged and laboratory tested as previously described. All three holes will then be tested by packer air-injection techniques (variable interval testing and cross hole testing).

Variable interval testing with the air-injection method (Montazer, 1982) will be used in these holes, as well as in all subsequently drilled test holes, to determine the optimum size for the packer test intervals. The chosen test intervals within two of the three exploratory holes will then be instrumented with pressure, temperature, and relative humidity instrumentation and cross-hole tests will be run. The test intervals within the third exploratory hole will be used to inject nitrogen or helium into the rock mass during the cross-hole testing procedure. The choice of nitrogen versus helium will be made later on the basis of a trade-off between cost and the opportunity to obtain additional or more precise results. Two or three different injection intervals (packer separations) will be used to test the uniformity of the data for various lengths tested. This pneumatic cross-hole testing will be conducted at various pressures to (1) delineate the magnitude of the Klinkenberg effect which is the additional flow due to slippage along the walls, and (2) determine the air permeability-capillary pressure relationships. Prototype testing is planned to develop the technical procedures for the cross-hole pneumatic testing.

Next, a test room that will be approximately 50 by 10 by 8 ft (15 by 3 by 2.4 m) will be excavated. This room will be excavated by controlled blasting techniques or machine bored with a minimum amount of water introduced during excavation procedures. Before the mining, stress meters will be installed in the three exploratory holes. These instruments will be monitored to determine

the degree of stress change caused by the process of excavation, which may be associated with permeability alteration (if any). The faces of the room will be mapped during excavation after every blast round or at about every 2.4 m. After excavation, all exposed walls of the room will also be subjected to detailed fracture mapping. This fracture mapping will be done as part of Activity 8.3.1.4.2.2.4, (geologic mapping of the exploratory shaft walls and drifts). The fracture data will be analyzed along with the data obtained from the holes to better define the anisotropic permeability axes.

From within the test room and in the direction of each of the three principal permeability axes, three parallel test holes will be air cored in an equilateral triangular pattern with sides of about 1.5 m. Attempts will be made to drill the three sets of holes on three different faces (walls and floor) of the room. This will allow for characterization of the rocks within a radius of 15 m from the center of the room (Figure 8.3.1.2-18). These holes will be cored and geophysically logged. The core from all the test holes will also be analyzed to determine the rock-matrix lithology and hydrologic properties as part of Activity 8.3.1.2.2.3.1 (matrix property sampling program for Yucca Mountain). Next these holes will be (1) variable-interval tested to determine optimal test interval sizes; (2) packed off at selected intervals and instrumented with pressure, temperature, and relative humidity instrumentation; and (3) cross-hole tested with nitrogen to delineate the magnitude of the Klinkenberg effect and determine the air permeability-capillary pressure relationships.

During the pneumatic testing of these radial test holes, preparation work for conducting the test in the entire room will be completed. A well-sealed double bulkhead (or modified ventilation doors) will be installed at the entrance to the room. The two bulkheads will be separated by about 3 m. The space between the two bulkheads will be instrumented to measure pressure, temperature, and humidity. Provisions will also be made for collecting tracer samples from the air. At several points within the room, instrumentation for pressure, temperature, and humidity will be installed.

Having completed the test setup, the pneumatic testing of the test chamber will begin. In this process, the entire room will be subjected to a partial vacuum with a ventilation fan. After steady state flow conditions are established in the entire system, the flow will be shut off and the recovery trend will be monitored to obtain a bulk permeability value for the rock mass. A gaseous tracer will be injected into some of the packed-off intervals, and its arrival time will be measured at the outflow point to determine the effective porosity of the system. After the system is returned to its original equilibrium state, the test room will be pressurized with the ventilation fan. This pressurization will continue until a steady state condition is reached, after which the inflow will be shut off and the pressure decay in the system observed to obtain an additional bulk permeability value for the rock mass. The length of time required to conduct these pneumatic tests will be predicted by computer modeling. These tests may be repeated to determine the reliability of the procedure and the permeability changes caused by the variability of the moisture content in the rock mass.

Following the pneumatic testing of the test chamber, all the holes will be cross-hole tested with water. The water will be injected into the intervals at various pressures, starting with the lower pressures. Following the

Figure 8.3.1.2-18. Layout showing locations of the test holes.

water-injection tests, the pneumatic testing of the test chamber will be repeated as described previously. Prototype tests are planned to develop the technical procedures for conducting this pneumatic and hydraulic experimentation within the test chamber.

These data will be used in a mathematical model (TOUGH) that simulates two-dimensional gas flow in nondeformable porous media. The model will use finite element numerical techniques to solve the gas-flow equation. The model will allow calculation of the pneumatic response of the system to imposed pneumatic stresses. The model will also be used to analyze and interpret data collected from long-term monitoring of the pressure and temperature within the holes.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.3 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
(NWM-USGS-)			
Fracture mapping and analysis	HP-07, RO	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, Nevada Test Site	30 Mar 87
	TBD ^a	Method for dry drilling and coring horizontal and vertical boreholes	TBD
	TBD	Method for cleaning horizontal and vertical boreholes using dry drilling techniques	TBD
	TBD	Method for determining optimal borehole orientations from fracture maps and orientation data	TBD
Packer air-injection testing	HP-10, R1	Packer-injection and shut-in tests	9 July 84

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Method	Technical procedure		Date
	Number	Title	
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84
	HP-17, R0	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-18, R0	Frequency of equipment calibration for unsaturated zone testing, NTS	20 July 84
	HP-19, R0	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at NTS	20 July 84
	TBD	Method for calibrating gas flow meters	TBD
	TBD	Method for construction of air-injection packer system	TBD
	TBD	Method for operation of packer air-injection system	TBD
	TBD	Method for calibration, testing, and monitoring of temperature for packer tests, using thermocouples	TBD

Method	Technical procedure		Date
	Number	Title	
	TBD	Method for linking packer testing instrumentation to a local data acquisition system (DAS)	TBD
	TBD	Method for transmitting data from local data acquisition system (DAS) to integrated data system (IDS)	TBD
	TBD	Method for calculating conductivity of individual fractures, joint sets, and fracture networks from air-injection packer tests	TBD
	TBD	Method for determining fracture geometric parameters from air-injection packer tests	TBD
Test chamber	TBD	Experimentation	TBD
Laboratory rock-matrix lithologic and physical properties testing	HP-12, R1	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, NTS	30 Mar 87
	HP-30, R0	Calibration and operation procedure for Quantachrome stereopycnometer model SPY-2 USGS petrophysics laboratory, Denver, Colorado	15 May 85

CONSULTATION DRAFT

Method	Technical procedure		Date
	Number	Title	
Laboratory hydraulic properties test of core	HP-73, R0	Calibration and use of the Sartorius electronic toploader (balance) Model 1507 MPS	29 Mar 85
	HP-74, R0	Use of the Stabil-Therm miniature batch oven	28 Oct 85
	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, NTS	30 Mar 87
	HP-15, R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 July 84
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84
	HP-28, R0	Laboratory procedures for the determination of moisture-retention curves on rock core	15 May 85
	HP-47, R0	Method of operating Micrometrics series 910 mercury penetration porosimeter USGS petrophysics laboratory, Denver, Colorado	14 Aug 84

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Method	Technical procedure		
	Number	Title	Date
Borehole drilling and coring	HP-73, R0	Calibration and use of the Sartorius elec- tronic toploader (balance) model 1507 MPS	29 Mar 85
	HP-74, R0	Use of the Stabil-Therm miniature batch oven	28 Oct 85
	HP-07, R0	TBD	TBD
	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone bore- holes at the well-site, NTS	30 Mar 87
	TBD	Method for dry drilling and coring horizontal boreholes	TBD
	TBD	Method for cleaning horizontal and vertical boreholes using dry techniques	TBD
	TBD	Method for determining optional borehole orientations from fracture maps and orientation data	TBD
	GP-11, R0	Logging fractures in core	15 May 85
Fracture logging of core			
Borehole video surveys	TBD	Method for cleaning the borehole walls prior to the television camera survey	TBD
	TBD	Operation of borehole television camera	TBD

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Method	Technical procedure		Date
	Number	Title	
	TBD	Method for digitizing electrical signals and interfacing with a digital computer	TBD
Borehole deviatometer surveys	TBD	Method for deviation surveys in horizontal and vertical boreholes	TBD
Borehole geophysical surveys	GP-10, R0	Borehole video fractures logging	12 Apr 85
	TBD	Method for geophysical logging in horizontal and vertical boreholes	TBD
	TBD	Method for video fracture logging in horizontal and vertical boreholes	TBD
	TBD	Method for determining fracture geometry parameters from geophysical surveys	TBD
	TBD	Method for determining fracture geometry from cross-hole topography	TBD
Test duration modeling	TBD	Method for using a computer model that simulates two-dimensional gas flow in nondeformable porous media	TBD
	TBD	Method for calibrating a computer model that simulates two-dimensional gas flow in a nondeformable porous media	TBD

Method	Technical procedure		
	Number	Title	Date
Excavation of test chamber	TBD	TBD	TBD
Test chamber instrumentation and monitoring	HP-18, RO	Frequency of equipment calibration for unsaturated zone testing, NTS	20 July 84
	TBD	Method for calibrating barometers for borehole air pressure monitoring	TBD
	TBD	Method for installing barometers in boreholes for air pressure monitoring	TBD
	TBD	Method for installing temperature thermocouples in boreholes for temperature monitoring	TBD
	TBD	Method for calibrating temperature thermocouples in boreholes for temperature monitoring	TBD
	TBD	Method for installing thermocouple psychrometers for relative humidity monitoring in boreholes	TBD
	TBD	Method for calibrating thermocouple psychrometers for relative humidity monitoring	TBD

CONSULTATION DRAFT

Method	Technical procedure		
	Number	Title	Date
Gaseous-tracer testing	TBD	Method for linking bore-hole and test room equipment to a local Data Acquisition Room (DAS)	TBD
	TBD	Method for linking local DAS to Integrated Data System (IDS)	TBD
	TBD	Method for gaseous tracer use in packer air-injection strings	TBD
	TBD	Procedure for installation of gaseous tracer detection instruments	TBD
	TBD	Procedure for calibrating gaseous tracer detection instruments	TBD
Packer water-injection testing	TBD	Procedure for determination of breakthrough curves from gaseous tracer concentrations of packer air-injection strings	TBD
	HP-10, R1	Packer-injection and shut-in tests	9 July 84
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84

Method	Technical procedure		Date
	Number	Title	
	HP-17, RO	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-18, RO	Frequency of equipment calibration for unsaturated zone testing, NTS	20 July 84
	HP-19, RO	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at NTS	20 July 84
	TBD	Method for calibrating flow meters	TBD
	TBD	Method for construction of water-injection packer system	TBD
	TBD	Method for operation of packer water-injection string	TBD
	TBD	Method for calibration, testing, and monitoring of temperature for packer tests using thermocouples	TBD
	TBD	Method for linking packer testing instrumentation to a local DAS	TBD
	TBD	Method for transmitting data from local DAS	TBD

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Method	Technical procedure		Date
	Number	Title	
	TBD	Method for calculating conductivity of individual fractures, joint sets, and fracture networks from water-injection packer tests	TBD
	TBD	Method for determining fracture geometric parameters from water-injection packer tests	TBD
Test chamber pneumatic experimentation	TBD	TBD	TBD
Test chamber hydraulic experimentation	TBD	TBD	TBD
Bulk-permeability test modeling	TBD	Method for using a computer model that simulates two-dimensional gas flow in nondeformable porous media	TBD
	TBD	Method for calibrating a computer model that simulates two-dimensional gas flow in nondeformable porous media	TBD

^aTBD = to be determined.

8.3.1.2.2.4.4 Activity: Radial borehole tests in the exploratory shaft facility

Objectives

The objectives of this activity are

1. To detect vertical movement of water in both the vapor and liquid forms and to evaluate the potential for lateral movement of water along the hydrogeologic contacts.
2. To evaluate the radial extent of shaft excavation effects on the hydrologic properties of unsaturated hydrogeologic units.

Parameters

The parameters of this activity are

1. Rock matrix hydrologic properties, which include gravimetric water content, volumetric water content, grain density, porosity, bulk density, water potential, matric potential, moisture retention, saturated gas permeability, saturated liquid permeability, relative gas permeability, relative water permeability, moisture content, and porosity pore-size distribution.
2. Rock mass hydrologic properties, which include matric potential, water potential, temperature potential, pneumatic potential, bulk air permeability, bulk water permeability, bulk porosity, tortuosity, dispersivity, gaseous diffusion coefficient, gas permeability before and after shaft excavation, and fracture permeability.
3. Hydrochemistry test, which includes composition of formation water, composition of formation gases, radioactive and stable isotope composition, and residence time.
4. Fracture characteristics, which include orientation (dip amount and direction), spacing, density, relative length of trace, surface regularity, fracture fill material, degree of weathering, and fracture aperture.

Description

Eight depths have been tentatively chosen as sites for drilling the radial boreholes (Figure 8.3.1.2-19). The boreholes will be used to obtain fracture sample statistics for each hydrogeologic unit, to measure conductive properties under ambient conditions beyond the relaxed zone, and to register effects of excavation. Interference testing (a procedure whereby the response to hydraulic stresses imposed on an interval in one hole is monitored in an interval of a second hole) will help evaluate the potential for lateral movement of water along hydrogeologic contacts. Core and cutting samples for laboratory hydrologic analysis will be obtained.

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.

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Figure 8.3.1.2-19. Schematic of the radial boreholes tests.

Air will be used instead of water in order to preserve, to the extent possible, the ambient moisture conditions of the core and surrounding rock mass. A tracer (namely, sulfur hexafluoride) will be added to the drilling fluid (air) so that contamination of the formation by the drilling fluid can be determined later during gas sampling.

Orientation of the radial boreholes at each depth location will be determined by analyzing fracture data collected during shaft wall mapping (see Activity 8.3.1.2.2.4 for mapping details). The fracture data, which include fracture orientation (i.e., strike, dip, and dip direction), length of trace, surface regularity, fracture fill material, degree of weathering, and aperture, will be used to estimate the anisotropic permeability tensor of the fractured-rock system. The projection of the estimated minimum and maximum principal permeability axes onto the horizontal plane will form the basis for locating the boreholes. The boreholes will be drilled parallel to these horizontal projections. Fracture data, obtained from the drill core, will be used to further refine the permeability tensor calculations and to determine the location of instruments. Therefore, maximum core recovery will be sought during the drilling process. A television camera will also be used to view, log, and record the fractures intersecting each borehole. This information will be used to (1) verify fracture orientation, if oriented core is taken during the drilling process or (2) determine orientations, if the core is not oriented. The holes will be cleaned before gas permeability testing or instrumentation of the boreholes.

Core and cutting samples, obtained during the radial borehole drilling process, will be sealed in wax or placed in air tight canisters, then transported to the surface-based field laboratories. At the field laboratory, the moisture content and matric potential of each sample will be determined using methods described in Activity 8.3.1.2.2.3.1 (matrix hydrologic properties laboratory analyses). Then, the samples will be sent to offsite laboratories to be tested for the following properties: gravimetric water content, volumetric water content, grain density, porosity, bulk density, water potential, matric potential, moisture retention, saturated water and gas permeability, and relative permeability.

Each of the radial boreholes will be logged with a neutron probe immediately after drilling the holes. Calibration charts will be used to convert the observed neutron count obtained during the survey into moisture content. The neutron probes will be calibrated in the laboratory before running the survey. Neutron surveys will be conducted during construction of the shaft to determine whether excavation or shaft lining change the moisture content of the host rock. The neutron surveys will be performed after each mining round until the effects of construction are no longer detected. This procedure will be repeated for all sets of radial boreholes.

Packer nitrogen-injection tests will be conducted to determine the bulk gas permeability of the rock mass surrounding the borehole and to quantify the effect that excavation and lining of the shaft have on bulk gas permeability. The packer test will also be used to determine the gas permeability of fractures and fracture apertures if they are present in the test zone. The tests will be conducted in each of the radial boreholes drilled at 12 different depths within the exploratory shaft. At least three different

test zones will be chosen and tested within each borehole using packer separations of the same order as the average fracture spacing. The test locations will be determined from TV logs, neutron-moisture logs and fracture logs obtained from the core in order to obtain optimum packer sealing. A straddle packer system, consisting of packers, pressure transducers, thermocouple psychrometers and temperature thermocouples, will be installed in each hole after the holes have been drilled and logged at the desired test level. Gas will then be injected into the formation and gas permeability will be calculated from the flow and pressure data. Once the boreholes have been tested at a given level, mining of the shaft will proceed one round (approximately, 2.1 to 2.4 m). The packer air-injection tests will be conducted again in each of the radial boreholes, then mining will continue. This alternate sequence of testing and mining will continue until the effects of the mining and shaft lining are no longer observed.

The long-term monitoring phase will consist of instrumenting the radial boreholes and periodically monitoring in situ matric, water, pneumatic, and thermal potentials. Heat dissipation probes (or tensiometers), thermocouple psychrometers, pressure transducers, and thermocouples, which are used to measure matric, water, pneumatic, and thermal potentials, respectively, will be installed in at least three different test zones within each of the 24 radial boreholes. Fluctuations of the pneumatic potential due to changes in barometric pressure will be used to calculate the permeability and porosity of the medium. Fluctuations in matric potential and temperature will be used to detect pulses of water percolating down through the unsaturated zone. Also, the temperature gradient and its fluctuations with time will be used to estimate liquid water flux.

Gas sampling will begin about six months after the boreholes have been instrumented for the long-term monitoring phase of the radial boreholes test. The scope and objectives of the gas sampling program are presented in greater detail in Section 8.3.1.2.2.4.8 (hydrochemistry tests in the exploratory shaft facility).

Using the existing radial boreholes, cross-hole testing will be conducted across four hydrogeologic contacts (see Figure 8.3.1.2-19) after the long-term monitoring and gas sampling programs have been completed. These locations were selected because large contrasts in hydrologic properties exist at these contacts that may cause lateral movement of water within the geologic units overlying the contacts or along the contact itself. These contrasts would affect the vertical movement of water through the unsaturated zone and might hasten or delay the time it takes for percolating water to reach the underlying water table. The radial boreholes will be used for the cross-hole flow tests; one borehole will overlie the geologic contact and will be used as the injection borehole, while the borehole located below the contact will serve as the observation borehole. Both air and water will be used as the testing fluids; however, air testing will be conducted before water testing so that ambient moisture conditions are present during air testing. Long-term injection of water tagged with a tracer will follow the air-injection tests. The observation zone will be monitored for an increase in pressure or changing moisture conditions. Prototype testing is planned to develop the technical procedures for cross-hole pneumatic testing.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.4 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Borehole drilling and coring	TBD ^a	Drilling and coring horizontal holes dry	TBD
	TBD	Borehole cleaning and verification technique	TBD
	TBD	Shaft wall fracture mapping	TBD
	TBD	Permeability tensor calculations leading to borehole location	
Onsite laboratory hydraulic properties testing of core and drilling-cutting	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone at the well-site, Nevada Test Site	30 Mar 87
	HP-74, R0	Use of the Stabil-Therm miniature batch oven	28 Oct 85
	HP-32, R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-73, R0	Calibration and use of the Sartorius electronic top-loader balance Model 1507 MPS	29 Mar 85

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Method	Technical procedure		Date
	Number	Title	
Offsite laboratory hydraulic and physical properties testing of core	TBD	Procedures for the measurement of (1) volumetric water content, (2) grain density, (3) porosity, (4) saturated water and gas permeability, and (5) relative permeability	TBD
	HP-55, RO	Hydrologic laboratory testing of core and drill cutting samples from unsaturated-zone test holes	9 Sep 85
	HP-18, RO	Frequency of equipment calibration for unsaturated-zone testing	20 July 84
	HP-28, RO	Laboratory procedures for the determination of moisture-retention curves of rock core	15 May 85
Fracture logging of core	TBD	Onsite fracture logging of core	TBD
	GP-11, RO	Logging fractures in core	15 May 85
Borehole video surveys	TBD	Borehole video logging in horizontal boreholes	TBD
	GP-10, RO	Borehole video fracture logging	12 Apr 85
Borehole geophysical surveys	TBD	Procedure for measuring moisture content in a horizontal borehole using a neutron moisture meter	TBD
	TBD	Neutron moisture meter field calibration	TBD

Method	Technical procedure		
	Number	Title	Date
In situ pneumatic testing	HP-17, R2	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated-zone	14 Aug 84
	HP-14, R1	Method for calibrating peltier-type thermo-couple psychrometers for measuring water potential of partially saturated media	9 July 84
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Laboratory procedure for mass flow meter calibration	TBD
	TBD	Laboratory procedure for data logger internal voltmeter	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Straddle packer system leak detection	TBD
	TBD	Straddle packer system placement procedure	TBD
	TBD	Single-hole gas injection test procedure	TBD
	TBD	Pressure pulse gas injection test procedure	TBD

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Method	Technical procedure		
	Number	Title	Date
Borehole instrumentation and monitoring	TBD	Flow test data identification, shipping, handling and archiving	TBD
	HP-17, R0	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-15, R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 July 84
	HP-14, R1	Method for calibrating peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Field procedure for in situ calibration of pressure transducer	TBD
	TBD	Field procedure for in situ evaluation of thermocouple psychrometer sensor performance	TBD
	TBD	Field procedure for stemming and instrumenting horizontal boreholes	TBD
	TBD	Field procedure for connection of sensor leads and initializing data acquisition system	TBD

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Method	Technical procedure		Date
	Number	Title	
	HP-19, RO	Method for identification, transport and handling of instrumentation packages and equipment for field testing in the unsaturated zone at NTS	20 July 84
	TBD	Preliminary probe installation and stemming plan for radial test holes, exploratory shaft NTS	TBD
	TBD	Preliminary plan for final checkout and acceptance of instrumentation packages and emplacement into radial test holes, exploratory shaft NTS	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Flow test data identification, shipping, handling, and archiving	TBD
Collect and transport gas samples	HP-56, RO	General procedure for soil gas sampling in unsaturated zone test holes	15 Nov 84
	TBD	Procedure for shipping and handling gas samples	TBD
	TBD	Gas sample analysis	TBD
Cross-hole pneumatic and hydraulic testing	HP-17, RO	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	14 Aug 84

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Method	Technical procedure		Date
	Number	Title	
	HP-14, R1	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	9 July 84
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Mass flow meter calibration and use	TBD
	TBD	Data logger internal voltmeter calibration	TBD
	TBD	Data acquisition system operations check	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Straddle packer system leak detection	TBD
	TBD	Straddle packer system placement procedure	TBD
	TBD	Cross-hole gas injection test procedure	TBD
	TBD	Procedure for introducing gas tracers into test interval	TBD
	HP-56, R0	General procedure for soil gas sampling in unsaturated zone test holes	15 Nov 84
	TBD	Gas sample analysis	TBD
	TBD	Field procedure for in situ calibration of pressure transducer	TBD

Method	Technical procedure		Date
	Number	Title	
	TBD	Field procedure for in situ evaluation of thermocouple psychrometer sensor performance	TBD
	TBD	Water flow meter calibration	TBD
	TBD	Cross-hole water injection test procedure	TBD
	TBD	Procedure for introducing an aqueous tracer into a test interval	TBD
	TBD	Procedure for collecting, shipping, and handling cross-hole test water samples	TBD
	TBD	Water sample analysis	TBD

^aTBD = to be determined.

8.3.1.2.2.4.5 Activity: Excavation effects test in the exploratory shaft facility

Objectives

The objective of this activity is to monitor stress changes caused by the excavation and lining of the shaft. The effects of stress redistribution on the fractured rock permeability in the vicinity of the shaft will be monitored in order to estimate expected changes around other openings in the proposed repository as well as those around the shaft.

Parameters

The parameters of this activity are

1. Air permeability profiles.
2. In situ stresses.
3. In situ rock physical properties.
4. Fracture mapping.
5. In situ water saturation.
6. Porosity.

Description

This test will be conducted from two breakout zones along the exploratory shaft at depths of 520 and 1,020 ft (158 and 366 m) (Figure 8.3.1.2-19). The present design is preliminary and includes 27 boreholes at each breakout horizon, as described here. The feasibility and need for drilling these boreholes and the possible impacts of these boreholes on ambient conditions and tests results will be evaluated before the design is finalized. After completing the breakout horizons, nine vertical holes in three rows of three holes each will be drilled with air for permeability measurements (Figure 8.3.1.2-20). These permeability holes will be 2.9 in. (75 mm) in diameter and 50 to 100 ft (15 to 30 m) in depth depending on the straightness of the holes. Distances of the holes from the shaft wall will be approximately 3.9, 7.8, and 11.8 ft (1.2, 2.4, and 3.6 m).

Another set of nine vertical holes will be drilled with air for installation of deformation gauges, and loading cells at each breakout. These in situ stress-measuring holes will be between 3 to 4 in (75 and 100 mm) in diameter with the same length and distance away from the shaft wall as the permeability holes. Maximum allowable deviation of the permeability and stress measuring holes will not exceed one unit per 100 units of length. At intervals of 20 ft (6 m), the permeability and stress measuring holes will be surveyed by the line-of-sight method or a borehole deviatometer.

Nine displacement measuring holes will also be percussion drilled with air at angles (up to 45 degrees). The deviation of the displacement measuring holes will be surveyed by a borehole deviatometer.

In situ stress changes will be estimated using deformation gages, flat-jacks, and/or loading cells. Deformation gages and loading cells will be emplaced at 10 ft (3 m) intervals to measure the deformation in at least two perpendicular directions before resumption of shaft excavation. The change in instrument response during and after shaft excavation will be recorded. The multiposition borehole extensimeters will be emplaced in the displacement measuring boreholes. In situ stress magnitudes and directions will then be estimated using data from these instruments along with rock physical properties data that will be measured in the laboratory.

Television camera logs will be run in the permeability and stress measuring holes. Individual fractures and joint sets will be mapped from the television log record so that air and water injection packer zones can be located where fractures occur. Borehole geophysical surveys will also be run in these holes to determine the porosity and moisture content in the vicinity of the shaft. Neutron moisture, porosity (epithermal neutron), and gamma-gamma logs will be recorded.

Permeability boreholes will be instrumented with air-injection packer strings to detect permeability changes along these holes due to stress changes caused by the shaft excavation. These packer air-injection permeability tests will be performed before excavation of the shaft below the breakout levels and after every two rounds of excavation until changes in permeability are no longer detected. When the shaft is excavated below the longest permeability borehole, packer air-injection strings will be installed

Figure 8.3.1.2-20. Conceptual cross-section through ES-1 shaft showing the relationship between the shaft and the boreholes drilled for the excavation effects tests.

at certain zones to detect long-term variations in permeability, temperature, and moisture content.

A coupled hydraulic-mechanical finite element model will be used to analyze the basic data. Model validation and calibration will be accomplished by comparing measured and predicted in situ stresses and permeability changes given an initial state of stress condition. The model that gives the best match between the measured and computed stresses and permeabilities will be used to predict disturbances around other openings within the repository.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.5 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Borehole drilling	TBD ^a	Reynolds Electric and Engineering Company (REECo) dry drilling and procedure--horizontal and vertical holes	TBD
Borehole deviatometer surveys	TBD	TBD	TBD
Borehole video surveys	TBD	Method of cleaning borehole walls prior to television camera	TBD
	TBD	Operation of borehole television	TBD
Borehole geophysical surveys	HP-96, RO	Neutron moisture meter calibration (vertical holes)	TBD
	HP-62, RO	Method for measuring subsurface moisture	16 Mar 87
	TBD	Porosity meter calibration	TBD
	TBD	Porosity meter operation	TBD
	TBD	Gamma-gamma meter calibration	TBD

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Method	Technical procedure		
	Number	Title	Date
Packer air-injection testing	HP-102, RO	TBD	TBD
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84
	HP-17, RO	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-18, RO	Frequency of equipment calibration for unsaturated zone testing, Nevada Test Site	20 July 84
	HP-19, RO	Method for identification, transport, and handling of instrumentation packages, and equipment for field testing in the unsaturated zone at NTS	20 July 84
	HP-20, RO	Instruction for operation of a standard dead-weight tester	20 July 84
	HP-48, RO	Method for calibrating hand-held glass thermometers	14 Aug 84
	HP-49, RO	Method for using hand-held glass thermometers	14 Aug 84

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Method	Technical procedure		
	Number	Title	Date
Borehole instrumentation and monitoring	TBD	Method for construction of air-injection packer system and air-leak detection	TBD
	TBD	Method for calibrating gas flow meters	TBD
	TBD	Method for calibrating thermocouples	TBD
	TBD	Method for operation of packer air-injection string	TBD
	TBD	Method of emplacement of borehole deformation gages	TBD
	TBD	Method of emplacement of flatjacks and load cells	TBD
	TBD	Method of emplacement of multiposition borehole extensometers	TBD
	TBD	Method of calibrating flatjacks	TBD
	GPP-04, RO	In situ stress investigations	27 June 83
	HP-17, RO	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-18, RO	Frequency of equipment calibration for unsaturated zone testing NTS	20 July 84

Method	Technical procedure		Date
	Number	Title	
	HP-20, RO	Instruction for operation of a standard dead-weight tester	20 July 84
	TBD	Data acquisition system for monitoring borehole deformation gages, flatjacks, and load cells	TBD
Excavation effects test modeling	TBD	Method for verifying the correctness of a coupled-hydraulic-mechanical finite element model (bench mark problem)	TBD
	TBD	Method for calibrating a coupled-hydraulic-mechanical finite element model	TBD

^aTBD = to be determined.

8.3.1.2.2.4.6 Activity: Calico Hills test in the exploratory shaft facility

Objectives

The objectives of this activity are

1. To determine the hydrogeologic properties and conditions of layers and fractures within the Calico Hills nonwelded unit.
2. To determine if perched water exists at or near the contact between the Topopah Spring welded unit and the Calico Hills nonwelded unit.
3. To investigate the permeability and flow conditions of the Ghost Dance fault where it transects the Calico Hills nonwelded unit.

Parameters

The parameters of this activity are

1. Matrix parameters, which include fracture characteristics, water content, porosity, pore-size distribution, hydraulic potential, water permeability, and air permeability.
2. Rock-mass parameters, which include water content, hydraulic potential, pneumatic potential, thermal potential, permeability to water and air convective dispersivity, and gaseous diffusion coefficient.
3. Chemical parameters, which include composition of saturated-zone water samples, composition of gases, carbon-14 and tritium activity, and stable isotope composition (oxygen-18, deuterium).

Description

The Calico Hills nonwelded unit is expected to be a principal barrier to the flow of ground water and transport of radionuclides. As such, the assessment of the unit's hydrologic conditions and hydrologic properties poses a dilemma. On the one hand, it is critical to have high confidence in the understanding of those aspects of the unit, in particular the effects that fractures and faults transecting the unit have on flow paths and travel times. On the other hand, exterior penetration or excavation of the unit for testing purposes may jeopardize the integrity of the unit as a barrier. Therefore, within this context, the tests described for this activity are presented with the technical need in mind, but they do not include details of test designs. Such details will be included in progress reports, once a decision has been made regarding the appropriate degree of allowable penetration and excavation.

In concept, the Calico Hills test should provide in situ access to fractures, to various layers within the unit, and to the Ghost Dance fault where it crosses the unit. The preferred approach is to drift horizontally from the Calico Hills breakout (Section 8.4.2), in the up-dip direction, through the Ghost Dance fault. Such an excavation would allow visual examination of the features to be tested and would provide a basis for siting short boreholes for tests to determine hydraulic properties and initial and boundary conditions. An alternative to drifting would be to drill a long lateral corehole. In the following activity descriptions, it is assumed that the drift will be constructed, the short boreholes will be drilled, and various tests will be conducted, although it is recognized that the extent of allowable drifting and drilling has not been decided.

Boreholes about 30 ft (9 m) long will be drilled in various directions for testing purposes. These short boreholes will be used for hydrologic testing of (1) fractures, (2) the Ghost Dance fault (if the fault is exposed by a drift), and (3) the contacts between the Topopah Spring welded unit and the Calico Hills nonwelded unit and between various layers within the nonwelded unit. One borehole will extend downward from the Calico Hills breakout to about 50 ft (15 m) below the water table. This borehole will be used to complete the sampling of the unsaturated rock column below the exploratory shaft, to obtain a water sample from the saturated zone, and to conduct hydraulic testing of the unsaturated zone and saturated zone below the shaft.

All boreholes will be drilled using air as the drilling fluid to minimize changes in ambient moisture condition. Onsite core examination will be conducted for preliminary determination of fracture frequency, orientation, location, and characteristics, as well as bedding characteristics. This information will be used in conjunction with geophysical and television camera logs for selecting test intervals for air-permeability testing and monitoring. The core and cutting samples will then be sealed in wax or placed in air-tight canisters and transported to the surface-based field laboratories. At the field laboratory, the moisture content and matric potential of each sample will be determined using methods described in Activity 8.3.1.2.2.3.1 (matrix hydrologic properties laboratory analyses). The samples will also be sent to offsite laboratories to be tested for gravimetric water content, volumetric water content, grain density, porosity, bulk density, water potential, matric potential, moisture retention, saturated water and gas permeability, and relative permeability.

Planned geophysical logs include natural gamma, gamma-gamma, neutron-moisture, and caliper. These logs will be used to assist in establishing stratigraphic contacts, moisture content distribution, and the condition of the borehole (enlargement, suitability for seating packers, etc.). Periodic thermal (temperature) logs will be made in some boreholes to help determine the thermal gradient and variations in flux through the Calico Hills non-welded unit.

Two types of television cameras will be used for borehole surveys. The first type views downhole just below the camera and will be used to qualitatively judge the condition of the borehole for such information as wall cake (dust, cuttings) and visible moisture. The second type will be a side view camera that will be used for establishing fracture characteristics.

Packer air-injection tests will be conducted to determine the distribution of permeability to air in each of the boreholes. A straddle packer system consisting of packers, pressure transducers, thermocouple psychrometers, and temperature thermocouples, will be installed in each hole after the holes have been drilled and logged at the desired test level. The packers are then inflated and nitrogen gas is allowed to flow into the injection zone. The flow rate and injection of the gas pressure are monitored continuously until steady state conditions (i.e., constant flow rate and pressure) are reached. The same procedure will be carried out at higher flow rates and pressures for that test zone and for other test zones within the same borehole. Gas permeability will be calculated from the flow and pressure data. Changes in pressure within the adjacent observation zones will also be monitored for packer blow-by and for fracture continuity.

Where feasible, cross-hole testing will be conducted using air injection and water injection. Cross-hole tests are basically the same as single borehole tests, but the effects of injection are monitored. Straddle packer systems will be installed in both the injection and observation boreholes. After inflating the packers, gas will be injected into the injection zone and the observation zone will be monitored for an increase in pressure. From the known fluid flow rate and pressure drop between the two boreholes, the permeability of the formation will be determined. Cross-hole testing techniques will be evaluated and developed during prototype testing.

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Water-injection cross-hole tests will be conducted to help establish transport properties, structures, permeability, and conditions for perching water near the contact of the Topopah Spring welded unit and the Calico Hills nonwelded unit. In one test, water will be injected into the Ghost Dance fault at the lower breakout level, and the water will be monitored in boreholes penetrating the fault in the underlying Calico Hills nonwelded unit. Water used for injection will include a tracer so that there will be no doubt as to the origin of any detected water. Primarily because of the distance between the lower breakout level and the deeper boreholes, some uncertainties may exist after conducting this test. If the injected water is detected in the boreholes penetrating the fault at the level of the Calico Hills unit, the objective of the test will have been met. If the injected water is not detected, however, the test will be inconclusive. The injected water may not be detected for various reasons, including (1) the fault is not conductive, (2) the fault is conductive but permeability is such that the injected water is not detected within the time frame of the test, and (3) flow paths in the fault may be localized and directional such that the injected water bypasses the boreholes. Before conducting this cross-hole test, modeling will be conducted to estimate the conditions required to optimize the successful completion of the test. If results of modeling show that the test is impractical because of time constraints or that site characteristics are likely to be significantly altered by the injected water, the test will not be conducted.

Cross-hole testing will also be conducted in short boreholes from the drift under better controlled conditions and in radial borehole sets that will allow testing across contacts of various subunits.

Methods and technical procedures

The methods technical procedures for Activity 8.3.1.2.2.4.6 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Borehole drilling and coring	TBD ^a	Reynolds Electrical & Engineering Co. (REEC) dry drilling and coring procedure-- horizontal and vertical holes	TBD
Onsite core sampling and lithologic analysis	HP-55, R0	Hydrologic-laboratory testing of core and drilling-cutting samples from unsaturated-zone test holes	9 Sep 85

Method	Technical procedure		
	Number	Title	Date
Offsite laboratory hydraulic properties testing of core	HP-28, RO	Laboratory procedures for the determination of moisture-retention curves on rock core	15 May 85
	HP-32, RO	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-55, RO	Hydrologic-laboratory testing of core and drilling-cutting samples from unsaturated-zone test holes	9 Sep 85
Fracture mapping and analysis	TBD	TBD	TBD
Petrographic and mineralogic analysis of core	TBD	TBD	TBD
Borehole video surveys	TBD	TBD	TBD
Borehole geophysical surveys	HP-50, RO	Method for neutron scatter and gamma ray attenuation logging using the USGS logging van (1-139055)	22 Aug 85
	HP-102, RO	TBD	TBD
Borehole thermal surveys	TBD	TBD	TBD
Packer air-injection testing	HP-10, R1	Packer-injection and shut-in tests	9 July 84
Cross-hole air-injection testing	TBD	TBD	TBD
Cross-hole water- injection testing	TBD	TBD	TBD

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Method	Technical procedure		
	Number	Title	Date
Borehole instrumen- tation and monitoring	HP-70, R0	TBD	TBD
	HP-14, R1	Method for calibrating Peltier-type thermo- couple psychrometers for measuring water potential of partially saturated media	9 July 84
	TBD	Pressure transducer use and calibration	TBD
	TBD	Mass flow rate meters - use and calibration	TBD
	TBD	Stemming vertical boreholes	TBD
Calico Hills Test modeling	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.2.4.7 Activity: Perched water test in the exploratory shaft facility

Objectives

The objectives of this subactivity are to (1) detect the occurrence of any perched water zones, (2) estimate the hydraulic properties of the zones, and (3) determine the implication of the existence of such zones on flux, flow paths, and travel times.

Parameters

The parameters of this subactivity are

1. Transmissivity.
2. Hydraulic conductivity.
3. Hydraulic head and storage coefficient.

Description

The shaft wall will be visually inspected following each excavation round to determine if any natural seepage or flow of water occurs in the

shaft. If enough water can be collected, it will be submitted to the laboratory for chemical analysis and age dating.

If a seep or wet zone of low discharge is encountered, a small-diameter lateral hole will be drilled into the shaft wall. This will increase the flow rate by concentrating and confining the flow to a perforated well casing to make accurate flow measurements and collect representative water samples.

Yields from seeps or flow zones will be determined by collecting the water in a graduated cylinder and using a stopwatch or by a calibrated flow meter to measure the flow rate. If sufficient water production occurs and water level (or pressure) measurements can be made using a water-level measuring device or transducer, then an appropriate pump will be used to run a pumping test. Aquifer tests will be conducted from the exploratory shaft to determine the extent, yield, and hydraulic coefficients of the perched-water zone. The aquifer tests probably will be constant discharge tests so that standard methods may be used to analyze the results. However, detailed plans for conducting and analyzing perched-water tests will be developed before starting the exploratory shaft, to ensure that procedures are in place for testing in this unusual environment, if encountered. The implications on flow paths, fluxes, and travel times due to perched water zones will then be determined.

Lateral boreholes in selected low productivity zones will be instrumented with pressure transducers and psychrometers. The pressure transducers will provide hydraulic head data and the psychrometers will provide water potential data in the capped boreholes at selected time intervals.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.7 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Shaft wall seep inspection and monitoring	TBD ^a	TBD	TBD
Perched water sampling and chemical/age-dating analysis	TBD	TBD	TBD
Borehole drilling (perched water zones)	TBD	TBD	TBD

Method	Technical procedure		
	Number	Title	Date
Water flow-rate measurement and pumping tests	HP-06, R0	Hydrologic pumping test	11 Jan 82
Low-productivity zone borehole instrumentation and monitoring	HP-17, R0	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Aug 84
	HP-14, R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 July 84

^aTBD = to be determined.

8.3.1.2.2.4.8 Activity: Hydrochemistry tests in the exploratory shaft facility

Objectives

The objectives of this activity are to:

1. Understand the gas transport processes within the unsaturated zone and to provide independent evidence of flow direction, flux, and travel time of gas.
2. Design and implement methods for extracting uncontaminated pore fluid from rock excavated during shaft construction.
3. Determine the flow direction, flux, and travel time of water in the unsaturated zone by isotope geochemistry techniques.
4. Determine the extent of the water-rock interaction so that geochemical modeling can be performed to deduce the flow path and to understand the geochemical evolution of the unsaturated zone water.

Parameters

The parameters of this activity are

1. Gas composition.
2. Carbon-isotope concentration (in carbon dioxide gas).
3. Hydrogen and oxygen isotopes (in water vapor).
4. Water quality (cations, anions).
5. Flow paths (oxygen-18, deuterium).
6. Travel time (hydrogen-3, carbon-14, chlorine-36).

Description

Carbon dioxide and water-vapor samples will be collected from radial boreholes in the exploratory shaft after the holes have been instrumented. Gas samples will be checked for contamination (SF_6 or a similar conservative gas tracer) caused by air coring or blasting before coring. Samples to be used for composition analysis will be drawn by peristaltic pumping, collected in glass or stainless steel collection cylinders, and analyzed by gas chromatography. The carbon dioxide gas will be collected in molecular sieve in stainless steel cylinders and analyzed for carbon-14 and carbon-13 to carbon-12 ratio. Water vapor will be collected in the cold trap by pumping the gas through the cold trap and analyzed for tritium, oxygen-18 to oxygen-16, and deuterium to hydrogen.

The age of the unsaturated zone gases will be determined from the carbon-14 and carbon-13 to carbon-12 isotope data. Stable isotope ratios oxygen-18 to oxygen-16 and deuterium to hydrogen which, can indicate the climatic and evaporative history of moisture, will be used to determine the time of recharge and flow path of the moisture. This information, combined with other moisture data, will be used to interpret the patterns of gas transport.

Pore fluids from the matrix and near fractures will be extracted from exploratory shaft rubble core for chemical and isotope analyses. Samples will also be checked for the presence of artificial tracers that would indicate contamination. The fluids will be extracted from the rubble cores by applying pressure, centrifuging, or vacuum distilling depending on the moisture content and core condition. These techniques for fluid extraction will be evaluated during prototype testing.

Fracture fluids are expected to permeate the surrounding matrix. Where fractures occur in core samples, the rock matrix around the fracture will be segregated. Fluids from this matrix with moisture contents greater than 11 percent will be extracted using the centrifuge method.

Fluids from samples with moisture contents less than 11 percent (including samples that have been squeezed and centrifuged) will be extracted using the vacuum distillation method.

Cation concentrations will be determined by using inductively coupled plasma (ICP), and anion concentrations will be determined by ion chromatography. Stable isotope ratios will be analyzed by mass spectrometry. Low-level gas counters or liquid scintillation counters will be used to determine

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tritium activity. Large carbon-14 samples will be analyzed using conventional gas counting methods, with small carbon-14 and chlorine samples analyzed by tandem accelerator mass spectrometry. All water samples will be analyzed for the presence of gas and water tracers using gas chromatography-mass spectrometry (GCMS). The usefulness and applicability of uranium-series disequilibrium analyses will be evaluated; if determined to be appropriate, these analyses will be done.

Apparent ages of water in the unsaturated zone will be determined from isotope data (carbon-14, tritium, and chlorine-36). Chemical analyses (cations and anions) will be used to verify flow paths indicated by isotope data and to indicate the extent of water-rock interaction. Chemical and isotope data for pore water and fracture-related water will indicate travel times since lower chemical concentrations and the presence of tritium will indicate younger water.

Additional discussions of these studies are included in Activity 8.3.1.2.2.8.2.

The bulk chemistry data determined in this activity will be used by Study 8.3.1.3.1.1 in its development of ground-water chemistry model. Furthermore, this information and task will be integrated with Activity 8.3.4.2.4.1.3 (composition vadose water from the waste package environment).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.8 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Collect and transport gas samples from radial boreholes	HP-56, RO	General procedure for soil-gas sampling in unsaturated zone test holes	15 Nov 84
	TBD ^a	Data archiving, shipping and handling procedure	TBD
Prepare gas samples for analysis	HP-86, RO	Method for degassing CO and H ₂ O (vapor) samples from unsaturated zone test holes	1985

Method	Technical procedure		Date
	Number	Title	
Analyze gas samples	HP-07, R1	Use of sulfur hexafluoride as a tracer gas for determining atmospheric contamination in a vacuum-drilled borehole	TBD
	TBD	Data archiving, shipping and handling procedure	TBD
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	HP-11, R0	Method for determination of radioactive substances in water	18 June 82
	HP-63, R0	Method for carbon-14 age dating of Walker Lake sediment core	
	HP-127	Carbon-14 dating by tandem accelerator mass spectrometer	TBD
Collect and transport core and rubble samples	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, NTS	30 Mar 87
Rubble coring	TBD	Air coring of 2-1/2 inch cores from rubble	TBD
Extract water from core and rubble core samples	HP-125	Method of extraction of pore water by tri-axial compression	TBD
	HP-110	Extraction of pore waters by centrifuge methods	TBD

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Method	Technical procedure		
	Number	Title	Date
Analyze water samples	HP-126	Extraction of pore waters by vacuum distillation	TBD
	TBD	Procedure for determining the presence of tracers in pore water samples	TBD
	TBD	Data archiving, shipping, and handling procedure	TBD
	HP-8, RO	Methods for determination of inorganic substances in water	6 Aug 82
	HP-11, RO	Methods for determination of radioactive substances in water	18 June 82
	HP-127	C-14 dating by tandem accelerator mass spectrometer	TBD
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	TBD	Method for analyzing water sample for Cl-36	TBD

^aTBD = to be determined.

8.3.1.2.2.5 Study: Diffusion tests in the exploratory shaft facility

There is one activity in this study.

8.3.1.2.2.5.1 Activity: Diffusion tests in the exploratory shaft facility

Objectives

The objective of this activity is to determine in situ the extent to which nonsorbing tracers diffuse into the water-filled pores of two of the

tuffs (Topopah Spring welded unit and Calico Hills nonwelded unit) that the exploratory shaft will penetrate.

Parameters

The parameter of this activity is the diffusivity coefficient.

Description

Diffusion tests in the exploratory shaft are to be conducted in small diameter boreholes drilled beyond the disturbed zone in both the Topopah Spring tuff and the Calico Hills tuff to model the transport of technetium-99 and iodine-129 from the repository to the water table.

This test requires the drilling of four boreholes, each of which will be drilled in an underground drift using air-drilling techniques and the smallest diameter bit available consistent with methods to be used in the testing activities. The drilling will be done with air to avoid adding drilling water to the pores where the diffusion will occur. The depth of the hole will be approximately 10 m to penetrate beyond the zone of stress relief induced by mining the drift.

Each borehole will be surveyed using television to identify any fractures intersecting the borehole walls in the region where the tracer solution will be placed. Tracer injection locations will be chosen in borehole segments that are free from fractures that might result in water flow through the diffusion volume. A small volume of nonsorbing tracers in aqueous solution will be introduced into the bottom of the borehole. Next, the borehole will be sealed with a packer of appropriate size to isolate the diffusion volume from the remainder of the underground environment. After approximately three months, the borehole will be overcored. The overcoring method has been chosen to ensure that the core recovery is adequate. The exact period of time before the overcoring will begin is contingent in part upon the results of the laboratory diffusion experiments. A year-long test will be run after all of the techniques being developed in the three-month test have been proven.

The core will be transported to an offsite laboratory for determination of tracer concentrations as a function of distance from emplacement. The data will be analyzed to derive diffusivity values. The measured tracer concentrations as a function of distance from emplacement will be analyzed in terms of the diffusion equation for solute transport through a porous geologic medium in the absence of fluid flow. The use of this equation is predicated on the absence of tracers in the tuff at the start of the experiment and on a constant tracer concentration in the source solution.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.5.1 are given in the following table.

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Method	Technical procedure		
	Number	Title	Date
(NWM-USGS)			
Borehole drilling	TBD ^a	Reynolds Electrical & Engineering Co. (REECo) drilling and coring procedure--horizontal and vertical holes	TBD
Borehole video surveys	TBD	Borehole video fracture logging (horizontal holes)	TBD
	GP-10, R0	Borehole video fracture logging (vertical holes)	TBD
Tracer-injection tests	TBD	TBD	TBD
Borehole overcoring	TBD	TBD	TBD
Laboratory tracer concentration analysis of core	TBD	TBD	TBD
Diffusivity analysis	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.2.6 Study: Characterization of flux within the Paintbrush nonwelded unit in the vicinity of the Ghost Dance fault

The potential for the development of perched water above the Paintbrush nonwelded unit and for the lateral diversion of flux to faults is highly significant for assessing flux at the repository horizon. As a result, a plan will be developed to evaluate the occurrence of these phenomena. One possible approach would be to use a small shaft to investigate the nature of fracturing, to test for air conductivity, and to evaluate mineralization and alteration or other evidence for lateral flow.

This study includes one activity.

8.3.1.2.2.6.1 Activity: Plan to characterize the flux within the Paintbrush nonwelded unit in the vicinity of the Ghost Dance fault

Objectives

The objectives of this activity are to develop a plan (1) to determine percolation conditions leading to formation of a perched water zone, (2) evaluate the occurrence and magnitude of lateral diversion of percolation, and (3) to test for concentrated ground-water flux in the Ghost Dance fault as a drain for laterally diverted flow.

Parameters

The parameters of this activity are

1. Matric potential.
2. Water content.
3. Hydraulic head.
4. Hydraulic and air conductivity.
5. Dispersion.
6. Flux.
7. Variability of hydraulic and pneumatic properties and geologic structures.
8. Characteristics of fractures and fault zone, including mineralization and alteration.
9. Tracer concentrations and activities.

Description

Knowledge of the distribution of moisture flux in the repository horizon is essential for evaluating site suitability. An initial conceptual model of flow in the unsaturated zone at Yucca Mountain was described by Montazer and Wilson (1984) and modeled in part by Rulon et al. (1985). This conceptual model includes the potential for lateral unsaturated or perched-water flow within or above the Paintbrush nonwelded unit, and for diversion of flow down the Ghost Dance fault. These conditions, if present, could have significant impacts on flow paths and flow rates through the proposed repository horizon. For example, lateral flow could result in markedly diminished flux throughout much of the repository horizon, whereas flow down the Ghost Dance fault could result in concentrated flow in a part of the repository horizon. Because of the technical complexities of assessing these conditions, a detailed plan to do so has not yet been developed. This activity describes the effort to develop such a plan, in recognition by the NNWSI Project of the importance of testing these concepts, and to document the intent to conduct such a testing program.

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In this activity, a plan will be developed for evaluating potential conditions for (1) lateral flow and perched water in the Paintbrush nonwelded unit near the Ghost Dance fault, and (2) a concentration of flux down the fault. Possible field methods of investigation to be evaluated include drilling and testing surface-based vertical or slant boreholes, and testing in a small-diameter shallow shaft or large-diameter borehole that would allow direct access to the test area. Numerical flow models would be used in the development of the plan, in order to evaluate alternative testing approaches and to optimize testing design. It is expected that once the plan is developed and approved, flow models would also be used to predict performance during testing and to assist in the analyses of experimental results.

One approach to be considered would be to drill boreholes parallel to bedding above the nonwelded tuff and fit them with perforated pipes. A large-scale infiltration test would be conducted across the entire nonwelded sequence, while numerous holes would be monitored for moisture and matric suction in the affected interval. The procedure is analogous to the infiltration test planned for the Topopah Spring welded unit in the exploratory shaft facility. The test would be conducted at various fluxes, and direct evidence of conditions leading to perched water would be gained. If lateral diversion toward the Ghost Dance fault develops, it would be monitored in drillholes penetrating the fault beneath its intersection with any potential perched water zones. Bulk permeability values for air and water at different saturations would be derived for the Tiva Canyon welded unit, the Paintbrush nonwelded unit, and a representative portion of the Ghost Dance fault. Fault-zone properties within the nonwelded units are expected to differ from those within the more coherent welded tuffs.

Development of the plan would take into account related activities that are described in this section to provide an integrated approach toward evaluating conditions of perching, lateral flow, and flow down faults.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.2.2.6.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Shaft sinking and drilling	TBD ^a	Reynolds Electrical and Engineering Co. (REECo), shaft excavation and drilling procedures	TBD
Shaft-wall mapping and drift mapping	TBD	TBD	TBD
Construction of breakouts and drifts	TBD	REECo, drifting procedures	TBD

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Horizontal (or inclined parallel to the dip) and slant-hole drilling	TBD	REEGo, drilling procedures	TBD
	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, NTS	30 Mar 87
	GP-11, R0	Logging fractures in core	15 May 85
	GP-15, R0	Inventory of drillhole core	20 Mar 87
	HP-28, R0	Laboratory procedures for the determination of moisture-retention curves on rock core	15 May 85
Borehole logging and testing	HP-10, R1	Packer-injection and shut-in tests	9 July 84
	HP-06, R0	Hydrologic pumping test	11 Jan 82
Emplacement of piezometers	TBD	TBD	TBD
Infiltration testing	TBD	TBD	TBD
Numerical modeling	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.2.7 Study: Characterization of gaseous-phase movement in the unsaturated zone

The objectives of this study are (1) to describe the pre-waste emplacement gas-flow field, (2) to identify structural controls on fluid flow, (3) to determine conductive and dispersive properties of the unsaturated zone for

gas flow, and (4) to model the transport of water and tracers in the gas phase. One activity is planned to collect the data required to satisfy these objectives: the gas-phase circulation study. The results of this activity will be important to the assessment of transport of gaseous radionuclides (e.g., carbon-14).

In the gas-phase circulation study, the approach is parallel to that used for hydraulic fluxes: Data will be collected near the steep western slope of Yucca Mountain to define the boundary conditions and conductive properties; a coupled model will predict the fluxes; and observations will verify and calibrate the model. Existing exsurgent and insurgent boreholes will be instrumented to relate flow to atmospheric conditions. New holes will be stemmed to isolate chambers for gas sampling and pressure measurement where the Solitario Canyon slope provides an unknown boundary condition for the repository block. In-hole, cross-hole, and transverse-site tracer tests, as well as analysis of natural and bomb-produced tracers, will be used to disclose fracture system transport properties (Table 8.3.1.2-9).

The Solitario Canyon horizontal borehole activity has been designed to augment the gas phase circulation study in determining the gaseous flux distribution on the western side of the repository. In this activity, two or more boreholes on the Solitario Canyon slope will be drilled to measure the discharge and gas samples will be taken to determine the boundary fluxes and potentials. Many tests of the effective air conductivity of the fractured rocks at many levels will provide model parameters for two- and three-dimensional simulations. Analysis of gas compositions will disclose effective fracture porosities by determination of mean travel times, while the breakthrough curves for conservative gas tracers will indicate effective porosities and convective dispersivities for the gas phase.

The magnitude of vapor fluxes and gas transport can only be evaluated by modeling, which requires the collection of sufficient data on properties of the fractured media and appropriate boundary conditions. Numerical models will be constructed to incorporate the presence of boreholes and underground openings, as well as topographic and structural controls. The flow field will depend upon the definition of the transient atmospheric boundary conditions, together with geothermal-drive mechanisms, and upon a spatial definition of conductive, storative, and dispersive properties of the unsaturated zone.

8.3.1.2.2.7.1 Activity: Gaseous-phase circulation study

Objectives

The objectives of this activity are

1. To describe and model the prewaste-emplacement gas-flow field and its effect on net water-vapor transport from the unsaturated zone by modeling the western portions of Yucca Mountain as a two-dimensional and/or three-dimensional boundary problem in compressible nonisothermal flow.

Table 8.3.1.2-9. Summary of gas-phase tests (page 1 of 3)

Hole or site	Test	Objectives	Methods
USW UZ-6, -6s (open holes)	Flow distribution in each open hole	Relate flux to atmospheric boundary conditions	Regression analysis
	Flow tests to each sampling chamber	Evaluate effective gas conductivity and storativity	Analytical solutions and 3-D modeling
	Relative humidity of discharging air	Determine moisture flux with time	Gas sampling and analysis
	Natural tracer tests	Determine ages of gases discharged, age of water evaporated Determine dispersivities	Composition of gases discharging at various depths: SF_6 , CBrCl_3 for drilling-air contamination, CCl_2F_2 , CCl_3F , and ratios of $^{14}\text{CO}_2$ to CO_2 , tritiated water to H_2O , and ^{18}O to ^{16}O , (sample bimonthly for age determinations).
	Flux distribution	Determine preferential flow paths; site subsequent test	Measure flux distribution (quality assurance) over boundary surface.

Table 8.3.1.2-9. Summary of gas-phase tests (page 2 of 3)

Hole or site	Test	Objectives	Methods
Solitario Canyon hole (vertical in Topopah Spring) and Solitario Canyon hole (horizontal in Tiva Canyon)	Shallow formation moisture contents	Determine seasonal effects of convective air flow on moisture contents	Measure saturation of sample gases from various depths
	Boundary conductivity	Determine fracture conductivity near (disturbed) surface	Pressure-transducers set in isolated chambers in holes; rates to open/chambered holes; validate models
	Structural controls	Determine if faults and non-welded strata are air-conductive or barriers	
	Geothermal test	Provide thermal parameters for compressible flow modeling	Measure temperature distribution, test conducted by J.Sass (GPP-02, 05)
UZ-6 borehole complex and UZ-9 borehole complex	Packer injection/interference/nonsteady flow tests	Determine anisotropic air conductivities, storativity for all unsaturated-zone units, parameters needed for all unsaturated-zone units, parameters needed for all large-scale modeling; validate models	Use 3m injection intervals in each hole, simultaneously measuring gas pressure in array of chambers of adjacent holes, apply the analysis for anisotropic fracture permeability from Hsieh, et al. (1985)

Table 8.3.1.2-9. Summary of gas-phase tests (page 3 of 3)

Hole or site	Test	Objectives	Methods
	Dispersivity tests	Determine fracture system air dispersivities as function of gradient direction and anisotropy. Parameters needed for large-scale modeling. Validate dispersivity model.	Injection nonsorbed gas tracers in interval, observe breakthrough at array of chambers in adjacent holes. Analyze according to method of Kremer (1982).

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2. To provide parameters necessary for modeling gas flow from and to the repository and the potential transport of radionuclides as well as the gaseous flux of moisture affecting deep percolation after the repository is in place.
3. To reconstruct the air circulation history at instrumented boreholes from the time of drilling until stemmed and instrumented in order to estimate the time required for poststemming recovery of ambient gas and moisture conditions as an aid in interpreting gas composition and thermocouple psychrometer data.
4. To determine, by flow and pressure measurements in single holes, and by cross-hole interference tests, the near-field air conductivities, storativity, and anisotropy of the unit above the repository horizon.
5. To determine effective porosities and dispersivities of the fracture system by the interpretation of natural and artificial gas tracer data as an aid in the modeling described in items 1 and 2.

Parameters

The parameters of this activity are

1. Moisture content.
2. Gas composition.
3. Air temperature.
4. Gas potential distribution.
5. Flux.
6. Fracture conductivity and anisotropy.
7. Fault conductivity.
8. Structural controls.
9. Effective porosity.
10. Convective dispersity.

Description

Atmospheric conditions will be characterized during the entire period of gas-flow measurement by using the site meteorological network (Activity 8.3.1.2.1.1.1) to determine and interpolate to drillhole sites of concern, the air temperature, barometric pressure, and relative humidity as a function of time and seasons. Atmospheric samples will also be collected. Their compositions will be analyzed using the same method used for borehole gas samples, described in the following paragraph.

Two existing open wells (USW UZ-6, USW UZ-6s) will be instrumented with recording hot-wire anemometer flow meters (Figure 8.3.1.2-21). The flow will be measured for extended periods of time under open-hole conditions and for partial shut-in conditions. These flow rates will be related to barometric pressure changes and air temperature by regression analysis. All the topographically affected wells along the crest of Yucca Mountain will also be periodically shut in and the pressure difference between the wells and atmosphere will be measured. In turn, each well will be opened, and the pressures will be measured in all surrounding wells to conduct interference

Figure 8.3.1.2-21. Gaseous-phase sampling locations.

tests. The results will be analysed to determine the horizontal and vertical permeability to air, the air-filled fracture porosity conventional temperature logging tool will be used whereas the device for flow logging remains undetermined. Gas samples will be obtained in open holes by lowering tubing downhole to various depths. The samples will be collected in syringes and analyzed on site for relative humidity and by gas chromatography to determine the percentage composition of carbon dioxide (CO_2), methane (CH_4), SF_6 , CBrCl_3 (BCF), CCl_2F_2 (F-12), and CCl_3F (F-11). Both CO_2 and methane may serve as natural tracers that indicate fracture zones of strong circulation, information that can be used to estimate the total volume of gas flow in individual zones within the total section tapped by the borehole. Such information is needed to estimate the time for ambient conditions to be recovered at different depths. SF_6 and BCF were added to the air during the drilling of USW UZ-6 and USW UZ-6s, respectively, and their presence and concentration will indicate the extent to which drilling air has been purged from the hole and surrounding rock by convective air flow. F-11 and F-12 behave as long-term man-made tracers that can give additional information on gas transport at the site. If the flux is slow, the long-term tracers tritium and chlorine-36 may be included in subsequent work. The logging will be conducted every two months until the holes are stemmed.

Fluorocarbon concentrations arising from diffusion transport alone through the unsaturated zone have been attenuated several-fold at a depth of about 50 m based on measurements made in the High Plains of Texas. Hence, near-atmospheric concentrations of F-11 and F-12 at depth would be indicative of convective gaseous-phase transport.

Gas composition data for USW UZ-1 suggest that natural conditions within the borehole require at least 2.5 yr after the hole was stemmed to approach equilibrium with the surrounding rocks. Modeling of open borehole flow will allow evaluation of the length of time required for the moisture content and gas composition for various zones to reequilibrate to ambient conditions once stemming is complete.

Sometime subsequent to the stemming of holes USW UZ-6 and USW UZ-6s, two holes (USW UZ-11 and USW UZ-12) will be drilled on either side of the Solitario Canyon fault. Also, a near-horizontal hole will be drilled into the Tiva Canyon welded unit or Topopah Spring welded unit above or below the nonwelded or bedded Paintbrush Tuff. Moisture content and pore-gas relative humidity, as inferred from the Kelvin equation, will be determined on cores and cuttings, and the holes will be instrumented to measure temperature, moisture tension, and pore-gas relative humidity and will be equipped for periodic gas sampling. Gas compositions in all three holes will be determined from periodically collected samples. Although gas-flow conditions will be altered by stemming holes USW UZ-6 and USW UZ-6, the data collected during this study will be invaluable in interpreting and modeling the temperature, relative humidity, and gas composition data collected during those studies, particularly in regard to seasonal variations in near-surface moisture content and trace gas composition. These moisture and trace-gas seasonal changes may provide insight on the magnitude of gas circulation under natural conditions.

In winter, gas tracer tests may be performed by shallow burial of permeation tubes at various horizons along the western scarp of Yucca Mountain. The trace gases will be sampled in the air stream blowing from the summit wells. The interpretation of tracer tests in the light of structural controls, fracture geometry, and breakthrough concentrations will require numerical modeling. These measurements will provide a large-scale test of dispersivity to gas flow and will provide much useful information for the gas-tracer tests planned in the UE-25 UZ#9 hole cluster, as described in the following paragraph.

Effective fracture porosity and dispersivity will be obtained by tracer tests conducted between adjacent boreholes, in the unsaturated portions of UE-25 UZ#9, 9a, and 9b. Unsaturated zone tracer testing in the cluster is expected to require about 60 days, based on solely diffusive transport and conservative estimates of tortuosity to that transport. While injecting a conservative tracer in one packed-off interval, adjacent boreholes, segmented by packer strings and tapped by sampling tubes, can be sampled to obtain breakthrough curves. Each hydrostratigraphic unit can be characterized by applying distinctly different tracers at several injection intervals, sampling at fixed packer intervals in the adjacent holes. These data could augment "huff-and-puff" tracer tests conducted routinely in connection with each packer air injection test of the exploratory shaft test plan, which would measure, on a small scale, the fracture-system dispersivities.

Gas-phase modeling will be used to interpret the results of observations made during this study, and to extrapolate those results to interpret gas circulation in Yucca Mountain under natural conditions. A two-dimensional model in vertical section normal to the slope will be developed to interpret the measured gas potentials and fluxes in terms of the temperature distribution, moisture contents and structural and stratigraphic controls. Three-dimensional modeling may be needed to incorporate borehole configurations. Average conductivities, porosities, and dispersivities for distinct units are expected results of this modeling. These results will be useful in evaluating water vapor and gaseous radionuclide transport from Yucca Mountain once the repository is in place. Preliminary modeling will be conducted using the HST code (Kipp, 1986).

Structural controls on the gas flow may be recognized by analysis of the flux distribution. Fault zones may be strong conduits for parallel flow and strong barriers to cross flow. Fine nonwelded beds, as exist in the Pah Canyon Tuff, may impede circulation in the mountain, or completely compartment the terrain. Models, substantiated by borehole tests of the degree of saturation at inlet and outlet regions during each season, provide a point of departure for computing ground-water depletion, believed to be a dominant flux component in the unsaturated zone, especially during interpluvial ages. Likewise, the models will provide a basis for estimating gaseous radionuclide transport and moisture migration due to the gas circulation as enhanced by the repository heat load.

If these gas-phase investigations indicate that movement of moisture, gas, or both in the unsaturated zone is potentially significant, either in reducing the potential for deep percolation through the repository or in discharging gasses to the atmosphere, additional open-borehole studies may be needed at other locations on Yucca Mountain.

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Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.7.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Site meteorologic conditions	TBD ^a	TBD	TBD
Instrumentation of open boreholes	TBD	TBD	TBD
Rotary drilling of test holes	TBD	TBD	TBD
Geothermal profiling	GPP-02, R0	Heat flow studies related to nuclear waste storage investigations	11 Jan 82
	GPP-05, R1	Heat flow studies calibration procedures	7 Jan 86
Instrumentation of new holes	TBD	TBD	TBD
Air sampling	TBD	TBD	TBD
Tracer tests	TBD	TBD	TBD
Modeling	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.2.8 Study: Hydrochemical characterization of the unsaturated zone

The objectives of this study are (1) to understand the gas transport mechanism, direction, flux and travel time within the unsaturated zone; (2) to design and implement methods for extracting pore fluids from the tuff; (3) to provide independent evidence of flow direction, flux, and travel time of water in the unsaturated zone; (4) to determine the extent of the water-rock interaction, and (5) to model geochemical evolution of ground water in

the unsaturated zone. Two activities are planned to collect the data that is required to satisfy these objectives.

8.3.1.2.2.8.1 Activity: Gaseous-phase chemical investigations

Objectives

The objective of this activity is to understand the gas transport mechanism, and to provide evidence of gas flow direction, flux, and travel time within the unsaturated zone.

Parameters

The parameters of this activity are

1. Gas composition.
2. Carbon-isotope concentration (in CO₂ gas).
3. Hydrogen and oxygen isotopes (in water vapor).

Description

Carbon dioxide and water-vapor samples will be collected from unsaturated zone holes after the holes have been packed and instrumented (Figure 8.3.1.2-22). Gas samples will be checked for contamination caused by air coring (using SF₆ or a similar conservative gas tracer). Samples to be used for composition analysis will be drawn by peristaltic pumping, collected in glass or stainless steel collection cylinders, and analyzed by gas chromatography. The carbon dioxide gas will be collected by a molecular sieve in stainless steel collection cylinders and analyzed for carbon-14 and carbon-13 to carbon-12 ratio. Water vapor will be collected in the cold trap by pumping the gas through the cold trap and analyzed for tritium and oxygen-13 to oxygen-16 ratio.

The age of the unsaturated zone gases will be determined from the carbon-14 and carbon-13 to carbon-12 ratio isotope data. Stable isotope ratios (oxygen-13 to oxygen-16 and deuterium to hydrogen), which can indicate the climatic and evaporative history of moisture, will be used to determine the time of recharge and flow path of the moisture. This information, combined with other moisture data, will be used to interpret the patterns of gas transport.

Data from this activity will be combined with data from the unsaturated zone gaseous-phase circulation study (Activity 8.3.1.2.2.8.1) in an assessment of the Yucca Mountain gas flow processes.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.8.1 are given in the following table.

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Figure 8.3.1.2-22. Gaseous and liquid-phase chemical sampling locations.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Collect and transport gas samples	HP-56, R0	General procedure for soil gas sampling in unsaturated zone test hole	15 Nov 84
Prepare gas samples for analysis	HP-86, R1	Method for degassing CO ₂ and H ₂ O (vapor) samples from unsaturated zone test holes	TBD ^a
Analyze gas samples	HP-07, R1	Use of sulfur hexafluoride as a tracer gas for determining atmospheric contamination in a vacuum-drilled borehole	TBD
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	HP-11, R0	Method for determination of radioactive substances in water	18 June 82
	HP-63, R0	Method for carbon-14 age dating of Walker Lake sediment core	TBD
	HP-127	Carbon-14 dating by tandem accelerator mass spectrometer	TBD

^aTBD = to be determined.

8.3.1.2.2.8.2 Activity: Aqueous-phase chemical investigations

Objectives

The objectives of this activity are

1. To design and implement methods for extracting pore fluids from unsaturated zone tuff units.

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2. To provide evidence of flow direction, flux, and travel time of water in the unsaturated zone.
3. To determine the extent of the water-rock interaction and to model geochemical evolution of ground water in the unsaturated zone.

Parameters

The parameters of this activity are

1. Water quality (cations, anions).
2. Flow paths (oxygen-18-oxygen-16, deuterium-hydrogen).
3. Travel times (hydrogen-3, carbon-14, chlorine-36).

Description

Pore fluids from the rock matrix and near fractures will be extracted from unsaturated zone drill cores for chemical and isotope analyses (Figure 8.3.1.2-22). Samples will also be checked for the presence of various tracers that will be used during the drilling of wells and the construction of the exploratory shaft. The fluids will be extracted by applying pressure, centrifuging, or vacuum distillation depending on the moisture content and core condition. These techniques will be evaluated during prototype testing.

Pore fluids from core samples of matrix with moisture contents greater than 11 percent will be extracted using the triaxial press method (below 11 percent, neither triaxial press nor centrifuge methods will extract any water). This method consists of placing the core in a triaxial confinement chamber and applying axial and confining pressure in step increases. The water chemistry at each pressure step will be determined. The changes in water chemistry as a function of pressure will be analyzed and the maximum pressure at which no significant water chemistry changes occur will be adopted for the future pressure limits.

Fracture fluids are expected to permeate the surrounding matrix. Where fractures occur in core samples, the rock matrix around the fracture will be segregated. Fluids from this matrix with moisture contents greater than 11 percent will be extracted using the centrifuge methods. This method consists of placing core samples in a centrifuge cup and spinning them for 2 hr, with the fluids draining through a perforated plate into a collection cup. Fracture fluids may also be available from perched water zones in the exploratory shaft.

Fluids from samples with moisture contents less than 11 percent (including samples that have been squeezed and centrifuged) will be extracted using the vacuum distillation method. This method consists of placing the core sample inside a glass container that is in an evacuated system, and heating it to 100°C to drive off the moisture. The moisture will then be collected in an alcohol-dry ice trap. This vacuum distillation method will yield distilled water, and therefore can only be used for tritium, oxygen, and hydrogen isotope analyses.

Cation concentrations will be determined by using inductively coupled plasma (ICP) and anion concentrations will be determined by ion chromatography. Stable isotope ratios will be analyzed by mass spectrometry. Low-level gas counters or liquid scintillation counters will be used to determine tritium activity. Large carbon-14 samples will be analyzed using conventional gas-counting methods, with small carbon-14 and chlorine-36 samples analyzed by tandem acceleration mass spectrometry. All water samples will be analyzed for the presence of gas and water tracers using gas chromatography-mass spectrometry (GCMS).

Apparent ages of water in the unsaturated zone will be determined from isotope data (carbon-14, tritium, and chlorine-36). Chemical analyses (cations and anions) will be used to verify flow paths indicated by isotope data and to indicate the extent of water-rock interaction. Chemical and isotope data for pore water and fracture-related water will indicate travel times, since lower chemical concentrations and the presence of tritium will indicate younger water.

Data from this activity will be integrated with and used by Study 8.3.1.3.1.1 in its development of a ground-water chemistry model. Furthermore, Section 8.3.4.2.4 (Activity 1.10.4.1.3) will also integrate with and use these data as it characterizes the unsaturated zone water to determine the water composition of the waste package environment.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.8.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Collect and transport core samples	HP-12, R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well-site, NTS	30 Mar 87
	HP-131	Method for handling and transporting samples of unsaturated core for hydro-chemical analysis	TBD ^a
Extract water from core samples	HP-125	Method of extraction of pore water by triaxial compression	TBD

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Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
	HP-110	Extraction of pore waters by centrifuge methods	TBD
	HP-126	Extraction of pore waters by vacuum distillation	TBD
Analyze water samples	TBD	Procedure for determining the presence of tracers in pore water samples	TBD
	TBD	Data archiving, shipping, and handling procedure	TBD
	HP-08, RO	Methods for determination of inorganic substances in water	6 Aug 82
	HP-11, RO	Method for determination of radioactive substances in water	18 June 82
	HP-127	Carbon-14 dating by tandem accelerator mass spectrometer	TBD
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	TBD	Method for analyzing water samples for chlorine-36	TBD

^aTBD = to be determined.

8.3.1.2.2.9 Study: Unsaturated-zone flow and transport modeling

The objectives of this study are (1) to select and adapt existing computer codes that simulate moisture flow and solute transport in variably saturated porous media for application to the Yucca Mountain site, (2) to develop new codes as needed to solve particular hydrologic problems peculiar

to the Yucca Mountain site, (3) to verify codes through testing and benchmarking activities, (4) to validate codes by application to the site hydrologic system or its component subsystems, (5) to construct a comprehensive three-dimensional, coupled heat and moisture flow model for the existing natural site hydrogeologic system, (6) to use this model to predict probable past and present states of the hydrogeologic system under changing environmental conditions, and (7) to use classical statistical and geostatistical methods to assess quantitatively the probable limits of uncertainty attached to the calculated results of the models. The analyses described here will be performed in conjunction with, and provide information to, the performance issues, Issues 1.1 through 1.6 (Section 8.3.5), which address numerical regulatory criteria.

These objectives are grouped under three activities: (1) preliminary numerical modeling of the site hydrologic system, (2) simulation of the natural hydrogeologic system, and (3) stochastic modeling and uncertainty analysis.

8.3.1.2.2.9.1 Activity: Preliminary numerical modeling of the site hydrogeologic system

Objectives

The objective of this activity is to select, adapt, develop, verify, and validate computer codes to simulate mathematically hydrologic processes occurring within the unsaturated zone underlying the Yucca Mountain site.

Parameters

The parameters of this activity are

1. Model geometry: One-, two-, or three-dimensional; allowable configurations for the spatial boundaries.
2. Hydrologic processes: Single-phase liquid water or pore-gas flow and storage, or two-phase moisture and pore-gas flow and storage in variably saturated, variably fractured porous media.
3. Solute-transport processes: Liquid- or gas-phase solutes, adsorption, radioactive decay, chemical interactions (in solution, with surrounding rocks or both).
4. Boundary conditions: Dirichlet, Neumann, and mixed; seepage face; evaporation; evapotranspiration.

Numerical procedures for this activity include

1. Discretization: Finite difference, finite-element, or integrated finite difference.

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2. Nonlinearity: Piccard iteration, Newton-Raphson linearization.
3. Matrix solver: Direct, iterative.

Description

Quantitative hydrologic evaluation of the unsaturated zone hydrogeologic system at the site will require the construction of numerical hydrologic models for the site hydrogeologic system as well as its component subsystems. These mathematical models, or representations, are constructed by formulating the controlling hydrologic and transport processes mathematically and solving the resultant set of integro-differential equations, subject to specified boundary and initial conditions, to yield a mathematical representation for the system. Because of the physical complexity of the Yucca Mountain system and the inherent mathematical nonlinearity of the moisture- and gas-flow equations in unsaturated media, the mathematical solution of the equations can be obtained practically only by using finite numerical algorithms implemented on high-speed digital computers. A number of computer codes are available with capabilities to simulate all or some aspects of multidimensional, multiphase, multicomponent fluid flow and storage in variably saturated, variably fractured porous media.

These aspects define the parameters for this activity as enumerated in the above list of parameters. Most requirements for hydrologic modeling at the site are expected to be met by selecting available codes having the requisite capabilities. Existing codes will be modified or new codes will be developed; however, to meet specific requirements peculiar to the site for which available codes may be inadequate or unsuitable. All codes will be verified and validated before their application to site problems. Code verification demonstrates that the code performs the numerical procedures correctly; whereas code validation establishes that the code is appropriate for solving the particular physical problem to which it is to be applied.

Numerical hydrologic modeling is to be used to (1) support other studies, for example, to perform preliminary analyses, to design tests and experiments, and to analyze and interpret data, (2) construct a flow model for the overall site hydrogeologic system, and (3) support the final system synthesis and integration. Although a single code may be sufficiently versatile and robust to solve many problems and, thus, to construct many models, it is expected that a repertoire of codes will be required to meet the diverse needs for site hydrologic evaluation. The requisite repertoire of codes is to be assembled through preliminary hydrologic modeling of the site and its subsystems to verify and validate codes for possible application to the site. Code verification is to be performed generically through formal benchmarking procedures established within the NNWSI Project, whereas code validation is application dependent and therefore must be undertaken on a code-by-code basis. Specific plans to validate the codes have not yet been developed.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.9.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS--)		
Code verification	TBD ^a	TBD	TBD
Code validation	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.2.9.2 Activity: Simulation of the natural hydrogeologic system

Objectives

The objective of this activity is to construct a three-dimensional, two-phase, coupled heat- and moisture-flow model for the natural site hydrogeologic system to (1) simulate and investigate the present existing state of the system and (2) predict probable future and past states of the system under changing environmental conditions.

Parameters

The parameters of this activity are

1. Time-dependent spatial distributions of liquid water matric potential and saturation, pore-gas pressure, moisture fluxes, and temperature.
2. Boundary fluxes, pressures, and potentials.
3. Hydrologic and thermal properties for the component hydrogeologic units.

Description

A numerical hydrologic model is to be constructed that simulates mathematically the coupled, simultaneous flow of moisture, gas, and heat within the unsaturated zone underlying the primary repository area. The construction of this flow model follows directly as a continuation and an expansion of the conceptual modeling (Activity 8.3.1.2.2.10.1) and the preliminary modeling (Activity 8.3.1.2.2.9.1). The basic purpose of this model construction remains largely heuristic; that is, to continue but enlarge the scope of identifying and testing the hydrologic conditions, concepts, and processes that control the site hydrogeologic system. It is intended, however, that this model construction will culminate in a mathematical representation of the hydrogeologic system that is consistent with respect to available hydrogeologic field and laboratory data and is as comprehensive as

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possible within the practical constraints imposed by finite numerical simulations of complex physical systems. The final flow model will be used subsequently to perform baseline analyses, predict possible future or past states of the hydrogeologic system, and to support the final system synthesis and integration (Activities 8.3.1.2.2.10.2 and 8.3.1.2.2.10.3).

The input and output data for the model define the parameters for this activity. Requisite input data include (1) the geologic framework for the site, which determines the model geometry and material composition, (2) the hydrologic, thermal, and mechanical properties of the hydrogeologic units that make up the unsaturated zone at the site, and (3) the extant environmental conditions, which determine the flux, potential, and pressure distributions on the spatial boundaries of the model. In general, the land surface will define the upper spatial boundary, and the water table will define the lower boundary for the model; the lateral boundaries must enclose the primary repository area and remain to be established. The material property data for the hydrogeologic units will be obtained from field and laboratory determinations that will become available as site characterization proceeds. The environmental conditions that establish the hydrologic boundary conditions are determined by the present and past site climatology. The output data generated by the model for a specified set of input data consist of predicted time-dependent spatial distributions of liquid water matric potential and saturation, pore-gas pressure, water-vapor concentration, temperature, and moisture and pore-gas fluxes. To the extent that the mathematical formulation on which the model is based incorporates all the hydrologic processes and conditions that control the physical hydrogeologic system, the flow model yields an internally self-consistent mathematical representation of the hydrologic system and its evolution over time. The probable accuracy and validity of this representation is considered under Activity 8.3.1.2.2.9.3 (stochastic modeling and uncertainty analysis). The moisture and pore-gas flux distributions computed from the flow model provide requisite input data for subsequent solute-transport and hydrochemical modeling.

Specific issues to be addressed during the construction of this model are to (1) assess the consequences of introducing the complication of allowing for three-dimensional fluid flow and boundary conditions, (2) investigate the relative contributions of liquid water and water-vapor fluxes to the net moisture flux within the three-dimensional system, (3) assess the likelihood for the occurrence of geothermally driven convection cells involving the upward flow of water vapor with a corresponding downward return flow of liquid water, (4) establish limiting conditions under which capillary barriers and perched water zones can be expected to occur, (5) assess the effects produced by variations in assumed land-surface net-infiltration rates, and (6) investigate the three-dimensional spatial distribution and movement of natural environmental tracers such as hydrogen-3, carbon-14, and oxygen-18. An important task of this activity is to identify those hydrologic processes and concepts that are essential for a valid mathematical representation and to eliminate those that can be shown to be of sufficiently negligible effect. The final flow model, thus, will constitute a summary numerical description of the site hydrologic flow system.

The final flow model will be used to perform a set of baseline simulations of the natural hydrogeologic system. Using the simulation of the

presently existing natural system as initial conditions, a sequence of simulations will be obtained to extrapolate the system both forward and backward in time. The forward extrapolation will be based on expected most-probable changes in the site climatological regime derived from Study 8.3.1.5.1.6 (characterization of the future regional climate and environments); whereas the backward extrapolations will be based on past climatological conditions and variations inferred from Study 8.3.1.5.1.4, (synthesis of the paleoenvironmental history of the Yucca Mountain region). The sequence of baseline simulations constitutes a standard set against which the effects of extreme or episodic changes in environmental conditions at the site may be assessed. The most-probable limits of uncertainty attaching to the baseline simulations is to be estimated as part of Activity 8.3.1.2.2.9.3 (stochastic modeling and uncertainty analysis). This flow model will be used to define flow paths and calculate fluxes and velocities within the unsaturated zone, as described under Activity 8.3.1.2.2.10.3 (system integration).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.9.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Three-dimensional, two-phase coupled heat and moisture flow modeling for variably saturated, variably fractured porous media	TBD ^a	TBD	TBD
Definition of hydrologic boundary conditions	TBD	TBD	TBD
Evaluation and compilation of hydrologic, thermal, and mechanical properties	TBD	TBD	TBD
Baseline analysis	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.2.9.3 Activity: Stochastic modeling and uncertainty analysis

Objectives

The objective of this activity is to assess the probable limits of uncertainty of the numerical model predictions due to uncertainties in the material properties and boundary condition data.

Parameters

The parameters of this activity are

1. Measurement errors.
2. Statistical distribution function.
3. Probable limits of uncertainty.

Description

The precision of the numerical results produced by a numerical hydrologic model is determined by that of the input data and the precision handling capability of the computer system used to perform the numerical calculations. The accuracy of the model predictions considers the discrepancy, or error, between the predictions and the actual conditions prevailing within the physical system being simulated by the model. Inadequate precision rarely is of practical concern, whereas the assessment of the accuracy of a simulation is of fundamental importance in establishing the adequacy and validity of the model.

The sequence of baseline simulations will provide the initial conditions for a set of Monte Carlo simulations in which the hydrologic property and boundary condition data will be varied in accordance with the empirically determined uncertainty distribution functions. The sensitivity of the model predictions to uncertainties in the input data will be evaluated and quantitative estimates of uncertainty will be estimated specifically for calculated values of liquid water potential and saturation. Not only will these analyses permit an assessment of the probable accuracy of the baseline simulations, but they also provide a means to generate cumulative distribution functions for the net uncertainty associated with predicted values of moisture flux within the unsaturated zone under existing natural conditions.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.9.3 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Estimation of hydrologic property uncertainty distribution function	TBD ^a	TBD	TBD
Monte Carlo simulation analysis	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.2.10 Study: Unsaturated-zone system analysis and integration

The purpose of this study is to integrate all the information provided by the previous studies and ultimately to provide a comprehensive description of the unsaturated-zone hydrology at the site. System analysis and integration is needed to develop conceptual models for the overall flow system within the unsaturated zone at Yucca Mountain, which will be used as a basis for numerical flow and transport models and as a guide for the design of testing programs. The results of modeling and testing programs will then be integrated and evaluated to answer questions related to specific information needs. The final product of this study, which will be in the form of a summary of report findings, is expected to be used in performance assessment and licensing activities.

The activities planned for this study are (1) the conceptualization of the unsaturated zone hydrogeologic system, (2) numerical simulation of the concepts and testing of the hypothesis, and (3) integration of the information to describe flow paths, fluxes, and travel times within the unsaturated zone.

8.3.1.2.2.10.1 Activity: Conceptualization of the unsaturated-zone hydrologic flow system

Objectives

The objective of this activity is to develop conceptual models for the overall flow system within the unsaturated zone at Yucca Mountain on which to base the construction of numerical flow and transport models, prediction of future hydrologic changes due to climatic and tectonic conditions, and design of hydrologic tests.

Parameters

The parameters of this activity are

1. Definition of the spatial distribution of the unsaturated zone hydrogeologic units and their hydraulic properties (hydraulic conductivity, effective porosity, flux, infiltration rates, percolation rates, moisture content, storage properties, transport properties, and fluid potential).
2. Description of fluxes, flow paths, and travel times within the unsaturated zone.

Description

An evolving conceptual model of flow and transport in the unsaturated zone will be developed to help systematically guide the process of site characterization. An initial conceptual model has been developed that consists of a description of the flow system that includes a set of reasonable, integrated, and compatible working hypotheses. These hypotheses are based on preliminary conceptualization of the fluid-flow processes. The testing of these hypotheses will first be carried out by mathematical and numerical modeling. On the basis of the results of this modeling, a series of field and laboratory tests will be conducted to test these hypotheses. During this process, each hypothesis will be verified, modified, or rejected, and the conceptual model and characterization program will be modified accordingly. In addition, proposed alternative conceptual models will be considered and tested, or the working conceptual model will be sufficiently broad and comprehensive so as to accommodate a wide range of alternative hypotheses. Through the characterization process, it is expected that sufficient evidence will be obtained to select the most viable hypotheses, which will form the basis for the final conceptual model that accurately describes flow paths, fluxes, and travel times in the unsaturated zone.

Development and refinement of the conceptual model will emphasize both macroscopic and microscopic aspects of flow. The microscopic aspects of flow considered are (1) flow through unsaturated, rough fractures, (2) flow between fracture and the matrix, (3) flow through a network of fractures and the representative elementary volume, (4) hysteretic effects of fracture-matrix systems (5) two-phase flow through a double-porosity system, and (6) small-scale capillary barrier effects between fractures and matrix and among fractures. In the macroscopic aspect, the following will be considered: (1) infiltration into the unsaturated-zone system, with emphasis on mechanisms of infiltration into exposed fractured-rock units, (2) potential for lateral flow in the layered system, (3) capillary-barrier effects between porous and fractured units, (4) flow through structures/fractures (faults and fractured zones), (5) potential for occurrence of perched waters, and (6) gaseous-phase movement within the unsaturated-zone system.

The microscopic aspects of the conceptual model will be tested and validated through numerical modeling and laboratory investigations. The laboratory investigations supporting this activity are described in part under exploratory shaft activities. Other aspects not covered under previous activities will be conducted as part of this activity.

The macroscopic aspects of the conceptual model will be tested by numerical modeling and field investigations. Many of the field activities, such as drilling across the Ghost Dance fault (Studies 8.3.1.2.2.3, surface-based borehole investigation, and 8.3.1.2.2.6, characterization of flux within the Paintbrush nonwelded unit), are designed to test the conceptual model.

Development of the initial conceptual model is considered complete; however, development, testing, and modification of alternative concepts will be carried out throughout the duration of the site-characterization program.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.10.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS--)		
Conceptual model development	TBD ^a	Data synthesis	TBD

^aTBD = to be determined.

8.3.1.2.2.10.2 Activity: Numerical simulation of the concepts

Objectives

The objectives of this activity are

1. To test hypotheses concerning vertical- versus lateral-liquid water flow, matrix- versus fracture-liquid water flow, capillary barriers, vertical infiltration rates, and movement of environmental isotopes
2. To evaluate concepts of gaseous-phase movement within the unsaturated zone.

Parameters

The parameters of this activity are

1. Time-dependent spatial distributions of hydraulic and pneumatic potential.
2. Saturation.

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3. Fluxes.

4. Isotopic composition.

Description

A sequence of steady state and transient simulations of increasing complexity will be generated to investigate heuristically the basic concepts of moisture flow (idealized as isothermal liquid water flow) within the unsaturated zone underlying Yucca Mountain. These simulations will be based on a three-dimensional moisture-flow model for the Yucca Mountain block. Specific effects to be investigated include (1) the consequences of both fixed but different as well as time-varying land-surface infiltration rates, (2) the effects of hydrologic property differences and anisotropies between and within the vertical sequence of hydrostratigraphic units, (3) the range of effects that may be attributed to the contribution of fracture networks to the effective hydraulic conductivity within the hydrostratigraphic units, (4) the effects induced by imposing different lateral boundary conditions, and (5) the relative contributions of lateral and vertical liquid water flow especially at or near contacts between hydrostratigraphic units and fault interfaces and, subsequently, the possibility of developing capillary barriers and perched water zones and the movement and distribution of environmental isotopes such as hydrogen-3, carbon-14, and oxygen-18 that may act as natural tracers within the liquid-water flow field. The results of these simulations will guide the development of a complete flow model for the unsaturated zone, as well as to refine the field-testing program.

A mathematical model will be constructed to simulate the existing pore-gas flow system within the unsaturated zone underlying Yucca Mountain. The pore gas will be treated as a compressible fluid and buoyancy effects due to the ambient geothermal temperature distribution will be included. The barometrically driven dynamical flow system will be investigated to predict the pore-gas pressure distribution within the unsaturated zone, as well as to evaluate the occurrence and movement of specific gas-phase constituents such as carbon-14 and oxygen-18. A set of transient simulations will be conducted. The resulting set of simulations will provide a means by which to interpret and assess quantitatively field determinations of pore-gas composition and movement and to construct theoretical hydrogen-3 and carbon-14 isochrons.

The models to be used for this activity will be those that are planned to be validated and benchmarked under Study 8.3.1.2.2.9. Specific plans to validate the codes have not yet been developed.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.2.2.10.2 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
(NWM-USGS-)			
Three-dimensional ground-water flow and mass-transport modeling for variable saturated porous media	TBD ^a	Unsaturated zone modeling	TBD
Numerical modeling of compressible gas flow in variably saturated porous media	TBD	Unsaturated zone modeling	TBD

^aTBD = to be determined.

8.3.1.2.2.10.3 Activity: System integration: Definition of flow paths and calculation of fluxes and velocities within the unsaturated zone

Objectives

The objectives of this activity are

1. To compile all the available facts from field data and the results of numerical and analytical simulations to determine the most likely paths of radionuclide transport in the unsaturated zone, to calculate the fluxes and velocities along these paths, and to provide this hydrologic model to help resolve Issues 1.1 through 1.6 (Section 8.3.5).
2. To analyze the relative importance of each path and to estimate the probability of occurrence of a specified flux and velocity along given paths.

Parameters

The parameters of this activity are

1. Flow paths.
2. Fluxes.
3. Velocities.

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Description

Many of the plans described under this investigation state, as their objectives, the determination of the flow paths and (or) the calculation of fluxes and velocities along these paths. Although each test by itself may contribute to the understanding of the flow paths and fluxes or velocities, none by itself satisfies this investigation. Most field studies are too site-specific; test plans are generally designed to examine a specific set of circumstances. Rather, the problem of flow paths and fluxes must be looked upon from many facets. The purpose of this activity is to focus the testing and modeling activities to answer the critical questions of site characterization and to compile and generalize the site-specific findings.

The main effort during the initial phase of this activity will be to focus the objectives of all the other activities. As more data becomes available, the system integration activity will assume a major role in compiling site information. The conclusions drawn will be presented in preliminary reports to be modified as more facts and figures are produced. The final phase of this activity, dominating all other activities, will be a synthesis of all the findings.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.10.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
System synthesis	TBD ^a	Calculations of fluxes and velocities	TBD

^aTBD = to be determined.

8.3.1.2.2.11 Application of results

The parameters evaluated by the planned studies and activities just described above will be used in the following issues, information needs, and investigations of site characterization, repository design, and performance assessment programs:

<u>Number</u>	<u>Subject</u>
1.1.1	Site information needed for calculations (to calculate the releases of radionuclides to the accessible environment) (Section 8.3.5.13.1)

<u>Number</u>	<u>Subject</u>
1.1.2	Potentially significant release scenario classes (Section 8.3.5.13.2)
1.1.3	Calculational models for release scenario classes (Section 8.3.5.13.3)
1.4.1	Waste package design features needed (Section 8.3.5.9.1)
1.5.1	Waste package design features (Section 8.3.5.10.1)
1.5.3	Scenarios and models (for release of radionuclides from the reference engineered barrier system) (Section 8.3.5.10.3)
1.6.1	Site information and design concepts needed (to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path) (Section 8.3.5.12.1)
1.6.2	Calculational models to predict ground-water travel time (in the unsaturated and saturated zones) (Section 8.3.5.12.2)
1.6.3	Identification of likely travel paths (Section 8.3.5.12.3)
1.6.4	Prewaste-emplacement ground-water travel time (Section 8.3.5.12.4)
1.7	Performance confirmation
1.8	NRC siting criteria
1.9(a)	Higher level findings--postclosure
1.9(b)	100,000-yr releases
1.11.1	Site characteristics needed for design (underground facilities) (Section 8.3.2.2.1)
1.11.3	Underground facility orientation and layout (Section 8.3.2.2.3)
1.11.6	Thermal loading and thermomechanical rock response (Section 8.3.2.2.6)
1.12.1	Information needed for seal design and placement (Section 8.3.3.2.1)
8.3.1.2.2	Site unsaturated zone hydrologic system

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<u>Number</u>	<u>Subject</u>
8.3.1.2.3	Site saturated zone hydrologic system
8.3.1.3.1	Water chemistry (within the potential emplacement horizon and along potential flow paths)
8.3.1.3.7	Radionuclide retardation investigations (by all processes along flow paths to the accessible environment)
8.3.1.5.2	Climate effects on hydrology
8.3.1.6.4	Erosion effects on hydrology
8.3.1.8.3	Tectonic effects on hydrology
8.3.1.9.3	Effects of human interference
2.4.1	Site and design information needed (to assess the ability to retrieve emplaced waste) (Section 8.3.5.2.1)
4.2.1	Site performance information needed for design (nonradiological health and safety) (Section 8.3.2.4.1)
4.4.1	Site and performance information needed for design (technical feasibility) (Section 8.3.2.5.1)
4.4.5	Reference preclosure design (potential impacts of hydrologic characteristics on design) (Section 8.3.2.5.5)
8.3.1.14.2	Soil and rock properties
8.3.1.16.3	Ground-water conditions (within and above the potential host rock)

8.3.1.2.2.12 Schedule and milestones

This investigation contains ten studies: 8.3.1.2.2.1 (characterization of unsaturated zone infiltration), 8.3.1.2.2.2 (water movement tracer tests using chloride and chlorine-36 measurements of percolation at Yucca Mountain), 8.3.1.2.2.3 (characterization of percolation in the unsaturated zone--surface based study), 8.3.1.2.2.4 (characterization of Yucca Mountain percolation in the unsaturated zone--exploratory shaft facility investigations), 8.3.1.2.2.5 (diffusion tests in the exploratory shaft), 8.3.1.2.2.6 (characterization of flux within the Paintbrush nonwelded unit in the vicinity of the Ghost Dance fault), 8.3.1.2.2.7 (characterization of gaseous-phase movement in the unsaturated zone), 8.3.1.2.2.8 (hydrochemical characterization of the unsaturated zone), 8.3.1.2.2.9 (unsaturated-zone flow and transport modeling), and 8.3.1.2.2.10 (unsaturated-zone system analysis and integration). In the figure that follows, the schedule information for these studies is presented

in the form of timelines. The timelines extend from the implementation of the approved study plans to the issuance of final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1. Additional schedule information for exploratory shaft activities can be found in Section 8.5.1.2.

Four of the studies in this investigation, 8.3.1.2.2.1, 8.3.1.2.2.3, 8.3.1.2.2.7, and 8.3.1.2.2.8, are ongoing. Studies 8.3.1.2.2.2 and 8.3.1.2.2.4 contain construction-phase exploratory shaft activities and are, therefore, constrained by the start of the exploratory shaft. Studies 8.3.1.2.2.5, 8.3.1.2.2.6, 8.3.1.2.2.9, and 8.3.1.2.2.10 are expected to start within the first year of site characterization. Study 8.3.1.2.2.1 is constrained by the availability of meteorological and runoff data collected under Studies 8.3.1.2.1.1 and 8.3.1.2.1.2. In turn, surficial materials data gathered under this study will be used in Study 8.3.1.5.1.4 for construction of a geologic map of surficial materials covering Yucca Mountain. Study 8.3.1.2.2.3 is constrained by the availability of samples obtained under Investigation 8.3.1.4.1 and the drilling schedule.

STUDY

8.3.1.2.2.1
UZ infiltration

8.3.1.2.2.2
Water movement
tracer tests

8.3.1.2.2.3
Percolation in
the UZ-surface
based study

8.3.1.2.2.4
Percolation in
the UZ-ES
investigations

8.3.1.2.2.5
Diffusion tests
in the ES

8.3.1.2.2.6
Flux within the
paintbrush non
welded unit

8.3.1.2.2.7
Gaseous phase
movement in the
UZ

8.3.1.2.2.8
Hydrochemical
characterization
of the UZ

8.3.1.2.2.9
UZ flow and
transport model-
ing

8.3.1.2.2.10
UZ system analysis
and integration

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Thermal and mechanical properties of the host rock, measured in Studies 8.3.1.15.1.1 and 8.3.1.15.1.6, are required for the completion of Study 8.3.1.2.2.3. Study 8.3.1.2.2.4 is constrained by the availability of fracture data from Study 8.3.1.4.2.2 and matrix hydraulic property data from Study 8.3.1.2.2.3, and by the start of construction of the exploratory shaft. Chemistry data from this study and from Study 8.3.1.2.2.8 will, in turn, be used by Studies 8.3.1.3.1.1 and 8.3.4.2.4.1. Study 8.3.1.2.2.5 is also constrained by the construction of the exploratory shaft. Study 8.3.1.2.2.9 requires data on the most-probable changes in the site climatological regime and past conditions and variations from Studies 8.3.1.5.1.4 and 8.3.1.5.1.6 for completion. Construction of a flow model in Study 8.3.1.2.2.9 follows directly as a continuation and expansion of the conceptual modeling performed in Study 8.3.1.2.2.10. Analyses performed as part of Studies 8.3.1.2.2.9 and 8.3.1.2.2.10 will be used in the resolution of Issues 1.1 through 1.6 (Section 8.3.5).

The study numbers and titles corresponding to each timeline are shown on the left of the preceding figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

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

<u>Point number</u>	<u>Description</u>
1	Meteorological and runoff data available from Studies 8.3.1.2.1.1 and 8.3.1.2.1.2.
2	Milestone P703. Issue report on the preliminary characterization of hydrologic properties of tuff matrix at the site.
3	Surficial materials data available to Study 8.3.1.5.1.4.
4	Milestone P728. Issue final report on the evaluation of infiltration under simulated conditions at the site.
5	Milestone P733. Issue final report on the evaluation of natural infiltration at the site.
6	Milestone P732. Issue final report on the evaluation of unsaturated zone fracture flow.
7	Milestone Q046. Issue report on characterization of unsaturated zone infiltration at Yucca Mountain.
8	Milestone M881. Issue report on the results of matrix property testing.
9	Additional chlorine analyses from Study 8.3.1.2.2.2 will assist in determination of active percolation zones.

<u>Point number</u>	<u>Description</u>
10	Milestone P707. Issue report on preliminary results of hydrologic monitoring of USW UZ-1.
11	Milestone M623. Complete chlorine-36 analysis report.
12	Milestone P729. Issue report on the results of air permeability studies in the unsaturated zone.
13	Samples available from Investigation 8.3.1.4.1.
14	Milestone Z250. Issue report on the significance of hydrologic features within the Solitario Canyon fault zone on unsaturated zone flow.
15	Matrix hydraulic property data from Study 8.3.1.2.2.3 will be used in bulk permeability and infiltration tests.
16	Milestone Z249. Evaluation of the need for further information on unsaturated zone flow within the Solitario Canyon Fault zone.
17	Milestone Z248. Issue report on the unsaturated zone hydrology of the Solitario Canyon fault zone.
18	Milestone Z410. Issue report on the results of in situ hydrologic monitoring of the unsaturated zone.
19	Milestone Z483. Issue report on the preliminary hydrologic description of the unsaturated zone at Yucca Mountain.
20	Milestone M017. Complete report on the results of the Calico Hills test in the exploratory shaft facilities--laboratory analyses of core.
21	Milestone M639. Complete report on the results of the infiltration tests in the exploratory shaft facility.
22	Milestone M633. Complete report on the results of diffusion tests in the exploratory shaft facility.
23	Milestone P735. Issue final report on the numerical model of the site unsaturated zone hydrology.
24	Milestone Z252. Complete plan to characterize flux within the Paintbrush nonwelded unit in the vicinity of Ghost Dance fault.
25	Milestone Z251. Determine whether to proceed with characterization of flux within the Paintbrush nonwelded unit in the vicinity of the Ghost Dance fault.

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<u>Point number</u>	<u>Description</u>
26	Milestone P708. Issue report on the update of the conceptual model of the unsaturated zone hydrologic flow system.
27	Milestone P737. Issue report on the preliminary description of unsaturated zone hydrology.
28	Milestone Q049. Issue report on the characterization of flux within the Paintbrush nonwelded unit.
29	Milestone P744. Issue final report on unsaturated zone percolation--results of surface-based tests and exploratory shaft facilities test.
30	Milestone Q062. Issue report on characterization of gaseous-phase movement in the unsaturated zone at Yucca Mountain.
31	Milestone P736. Issue final report on aqueous-phase chemistry of the unsaturated zone.
32	Milestone Q125. Begin testing and monitoring of the unsaturated zone.
33	Construction of a flow model in Study 8.3.1.2.2.9 follows directly as a continuation and expansion of the conceptual modeling performed in Study 8.3.1.2.2.10.
34	Milestone M385. Complete hydrologic testing of the unsaturated zone.
35	Milestone M391. Issue report on the hydrologic description of the unsaturated zone at Yucca Mountain.

8.3.1.2.3 Investigation: Studies to provide a description of the saturated zone hydrologic system at the site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

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

<u>SCP section</u>	<u>Subject</u>
3.9.1.1.2	Baseline monitoring (saturated zone)
3.9.1.2.2	Potentiometric levels (saturated zone)
3.9.2.2.1	Permeability and fractures (saturated zone)

<u>SCP section</u>	<u>Subject</u>
3.9.2.2.2	Transmissivity and hydraulic conductivity (saturated zone)
3.9.2.2.3	Porosity and storage coefficients (saturated zone)
3.9.3.1	Accessible environment and credible pathways (saturated zone)
3.9.3.2.2	Potentiometric levels and head relationships (saturated zone)
3.9.3.3	Recharge-discharge and leakage
3.9.4.1	Definition of flow paths for travel time calculations
3.9.4.4	Calculation of saturated zone travel time
3.10.1	Summary of significant results (saturated zone)
3.10.3	Identification of investigations (saturated zone)

Parameters

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

1. Geohydrologic units characteristics-spatial distribution of the physical and hydraulic properties of the rock units in the saturated zone at the site.
2. Ground-water flow characteristics-spatial distribution and rate of horizontal and vertical water flux and areally distributed fluxes (recharge and discharge).

Other site studies that provide information that support the determination of the previously listed parameters include the following:

<u>Study</u>	<u>Subject</u>
8.3.1.2.1.3	Characterization of the regional ground-water flow system (saturated zone hydrologic boundary conditions)
8.3.1.2.1.4	Regional hydrologic system synthesis and modeling (saturated zone hydrologic boundary conditions)
8.3.1.2.2.3	Characterization of percolation in the unsaturated zone (unsaturated zone recharge boundary condition to saturated zone)

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<u>Study</u>	<u>Subject</u>
8.3.1.2.2.9	Unsaturated zone system analysis and integration (unsaturated zone recharge boundary condition to saturated zone)
8.3.1.4.2.1	Characterization of the vertical and lateral distribution of stratigraphic units within the site area (saturated zone geologic framework)
8.3.1.4.2.2	Characterization of site structural features (saturated zone geologic framework)
8.3.1.4.2.3	Development of a three-dimensional model of the site geology (saturated zone geologic framework)

Purpose and objectives of the investigation

The objective of this investigation is to develop a model of the saturated-zone hydrologic system of Yucca Mountain, which will assist in assessing the suitability of the site to contain and isolate waste. Developing this model requires an understanding of ground-water flow. This understanding will be provided through studies focusing on the determination of boundary conditions imposed by structure, recharge, and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of hydrostratigraphic units. Modeling activities will use the resulting information to calculate flow paths, fluxes, and velocities within the saturated zone.

Technical rationale for the investigation

Site characterization of the ground-water system within the saturated zone focuses on the determination of boundary conditions imposed by structure, and conditions of recharge and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of hydrostratigraphic units. The resulting description of boundary conditions, hydraulic gradients, and aquifer properties will form the basis for synthesis and modeling activities that will conclude with calculations of flow paths, fluxes, and velocities within the saturated zone.

Boundary conditions

The importance of faults to ground-water movement has not been determined. A number of normal, west-dipping faults lie east of the repository block, and the block is bounded on the west by the Solitario Canyon fault zone. Strike-slip faults of northwest strike may underlie Drill Hole Wash, bounding the block on the northeast side. Northeast-trending faults of strike-slip or oblique-slip splay off the Solitario Canyon fault zone. Fluid flow can be influenced by faults, depending upon the properties of the faults, and they may be either conductors or barriers. Any faults that are highly conductive may control fluid flow and thereby dominate transport properties of the system.

Whether the Solitario Canyon fault zone is a hydraulic barrier or a conduit will be investigated by pumping from one or more holes and observing responses in nearby holes. Investigation of probable reasons for a steep gradient immediately north of the repository block may indicate the hydraulic nature of faults located in that area.

Hydraulic and water-chemistry data from proposed drillholes USW WT-8 and USW H-7, both located east of drillhole USW H-6, will be used principally to help determine (1) if the ground-water flow paths in the vicinity are from west to east across the Solitario Canyon fault, as suggested by differences in water levels in holes on either side of the canyon, and (2) the nature and degree of any hydraulic connection across the fault zone. If there is no significant eastward movement across the fault, this would have a major impact on both conceptual and computer models. The models have assumed that ground-water flow in the saturated zone beneath the repository block generally is toward the south and southeast (e.g., from drillhole USW H-4 toward well J-13), even though present resolution of water-level data from south or east of the block is not enough to determine with high assurance the magnitude or direction of apparent gradients.

Hydraulic gradients

At drillhole UE-25 p#1, the hydraulic potential is 20 m higher in the Paleozoic carbonate rocks and the lowest 134 m of the Tertiary rocks than in the overlying volcanic rocks (Craig and Robison, 1984). Higher heads were observed at a depth of 1,800 m in drillhole USW H-1, where the level is about 773 m, whereas the water table is about 730 m above sea level. Data from Robison (1984, 1986) show that within the upper 500 m of the saturated zone, there is no upward gradient (drillholes UE-25b#1, USW H-1, USW H-3, USW H-4, USW H-5, and USW H-6) (Figure 8.3.1.2-23).

In the vicinity of the repository block at Yucca Mountain and eastward into Jackass Flats for 5 km or more, the potentiometric surface is nearly flat (730 m above sea level). Water-level altitudes in nearby drillholes are higher to the west of the block (775 m) and to the north (778 to 1,031 m).

Beneath the repository block and downgradient from it, the water table is so flat that periodic water-level measurements (every several weeks), even when made with very high accuracy and precision, cannot be used to determine average water-level differences and gradients among wells. The reason for this, based on preliminary measurements, is that in many drillholes the short-term water-level variations due to barometric changes, earth tides and possibly other phenomena, although they are small, are greater than apparent differences among nearby drillholes. Therefore, water-level averages of months or perhaps years are necessary to determine gradients and probable flow paths near the repository. The present and planned expansion of continuous water-level measurements in observation drillholes will provide the data for determining the needed average water levels.

Continuous water-level data, in addition to being used for calculating average levels, may be helpful for evaluating the general hydraulic character of intervals penetrated by observation drillholes, and for estimating hydraulic parameters from responses to short-term stresses, such as earth tides, barometric changes, seismic events, or pumping of nearby wells. For those

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Figure 8.3.1.2-23. Preliminary composite potentiometric-surface map of the saturated zone, Yucca Mountain (modified from Robison, 1984).

drillholes with multiple instrumentation, it will be possible to make separate evaluations of each depth interval represented.

Aquifer properties

The fracture network at Yucca Mountain has a major influence on ground-water flow and solute transport. The ground-water system is so extensively fractured that discrete fracture-network modeling at the scale of the mountain may not be a practical method for calculating travel time of ground water. Nevertheless, models used to calculate travel time must be based on an understanding of the fracture network.

Because fractures are individually different, with apertures, orientations, spacing, lengths, and in-filling characteristics subject to statistical description, in situ tests encompassing scores of fractures are needed to describe hydraulic conductivity and other bulk aquifer properties. Hydraulic conductivity of the fracture network is several orders of magnitude greater than matrix permeability in welded units, and may be an order of magnitude greater in nonwelded units. At the scale of well tests, it may not be possible to describe hydraulic conductivity as a tensor analogous to that of an equivalent porous medium. Criteria for porous-medium equivalence may be more strict for solute transport than for ground-water flow. The character of effective porosity and hydrodynamic dispersion may be completely different from that which would be expected in a porous medium.

Reliable estimation of bulk aquifer properties depends on application of the appropriate conceptual model of flow to results of well tests. Hydraulic tests conducted in wells USW H-4, UE-25p#1, UE-25b#1, UE-25C#1, UE-25C#2, and UE-25C#3 indicate that simple radial flow models may not be adequate to describe the flow of ground water at the scale of the tests. The predominant subvertical orientation and differential connectivity of fractures indicates that a more complex heterogeneous flow model may be needed for interpretation of well-test results. Additional analysis of previously completed hydraulic-stress tests is needed to form a conceptual model of flow during well tests. Additional tests, designed on the basis of this conceptual model, will give more reliable estimates of aquifer properties as well as refine the conceptual model of flow in fractured rock. In general, multiple-well tests will be needed to evaluate complex heterogeneous flow models. While useful for investigating many aspects of saturated-zone hydrology beneath Yucca Mountain, results of single-well tests have limited use in understanding the nature and areal distribution of bulk aquifer properties.

Results of production surveys, combined with hydraulic-test results, have failed to identify definitive hydrostratigraphic units. Instead, the results indicate that discrete production zones associated with fractures in one well may be connected to fractures occurring in overlying or underlying stratigraphic units in other wells. Additional multiple-well testing using packers to isolate production zones is needed to confirm or refute this hypothesis. The hydrologic significance of intervening bedded units is not known. If pervasive fracturing crosses stratigraphic boundaries and accounts for orders of magnitude greater hydraulic conductivity than does the matrix, it may not be appropriate to simulate ground-water flow within a framework of hydrostratigraphic units. Additional well tests are needed to determine three-dimensional relations between stratigraphy, fracture connectivity, and

bulk aquifer properties. Single-well tests may have limited use in evaluating many of these relations.

Well tests at Yucca Mountain will be completed in two steps. The first step will consist of a large number of hydraulic and conservative-tracer tests in wells UE-25C#1, UE-25C#2, and UE-25C#3 (i.e., C-hole complex) (Figure 8.3.1.2-23). The tests will include a variety of field procedures and interpretive methods to form a conceptual model of flow in a fractured aquifer system. The site for the C-hole complex was chosen because of its position (down the hydraulic gradient from Yucca Mountain) and because the saturated zone at the site was believed to represent stratigraphic and structural conditions along a flow path to the accessible environment. The second step will consist of either a series of single-well tests at existing wells throughout Yucca Mountain, or drilling and testing at a second multiple-well complex. The purpose of the second step is to verify and refine the conceptual model formed during tests at the C-hole complex.

Characterization of aquifer properties of the saturated zone has been divided into four activities. These activities are as follows:

1. Analysis of previously completed hydraulic-stress tests, including pumping and nonpumping intraborehole flow surveys, packer and open-hole injection and withdrawal tests, and transient pressure response of aquifers to barometric and earth-tide stress. Most interpretations will be restricted to data collected at the C-hole complex. Results of interpretations will be used to improve the design of planned well tests and, when possible, to provide preliminary estimates of aquifer properties.
2. Multiple-well interference tests at the C-hole complex, including cross-hole hydraulic tests and long-term pumping tests. Cross-hole tests will use packers to isolate selected intervals in wells for the purpose of monitoring response to a hydraulic stress applied in an isolated interval in a neighboring borehole. Cross-hole tests will be conducted to determine if the fractured rock can be treated as a homogeneous equivalent porous medium or if a more complex conceptual model is needed. Hydraulic conductivity and specific storage will be estimated from results of cross-hole tests. Long-term pumping tests will be conducted to evaluate aquifer properties in a larger rock volume than typically considered in pumping tests.
3. Tests of the C-hole complex with conservative tracers, including drift-pumpback tests, two-well recirculating tests, and two-well convergent tests. Test results will be used to determine properties of conservative-solute transport, evaluate relations between transport properties and fracture characteristics, and determine whether single-well tests can be used to characterize transport properties. By conducting a variety of tests, several relations between principal fracture orientation and hydraulic gradient will be considered. Different volumes of rock also will be tested to evaluate the scale-dependence of transport characteristics.

4. Well tests with conservative tracers throughout the site. If the results of tests at the C-hole complex demonstrate that single-well tests can be used successfully to characterize transport properties, then either a series of single-well tests (drift-pumpback tests) will be conducted at existing wells. If single-well tests cannot be used, then a series of multiple-well tests will be completed at a second site, tentatively planned for construction in the southern part of the study area. The purposes of this activity are to verify the conceptual model (formed during tests at the C-hole complex) of flow and transport in fractures and to evaluate areal variations in aquifer properties.

Synthesis and modeling

The description of ground-water flow paths, fluxes, and velocities within the site area is the ultimate objective of site-hydrologic investigations in the saturated zone. This description will be obtained through the development of digital ground-water flow models. Results of field activities and tests described previously will provide an understanding of boundary conditions, hydraulic gradients, and aquifer properties. Interpretation of field data will be used to form a conceptual model of the flow system at Yucca Mountain. Fracture-network modeling will aid in forming a conceptual model that treats aquifer properties in a manner that realistically accounts for the influence of the fracture network. Numerical models of the region and/or site will be developed on the basis of the conceptual model and tested by calibration with field data. Once calibrated, the numerical models will be used to estimate flow paths, fluxes, and velocities. These modeling efforts will be coordinated with activities to model flow in this saturated zone called for under Issues 1.1 and 1.6 (Sections 8.3.5.9 and 8.3.5.12).

8.3.1.2.3.1 Study: Characterization of the site saturated-zone ground-water flow system

The objectives of this study are (1) to determine the internal and external boundary conditions that can be applied to the site saturated zone model and (2) to determine the ground-water flow magnitudes and directions at the site.

Eight activities are planned to collect the data that are required to satisfy these objectives: (1) Solitario Canyon fault study, (2) site potentiometric level evaluation, (3) analysis of previously completed hydraulic stress tests, (4) multiple-well interference testing, (5) testing at the C-hole sites with conservative tracers, (6) well testing with conservative tracers throughout the site, (7) testing at the C-hole sites with reactive tracers, and (8) well testing with reactive tracers throughout the site.

8.3.1.2.3.1.1 Activity: Solitario Canyon fault study in the saturated zone

Objectives

The objective of this activity is to determine the nature of the Solitario Canyon fault and if it is a barrier to eastward movement of ground water through the repository block.

Parameters

The parameters of this activity are

1. Nature and extent of hydraulic gradients.
2. Orientation and extent of fault zones.
3. Fracture orientations, apertures, and filling characteristics.

Description

To define better the water table west of the Solitario Canyon fault, water-table series drillholes USW WT-8 and USW WT-9 will be drilled using an air-foam method to depths of about 2,100 to 2,200 ft (640 to 670 m). Only surface casing will be installed, and the drillhole diameters will be about 8.75 in. (22 cm). Drillhole USW WT-8 will penetrate about 150 to 270 ft (50 to 90 m) of the saturated zone; USW WT-9 will penetrate about 240 to 390 ft (80 to 130 m) of the saturated zone. East of the Solitario Canyon fault on the ridge crest of Yucca Mountain, a hydrologic test drillhole, tentatively designated USW H-7, will be drilled in the same manner as previously drilled hydrologic test drillholes at Yucca Mountain. The depth of this drillhole will be about 3,000 ft (914 m); it will penetrate about 450 to 600 ft (150 to 200 m) of the saturated zone and will have a diameter of about 8.75 in. (22 cm). Drillhole locations are shown in Figure 8.3.1.2-24. Drilling of these drillholes will be integrated and coordinated with the drillholes planned under Section 8.3.1.4.1.

Geophysical and television surveys will be run in each of the drillholes. The logging programs will include a gyroscopic survey, vibroseis survey, optical television survey, and dielectric, spectral gamma-caliper, fluid density, electric, density, and epithermal neutron logs. After downhole geophysical logs are completed in each water-table drillhole, a small-capacity pump will be hung in the drillhole on tubing, and the pump will be run for about a week to obtain water samples for chemical and isotopic analyses. The pump will be removed, and the tubing reinstalled to enable measurements of the water levels.

After the initial development and testing of drillhole USW H-7, including a borehole-flow survey, a long-term test (perhaps as much as 30 days) will be conducted. This test will consist of pumping drillhole USW H-7 at an expected rate of 25 L/s or more while observing hydraulic responses in water-level monitoring drillholes located throughout Yucca Mountain, especially those located across (west of) the fault, such as drillholes USW H-6 and the proposed USW WT-8 (Figure 8.3.1.2-24). It will be necessary to disperse or transport the pumped water a substantial distance away from drillhole USW H-7 to prevent disturbance of local infiltration studies.

Figure 8.3.1.2-24. Location of the proposed drillholes for the Solitario Canyon fault study in the vicinity of perimeter drift.

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After the pumping test at drillhole USW H-7 is complete, it may be determined appropriate to pump drillhole USW H-6 while observing responses in drillhole USW H-7 and other drillholes east of the fault. By observing the responses of wells across the fault, it should be possible to determine if the Solitario Canyon fault acts as a barrier to eastward flow.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.1.1 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
(NWM-USGS-)			
Test drilling	TBD ^a	Reynolds Electrical and Engineering Company drilling and completion procedures	TBD
Borehole geophysical and television surveys	GP-10, R0	Borehole video fracture logging	12 Apr 85
	HP-02, R0	Acoustic televiewer investigations	14 Aug 84
	HP-50, R0	Method for neutron scatter and gamma ray attenuation logging using the USGS logging van (I-139055)	15 Nov 84
Water sampling	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
Measurement of water levels	HP-01, R0	Methods for determining water level	11 Jan 82
	HP-25, R0	Methods for measuring water levels using the Dodge logging van (I-127410)	20 July 84
	HP-26, R0	Method for calibrating water-level measurement equipment using the reference steel tape	14 Aug 84

Method	Technical procedure		Date
	Number	Title	
Borehole flow surveys	TBD	TBD	TBD
Pumping tests	HP-06, R0	Hydrologic pumping test	11 Jan 82

^aTBD = to be determined.

8.3.1.2.3.1.2 Activity: Site potentiometric-level evaluation

Objectives

The objectives of this study are to

1. Analyze the character and magnitudes of water-level fluctuations to determine their causes, and, if possible, to estimate system parameters.
2. Refine the potentiometric surface.
3. Measure water-level variations with time in existing borehole and calculate average levels, as input data for hydraulic gradient calculations.

Parameters

The parameters for this activity are

1. Physical characteristics of the hydrogeologic units.
2. Hydraulic gradients.
3. Storage coefficients.

Description

Presently, about 25 geologic, hydrologic, and water-table drillholes are part of a monitoring network near the site (Figure 8.3.1.2-8). Water levels in 15 holes have been measured periodically during onsite visits about every two weeks. Ten drillholes have pressure transducers installed below the water surface, that are connected to digital equipment at the surface, and electrical output from the transducers is automatically recorded every hour. The periodically measured drillholes in the network are being converted to this automated monitoring system. Raw data from these field installations are taken to the office and water-level depths or altitudes are calculated, following a process of conversions, adjustments, and determination and verification of equipment calibrations.

Proposed new test drillholes to be added to the water-table monitoring network include water-table drillholes in the USW series WT-8, WT-9, WT-21, WT-22, WT-23, and WT-24; and UE-25 series WT#19 and WT#20 (Figure 8.3.1.2-25). Water-table drillholes USW WT-8 and USW WT-9 will be located near the Solitario Canyon fault to help determine the hydraulic nature of that structural feature, as discussed in Activity 8.3.1.2.3.1.1 (Solitario Canyon fault study in the saturated zone). Water-table holes USW WT-21 and USW WT-22 are considered under Activity 8.3.1.2.1.3.2 (regional potentiometric level studies). The drilling of these drillholes will be coordinated with the drilling program described under Section 8.3.1.4.1.

Water table drillholes USW WT-23 and USW WT-24 will be located to the north near Drill Hole Wash to obtain additional data on the steep gradient in this area. Water-table drillhole USW WT-23 will be located in Drill Hole Wash northwest of drillhole USW UZ-1. This drillhole will be drilled to a probable depth of about 670 m. Drillhole USW WT-24 will be located between drillholes USW G-2 (Figure 8.3.1.2-26) and UE-25 WT#18, and will also be about 670 m deep. Both of these drillholes will have diameters of about 22 cm, and will be constructed and completed in the same manner as previously drilled water-table drillholes. The lithologic and geophysical logs will be analyzed and compared with those of other drillholes near Yucca Mountain in order to determine if the permeability of the rocks in this area is significantly lower than elsewhere, so as to produce a steeper hydraulic gradient than to the south near the Yucca Mountain repository block. Proposed geologic drillhole USW G-5 (Activity 8.3.1.4.1.11) (Figure 8.3.1.2-26), located generally north of Yucca Mountain, is expected to provide stratigraphic and other relevant information that will be used to help determine the probable cause and nature of the steep hydraulic gradient. Water-level measurements will also be used to help determine if the gradient is linear though steep, or is stepped.

Water table drillholes UE-25 WT#19 and UE-25 WT#20 will be drilled to determine the potentiometric levels to the south and east of the repository site (Figure 8.3.1.2-25). Drillhole UE-25 WT#19 will be located 3 km east of well J-13 and will be drilled to a depth of about 1,100 ft (335 m). Drillhole UE-25 WT#20 will be located 5 km southwest of well J-13 and will be drilled to a depth of about 1,100 ft (350 m). The drilling, construction, logging, and water sampling of these drillholes will be similar to previously drilled water table drillholes.

Water-level data from the monitoring program will be plotted to show variations and trends with time. Seasonal trends will be evaluated and the data will be averaged over appropriate periods (e.g., annually) so that hydraulic gradients and probable ground-water flow paths can be determined more accurately, especially in areas where the water table is nearly flat.

For wells showing appropriate responses, water-level variations due to earth tides or barometric fluctuations may be used to estimate hydraulic parameters such as storage coefficients.

Water-level responses in observation wells during pumping of other wells will be analyzed in terms of general hydraulic connectivity and, where appropriate, the permeability of the rocks will be evaluated. Responses among the

○ PROPOSED DRILL HOLE

Figure 8.3.1.2-25. Locations of the proposed water-table holes for the site potentiometric-level evaluation.

Figure 8.3.1.2-26. Location of existing and proposed geologic drillholes.

observation wells will be compared, with the purpose of estimating the areal anisotropy of the hydraulic parameters that may be controlled by faults or fractures.

Methods and technical procedures

The methods and technical procedures on Activity 8.3.1.2.3.1.2 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
(NWM-USGS-)			
Drilling of water-table drillholes	TBD ^a	Reynolds Electrical and Engineering Company drilling and completion procedures	TBD
Geophysical and tele- vision surveys	GP-10, RO	Borehole video fracture logging	12 Apr 85
	HP-02, RO	Acoustic televiewer investigations	14 Aug 84
	HP-50, RO	Method for neutron scatter and gamma ray attenuation logging using the USGS logging van (I-139055)	15 Nov 84
Water sampling	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
Periodic and contin- uous water-level measurement	HP-01, RO	Methods for determin- ing water level	11 Jan 82
	HP-25, RO	Methods for measur- ing water levels using the Dodge logging van (I-127410)	20 July 84

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Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
	HP-26, RO	Method for calibrating water-level measurement equipment using the reference steel tape	14 Aug 84
Analytical and mathematical methods of data interpretation	TBD		

^aTBD = to be determined.

8.3.1.2.3.1.3 Activity: Analysis of previously completed hydraulic-stress tests

Objectives

The objectives of this activity are to

1. Determine intraborehole flow profiles for each of the C-holes during static conditions and while pumping.
2. Correlate lithology, fractures, and intraborehole flow rates.
3. Characterize the type of flow (linear, radial, spherical, fracture, porous) that is occurring between boreholes.
4. Identify the nature of significant hydraulic boundaries present at the scale of the tests. This information will be especially important in designing multiple-well interference tests and tracer tests at the C-holes.
5. Determine bulk estimates of aquifer properties: transmissivity, storage coefficient, specific storage, and effective hydraulic porosity.
6. Determine to what extent the ground-water system responds to hydraulic stress as confined or unconfined.

Parameters

The parameters for this activity are

1. Intraborehole flow rates.
2. Type of flow and nature of significant hydraulic boundaries present at the scale of well tests.
3. Transmissivity, storage coefficient, specific storage, and effective hydraulic porosity.

Description

Well hydraulic tests completed in test wells USW H-4, UE-25p#1, UE-25b#1, and especially UE-25C#1, UE-25C#2, and UE-25C#3 to determine aquifer hydraulic conductivity and specific storage indicate that simple nonsteady radial flow models may not adequately describe the movement of ground water through most of the formations tested (Figure 8.3.1.2-23). Attempts to identify definitive hydrostratigraphic units on the basis of well-test results and production surveys have not been successful. Instead, these data have indicated that discrete production zones associated with fractures in one test well may be well connected to fractures occurring in other stratigraphic units. The role of intervening bedded units is unclear. Because of the predominant subvertical orientation of fractures and their differential connectivity, a complex heterogeneous reservoir flow model probably is needed for interpretation of past hydraulic test results. On the basis of these interpretations, additional tests need to be conducted to determine the three-dimensional relations between stratigraphy, fracture connectivity, and hydraulic conductivity.

Three categories of hydraulic-test data have been collected in the past and will be analyzed for site characterization: (1) intraborehole flow data, including pumping and nonpumping temperature logs and tracejector surveys, (2) packer and open-hole fluid injection and withdrawal test data, and (3) aquifer fluid pressure and barometric pressure data to monitor aquifer response to barometric loading and earth-tide stress. The data to be analyzed for site characterization was collected primarily from wells at the C-hole complex since September 1983.

Intraborehole hydraulic test data will be analyzed for site characterization. Temperature logs and tracejector surveys will be used to identify points or zones where fluid enters or leaves boreholes, and may be used to determine the direction and rate of flow. It may be possible to correlate points where fluid enters or leaves a borehole with specific fractures while zones where fluid enters or leaves a borehole may correlate with groups of fractures or zones where permeability is due to porous rock. The distinction is important in formulating a conceptual model of flow near the boreholes and will be useful in the design and analysis of fluid injection and withdrawal tests.

Tracejector surveys completed while pumping the wells were done according to the method described by Blankennagel (1967) using iodine-131 as a tracer and will be analyzed by a method similar to the method described by

Blankennagel (1967). A wireline tool consisting of an ejector with two gamma detectors on each side of the ejector is used to conduct a tracejector test. Tracer is ejected in the borehole fluid at a selected depth and allowed to travel with the fluid past the stationary gamma detectors. The time of travel between the two detectors is recorded and the velocity is calculated as the ratio of the distance between the detectors and the time of travel. The flow rate is calculated from the fluid velocity and the borehole volume in the interval between the detectors. By repeating the tracejector survey at several depths, a production profile of the pumping well can be described where the relative contributions of the various flow zones to the total flow can be identified.

Analysis of temperature logs made when pumping the boreholes will be divided into qualitative and quantitative interpretations. All analysis will be based on heat transfer theory that accounts for heat flow within the fluid, between the fluid and the formation, and between the fluid and the well plumbing. Qualitative interpretations will include examining the shapes of the temperature profiles to deduce the location and nature of flow points or zones, and the direction of flow. Quantitative analysis will include estimating rate of flow and will be based on the subtangent or delta function (Kunz and Tixier, 1955; Schonblom, 1961; Murphy, 1982). Temperature profiles calculated from known pumping rates and reasonable estimates for formation and fluid thermal properties, and the geothermal gradient will be compared with temperature logs to calibrate thermal properties. The calibrated temperature profiles will be used to calculate intraborehole flow rates.

Temperature logs and tracejector surveys completed under static or non-pumping conditions will be used to identify steady-state flow rates, directions of vertical movement, and permeability contrasts. Methods for conducting static tracejector surveys and the proposed analytical techniques are described by Erickson and Waddell (1985) and Galloway and Erickson (1985). Flow rates will be calculated for static temperature logs using the calibrated thermal model of fluid flow.

Injection and withdrawal hydraulic-test data will be analyzed for site characterization. Twenty-nine injection and withdrawal tests have been conducted in the C-holes to examine the pressure-transient response of the aquifer. Analysis of pressure transients can give information regarding the type of flow, hydraulic boundaries, and aquifer properties, specifically hydraulic conductivity and specific storage. Because estimation of aquifer properties depends on the type of flow and boundaries hypothesized, it is important to develop a conceptual model of the flow before estimating aquifer properties. The primary purpose of analyzing previously completed injection and withdrawal tests is to form a conceptual model of ground-water flow at the scale of the C-hole complex. Where appropriate, estimates of aquifer properties will be made. The conceptual model will be used as a basis for designing additional hydraulic and tracer tests that will enable more reliable calculation of aquifer properties.

Several types of stress tests have been completed at the C-hole complex. Twenty-three falling-head injection tests with packers were run in drillhole UE-25C#1 (Figure 8.3.1.2-27). Two additional falling-head injection tests were run in drillhole UE-25C#1 to ascertain pipe-friction head loss. A quasi-constant flux injection test with packers was run in drillhole UE-25C#2

Figure 8.3.1.2-27. Test well configuration for drillhole UE-25C#1 packer-injection and open-hole pumping tests.

(Figure 8.3.1.2-28) and monitored in drillholes UE-25C#1 and UE-25C#3 (Figure 8.3.1.2-29). A constant-flux withdrawal test without packers was done in each of the C-holes after completion of drilling such that drillhole UE-25C#1 was used as an observation well during the drillhole UE-25C#2 test, and drillholes UE-25C#1 and UE-25C#2 were used as observation wells during the drillhole UE-25C#3 test. Straddle packers were used in observation wells (Figures 8.3.1.2-27, -28, and -29).

The approach to analyzing the stress tests will involve a search for the theoretical reservoir model with a response to an imposed stress that most closely matches that of the actual reservoir and with constraints that are consistent with other information concerning the rock properties of the reservoir. Flow-analysis procedures are well established for porous media that are reasonably homogeneous but are not well established for aquifers with heterogeneities evident at the C-hole complex. New techniques that include aquifer heterogeneity may be needed to develop an adequate conceptual model of flow at the C-hole complex.

The analysis of pressure transients from C-hole pumping and injection tests initially will consider solutions for porous media that are radially infinite, homogeneous, and isotropic. Complexity, in the form of solutions for fissured reservoirs, will be considered as needed. This approach, from simple to more complex flow solutions, will enable the development of a conceptual model for pressure-transient behavior by contrasting the C-hole response to the ideal porous-media response. Porous-media solutions that will be considered include those of Theis (1935) for isotropic confined conditions; Hantush and Jacob (1955), Hantush (1960), and Neuman and Witherspoon (1969a, 1969b) for leaky conditions; and Boulton (1963) for unconfined aquifers with delayed yield from storage. The possible effects of well-bore storage and skin, partial penetration, and outer boundaries such as no flow or constant-head boundaries will be examined.

If porous-media solutions do not adequately match the response of the actual fissured reservoir, more complex solutions will be considered. Homogeneous models that may be considered include the following:

1. Those that consider single and regularly spaced and offset systems of vertically and horizontally fractured systems (Prats, 1972; Asfari and Witherspoon, 1973).
2. Those that implicitly consider fractures by including anisotropy in permeability (Papadopoulos, 1965; Saad, 1967).
3. Those that consider a stressed well intersecting a single fracture in an otherwise radially infinite porous medium (Gringarten and Witherspoon, 1972; Gringarten et al., 1974; Gringarten and Ramey, 1974; Cinco et al., 1978).
4. Those that consider well-bore storage and skin effects in combination with previously mentioned characteristics (reviewed by Gringarten et al., 1979).
5. Those that consider partial penetration of wells (reviewed by Karasaki et al., 1986).

Figure 8.3.1.2-28. Test well configurations for drillhole UE-25C#2 pumping test (March 1984).

Figure 8.3.1.2-29. Test well configurations for drillhole UE-25C#3 pumping tests (May 1984, November 1984) and drillhole UE-25C#2 packer injection test (October 1984).

If an equivalent homogeneous model is not an adequate representation of the actual system behavior, heterogeneous models will be investigated. Heterogeneous models include double-porosity models (reviewed by Gringarten, 1982; Moench, 1984), multilayered models (reviewed by Gringarten, 1982) and composite models (reviewed by Karasaki et al., 1986).

Preliminary analysis of falling-head injection tests has been reported by Erickson et al. (1985) and Karasaki et al. (1986). Observed pressure transients from many of the tests could not be represented adequately using available solution techniques. Solutions evaluated included those of Cooper et al. (1967), Moench and Hsieh (1985), and several developed by Karasaki (1986). Two probable causes for deviations have been identified; large initial heads may have induced excessive pipe-friction losses, and large velocity may have caused non-Darcian flow in the formation near the well bore.

Additional interpretation of the well-test data may be useful on the basis of results of future well tests. Such tests could be designed to mitigate pipe-flow head losses. Although an analytical model that considers non-Darcian flow in the formation is not available, an equivalent analytical model or a numerical model may be applied to these data.

Barometric and earth-tide analysis will be performed using water-level data collected from test holes at the site. Water levels were monitored in the C-holes and in drillhole UE-25p#1 to analyze aquifer responses to solid earth tidal strains and surface barometric pressure loads. Techniques have been developed that relate the tidal potential and the resulting aquifer dilatation to aquifer properties such as specific storage, matrix bulk modulus, and hydraulic effective porosity (Bredehoeft, 1962; Rhoads and Robinson, 1979; Kanehiro and Narasimhan, 1980; Hanson, 1984). Each of the techniques is developed for ideal confined aquifers or undrained conditions (although Bredehoeft (1962) presents an analysis for an ideal unconfined aquifer), and thus, the status of the monitored aquifer, confined or unconfined, must be determined before applying these techniques.

The existence of a strong hydraulic-head contrast between two monitored zones in the same borehole is a good indication that the units are not well connected hydraulically and that one unit may be confined to a certain degree. Such a situation exists between the Paleozoic dolomites in drillhole UE-25p#1 and the overlying tuffs where hydraulic heads in the dolomites, 20 m greater than those in the tuffs, indicate a confined aquifer in the Paleozoic section (Craig and Robison, 1984). The lack of a significant contrast of hydraulic heads (<0.5 m) in the vertical section from the water table in the Paintbrush Tuff, through the Calico Hills to the Crater Flat Tuff at depth, indicates that there may be sufficient vertical hydraulic connection to be consistent with an unconfined aquifer in the tuffs. Weeks (1978) presented a study of the response of the deep unconfined aquifer to barometric fluctuations that proposes a model of water-level and aquifer and barometric interaction. Another way to assess the confined status of the aquifers is to examine measured, water-level, and barometric fluctuations for conformance to Weeks' model.

Some preliminary analyses of aquifer response has been undertaken and reported (Galloway and Sullivan, 1986). Water levels were measured in the C-holes in five intervals (zones) (Figure 8.3.1.2-30) open to the extensively

Figure 8.3.1.2-30. Test well configuration for analysis of C-hole earth-tide and barometric induced water-level fluctuations.

fractured Crater Flat Tuff and in drillhole UE-25p#1 in one interval open to the Paleozoic dolomite. Barometric pressure was monitored at land surface near drillhole UE-25C#2. Measurements were made at 30-min intervals using sensitive pressure transducers, during the period December 5, 1985, to July 17, 1986. A period of uninterrupted measurements from February 23 to April 1, 1986, was selected for analysis. Tidal harmonic analysis of the barograph and the six hydrograph records showed periodic fluctuations in all seven records corresponding to earth tides. An analysis of the periodic and aperiodic fluctuations for drillhole UE-25p#1 based on Rhoads and Robinson (1979) gave estimates of barometric efficiency, 0.57; specific storage, $6.0 \times 10^{-9} \text{ cm}^{-1}$; matrix bulk modulus, 36.4 GPa; and effective hydraulic porosity, 7.7×10^{-2} . Although earth-tide induced water-level fluctuations were observed and calculated for the C-hole hydrographs, the analysis was not extended to these records because of the apparent unconfined-like response in the water-level and barometric fluctuations. Porosities were estimated from Bredehoeft (1967) based on the earth-tide induced water-level fluctuations and were in the range, 2×10^{-4} to 2×10^{-3} .

Although the unconfined-like response observed in the C-holes can be described by the model of Weeks (1978), additional work needs to be done to rule out other phenomena that could explain the response, such as well-bore storage effects. Other monitored zones in other boreholes on Yucca Mountain need to be examined to determine whether an unconfined-like response is evident and if so to relate the response to stratigraphy, well-bore storage, and other conditions. A preliminary analysis of drillhole USW H-1, USW H-4, and USW WT-2, UE-25 WT#3, and UE-25 WT#13 water-level fluctuations indicate an unconfined-like response to barometric fluctuations is occurring.

A situation exists in drillhole UE-25C#1 that may permit a direct evaluation of the phase shift. A vent in the well cover that is connected to the annular space adjacent and open to the unsaturated thickness of the well bore is exchanging air with the atmosphere similar to that observed by Weeks (1986) for drillholes USW UZ-6 and USW UZ-6s on the crest of Yucca Mountain. It may be possible to correlate fluctuations in barometric pressure, annular space pressure, or air flow, or both, to fluctuations in water level, in order to address the phase shift in water-level and barometric fluctuations characteristic of the unconfined response.

Additional work may be done on the earth-tide analysis by using a technique presented by Hanson (1984). This technique accounts for well-bore storage and well-completion effects, and the presence of discrete fluid-carrying fractures. The method is attractive because it may also provide a first-order approximation of the hydraulic conductivity tensor.

Methods and technical procedures

All work performed under this activity consists of analysis of previously acquired data. No field or laboratory work will be performed and no new data collected. Therefore, technical procedures are not required.

CONSULTATION DRAFT

8.3.1.2.3.1.4 Activity: Multiple-well interference testing

Objectives

The objectives of this activity are to

1. Determine hydraulic properties, including hydraulic conductivity and storage coefficient, needed for quantitative evaluation of ground-water flow.
2. Determine if the fractured media of Yucca Mountain can be represented as an anisotropic porous media at the scale of multiple-well tests or if a fracture-network model is more appropriate.
3. Evaluate the relation between hydraulic properties determined by single well tests and those determined by multiple-well tests.

Parameters

The parameters for this activity are

1. Hydraulic conductivity.
2. Storage coefficient.
3. Fracture characteristics.

Description

A series of tests will be conducted at the C-hole complex (Figure 8.3.1.2-31). In these tests, water will be pumped from small isolated intervals of one C-hole and the hydraulic response will be monitored in isolated intervals of other C-holes. Approximately 20 tests, using various combinations of pumping well, pumping interval, and observation intervals, will be conducted to identify the nature of the hydraulic connection between the C-holes. Large variations in the fracture characteristics of the rocks penetrated by the C-holes could affect movement of water in the saturated zone. By conducting cross-hole tests at various depths, the hydraulic significance of these variations will be identified.

Each test will be conducted in the following manner. Straddle packer systems will be installed in both pumping and monitoring wells. Packers will be used to isolate intervals identified on tracejector logs as producing zones. Six producing zones have been identified in UE-25C#1; at least two in UE-25C#2 and six in UE-25C#3. After packers have been inflated and tested for effective seals, pressure transducers will be installed in monitoring intervals. A submersible pump will be installed and water will be withdrawn from the selected pumping interval for approximately three days at a rate of between 3.2 and 12.6 L/s. Water temperature will be monitored by a thermocouple in the discharge line. Pressure changes measured in monitoring intervals will be digitally recorded by a data logger. After three days, the pump will be shut off and pressure recovery will be monitored for at least three additional days.

Figure 8.3.1.2-31. Location of C-hole complex.

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The combinations of pumping and monitoring intervals used in cross-hole testing will be selected in order to describe vertical variations in horizontal hydraulic conductivity, as well as the degree of hydraulic connection between units. For this reason, tests will be conducted by pumping water from the permeable part of the lower Bullfrog Member and monitoring pressure changes in observation wells within the upper Bullfrog, lower Bullfrog, and upper Tram members. Tests will also be conducted by pumping water from the permeable zone of the upper Tram and monitoring pressure response in both the upper Tram and lower Bullfrog members. Permeable zone of the lower Bullfrog Member exists at approximately 716 to 780 m below land surface depending upon the well. The permeable zone in the upper Tram Member is from approximately 838 to 870 m. Tests will be conducted alternately using UE-25C#1, UE-25C#2, and UE-25C#3 as pumping wells. In each test, the wells not used for pumping will be used as monitoring wells. By varying the pumping well, it will be possible to demonstrate the symmetric or unsymmetric nature of the hydraulic conductivity tensor.

A 30-day pumping test will be conducted by pumping UE-25C#1, UE-25C#2, or UE-25C#3 at a rate of between 6.4 and 25.2 L/s, and monitoring the pressure decline in other C-holes, UE-25p#1, USW H-4, and other nearby wells. Pressure recovery will be monitored in all wells for at least 30 days after pumping stops. Water will be pumped from the permeable zone of the lower Bullfrog Member. Pressure response in the C-holes will be monitored in isolated zones of the upper Bullfrog, lower Bullfrog, and upper Tram members. The pressure response in other nearby wells will be monitored without the use of packers to isolate zones.

Results from this pumping test will be used to estimate aquifer properties at a scale larger than the C-holes scale and to identify the hydrologic significance of the Bow Ridge normal fault. Large-scale estimation of aquifer properties is important to describe accurately ground-water flux within the repository block. Observation wells used during the pumping test will be located on both sides of the Bow Ridge fault. The pressure response in these wells will be used to identify the fault as a barrier or conduit for ground-water flow.

The following porous-media techniques will be useful in evaluating multiple flow hypotheses. Current hypotheses, based on existing knowledge of Yucca Mountain, are equally plausible. The analytical method of Hsieh et al. (1985) is based on an assumption of aquifer homogeneity and may be applied to cross-hole data to determine a three-dimensional hydraulic-conductivity tensor and storage coefficient for the C-hole area. Composite analytical methods of Karasaki (1986) may be used to investigate the assumption that flow in the fracture system occurs in an inner region near the pumping well dominated by a small number of fractures and an outer region where the rock is similar to a homogeneous porous medium. If test results indicate the assumption of homogeneity is poor, a numerical model such as Reily (1984) may be used. Results of the large-scale test may be interpreted using classical Theis theory in addition to the techniques listed previously. If test results indicate the aquifer behaves as a dual-porosity medium, methods such as Moench (1984) may be used.

The fracture-network model developed by Lawrence Berkeley Laboratory (Activity 8.3.1.2.3.3.2) will be applied to interpret the results of both

cross-hole and large-scale pumping tests. A set of fracture networks will be generated that brackets the range of uncertainty in fracture statistics. For example, networks with different mean apertures or different distributions of apertures (or both) might be included. Networks will also be developed that correspond to differing hypotheses for describing the distribution of fractures at Yucca Mountain. For example, fractures may be treated either as stratigraphically controlled, or independent of stratigraphy. Fracture networks, initially generated on the basis of geologic evidence, will be used to simulate multiple-well test results. Those networks that best match measured hydraulic response to pumping will be considered for analysis of tracer-test data.

Aquifer properties, estimated by porous-media techniques and fracture networks that successfully simulate hydraulic-test results, will be compared. Differences and similarities in the results of the two methods will be identified. Situations, where each approach is likely to produce meaningful results, will be identified. Limitations of each method will be described.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.1.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Cross-hole testing at C-holes	TBD	TBD	TBD
Large-scale pumping test	HP-06, RO	Hydrologic pumping test	11 Jan 82
Analysis of multiple-well tests	TBD	TBD	TBD

^aTBD = to be determined.

CONSULTATION DRAFT

8.3.1.2.3.1.5 Activity: Testing of the C-hole sites with conservative tracers

Objectives

The objectives of this activity are to

1. Determine the following properties by single-well and multiple-well tests at the C-holes: (1) effective porosity, (2) longitudinal dispersivity, (3) regional pore-water velocity, and (4) possibly matrix diffusion.
2. Evaluate the relation between aquifer properties estimated by porous-media techniques and fracture characteristics used in fracture-network modeling.

Parameters

The parameters for this activity are

1. Effective porosity.
2. Dispersivity.
3. Velocity and fracture characteristics.

Description

Approximately three drift-pumpback tests will be conducted in the C-hole intervals that have large hydraulic conductivity. These tests will be coordinated with testing with reactive tracers (Activity 8.3.1.2.3.1.7). The depths that will be considered for these tests include approximately 780 m (lower Bullfrog) and 850 m (upper Tram) below land surface in UE-25C#1, 730 m (lower Bullfrog) in UE-25C#2, and 740 m (upper Tram) in UE-25C#3 (Figure 8.3.1.2-32). Straddle packers will be used to isolate the test intervals.

Each drift-pumpback test will consist of placing a tracer in the test interval, letting it drift into the formation and then pumping it back out. The tracer to be placed in the selected intervals, including 3-trifluoromethylbenzoate, will drift into the formation under steady-state hydraulic gradients. Pretest sensitivity analysis and simulation of the flow system at the C-hole location will be used to identify reasonable periods of time for the drift phase of tests. The drift phase will be sufficiently long to permit the tracer to move out of the fractures that intercept the borehole and into the fracture network. In this manner, the influence of individual fractures on seepage velocity will be minimized. A pump will then be installed in the selected interval and water will be withdrawn to begin the pumpback phase of the test. The pumping rate will be 3.2 to 9.5 L/s. The rate of pumping will be measured by an in-line flow meter, and water temperature will be monitored by a thermocouple. Samples of pumped water will be collected and analysed for tracer concentration. Pumping will continue for at least three days or until virtually all tracer is recovered.

Results of drift-pumpback tests may be virtually impossible to interpret. The rate of diffusion in the borehole and deviations of gradient and velocity from regional conditions due to individual fractures that intersect

Figure 8.3.1.2-32. Location of test intervals for the drift-pumpback tests.

the well bore may confound the analysis of bulk aquifer properties. The influence of these well bore characteristics may be most important during the drift phase of the tests. If experience with drift-pumpback tests shows that interpretation of results will not be possible, injection-pumpback tests may be substituted for remaining drift-pumpback tests.

Two-well recirculating tests will be conducted in the C-hole intervals that have large hydraulic conductivity. Two tests will be conducted in the permeable zone of the lower Bullfrog Member. One test will use wells UE-25C#2 and UE-25C#3 while the second test will use either UE-25C#1 and UE-25C#3, or UE-25C#1 and UE-25C#2. If the results of these multiple-well hydraulic tests show hydraulic connection between the lower Bullfrog and upper Tram members, a cross-hole recirculating test may be conducted by injecting water into the Bullfrog and pumping from the Tram Member.

Each two-well recirculating test will be conducted in the following manner: Packers will be used to isolate the test intervals in a pumping and injecting well. Water will be pumped from one well at a rate of between 6.3 and 18.9 L/s and injected into the second well. Pumping will continue for approximately three days until a steady-state flow system is established. Pressure transducers will be used to monitor the pressure changes. Conservative tracers, including 3-trifluoromethylbenzoate, will be mixed with water and injected into the aquifer. The tracer will be injected as a short pulse. The steady-state recirculating flow pattern will be maintained following tracer injection. Samples of pumped water will be collected and analysed for tracer concentration. Sampling will continue for at least one week to ensure that all the tracer has time to move through the formation.

Two-well convergent tracer tests will be conducted in the C-hole intervals that have large hydraulic conductivity. One test will be conducted in the permeable zone of the lower Bullfrog Member and one test will be conducted in the upper Tram Member. Each test will be conducted by installing packers in two wells to isolate the permeable interval. Pressure transducers will be installed in all C-holes. Water will be pumped at a rate of between 6.3 to 18.9 L/s from the isolated interval in one well until a steady-state flow system develops. Conservative tracers will be placed in the isolated interval of the second well and will move along converging flow paths toward the pumping well. Water samples obtained from the pumping well will be analysed for tracer concentration. Pumping and water-quality monitoring will continue for at least four weeks or until measurements indicate that no further recovery of tracer is made by continuing the pumping.

Porous-media techniques will be used to interpret the results of the tracer tests at the C-holes. Analytical methods such as Grove and Beetem (1971) will be used to interpret the results of the two-well recirculating tests. Analytical methods will be useful if the flow system can be represented as a homogeneous medium. Numerical models will be useful in both homogeneous and heterogeneous media. Two-dimensional numerical models will be used to interpret drift-pumpback tests and converging tests. If the results of the hydraulic tests indicate that flow is three dimensional, numerical transport models such as Glover (1986) will be adopted for use at the C-holes. Dual-porosity models such as Huyakorn et al. (1983) will be used if test data show evidence of transport in both fractures and intervening unfractured blocks.

Initial porous-media interpretation of tracer-test results will be done using a constant dispersion coefficient or scale dependent dispersion similar to Winter et al. (1984). If test results show transport behavior is not Fickian, analysis of dispersion will be conducted within a stochastic framework similar to one used by Smith and Schwartz (1980) to investigate transport in a parallel-flow field. Stochastic analysis of dispersion in conjunction with field-scale tracer tests has not been attempted previously.

The fracture-network model developed by Lawrence Berkeley Laboratory (Activity 8.3.1.2.3.3.2) will be applied to interpret the results of the tracer tests at the C-holes. Network modeling, described in Activity 8.3.1.2.3.1.4 (multiple-well interference testing), will result in a set of fracture networks that successfully simulate pumping-test results. This set of networks will be used in attempts to simulate tracer-test results. The subset of networks that successfully simulates both hydraulic and tracer tests, will be considered representative of the fracture system at the C-hole location.

Aquifer properties, estimated by porous-media techniques and fracture networks that successfully simulate tracer-test results, will be compared. Differences and similarities in the results of the two methods will be identified. In comparing the two methods, special attention will be given to differences in estimates of the magnitude and distribution of hydrodynamic dispersion and effective porosity. Evidence to support the idea of using a porous-media model to simulate flow and transport in fractured rocks would include dispersion with a normal distribution and constant effective porosity. Evidence to support the idea of using a fracture-network model would include nonnormal dispersion and directional variation in effective porosity, even at large scales.

Results of multiple-well tests will be compared with the results of the single-well tests. Possible reasons for differing results will be identified. The comparisons will be used to decide if the single-well tests can be conducted throughout Yucca Mountain and produce meaningful results, or if additional drilling of multiple-well sites will be needed.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.1.5 are giving in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Drift-pumpback tests	TBD ^a	TBD	TBD
Two-well recirculating tests	TBD	TBD	TBD

Method	Technical procedure		Date
	Number	Title	
Two-well convergent results	TBD	TBD	TBD
Analysis of test results	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.3.1.6 Activity: Well testing with conservative tracers throughout the site

Objectives

The objective of this activity is to determine the following properties at the Yucca Mountain site: (1) effective porosity, (2) longitudinal dispersivity, and (3) regional pore-water velocity.

Parameters

The parameters of this activity are

1. Effective porosity.
2. Dispersivity.
3. Velocity.
4. Hydraulic conductivity.
5. Storage coefficient.
6. Fracture characteristics.

Description

The methods used for testing throughout the site will depend on the results of testing at the C-holes. If drift-pumpback tests give reliable results at the C-holes, then several wells will be selected for single-well testing. If drift-pumpback testing at the C-holes shows that single-well tests cannot be used with confidence, then single-well testing throughout the site will not be conducted. Instead, a second multiple-well location will be proposed and, if developed, tests will be conducted to indicate the range of variations in aquifer properties and transport characteristics that might be expected throughout the site. The methods that might be used at the other wells and proposed multiple-well location are described in the following paragraphs.

Existing geophysical logs for all hydrologic wells in the saturated zone will be reviewed to identify appropriate intervals for conducting tracer

tests. Approximately, five to ten wells will be selected for testing (Figure 8.3.1.2-33). The wells will be distributed throughout the site in areas that are likely to be hydraulically downgradient from the repository block. If existing geophysical logs are not sufficiently detailed for the needs of the tracer testing, additional sonic-televiwer, tracejector and heat-pulse logs will be run. Fracture logs will be used to describe the statistical characteristics of fractures intercepted by the boreholes. Results of the log analysis will be used to identify several intervals in each well where tracer tests will be conducted.

Pumping tests will be conducted in each well. Packers will be installed to isolate intervals that will be used in tracer tests. Pressure transducers will be installed in the well to be pumped and any nearby wells that may respond to pumping. In most instances, no observation well will be available. A pump will be installed; water will be withdrawn from the isolated test interval at a rate of between 3.2 to 12.6 L/s; and the pressure response will be monitored. Emphasis will be placed on collecting pressure-response data during the early part of each test because the data may be useful in understanding the average distance that the tracer will need to move before entering the fracture network near the well. Pumping will continue for approximately 3 to 5 days or until a steady-state flow is established. The pump will be turned off and pressure-recovery data will be collected for a period that is at least equal to the pumping period. Test results will be interpreted using porous-media and/or fracture-network techniques that proved successful when applied to pumping-test results at the C-holes.

Drift-pumpback tests will be conducted in approximately five to ten wells. Within each well, drift-pumpback tests will be conducted in two intervals that have a large hydraulic conductivity. The tracer that is placed in the selected intervals, including 3-trifluoromethylbenzoate, will drift into the formation under steady-state hydraulic gradients. Pretest sensitivity analysis and simulation of the flow system at each well tested will be used to identify reasonable periods of time for the drift phase of these tests. The drift phase will be sufficiently long to permit the tracer to move out of the fractures that intercept the borehole and into the fracture network. In this manner, the influence of individual fractures on seepage velocity will be minimized. Upon completion of the drift phase, a pump will be installed and water withdrawn from the tested interval to begin the pumpback phase of the test. The pumping rate will be 3.2 to 9.6 L/s. The rate of pumping will be measured by an in-line flow meter, and water temperature will be monitored by a thermocouple. Samples of pumping water will be collected and analyzed for tracer concentration. Pumping will continue for at least three days or until virtually all the tracer is recovered. Effective porosity, longitudinal dispersivity and regional pore-water velocity will be determined at each well tested. Porous-media and/or fracture-network techniques will be used to interpret the results of these drift-pumpback tests. Interpretive techniques to be used in the tracer studies at the C-holes will be compared to identify an appropriate technique for application throughout the site.

If the results of the tracer studies at the C-holes show that single-well tests do not give reliable estimates of aquifer properties, then a second multiple-well location will be proposed; if accepted, wells will be drilled and hydraulic and tracer testing will be conducted. A location

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Figure 8.3.1.2-33. Location of the saturated-zone wells that might be used for additional tracer testing.

southwest of the repository block will be selected. The wells will be located as close to the block as practical. A location will be selected where the physical rock properties are significantly different from those of the C-hole location. Three wells will be drilled to depths of approximately 300 m below the water table. Well construction and completion will be similar to the C-holes. Spacing of the wells cannot be stated exactly but some change from the spacing of the C-holes can be expected. Geophysical logs, including sonic televiewer, tracejector and heat pulse, will be run and interpreted to characterize fractures and identify appropriate intervals for tracer testing.

Pumping tests will be conducted at this second multiple-well location to determine the nature of hydraulic connection among wells. Packers will be installed to isolate intervals that will be used in the tracer tests. Pressure transducers will be installed in all three wells and any nearby wells that may respond to pumping. In each test, a pump will be installed; water will be withdrawn from the isolated test interval at a rate of between 3.2 and 12.6 L/s; and the pressure response will be monitored. Emphasis will be placed on collecting pressure-response data during the early part of each test because the data may be useful in understanding the average distance that the tracer will need to move before entering the fracture network near the well. Pumping will continue for approximately 3 to 5 days or until steady-state flow is established. The pump will be turned off and pressure-recovery data will be collected for a period that is at least equal to the pumping period. Test results will be interpreted using porous-media and/or fracture-network techniques that proved successful when applied to pumping-test results at the C-holes.

Two-well recirculating tests will be conducted in well intervals that have large hydraulic conductivity. Two tests, each using different pumping and injecting wells, will be conducted in an approximately horizontal zone of increased hydraulic conductivity. These tests will be used to investigate the symmetric and isotropic nature of transport characteristics. A third test will be conducted in a separate permeable interval. If the results of the multiple-well hydraulic tests show vertical hydraulic connection between permeable zones, a cross-hole recirculating test may be conducted.

Each two-well recirculating test will be conducted in the following manner. Packers will be used to isolate test intervals in a pumping and injecting well. Water will be pumped from one well at a rate of between 6.3 and 18.9 L/s, and injected into the second well. Pumping will continue approximately 8 days until a steady-state flow system is established. Pressure transducers will be used to monitor pressure changes. Conservative tracers, including 3-trifluoromethylbenzoate, will be mixed with water and injected into the aquifer. The tracer will be injected as a short pulse. The steady-state recirculating flow pattern will be maintained following the tracer injection. Samples of pumped water will be collected and analyzed for tracer concentration. Sampling will continue for 1 to 3 weeks to ensure that all the tracer has had time to move through the formation. Test results will be interpreted using porous-media and fracture-network techniques that proved successful when applied to tracer-test results at the C-holes.

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Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.1.6 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Identification and characterization of existing wells to be used in tracer tests	TBD ^a	TBD	TBD
Sonic televiewer, tracejector, and heat-pulse logging of existing wells	HP-02, R0	Acoustic televiewer investigations	14 Aug 84
	HP-03, R0	Hydrologic tracejector test	11 Jan 82
Drift-pumpback tests at existing wells	TBD	TBD	TBD
Multiwell testing with conservative tracers	TBD	TBD	TBD
Pumping tests	HP-06, R0	Hydrologic pumping test	11 Jan 82

^aTBD = to be determined.

8.3.1.2.3.1.7 Activity: Testing of the C-hole sites with reactive tracers

Objectives

The objective of this activity is to characterize the chemical and physical properties of the geological media in the saturated zone in the vicinity of the C-holes that will affect radionuclide retardation during ground-water flow within the saturated zone.

Parameters

The parameters for this activity are

1. Adsorption rate constants.
2. Sorption equilibrium constants.

Description

Identification and characterization of reactive tracers to be used

Two classes of reaction occur between solutes in ground water and geologic media. One is chemical reaction, in which the product is a chemical combination of atoms in the solute and the geologic medium. The other is sorption, in which the solute molecule, atom, or ion becomes attached to the medium and can be removed at some later time. The tests described here use sorption, because it has the greater potential for probing radionuclide retardation characteristics of the geologic media. The sorbing tracers for these tests will have to fulfill the unusual requirements of other tracers (i.e., they must be soluble in the bulk fluid (water), and quantitatively detectable in low concentrations). In addition, sorbing tracer must attach itself to the surface rather weakly. If a substance forms strong sorption bounds with the surface, it will not desorb for a long period and then in amounts too low to be detected. Four types of sorption can provide information about a geologic medium and its potential for radionuclide retardation: chemisorption, molecular-sieve adsorption, ion exchange, and electrostatic, electronic, or electrical adsorption. A fifth type, physical adsorption, usually contributes very little to understanding the natures of solid, solvent, or solute when studying aqueous systems and is not suggested for use in the tests. Needs prior to use for the other four types of sorption are treated in the following paragraphs.

Chemisorption, or chemical adsorption, involves the formation of chemical bonds between the adsorbate and the adsorbing solid. For our situation, two types of chemisorption might be useful. Various radionuclides may form complexes involving the solid surface, and analog complexes can be developed that will exhibit adsorption of sufficient weakness for a tracer experiment. This would detect the potential of a geologic medium for radionuclide retardation through complex formation. In addition, specific chemical interactions can be developed that will identify particular characteristics of the solid surface. An analogous example in gas-phase adsorption is the use of carbon monoxide to detect the number of active sites on a supported platinum catalyst. Following an intensive literature search to identify candidate tracers for chemisorption, a program of laboratory experiments will be carried out using the candidate tracers. The program of laboratory experiments is essentially common for the different types of sorption, and is discussed following the description of the different sorption types.

In molecular-sieve adsorption, molecules are caught in cage-like structures within the solid. Sizes of the entrances to these "cages" are only fractions of a nanometer, and determine what sizes of molecule, ion, or other species may be adsorbed in a molecular sieve. Montmorillonite and clinoptilolite are two minerals in the Yucca Mountain area that contain molecular sieves. Thus, Yucca Mountain tuffs probably exhibit molecular-sieve adsorption, and take up very small atoms, molecules, or ions. A krypton-neon tracer duet appears to be usable for detecting the presence and extent of these molecular sieves. Laboratory experiments are needed to investigate the ability of the sieves to trap and retard radionuclides, as discussed in the following paragraph.

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Ion exchange involves the actual exchange of ions in a zeolite mineral structure. In the Yucca Mountain-area zeolites, it is the sodium ion that usually is removed from the zeolite and replaced with another. Ion exchange is a major source of the radionuclide retardation capacity of the geologic media around Yucca Mountain. The capacity for ion exchange can be measured by using as a tracer some simple ion that will replace sodium. The ion should not attach itself too strongly to the medium, or else it will not appear in the effluent. It appears that the lithium ion usually is the most weakly attached to ion-exchange materials, and probably would make the most appropriate tracer for this purpose. Laboratory measurements of the ion-exchange capacity of the minerals found in the Yucca Mountain area and the kinetics constants of the ion-exchange reaction will be necessary for accurate modeling of this system to be performed, and for analysis of tracer results, as discussed in the following paragraph.

Electrical charges on the sorbate molecules and on the solid surface cause a type of adsorption known as electrical, electronic, or electrostatic adsorption. It can range from the very weak, where polar molecules are usually involved, to the extremely strong. This adsorption has possibilities for giving two types of information about the geologic surfaces for radionuclide retardation. Most geologic media possess surfaces covered with oxygen atoms; if an adsorbing polar molecule is attracted to the surface oxygens, then this sorbate could be used to determine the interfacial surface area of the rock through which the fluid passes during a tracer test. Adsorption of this type is probably the cause of the retardation of fluorocarbons reported in the literature. Laboratory tests will be carried out to confirm this application. Electrical characteristics of the surface also can be measured by this type of adsorption. Electrical characteristics can identify different mineral properties, including some that would be important in radionuclide adsorption and retardation. Again, the laboratory program for studying this is described in the following paragraph.

For all four types of sorption, candidate tracers will be identified by an intensive literature search. Following the selection of candidate tracers, a program of laboratory experiments will be pursued to characterize the sorption properties of the candidates and how they predict the retardation properties of the geologic media. The experiments will use both model substances as well as tuff samples from the Yucca Mountain vicinity to define sorbate and sorbent properties and characteristics. Both batch experiments and column-flow sorption experiments will be carried out. The goals of the experiments will be to measure the adsorption kinetic parameters and the sorption equilibrium parameters. These parameters then will be related to the chemical and physical nature of the geological media tested, and the results correlated with the radionuclide retardation properties of the media. Finally, these will be correlated with the radionuclide sorption characteristics of the tuffs taken from the Yucca Mountain vicinity.

Modeling of tests

Concurrently with the identification and characterization of the tracers to be used in these tests, an extensive program of numerical modeling of the reactive-tracer tests will be carried out. The goal of this modeling is the identification of sorption-parameter ranges that will give interpretable results from field tracer tests. Modeling of both injection-backflow and

between-well tests (the two types of intended field experiments) will be carried out. The primary codes for the numerical modeling will be TRACR3D and FEHM, two codes presently in use for modeling flow and transport in fractured and porous materials. The media properties used in the numerical modeling will be obtained on a continuing basis; as the tests yield more information about the flow and media characteristics in the regions of the intended tests, these data will be incorporated into the numerical modeling.

Injection-backflow tests

The procedures, pumping rates, tracers used, tracer concentrations, and durations of the tests will be specified by the results of the numerical modeling studies. The regions investigated will be the same as those studied in the drift-pumpback tests (Activity 8.3.1.2.3.1.4). Three reactive-tracer injection-backflow tests with two overall goals are intended: (1) to confirm the use of such reactive-tracer field tests and (2) to evaluate radionuclide retardation characteristics of the saturated zone in the vicinity of the C-holes.

Two- and three-well tests

As for the injection-backflow tests, the procedures, pumping rates, tracers used, tracer concentrations, and durations of the tests will be specified by the results of the numerical modeling studies. Where the modeling shows it will be profitable, tracer concentrations will be measured in all three wells. Two of these tests are planned.

Analysis of test results

Numerical evaluation of the field test results will yield the adsorption kinetics parameters and the sorption equilibrium parameters. The principal codes that will be used initially in the evaluations will be TRACR3D and FEHM, described previously. These parameters obtained using the codes will then be compared with the results of the laboratory experiments described earlier to calculate the radionuclide retardation characteristics of the tested regions.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.1.7 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Identification and characterization of reactive tracers to be used in tracer tests	TBD ^a	TBD	TBD
Modeling of tests	TBD	TBD	TBD

Method	Technical procedure		
	Number	Title	Date
Injection-backflow tests	TBD	TBD	TBD
Two- and three-well tests	TBD	TBD	TBD
Analysis of test results	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.3.1.8 Activity: Well testing with reactive tracers throughout the site

Objectives

The objective of this activity is to characterize the chemical and physical properties of the geological media in the saturated zone throughout the site that will affect radionuclide retardation during ground-water flow within the saturated zone.

Parameters

The parameters for this activity are

1. Adsorption rate constants.
2. Sorption equilibrium constants.

Description

Modeling of tests

The wells used for these tests will be the same as those used for conservative-tracer tests throughout the site (Section 8.3.1.3.1.6). The modeling will follow the same route as the pre-test modeling of the C-holes reactive tracer field tests (i.e., the sorption-parameter ranges, which will give interpretable results from the field tests, will be identified by modeling different experimental scenarios covering appropriate ranges of the sorption parameters). Once the sorption-parameter ranges are specified, appropriate tracers can be chosen from the candidate tracers tested earlier for the C-holes experiments (Activity 8.3.1.2.3.1.5). Modeling of both injection-backflow and multiwell tests will be carried out, and the primary codes for the numerical modeling will be TRACR3D and FEHM. The media properties used in the numerical modeling will be obtained on a continuing basis, so the modeling will be the most accurate possible. The extensive

modeling carried out for the C-holes experiments is expected to reduce significantly the amount of modeling needed for these tests.

Injection-backflow tests

If injection-backflow tests in the C-holes show that good information on radionuclide retardation properties can be obtained from single-well sorbing-tracer tests, further single-well tests will be performed throughout the site. The number of tests will be determined by the availability of test wells, amount of information desired, and quality of information attainable. As noted previously, test procedures and specifications will be determined by the pre-test numerical modeling studies.

Multiple-well tests

If drift-pumpback tests do not provide sufficient information, a multiple-well location will be selected and tests conducted. If this occurs and the C-hole tests show that multiple-well tests give useful information about radionuclide retardation properties in the saturated zone, then this multiple-well location will be used for further reactive tracer tests.

Analysis of test results

As for the C-holes, numerical evaluation of the field test data from wells throughout the site will yield the adsorption kinetics parameters and sorption equilibrium parameters between the sorbents and geological media in the vicinities of the test wells. These parameters will be used to calculate the radionuclide retardation properties in the vicinities of the test wells, and conclusions will then be drawn about the values, variations, and ranges of the radionuclide retardation properties of the saturated zone of the site.

Methods and technical procedures

This task is in early stages of development; therefore, no technical procedures are available.

8.3.1.2.3.2 Study: Characterization of the site saturated zone hydrochemistry

The study objectives are (1) describe the chemical composition of and the spatial compositional variations in waters in the saturated zone at the site, (2) develop and test hypotheses about the geochemical and geohydrologic factors controlling water compositions, and (3) relate spatial variations to the physical nature of the ground-water flow system. Two activities are planned to acquire the data needed to meet these objectives. The activities are (1) assessment of site and regional hydrochemical data availability and needs, and (2) hydrochemical characterization of water in the upper part of the saturated zone.

8.3.1.2.3.2.1 Activity: Assessment of site hydrochemical data availability and needs

Objectives

The objectives of this activity are to

1. Compile and evaluate existing hydrochemical data for the saturated zone at the site and within the region.
2. Identify data deficiencies and potential sampling sites and assemble requisite materials for sample collection and field data determinations.

Parameters

The parameters for this activity are

1. Chemical concentration.
2. Isotope ratio.
3. Water temperature.
4. Ionic balance.

Description

Existing hydrochemical data for the saturated zone at the site and within the surrounding region will be compiled. The cation-anion balance of each analysis will be calculated for preliminary data-quality verification. Preliminary maps of areal distributions of selected dissolved species and/or physical parameters will be prepared to depict areal and vertical hydrochemical variations. Published water-level maps will provide information regarding ground-water flow directions and gradients. Published geologic descriptions of the site and the surrounding region will provide locations of major structural features and available information regarding formation geometries. All of the previously described data will be integrated to delineate areas where additional data are needed.

8.3.1.2.3.2.2 Activity: Hydrochemical characterization of water in the upper part of the saturated zone at the site

Objectives

The objectives of this activity are to collect representative water samples from about the upper 100 m of the saturated zone at the site for comprehensive chemical analysis; to use the analytical data to describe the water chemistry; and to relate compositional variations to water-rock interactions and the physical nature of the ground-water flow system. The bulk of these data will be used by Investigation 8.3.1.3.1 in the development of a ground-water chemistry model (Study 8.3.1.2.1.1).

When the boreholes are entered for sampling, the opportunity will be used to collect new geophysical data in the sampled wells to (1) aid in the

evaluation of physical formation properties; (2) assist in stratigraphic correlations, and (3) determine vertical profiles of water content in the unsaturated zone.

Parameters

The parameters for this activity are

1. Chemical concentration.
2. Isotope ratio.
3. Radioisotope activity.
4. Water temperature.

Description

Fourteen of the wells at the site were constructed to depths ranging from about 43 to 98 m below the top of the saturated zone (Table 8.3.1.2-10). Well depths range from 348 to 628 m. These water-table wells are presently part of the water-level monitoring program. Each has access tubing for water-level measurement; some contain transducers for continuous water-level data collection.

Water samples collected to date from the saturated zone at the site have been from saturated intervals much deeper than those of these wells (Table 8.3.1.2-10). Samples from these wells will enable determination of vertical variations in water chemistry and age. This information will conceivably provide important insight to consideration of conceptual models of fluid movement in the saturated zone and to fluid flow paths, residence times, and velocities.

The collection of additional geophysical data, including some experimental logging, will facilitate determination of physical properties of the formations penetrated and inter-well correlation of lithologic units. Collection of new neutron logging data may help in determining water content in the unsaturated zone at each well site. Data and sample collection will entail the following activities. Access tubing, screens, and transducers will be removed from each well, as needed. The tubing will be cleaned of rust and other foreign materials, and a Moyno variable-discharge pump will be attached. The tubing, pump, and any other appropriate hardware will be installed in the well and tested for proper and reliable operation. Water levels will not be monitored during this activity; therefore, no access tubing for this purpose will be installed. The pump will be operated continuously for about 1 week, until field analyses of samples of the discharged water indicate that the water composition has stabilized and is likely representative of the water in the formation. At this time samples will be collected for field analyses of unstable constituents and extensive properties, and for comprehensive chemical and isotopic laboratory analyses. Laboratory analyses will include determinations of the radioisotope activities of carbon and hydrogen (carbon-14 and tritium); ratios of stable isotopes of sulfur, oxygen, hydrogen, and carbon; and water chemistry. The usefulness and applicability of uranium-series disequilibrium analyses will be evaluated; if determined to be appropriate, those analyses will also be conducted.

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Table 8.3.1.2-10. Existing (November 1986) water-table wells to be sampled and logged

Well number	Well depth (m/ft)	Depth to water (m/ft)	Tubing length (m/ft)
USW WT-1	515/1,689	471/1,545	507/1,665
USW WT-2	628/2,060	571/1,873	622/2,040
UE-25 WT#3	348/1,142	302/986	343/1,125
UE-25 WT#4	482/1,580	439/1,440	478/1,568
UE-25 WT#6	383/1,256	284/932	372/1,221
USW WT-7	491/1,610	421/1,382	481/1,579
USW WT-10	431/1,413	343/1,142	403/1,321
USW WT-11	441/1,446	364/1,194	416/1,365
UE-25 WT#12	399/1,310	345/1,132	389/1,276
UE-25 WT#13	352/1,155	303/994	346/1,135
UE-25 WT#14	399/1,310	346/1,136	397/1,303
UE-25 WT#15	415/1,360	354/1,162	407/1,335
UE-25 WT#16	518/1,710	473/1,552	514/1,686
UE-25 WT#17	443/1,453	395/1,296	419/1,376

The resultant analytical data will be studied using graphic methods and speciation-solubility and mass transfer calculations. The equilibrium model used will be that of Wolery (1983) or Plummer et al. (1976). Mass transfer calculations will be made with codes written by Wolery (1979) or Parkhurst et al. (1980).

After sample collection, the pump will be stopped and the sampling hardware taken out of the well. Caliper, epithermal-neutron porosity, magnetometer, magnetic susceptibility, and possibly other experimental and supporting logs will be run from total well depth to land surface. This activity will precede sampling if it is logistically more efficient. After the completion of all data-collection activities at each site, the ground-water monitoring hardware will be reinstalled at about the original depth. The surface cap or seal will then be reinstalled.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.2.2 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
	(NWM-USGS-)		
Analysis of dissolved inorganic substances	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82
Carbon-14 analysis	HP-11, R0	Methods for determination of radioactive substances in water	18 June 82
	HP-127, R0	Carbon-14 dating by tandem accelerator mass spectrometer	
Ground-water sample collection	HP-23, R1	Collection and field analysis of saturated zone ground-water samples	4 Nov 83
	HP-49, R0	Method for using hand-held glass thermometer	14 Aug 84
Geophysical logging	GPP-15, R0	Magnetic susceptibility borehole logging operations	27 May 86
	GPP-12, R0	Borehole gravity measurement and data reduction	20 Mar 85

8.3.1.2.3.3 Study 1.13.3.3: Saturated zone hydrologic system synthesis and modeling

The objectives of this study are to (1) synthesize the available data into a model and make a qualitative analysis of how the system is functioning and (2) represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive flow model. Three activities are planned to analyze and integrate the data in order to satisfy these objectives. The planned activities are the conceptualization of the saturated zone flow models within the boundaries of the accessible environment, the development of a fracture network model, and the calculation of flow paths, fluxes, and velocities within the saturated zone.

8.3.1.2.3.3.1 Activity: Conceptualization of saturated zone flow models within the boundaries of the accessible environment

Objectives

The objectives of this activity are to synthesize the available data into a model and make a qualitative analysis of how the system is functioning.

Parameters

The parameters for this activity are spatial distribution of the hydrogeologic units and their hydraulic properties, including

1. Hydraulic conductivity.
2. Hydraulic gradient.
3. Effective porosity.
4. Flux.
5. Water chemistry.
6. Storage properties.

Description

All reliable data and reasonable interpretations of them will be assimilated into a description of the flow system within the boundaries of the accessible environment. This description will include the physical and hydraulic characteristics of the rock units and structural features, as well as the likely ways that the flow system operates within this framework. The data will contain information attained from the published literature and the NNWSI Project activities. This conceptual description of the flow system will be incorporated into computer models as the baseline condition for ground-water flow at the site.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.3.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Interpretation and integration of hydrologic, geologic, and geophysical data	TBD ^a	TBD	TBD

Method	Technical procedure		
	Number	Title	Date
Mapping the spatial distribution of boundaries and hydrogeologic units and features	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.3.3.2 Activity: Development of fracture network model

Objectives

The objective of this activity is to develop a fracture-network model for simulating hydraulic and tracer tests at a scale similar to that of the C-hole tests.

Parameters

The parameters are the steady-state and transient flow-and-transport characteristics of fractures.

Description

A model will be developed that is capable of simulating ground-water flow and conservative-solute transport in a discrete-fracture network. The model will be used to simulate pumping and tracer tests at the C-holes. Existing codes are specialized for column research and do not include well-boundary conditions that occur during pumping and tracer tests. The new model will include two computer codes, a fracture-mesh generator and a flow-and-transport code. The fracture-mesh generator will be capable of reproducing statistical descriptions of fracture characteristics. The flow-and-transport code will be capable of simulating both steady-state and transient conditions within the fracture network.

Although the fracture-network model will be developed primarily for application at the C-holes, it will be written with a broad range of potential applications in mind. Boundary conditions will not be restricted to those that will be encountered during pumping and tracer tests but will include boundaries that would be encountered at other scales. Initially the model will be developed on the basis of parallel-plate theory but will also be written in a modular manner so that new theories, such as channeling within single fractures, can be readily included in the codes as they become available. By writing the model in this manner, it will be relatively easy to evaluate the significance of alternative theories when applied to fracture

networks. The model will be designed primarily for application in a perturbed flow system that develops during pumping and tracer tests, but also for possible application in a natural system that may exist after radioactive waste is placed in the repository. o

The fracture-mesh generator will be similar to one described by Long et al. (1982). Fractures will be modeled as linear or disc-shaped discontinuities in an impermeable matrix. Fractures will be arbitrarily located within the rock and will have statistical distributions of aperture, length, orientation, and density that can be specified by the user. The mesh generator will be capable of reproducing discrete fractures observed in boreholes.

The flow and transport code will use a mixed Eulerian-Lagrangian solution technique. Ground-water flow in fractures will be solved using parallel-plate theory within the usual Eulerian framework. Advective transport will be solved by a Lagrangian formulation using particle-tracking techniques. Several techniques, including random-walk theory, will be evaluated before deciding on a method for treating dispersion within single fractures. Modular-program design will make it relatively easy to evaluate techniques for modeling dispersion. Alternate methods for modeling transport at fracture junctions, including complete mixing of solute from different fractures and no mixing, will also be evaluated before finally selecting a method.

A series of simulations will be designed to ensure that the model successfully reproduces known analytical solutions and to evaluate the significance of approximations used in the solution method. Documentation will include descriptions of model theory, use (including input and output descriptions), benchmark simulations, and program listings.

Parametric studies, using fracture-characteristic data measured in the drillholes UE-25C#1, UE-25C#2, and UE-25C#3 (Figure 8.3.1.2-31) will be done for the following two purposes:

1. To evaluate the effects of fracture characteristics on results of well tests. Such studies may indicate important needs in field investigations including needs for specific types of well tests. Test designs that are typically used in a porous medium may not be optimal for understanding the hydrologic nature of the fractured rock at Yucca Mountain.
2. To evaluate the general hydrologic behavior of the saturated zone, in so much as fracture statistics measured in boreholes at Yucca Mountain are representative of the saturated zone. Special emphasis will be given to (a) identifying scales where flow and transport in a fracture network can be simulated appropriately by analogy to an equivalent porous medium, and (b) investigating the character of convective dispersion.

Fracture networks, used in parametric studies, will bracket the range of uncertainty in fracture characteristics. Fracture frequency and orientation has been measured in boreholes from television and televiwer logs; however, fracture data to describe the distribution of fracture lengths and fracture

apertures are not available. Therefore, initial parametric studies will consider fracture networks with uniform lengths and apertures. After the hydrologic response of fracture networks with uniform lengths and apertures is understood sufficiently, distributed lengths and apertures will be used in parametric studies.

Each fracture network that is generated will be used in the finite-element program to calculate rates of ground-water flow across the network under linear-flow boundary conditions. Rates of flow will be related to hydraulic conductivity of an equivalent porous medium using an approach similar to that described by Long et al. (1982). An approach similar to Endo et al. (1985) will be used to relate flow rate to hydraulic effective porosity. Methods described by Long et al. (1982) also will be used to identify the scale of representative elementary volumes (REV) of fracture networks; and hence to determine scales where a fracture network can be described by analogy to an equivalent porous medium. The scale of REV may be different for flow and transport.

Multiple fracture networks generated from the same set of fracture statistics may have significantly different hydrologic character. If a fracture system has a REV and the scale of simulation is larger than the REV, by definition, multiple realizations should have reasonably similar hydrologic character. If the scale of simulation is smaller than the REV, the probability of significantly different hydrologic character depends on various parameters, of which fracture frequency and aperture are most critical.

The importance of generating multiple fracture networks when applying the fracture-network model in well tests cannot be evaluated until preliminary parametric studies are completed. If preliminary parametric studies indicate that different realizations from the same set of fracture statistics have different hydrologic character, then later parametric studies will be done with multiple realizations of fracture networks. The most appropriate method for selecting fracture networks cannot be selected until preliminary parametric studies are complete. The methods that will be considered for use include (1) Monte Carlo simulation, (2) response-surface methodology, and (3) Latin hypercube sampling.

If multiple realizations of fracture networks generated from a single set of fracture statistics have similar hydrologic response, the relations between fracture characteristics and hydrologic response will be deterministic; otherwise, the relations will be stochastic. If the relations are stochastic, then parametric studies will be used to estimate the likely range of the relations. Depending on the method used to select fracture networks, it may be possible to estimate statistical confidence regions of the relations. Specific plans for verification and validation have not yet been developed but will follow the general approach described in the issue resolution strategy for Issue 8.3.1.2.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.3.2 are given in the following table.

CONSULTATION DRAFT

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Program design and coding	TBD ^a	TBD	TBD
Benchmark simulations and model documentation	TBD	TBD	TBD
Parametric studies	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.3.3.3 Activity: Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment

Objectives

The objectives of this activity are

1. To estimate ground-water flow direction and magnitude for input into travel-time calculations.
2. To evaluate the porous-media concept and fracture-network concept for determining flow paths, fluxes, and velocities.

Parameters

The parameters for this procedure are

1. Flow paths.
2. Fluxes.
3. Velocities.

Description

Techniques used to interpret results of hydraulic and chemical-tracer tests will be evaluated by the following two criteria:

1. Data must be available at the scale of hydrologic-well tests to justify using the technique. In other words, the technique must not have overly complex data requirements when compared with test data that typically are available.
2. Estimates of flow paths, fluxes, and velocities obtained by applying the technique at the scale of hydrologic-well tests must be reasonably reliable.

While it is not known if any technique will meet these criteria completely, it is important to make such an evaluation. Techniques that will be evaluated include those based on the concept of an equivalent porous medium, a dual-porosity medium, and a discrete-fracture network. Techniques are described in greater detail in Study 8.3.1.2.3.1 (characterization of the site saturated-zone ground-water flow system).

The relation between techniques applicable at the scale of hydrologic well tests and techniques applicable at regional scales has not been established for most fractured media. Techniques that successfully simulate results or hydrologic-well tests will be extended on a theoretical basis for use in large-scale models. Scale dependence of many model parameters is expected. Hydrologic well tests are conducted in a perturbed flow system, while large-scale models evaluate a relatively unperturbed system. This raises questions when using well test results in regional analyses.

Applicability of techniques proved successful at the scale hydrologic-well tests to large-scale problems will be evaluated by conducting sensitivity analyses and simulations of flow and transport in hypothetical flow systems. The hypothetical systems will be similar conceptually and will retain many of the important hydrologic characteristics of Yucca Mountain but will be simplified for ease of data input.

If fractured rock at Yucca Mountain can be represented by an equivalent porous medium with aquifer properties that are statistically homogeneous at a local scale, then a technique described by Winter et al. (1984) will be evaluated. Winter et al. (1984) recognize the scale dependence of dispersion and velocity but show that, at large scales in statistically homogeneous porous media, these parameters are approximately constant. Large-scale estimates are calculated from local-scale measurements of hydraulic conductivity and dispersion coefficient.

If results of hydrologic well tests show that fractured rocks at Yucca Mountain are realistically represented by equivalent porous media with aquifer properties that are statistically heterogeneous at a local scale or by a discrete fracture network, then a technique described by Schwartz and Smith (1985) will be evaluated. In this technique, local-scale models of flow paths, fluxes, and velocities are developed as a preliminary to a large-scale model. The local-scale models are based either on discrete fracture networks or equivalent porous media with statistically heterogeneous aquifer properties. Boundaries of the local-scale models are established to reproduce conditions expected at the large scale. In practice only a small number of local-scale models, representative of variations in regional conditions, are constructed. The large-scale model uses either finite difference or finite-element medium. Statistics obtained during simulations with the local-scale models are used to describe the character of ground-water movement within large-scale blocks or elements. In this manner, the large-scale model accounts for the influence of fractures in a realistic way.

Flow paths, fluxes, and velocities will be estimated during development of the regional and site model of ground-water flow and transport. The models will be based on the concept of an equivalent porous medium and the classical advection-dispersion equation. Methods for developing these models are described elsewhere (Activities 8.3.1.2.1.4.1 through 8.3.1.2.1.4.4, and

8.3.1.2.3.3.1). The models include site information describing recharge and discharge boundaries, potentiometric surfaces, and aquifer properties such as hydraulic conductivity and effective porosity. Sensitivity analyses, formal parameter-estimation techniques, or both will be used to evaluate the reliability of estimates of flow paths, fluxes, and velocities. These modeling activities will be coordinated with flow modeling activities described in Section 8.3.5.12. Specific plans for verification and validation have not yet been developed.

The technique identified previously to account for the influence of fractures in a realistic way will be used with the existing flow and transport models of Yucca Mountain. Sensitivity analyses will be conducted to provide physically based estimates of confidence in flow paths, fluxes, and velocities. If results of investigations show that the fractured rock at Yucca Mountain can be described realistically by an equivalent porous medium with aquifer properties that are statistically homogeneous at a local scale, then a technique similar to that of Winter et al. (1984) will be used and refined estimates probably will be unchanged from initial estimates of flow paths, fluxes, and velocities. Otherwise, a technique similar to that of Schwartz and Smith (1985) will be applied and refined estimates may be significantly different from initial estimates.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.3.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
(NWM-USGS-)			
Evaluation of flow paths, fluxes, and velocities at tracer-test locations	TBD ^a	TBD	TBD
Evaluation of constraints when assuming a porous-media equivalent of tested sites	TBD	TBD	TBD
Evaluation of methods for calculating flow paths, fluxes, and velocities throughout the site	TBD	TBD	TBD
Discrete-fracture modeling	TBD	TBD	TBD

Method	Technical procedure		Date
	Number	Title	
Porous-media equivalent modeling	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.2.3.4 Application of results

The information derived from the studies and activities of the plans described previously will be used in the following areas of site characterization, repository design, and performance assessment:

<u>Information need or investigation</u>	<u>Title</u>
1.1.1	Site information needed for calculations (to calculate the releases of radionuclides to the accessible environment) (Section 8.3.5.13.1)
1.1.2	Potentially significant release scenario classes representative release scenarios that address both anticipated and unanticipated conditions (Section 8.3.5.13.2)
1.1.3	Calculational models for release scenario classes (Section 8.3.5.13.3)
1.6.1	Site information and design information needed (to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path) (Section 8.3.5.12.1)
1.6.2	Calculational models to predict ground-water travel time (in the unsaturated and saturated zones) (Section 8.3.5.12.2)
1.6.4	Prewaste-emplacement ground-water travel time (Section 8.3.5.12.4)
1.8	NRC siting criteria (Section 8.3.5.17)
8.3.1.2.2	Site unsaturated-zone hydrologic system
8.3.1.2.3	Site saturated-zone hydrologic system
8.3.1.3.1	Water chemistry (within the potential emplacement horizon and along potential flow paths)

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Information need or investigation

Title

8.3.1.3.6	Radionuclide dispersion, diffusion, and advection
8.3.1.3.7	Radionuclide retardation investigations
8.3.1.5.2	Climate effects on hydrology
8.3.1.8.3	Tectonic effects on hydrology
8.3.1.9.3	Effects of human interference. Potential effects of exploiting natural resources on hydrologic characteristic

8.3.1.2.3.5 Schedule and milestones

This investigation contains three studies: 8.3.1.2.3.1 (characterization of the site saturated-zone ground-water flow system), 8.3.1.2.3.2 (characterization of the site saturated zone hydrochemistry), 8.3.1.2.3.3 (saturated zone hydrologic system synthesis and modeling). In the figure that follows, the schedule information for these studies is presented in the form of time-lines. The lines extend from the implementation of the approved study plans to the issuance of final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

One study in this investigation, 8.3.1.2.3.1, is ongoing. The other two studies, 8.3.1.2.3.2 and 8.3.1.2.3.3, are expected to start within the first year of site characterization.

Studies 8.3.1.2.3.1 and 8.3.1.2.3.2 perform basic data gathering and analysis whereas Study 8.3.1.2.3.3 assembles the results of this work plus information on the regional hydrologic system, unsaturated zone system, and rock characteristics program to develop an overall hydrogeologic model of the saturated zone at the site. Characterization of the saturated zone at the site (Study 8.3.1.2.3.1) is constrained by the availability of stratigraphic and other relevant information from Study 8.3.1.4.1.1 and by the drilling schedule. Characterization of the saturated zone hydrochemistry at the site (Study 8.3.1.2.3.2) is also constrained by the drilling schedule. Water chemistry data collected under Study 8.3.1.2.3.2 will be used in Investigation 8.3.1.3.1 in the development of a ground-water chemistry model. The synthesis phase of the investigation (Study 8.3.1.2.3.3) draws on the existing conceptual model plus incoming data from Studies 8.3.1.2.3.1 and 8.3.1.2.3.2 to produce at least four numerical models of the saturated zone at the site; these models differ in their conceptual approaches to simulating flow in the saturated zone. Comparison of these models, in conjunction with the data obtained in the previous two studies, will be used to finalize the model of the saturated zone at the site. The fracture-network model developed in synthesis study (8.3.1.2.3.3) will be used to interpret the results of both cross-hole and large-scale pumping tests.

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The study number and titles corresponding to each timeline are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

The points on the timeline are described in the following table:

Point number	Description
1	Input of stratigraphic and other relevant information from Study 8.3.1.4.1.1.
2	Milestone P891. Issue report on the analysis of hydraulic stress tests at UE-25c wells.
3	Milestone P929. Issue report on the analysis of static-drift/pumpback tests using conservative tracers at UE-25c wells.
	Milestones Z245 and Z246. Issue reports on water-level data (1981 through 1986; 1987-1988) at Yucca Mountain.

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<u>Point number</u>	<u>Description</u>
4	Milestone Q104. Begin tracer testing at C-hole complex. Milestone Z244. Issue report on water-level data (1989) at Yucca Mountain.
5	Milestone Q106. Complete testing at C-hole complex.
6	Milestone Z247. Issue report on water-level data (1990) at Yucca Mountain.
7	Milestone Q109. Begin drilling hydrologic hole USW H-7.
8	Milestone P105. Issue summary report for multiple-well tracer tests in the saturated zone at UE-25c wells.
9	Milestone M380. Complete hydrologic testing of the saturated zone. Milestone Q110. Complete drilling and testing of hydrologic hole USW H-7.
10	Milestone P738. Issue report on the saturated zone geohydrology of the Solitario Canyon fault zone. Milestone 359. Issue report on water-level data (1991) at Yucca Mountain.
11	Milestone P931. Issue report on the evaluation of steep hydraulic gradients near Yucca Mountain.
12	Milestone P897. Issue report on the preliminary hydrologic description of the saturated zone for input to the draft environmental impact statement.
13	Milestone Z411. Issue report on the potentiometric surface at Yucca Mountain. Milestones Z354 and Z355: Issue reports on water-level data (1992 and 1993) at Yucca Mountain.
14	Milestone Z256. Issue report on hydrochemical characterization of water in the upper part of the saturated zone.
15	Water chemistry data to Investigation 8.3.1.3.1.
16	Milestone Q067. Issue report on the characterization of the Yucca Mountain site saturated zone hydrochemistry.
17	Milestone P932. Complete conceptual model of saturated zone hydrology at Yucca Mountain and vicinity.

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<u>Point number</u>	<u>Description</u>
18	Milestone Z412. Issue report on the analysis of water fluctuation at Yucca Mountain.
19	Milestone P895. Complete preliminary fracture network models for simulating UE-25c well tests.
20	Milestone P754. Issue report on the analysis of flow in saturated zone fractured rock.
21	Milestone M389. Issue report on the description of the site saturated zone hydrology at Yucca Mountain.

Nuclear Waste Policy Act
(Section 113)

Section 8.3.1.3

Consultation Draft

GEOCHEMISTRY

Site Characterization Plan

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

Volume IV

January 1988

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

8.3.1.3 Overview of the geochemistry program: Description of the present and expected geochemical characteristics required by the performance and design issues

Summary of performance and design requirements for geochemical information

Performance allocation is being used in developing the issue resolution strategy for the performance and design issues and to determine what geochemical information must be developed during site characterization. Performance allocation is an iterative process incorporating sensitivity analysis to determine data needs. Specifically, an identification of a data need by a performance or design issue results in a request for that information to be generated by the geochemical program. Secondary and supporting data must be obtained to provide the necessary information to satisfy the requested data need. These data will be used to develop the conceptual and numerical model to be used in understanding geochemical processes and evaluating subsystem performance.

Figure 8.3.1.3-1 shows the performance and design issues that call for geochemical data, summarizes the data needed, and indicates the relevant model for each data need. The models will be discussed in detail later and are shown in the figure as an introduction. The specific data needs by the performance and design issues are as follows:

1. Issue 1.1 (total system performance, Section 8.3.5.13) calls for retardation factors for radionuclides in the rock units along the flow paths under expected and unexpected conditions for 10,000 to 100,000 years. Issue 1.1 also calls for major ion water chemistry, dispersion coefficients, and matrix diffusion coefficients.
2. Issue 1.2 (individual protection, Section 8.3.5.14) calls for the same data as Issue 1.1, except only for expected conditions and only for 1,000 years. In addition, data on gas phase transport is requested.
3. Issue 1.3 (ground-water protection, Section 8.3.5.15) again calls for the same data as Issue 1.1, except only for expected conditions and only for 1,000 years.
4. Issue 1.5 (engineered-barrier system release rates, Section 8.3.5.10) calls for changes in geochemical conditions to serve as input to scenarios, and for radionuclide sorptive and transport properties of the host rock.
5. Issue 1.6 (ground-water travel time, Section 8.3.5.12) calls for geochemical data relevant to determining the extent of the disturbed zone, specifically, data on silica mobilization as it affects permeability.
6. Issue 1.8 (NRC siting criteria, Section 8.3.5.17) calls for data on geochemical conditions and processes at the site for the evaluation of the presence or absence of the favorable and potentially adverse conditions and analysis of geochemical effects on subsystem/system performance.

CONSULTATION DRAFT

8313-1

Figure 8.3.1.3-1. Parameter calls and corresponding model from geochemistry test program.

7. Issue 1.9a (higher level findings--postclosure system and technical guidelines, Section 8.3.5.18) calls for geochemical data for making the higher level finding on the technical guideline on geochemistry.
8. Issue 1.10 (waste package characteristics--postclosure, Section 8.3.4.2) requests data on the vadose zone water chemistry to support the waste package design and testing programs.
9. Issue 1.11 (configuration of underground facilities--postclosure, Section 8.3.2.2) requests data on mineral stability to support testing to determine the stability of mined openings and the thermal response of the host rock.
10. Issue 1.12 (seal characteristics, Section 8.3.2.2) requests data on the vadose zone water chemistry to support the testing of ground water-seals materials interactions.

Table 8.3.1.3-1 shows the progression from performance and design issue needs for geochemical data to the parameters that define the testing program (activity parameters on Table 8.3.1.3-1). The left hand column shows the issues that require geochemical data. These issues are linked to appropriate common parameter categories. The common parameter category is chosen as a general subject area under which related parameters, including closely related performance parameters, can be grouped. The common parameter categories, in turn, are linked to activity parameters that represent the focus of the testing programs (given as the SCP sections) that address the data included in the common parameter categories. These activity parameters will become characterization parameters when test bases are finalized for them. As an example of the progression shown on Table 8.3.1.3-1, consider the requirement for radionuclide retardation factors (R_f s) for Issue 1.1. Sorption data for the unsaturated zone is included in the common parameter category called unsaturated zone geochemical properties. The program to supply the sorption data is built around laboratory testing of sorption as functions of the important variables, summarized as the activity parameters on Table 8.3.1.3-1. These activity parameters will become characterization parameters when test basis are developed to determine the testing goals and confidences needed to satisfy the performance parameter allocations.

The logic of the geochemistry program is described later. Justification is also provided for the secondary and supporting data that must be obtained to provide the necessary information to satisfy the requested data needed by the various performance or design issues.

Approach used to satisfy performance and design requirements

The bulk of the geochemical program has been developed in response to the needs of the total system performance assessments described in Issue 1.1. The calculations of the total site performance, as shown in Section 8.3.5.13, are based on equivalent porous media transport through the matrix with adsorptive retardation. The geochemistry test program must provide the sorption data as well as the supporting geochemical information required for the total system modeling approach used for Issue 1.1. A combination of laboratory experiments and modeling will be used by the geochemistry program to support the use of R_f s and the one-dimensional system model described in

Table 8.3.1.3 1. Activity parameters provided by the geochemistry program that support performance and design issues (page 1 of 5)

Calls by performance and design issues		Parameter category	Response by geochemistry characterization program	
Issue	SCP section		Activity parameter	SCP activity
1.1, Total system performance	8.3.5.13	Unsaturated zone geochemical properties (sorptive)	Sorption as a function of solid phase composition	8.3.1.3.4.1.1
			Sorption as a function of sorbing element concentration	8.3.1.3.4.1.2
			Sorption as a function of ground-water composition	8.3.1.3.4.1.3
			Sorption on particulates and colloids	8.3.1.3.4.1.4
			Statistical analysis of sorption data	8.3.1.3.4.1.5
			Biological sorption and transport	8.3.1.3.4.2
		Unsaturated zone geochemical properties (solubility of radionuclides)	Solubilities of compounds bearing radionuclides having significant representation in the inventory and half lives > 20 yr	8.3.1.3.5.1
		Saturated zone geochemical properties (sorptive)	Sorption as a function of solid phase composition	8.3.1.3.4.1.1
			Sorption as a function of sorbing element concentration	8.3.1.3.4.1.2
			Sorption as a function of ground-water composition	8.3.1.3.4.1.3
			Sorption on particulates and colloids	8.3.1.3.4.1.4

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 2 of 5)

Calls by performance and design issues		Parameter category	Response by geochemistry characterization program	
Issue	SCP section		Activity parameter	SCP activity
1.1, Total system performance (continued)	8.3.5.13	Saturated zone geochemical properties (sorptive) (continued)	Statistical analysis of sorption data	8.3.1.3.4.1.5
			Biological sorption and transport	8.3.1.3.4.2
		Saturated zone geochemical properties (diffusive)	Effective diffusivities for saturated tuff	8.3.1.3.6.2.1
		Saturated zone geochemical properties (solubility of radionuclides)	Solubilities of compounds bearing radionuclides having significant representation in the inventory and half lives > 20 yr	8.3.1.3.5.1
		Rock unit characteristics (mineralogy-petrology)	3-dimensional mineral distribution	8.3.1.3.2.1
		Fracture characteristics (mineralogy-petrology)	3 dimensional mineral distribution	8.3.1.3.2.1
		Fault characteristics (mineralogy petrology)	3-dimensional mineral distribution	8.3.1.3.2.1

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 3 of 5)

Calls by performance and design issues		Parameter category	Response by geochemistry characterization program	
Issue	SCP section		Activity parameter	SCP activity
1.1, Total system performance (continued)	8.3.5.13	Saturated zone hydrologic properties and conditions (transmissive)	Longitudinal diffusion, crushed tuff	8.3.1.3.6.1.2
			Major ion chemistry	8.3.1.2.1.3.5
			Dispersion characteristics for crushed tuff	8.3.1.3.6.1.1
		Saturated zone hydrologic properties and conditions (dispersive)	Hydrodynamic dispersion for solid rock column	8.3.1.3.6.1.2
			Heterogeneity, solid rock	8.3.1.3.6.1.2
			Hydrodynamic dispersion for fractured tuff	8.3.1.3.6.1.4
			Channeling--non-Fickian dispersion	8.3.1.3.6.1.4
		Unsaturated zone hydrologic properties and conditions (dispersion)	Permeability as a function of pressure (matrix potential)	8.3.1.3.6.1.3
			Matrix potential of the unsaturated tuff	8.3.1.3.6.1.3

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 4 of 5)

Calls by performance and design issues		Parameter category	Response by geochemistry characterization program	
Issue	SCP section		Activity parameter	SCP activity
1.1, Total system performance (continued)	8.3.5.13	Unsaturated zone hydrologic properties and conditions (fluid chemistry)	Major ion chemistry	8.3.1.2.2.4.2
1.2, Individual protection	8.3.5.14	Same as Issue 1.1	Same as Issue 1.1	
1.3, Ground-water protection	8.3.5.15	Same as Issue 1.1	Same as Issue 1.1	
1.6, Ground-water travel time	8.3.5.12	Rock unit characteristics (mineralogy-petrology)	Mineral stability	8.3.1.3.2.2.2
1.8, NRC siting criteria	8.3.5.17	Same as Issue 1.1	Same as Issue 1.1	
1.9, DOE siting guidelines	8.3.5.18	Same as Issue 1.1	Same as Issue 1.1	

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Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 5 of 5)

Calls by performance and design issues		Parameter category	Response by geochemistry characterization program	
Issue	SCP section		Activity parameter	SCP activity
1.10, Waste package characterization	8.3.4.2	Unsaturated zone hydrologic properties (fluid chemistry)	Major ion chemistry	8.3.1.2.2.4.2
		Rock unit characteristics (mineralogy-petrology)	Mineral stability	8.3.1.3.2.2.2
1.11, Repository design	8.3.2.2	Rock unit characteristics (mineralogy-petrology)	Mineral stability	8.3.1.3.2.2.2
1.12, Seal characteristics	8.3.3.2	Unsaturated zone hydrologic properties (fluid chemistry)	Major ion chemistry	8.3.1.2.2.4.2

Section 8.3.5.13. In addition to providing the requested data to the performance issues, the results of the geochemistry program must prove with reasonable assurance that

1. Sorption, expressed in terms of K_d , as a function of water composition, radionuclide concentration, and rock type is sufficient for meeting the performance objectives.
2. The sorptive phases will remain stable under the conditions expressed in Issue 1.1 for 10,000 years.
3. The ground-water composition is predictable over the time and conditions called for in Issue 1.1.
4. No "short circuit" of the sorptive barrier exists, i.e., transport by particulates, colloids, or by microbes.

Additionally, the program results must

1. Define the relative role of physical retardation processes such as dispersion and matrix diffusion.
2. Determine the solubility and speciation of radionuclides to support the K_d tests and analyses of transport when sorption is not considered.
3. Provide information for analysis of gaseous transport.

A summary logic diagram for the geochemistry program is given in Figure 8.3.1.3-2. The data generated by the investigations will be used to develop conceptual and numerical models on ground-water chemistry, mineral evolution, sorption, and a geochemical-geophysical model of Yucca Mountain. These models and their supporting data will provide the basis for the analyses just described, thus satisfying the performance and design requirements. Detailed logic diagrams for each investigation will be described in the following section.

The applicability of the data obtained in the laboratory investigations to total system performance will have to be established. The interactions and relative importance of the physical and chemical retardation processes is being evaluated in Investigation 8.3.1.3.7 (radionuclide retardation investigations). This investigation will identify the significant physical and chemical retardation processes that need to be included in the one-dimensional system performance model used in Section 8.3.5.13.

The applicability of extrapolating the laboratory data to field scale will also have to be established. The elements to be considered in developing the strategy for this are described in Study 8.3.1.3.7.2. The elements include scaling testing, field testing, conservative and reactive tracer testing in the C-wells, and natural analogs, where applicable.

The geochemical program will provide information on the geochemical processes defining potential changes in the near-field processes relevant to the definition of the disturbed zone. This information is important to

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Figure 8.3.1.3-2. Logic diagram for geochemistry program 8.3.1.3.

performance Issue 1.6 (ground-water travel time, specifically Information Need 1.6.5 (disturbed zone boundary)), and repository Design Issue 1.11 (configuration of underground facilities--postclosure), which must develop a predictive model assessing the stability of underground openings. Data on the vadose zone water chemistry will support the waste package design, testing, and modeling of engineered-barrier system release rates. The ground-water chemistry model will be a starting point for predicting the vadose zone water chemistry changes due to waste emplacement, and the conceptual model of mineral evolution will be the basis for the analysis of future mineral stability. Finally, the basic characterization data on geochemical conditions and processes that support the system and subsystem performance Issues 1.1, 1.2, 1.3, and 1.5 are also used to support performance Issues 1.8 and 1.9.

Interrelationships of the geochemical investigations

Eight investigations are included in the geochemical characterization program. These investigations are summarized in the following paragraphs, and logic diagrams are given for each investigation. Information will be passed between these investigations; this is indicated on the logic diagrams by the "other investigations" box.

Investigation 8.3.1.3.1 (Figure 8.3.1.3-3) addresses water chemistry within the potential emplacement horizon and along potential flow paths to the accessible environment. Performance Issue 1.5 (engineered barrier system release rates, Section 8.3.5.10) and design Issues 1.10 (waste package characteristics, Section 8.3.4.2) and 1.11 (configuration of underground facilities, Section 8.3.2.2) require that the unsaturated zone water chemistry be well known. The design requirements include a certain tolerance for ground-water composition changes. If the variation in concentration of certain aqueous species (i.e., Cl and F) in the unsaturated zone is outside the constraints of the waste package design then the design may have to be adjusted. Issue 1.5 also uses the ground-water composition constraints to assess performance of the engineered barrier system, including the waste form and container. However, once the present ground-water composition is well defined and the design is set, the performance issue would have to use a ground-water chemistry model to assess ground-water or vadose zone chemistry changes and the effects of the changes on the performance of the waste package.

Investigation 8.3.1.3.1 will use the ground-water chemistry data already available and to be obtained in Activities 8.3.1.2.1.3.5 and 8.3.1.2.3.2.2 (saturated zone) and data from the ground-water chemistry activities in Activity 8.3.1.2.2.8.2 (unsaturated zone). These data will be incorporated into the conceptual-predictive ground-water chemistry model. This model will explain the present ground-water chemistry, the composition defined by the interactions of the ground water with minerals in the rock. This model will then be able to predict future variations in ground-water chemistry given a thermal component introduced by waste emplacement or an increase in flux through the unsaturated zone induced by climatic changes. These predictions are important to Issue 1.5, which must assess the engineered barrier system performance. Furthermore, the future ground-water chemistry is important in defining the sorption and solubility studies supporting Issues 1.1 to 1.3.

Figure 8.3.1.3-3. Logic diagram for Investigation 8.3.1.3.1 (ground-water chemistry along flow paths to the accessible environment).

Investigation 8.3.1.3.2 (Figure 8.3.1.3-4) addresses mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths to the accessible environment. This investigation addresses two major questions: (1) how are the mineral distributions at Yucca Mountain going to affect radionuclide retardation by sorption and (2) what processes account for the minerals found at Yucca Mountain and are the processes still operating and likely to alter the mineralogy in the next 10,000 yr enough to alter sorption behavior at the site. This investigation will provide the descriptive baseline for mineralogy-petrology data for other investigations in this program and for the performance and design issues. To answer the questions, a three-dimensional distribution of minerals will be developed that will aid in determining the mineral controls on sorption and will include a description of the fracture mineralogy along potential flow paths. This investigation will also provide the data necessary to understand past mineral alteration. All these data are important for determining the impact of repository development on the host rock, the extent of the disturbed zone, and the potential geochemical changes beyond the disturbed zone.

Issue 1.1 (Section 8.3.5.13) is relying on mineralogically based stratigraphic units at Yucca Mountain (i.e., vitric and zeolitic) for waste isolation. Therefore, the mineralogy, petrology, and rock chemistry must be well known for the stratigraphic units along flow paths to the accessible environment. This investigation also ties to other investigations in this program such as Investigations 8.3.1.3.4 (sorption) and 8.3.1.3.6 (dynamic transport).

Investigation 8.3.1.3.3 (Figure 8.3.1.3-5) addresses the stability of minerals and glasses. Issue 1.1 requires distribution coefficients for all units in the saturated and unsaturated units below the repository in the controlled zone. Therefore, it is important that the stability of the sorptive minerals in these units be investigated to determine if long-term heating from waste emplacement could alter the sorptive minerals. The waste package and engineered barrier system design (Issues 1.10 and 1.11, Sections 8.3.4.2 and 8.3.2.2) will also need mineral stability information so that impacts on sorptive minerals can be assessed. The conceptual model will support this design need and also support the definition of the disturbed zone (Issue 1.6, Section 8.3.5.12).

A conceptual model of mineral and glass evolution at Yucca Mountain is needed to predict future mineral evolution by natural processes and repository induced thermal loading. This investigation is designed to develop such a conceptual model. Natural analog environments will be studied to better understand the origin of altered minerals at Yucca Mountain and improve the predictive capabilities of geochemical modeling codes. Other studies include obtaining data on the kinetics of glass and silica polymorph transitions and their relationship to aqueous silica activity, which influences zeolite stability. Thermodynamic data on stable and metastable mineral assemblages, specifically the zeolite analcime, and albite will also be obtained. These studies are the experimental basis for determining the overall mineral stability at Yucca Mountain.

Investigation 8.3.1.3.4 (Figure 8.3.1.3-6) addresses radionuclide retardation by sorption processes along flow paths to the accessible environment. Sorption in the far field (beyond the disturbed zone) at Yucca Mountain will

Figure 8.3.1.3-4. Logic diagram for Investigation 8.3.1.3.2 (mineralogy, petrology, and rock chemistry along flow paths to the accessible environment).

Figure 8.3.1.3-5. Logic diagram for Investigation 8.3.1.3.3 (stability of minerals and glasses).

Figure 8.3.1.3-6. Logic diagram for Investigation 8.3.1.3.4 (radionuclide retardation by sorption processes along flow paths to the accessible environment).

be studied in the investigation. Performance Issue 1.1 (Section 8.3.5.13) has called for retardation factors for each species known to be chemically sorbing and for each rock unit in the saturated and unsaturated zone in the controlled area under the range of water and rock chemical conditions expected for each unit. Laboratory data will be collected on sorptive behavior, and a sorption model will contribute to the understanding of the expected behavior in the site system. Contours of iso- K_d s for each sorbing species (zones of equal average sorption behavior) and isobetas (zones of equal sorption heterogeneity) may be developed as part of the modeling task. The K_d s give a measure of the average retardation of radionuclides and the betas when derived from the modified Freundlich isotherm give a measure of sorption heterogeneity. The parameter beta has been described as a measure of how sharply peaked the statistical function for the distribution of energies is about an average value or as the spread of the statistical function for the distribution of adsorption-desorption rate constants.

Because numerous variables can affect sorption, the potentially very large amount of laboratory testing must be constrained by experiments designed to identify significant system variables and quantify their effect on radionuclide transport. The radionuclides of primary concern are identified in Section 4.1.3.1.1 as the key radionuclides, based on waste inventories and projected chemical behavior of the system. Issue 1.1 has required information on specific radionuclides: strontium, cesium, plutonium, americium, carbon, uranium, neptunium, technetium, zirconium, iodine, and curium. The radionuclides of strontium and cesium have been investigated and are well understood (Chapter 4); therefore, actinide sorption will be emphasized in laboratory experiments because of the complexity of actinide aqueous chemistry, sorptive behavior, and waste inventories. Of lesser importance for sorption studies are radionuclides expected to be in a poorly sorbable anionic form such as carbon-14 or technetium-99. Sorptive behavior will be determined as a function of mineral composition. Sorption will also be studied as a function of the sorbing element concentrations (isotherms). Further scoping will be done by considering the ground-water composition and expected radionuclide concentrations. Preliminary testing will also help define future testing needs; thus, radionuclides showing consistently high sorption coefficients in initial testing may not need extensive testing. A part of this investigation will also include study of microbial effects on radionuclide sorption and transport. Another independent activity is the study of radionuclide sorption on particulates and colloids.

Investigation 8.3.1.3.5 (Figure 8.3.1.3-7) addresses radionuclide retardation by precipitation along flow paths to the accessible environment. This investigation will produce results that will supply limits on the concentration of dissolved waste elements and limits on natural colloid concentration that might occur under expected conditions.

Issue 1.1 (Section 8.3.5.13) has identified the need for the determination of solubility limits of chemical species associated with the i^{th} radionuclide (i.e., mean and variance) for the range of expected water-and-rock chemical conditions. Furthermore, information is required on the precipitate that forms when the solute exceeds its solubility. Issue 1.1 will use the solubility and precipitation data as possible input to, and support for, the system performance model for radionuclide transport.

Figure 8.3.1.3-7. Logic diagram for Investigation 8.3.1.3.5 (radionuclide retardation by precipitation processes along flow paths to the accessible environment).

This study is organized to define and implement experiments to measure the solubility of important waste elements. Geochemical modeling codes, EQ 3/6, will be used to assess the sensitivity of several parameters that might control solubility. The results of the solubility measurements and the modeling will be used to define speciation experiments, if needed. Colloid formation as well as characterization and stability are other aspects of this investigation that will be studied as additional data necessary to understand the potential for transport of a precipitate through tuff. Colloid formation and transport are important because it is a possible mechanism for bypassing the sorptive barrier. These data are also required by Investigation 8.3.1.3.6 where the determination of the actual transport potential of colloids, precipitates, and particulates will be determined.

Investigation 8.3.1.3.6 (Figure 8.3.1.3-8) addresses radionuclide retardation by dispersive, diffusive, and advective transport processes along the flow paths to the accessible environment. This investigation will determine experimentally the rate of movement and effective retardation of radionuclides by dispersive, diffusive, and advective processes. Specifically, Issue 1.1 requires experimental evidence that could confirm or deny the theory of advective-diffusive coupling of solute concentrations in matrix and fracture flows that is currently embodied in the transport model of TOSPAC. Issue 1.1 states that this information is crucial in establishing the credibility of transport phenomenology embodied in any models used to assess the consequences of the release scenarios associated with the water pathways. Investigation 8.3.1.3.6 will provide to the total system performance the effective diffusivity of species in the matrix of each rock unit in the saturated and unsaturated zones. The parameter called for by total system performance is an empirical parameter measuring the effective diffusivity of the fracture matrix interface (constrictivity-tortuosity factor) for the saturated and unsaturated zone. This investigation will also provide information on the transport of colloids, the validation of the use of the batch distribution coefficients by total system performance in an advective system and validation of the use of data produced in saturated systems for application to an unsaturated system.

Investigation 8.3.1.3.6 is divided into the diffusion study and the dynamic transport column study. The diffusion study will investigate matrix diffusion in a nonadvective system and the dynamic transport column study will investigate matrix diffusion and other processes in an advective system. The column study includes five activities that use an advective (tuff column) system: (1) crushed tuff column tests, (2) mass transfer kinetics, (3) unsaturated tuff column tests, (4) fractured tuff column tests, and (5) filtration tests. All these activities essentially measure the breakthrough or elution curve for tracers through tuff columns. The elution curve can be characterized by the time of arrival and the broadness or dispersion of the curve. These two properties depend on several process parameters such as distribution coefficients, speciation, colloids, kinetics, matrix diffusion, longitudinal diffusion, hydrodynamic dispersion, channeling, and heterogeneity. This investigation will elucidate these coupled processes so that the information needs of Issue 1.1 (Section 8.3.5.13) can be resolved. The technical rationale section of Investigation 8.3.1.3.6 and the discussion of each study and activity within the investigation will develop further the dynamic transport testing strategy to quantify the variables operating in the five testing activities.

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Figure 8.3.1.3-8. Logic diagram for Investigation 8.3.1.3.6 (radionuclide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment).

Investigation 8.3.1.3.7 (Figure 8.3.1.3-9) addresses radionuclide retardation by all processes along flow paths to the accessible environment, and the question of establishing that laboratory data can be reliably extrapolated to field conditions. The modeling portion of this investigation will use a three-dimensional transport model and other multidimensional process codes to determine, characterize, and quantify the cumulative effects of all significant processes, physical and geochemical, acting on or controlling radionuclide transport at Yucca Mountain. This will support Issue 1.1 by validating the simplifying assumptions and identifying the processes that can be ignored in the system performance assessments. The integrated transport calculations will use the geochemical information obtained from all the investigations under this geochemistry program and other specific geophysical data needed to do complete calculations. The results of this investigation will provide support and give confidence to the systems performance calculations of performance Issue 1.1. Issue 1.1 requires calculational models of radionuclide transport in the unsaturated and saturated zone that are capable of representing the effects of flow in at least two dimensions on the transport of dissolved, reactive solutes and of testing the theory embodied in the one-dimensional systems-level model used by the performance issue.

The geochemistry program will use investigations, specifically, Study 8.3.1.3.7.1 (retardation sensitivity analysis) to evaluate, synthesize, and integrate the geochemistry site and experimental data. This does not preclude the understanding that performance and design may obtain characterization data directly from a particular study or activity of other geochemistry investigations, but rather the integration done by this investigation will show coupled effects that may not be evident if the geochemical or physical process data are used separately.

The retardation sensitivity study (8.3.1.3.7.1) will interface with the sorption and transport investigations and provide input into the design and interpretation of the experimental work. Study 8.3.1.3.7.2 outlines the strategy that will be used to demonstrate that the results of this program are applicable to the calculations for total system performance.

Investigation 8.3.1.3.8 (Figure 8.3.1.3-10) addresses retardation of gaseous radionuclide along the flow paths to the accessible environment. This investigation outlines the scientific plan that may be needed if Issue 1.1 (Information Needs 8.3.5.13.1, 8.3.5.13.4, and 8.3.5.13.5) indicates that gaseous transport of radionuclides should be investigated. Preliminary calculations of the rates of transport of gaseous radionuclide species will be done. A calculational model will be used to calculate transport and possibly identify the potential retardation mechanism. An experimental program will be used to verify the calculational results if needed.

Issue 1.1 requires a model calibration and validation of gas-phase carbon-14 transport in the overburden of the unsaturated zone units. The results of Investigation 8.3.1.3.8, if needed, will be useful to Issue 1.1. Gaseous radionuclide transport also will have to be considered for the evaluation of radionuclide releases to the environment for 100,000 yr after repository closure (10 CFR 960.3-1-5, Section 8.3.5.18).

The schedule information provided for investigations in this section includes the sequencing, interrelationships, and relative durations of the

Figure 8.3.1.3-9. Logic for diagram for Investigation 8.3.1.3.7 (radionuclide retardation by all processes along flow paths to the accessible environment).

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Figure 8.3.1.3-10. Logic diagram for Investigation 8.3.1.3.8 (radionuclide retardation by gaseous transport processes along flow paths to the accessible environment).

studies in the investigation. Specific durations and start/finish dates for the studies are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.1.3.1 Investigation: Studies to provide information on water chemistry within the potential emplacement horizon and along potential flow paths

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

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

<u>SCP section</u>	<u>Subject</u>
4.1.2	Ground-water chemistry
4.1.2.1	General description of the hydrochemistry
4.1.2.6	Background radioactivity
4.1.2.7	Particulates and colloids
4.1.2.9	Mineralogical controls on water composition
7.4.1.7	Rock-water interactions
7.4.1.1	Stability of borehole openings
7.4.1.3	Reference water for experimental studies

Parameters

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

1. Saturated and unsaturated zone ground-water chemistry.
2. Ground-water chemistry model development.

Purpose and objectives of the investigation

The goal of this investigation is to provide a conceptual model of the ground-water chemistry at Yucca Mountain that would (1) explain the present ground-water composition as a result of interactions of the ground water with minerals along potential flow paths, and (2) would be able to predict future variations in ground-water chemistry under anticipated and unanticipated conditions, as required by Issue 1.1 (Section 8.3.5.13), that would alter radionuclide flux through the saturated and unsaturated zone. These changes could only be significant if the geochemical retardation (sorption) were affected. Investigation 8.3.1.3.7 will investigate this sensitivity.

Issues 1.5, 1.10 and 1.11 (Sections 8.3.5.10, 8.3.4.2, and 8.3.2.2, respectively) also require that the ground-water chemistry surrounding the waste package and engineered barrier system be understood so that the design and performance of these system components of the repository can be assessed.

Furthermore, other investigations within this test program require the conceptual model of ground-water chemistry, namely, Investigations 8.3.1.3.3 (stability of minerals and glasses) and 8.3.1.3.4 (sorption) and Study 8.3.1.3.7.1 (retardation sensitivity analysis).

The ground-water composition at Yucca Mountain and the surrounding area has been determined for the saturated zone (Chapter 4). Saturated zone studies will continue but, more importantly, the unsaturated zone ground-water compositions must be obtained. The unsaturated zone ground-water compositions are necessary for determining waste element speciation, solubility, and source term concentrations because the unsaturated zone ground-water compositions will partially define the starting conditions and rates of corrosion of the canister, and dissolution of the waste form. Furthermore, the water compositions are needed to determine the overall retardation of waste elements (Investigations 8.3.1.3.4 (radionuclide sorption) and 8.3.1.3.7 (radionuclide retardation investigations)) from the repository to the accessible environment under expected and unexpected conditions.

A necessary prerequisite for understanding the overall retardation of radionuclides is the development of a ground-water chemistry model. This model must use the ground-water chemistry data, include the processes that control ground-water compositions, and determine their relative importance. The relative importance of the processes controlling ground-water composition will be useful for understanding the present variations in the ground-water compositions and predicting future variations.

Technical rationale for the investigation

The rationale for this investigation is to develop an understanding of the processes controlling the natural variability in ground water, and use this understanding to predict present and future variations. Mineral stability studies, mineralogy-petrology studies, and input from the climate and tectonics programs on rates and magnitudes of future processes and events will serve as the basis for establishing the ground-water chemistry conceptual model.

8.3.1.3.1.1 Study: Ground-water chemistry model

Objectives

The goal of this study is to develop a conceptual model that will aid in predicting current and future variations in ground-water composition in the unsaturated zone in Yucca Mountain and in the saturated zone between the disturbed zone and the accessible environment. This conceptual model will be used to provide information requested by Information Need 1.1.1 (Section 8.3.5.13.1) in its total systems performance model calculations and by Issue 1.5 (engineered-barrier system release rates, Section 8.3.5.10). The latter must assess the waste package design by determining the significance of a potential change in the ground-water compositions in the waste package environment. If significant, this change could compromise the waste package. Investigation 8.3.1.3.3 (stability of minerals and glasses at the site) will

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integrate with this study through Study 8.3.1.3.3.1 (natural analogs) and the conceptual model of mineral evolution (Study 8.3.1.3.3.4) to further improve the ground-water model.

Parameters

The data needed are as follows:

1. Processes that control ground-water composition and their relative importance.
 - a. Mineral stability (Investigation 8.3.1.3.3).
 - b. Natural analogs (Investigation 8.3.1.3.3).
2. Mineralogy and petrology (Investigation 8.3.1.3.2).
3. Spatial distributions of thermal and mechanical properties (Investigation 8.3.1.4.2).
4. Saturated zone ground-water compositions.
5. Unsaturated zone ground-water composition.
6. Range of future climatic conditions (Investigation 8.3.1.5.1).
7. Rates and magnitudes of potential igneous activity (Investigation 8.3.1.8.1).

The data obtained are as follows:

1. Analysis. Predictions of future variations in ground-water compositions between the repository and the accessible environment.
2. Models. Ground-water chemistry model.

Description

Prior work defining the dissolved chemical constituents of water in the underlying saturated zone between the repository and the accessible environment provides sufficient data for assessments of potential radionuclide transport, as discussed in Chapter 4 of this document. These data include major, minor, and trace element concentrations, pH and Eh, and the concentration of dissolved gases. A current report (Kerrisk, 1987) summarizes and evaluates the most recent information on the saturated zone ground-water chemistry at Yucca Mountain and the surrounding area. No further work on the characterization of the saturated zone water chemistry is planned in this investigation; however, Study 8.3.1.2.3.2 will continue characterizing and evaluating the saturated zone ground-water chemistries on both a regional and site scale in order to understand the physical nature of the ground-water flow system. Particulates may need to be collected from the saturated water if Investigation 8.3.1.3.4 requires the material for the sorption tests.

Limited data on the unsaturated zone water chemistry are available. The activities involving the characterization and evaluation of the unsaturated

zone ground-water chemistry are found in Activity 8.3.1.2.2.8.2 (aqueous phase chemical investigation of the unsaturated zone). Data will also be obtained from Activity 8.3.1.2.2.4.8 (exploratory-shaft facility and investigations--hydrochemistry tests in the exploratory shaft). Under these activities, water chemistry data will be obtained primarily to determine apparent ages of gas and water in the unsaturated zone and investigate the extent of water-rock interactions. Furthermore, under Activity 1.10.4.1.3 (Section 8.3.4.2.4.13), the unsaturated zone ground water will also be characterized to predict the chemical composition of the water near the waste package.

The conceptual model development will involve compiling the data described previously on the unsaturated and saturated zone water chemistries. As was discussed previously, data from Investigations 8.3.1.2.2, 8.3.1.2.3, and Section 8.3.4.2.4 will be used. Data on mineralogy and petrology (Investigation 8.3.1.3.2), stability of minerals and glasses (Investigation 8.3.1.3.3), spatial distributions of thermal and mechanical properties (Investigation 8.3.1.4.2), natural analogs (Investigation 8.3.1.3.3), the range of future climatic conditions (Investigation 8.3.1.5.1), and the rates and magnitudes of potential igneous activity (Investigation 8.3.1.8.1) will also be used in the ground-water chemistry model.

To aid the modeling task, a statistical analysis of the presently available saturated zone ground-water chemistry data may be conducted. This statistical effort using standard methods may help determine the areal distribution of unsaturated zone samples (locations) and how much data are needed to successfully model the current variations in ground-water composition.

All of the computer codes that may be used to model the current ground-water chemistry and predict future variation in that chemistry have yet to be identified; however the computer code EQ 3/6 will be one code used by the conceptual model.

8.3.1.3.1.2 Application of results

The information derived from the studies and activities described in the previous section will be used in the following issues, investigations, and information needs:

<u>Issue, investigation, or information need</u>	<u>Subject</u>
8.3.1.3.3	Stability of minerals and glasses
8.3.1.3.4	Radionuclide retardation by sorption processes along flow paths to the accessible environment
8.3.1.3.5	Radionuclide retardation by precipitation processes along flow paths to the accessible environment

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Issue,
investigation, or
information need

Subject

8.3.1.3.6	Radionuclide retardation by dispersive/diffusive/ad- vective transport processes along flow paths to the accessible environment
8.3.1.3.7	Radionuclide retardation by all processes along flow paths to the accessible environment
1.8	NRC Siting Criteria (Section 8.3.5.17)
1.5.3	Scenarios and models to predict release from the waste package and engineered barrier system (Section 8.3.5.10.3)
1.1.1	Site information needed to calculate releases to the accessible environment (Section 8.3.5.13.1)
1.1.4	Determination of radionuclide releases to the accessible environment associated with realizations of potentially significant release scenario classes (Section 8.3.5.13.4)

8.3.1.3.1.3 Schedule and milestones

This investigation contains one study: 8.3.1.3.1.1 (ground-water chemistry model). In the figure that follows, the schedule information for this study is presented in the form of a timeline. The timeline extends from implementation of the approved study plan to the issuance of final products associated with the study. Summary schedule information for this investigation can be found in Section 8.5.1.1.

This study, which will produce a ground-water model is constrained by Activities 8.3.1.2.2.4.2 and 8.3.1.2.2.2.2, which must characterize the unsaturated zone water. These activities are constrained by the start of the exploratory shaft, the drilling schedule, and by the technical consideration in extracting water samples from unsaturated tuff. Studies on waste package performance, mineral stability, and total system performance can be conducted in parallel with this investigation. This study currently has no ongoing work.

The study number and title corresponding to the timeline are shown on the left of the following figure. Points shown on the timeline represent major events or important milestones associated with the study. Solid lines represent study durations and dashed lines represent interfaces.

The points on the timeline are described in the following table.

<u>Point number</u>	<u>Description</u>
1	Milestone R486. Modeling results available for variations in pore and ground-water compositions.
2	Milestone M374. Final report available on ground-water chemistry model. This model must be complete before the final development of the conceptual model of mineral evolution (Study 8.3.1.3.3.3). This model, which completes this study, will be available for incorporation into the system performance contribution to the draft environmental impact statement.
3	Milestone Q001. Report available on the summary results defining the geochemical characteristics (mineralogy-petrology, mineral stability, and water chemistry) at Yucca Mountain. This is a higher-level report that summarizes the results of Investigations 8.3.1.3.1, 8.3.1.3.2, and 8.3.1.3.3 and will be compiled as part of Study 8.3.1.3.2.1.

8.3.1.3.2 Investigation: Studies to provide information on mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

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

<u>SCP section</u>	<u>Subject</u>
4.1.1.2	Analytical techniques

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<u>SCP section</u>	<u>Subject</u>
4.1.1.3.1	The potential host rock
4.1.1.3.2	Surrounding units
4.1.1.4	Mineral stability
4.2.2.1	Hydrothermal alteration of zeolites
4.2.2.2	Hydrothermal alteration of smectites
4.2.2.3	Hydrothermal alteration of rhyolite glasses
4.4.2	Potential effects of natural changes

Parameters

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

1. Mineral distributions in bulk rock.
2. Mineral distributions in fractures.
3. Bulk rock chemistry.
4. Chemistry of fracture deposits.
5. Mineral origins and alteration history.
6. Data on dehydration of smectites, zeolites, and glasses.

The following parameters are needed to satisfy this investigation:

1. Hydrologic conditions.
2. Geometry of the flow paths.

Purpose and objectives of the investigation

This investigation will provide the baseline set of data and understanding of the natural environment in which geochemical and other processes interact. Two studies are proposed and designed to provide the data needed as represented by the parameters just listed. The first study will provide a three-dimensional distribution of mineral types, rock and mineral compositions, and mineral abundances within the potential host rock and along potential flow paths to the accessible environment. The second study will determine the history of mineralogic and geochemical alteration at Yucca Mountain.

The three-dimensional distribution of mineral types and abundances at Yucca Mountain must be known to use the data on mineralogic controls of sorption (Investigation 8.3.1.3.4) for transport calculations. Investigation 8.3.1.3.7 will use this information in integrated transport calculations and sensitivity analyses, and Issue 1.1 (Section 8.3.5.13) will evaluate this work to assess the contribution of geochemical retardation along flow paths in the total system performance calculations.

The purposes of second study (history of alteration) are the following:

1. Determination of the impact of repository development on the host rock, which requires the following information:
 - a. Host rock mineralogic and chemical variability and internal stratigraphy for Investigation 8.3.1.4.2.
 - b. Evaluation of any hazardous mineral occurrences (fibrous zeolites) in the intervals to be mined for Information Need 4.2.1 (Section 8.3.2.4.1).
 - c. Evaluation of any past evidence for rock dissolution for Program 8.3.1.7.
2. Definition of the disturbed zone (Information Need 1.6.5, Section 8.3.5.12.5), which requires the following information:
 - a. Studies of the amounts and types of mineralogic responses to elevated temperatures in the past; these data will also help to address Information Need 1.11.6 (Section 8.3.2.2.6).
 - b. Quantitative analysis of sorptive mineral distributions in the potential repository horizon and on the surrounding rocks for evaluation of mineral stability.
3. Projecting the geochemical changes beyond the disturbed zone throughout the life of the repository for Issue 1.1 (Section 8.3.5.13), which requires the following information:
 - a. The assessment of past hydrothermal alteration in terms of timing and temperature.
 - b. The assessment of past hydrothermal alteration in terms of analogous changes that may be anticipated due to repository emplacement.
 - c. The evaluation of mineral and glass assemblages (stable and metastable) present at Yucca Mountain as a baseline for comparing accelerated or deviant geochemical changes anticipated around a repository.

Technical rationale for the investigation

The three-dimensional mineral work already completed shows that there may be large differences between minerals that occur in the bulk rock and minerals that occur along fractures. Since hydrologic conditions affect the extent to which matrix and fracture lining minerals are exposed to radionuclides by the ground water, it will be necessary to obtain data on hydrologic properties (Investigations 8.3.1.2.2 and 8.3.1.2.3) when considering sorptive mineralogy for performance assessment. The final application of these data will also depend on the geometry of flow paths from the disturbed zone to the accessible environment (Information Need 1.6.3, Section 8.3.5.12.3).

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The history of alteration study will investigate what processes account for the minerals found at Yucca Mountain, whether those processes have been completed or are still operating, and the impact of projected processes on the potential repository at Yucca Mountain. The geochemical history of Yucca Mountain can be studied from the minerals present, where conditions and times of formation can be obtained. These data will be used in three different contexts at Yucca Mountain: (1) to estimate the impact of repository development on the host rock, (2) to assist in determining the extent of the disturbed zone, and (3) to estimate the rates and directions of geochemical changes beyond the disturbed zone throughout the life of the repository. Each of these three contexts are related to the several specific performance and design activities listed in the previous section.

There are two studies under this investigation: (1) the study of three-dimensional mineral distributions at Yucca Mountain (three activities) and (2) the study of geochemical processes at Yucca Mountain inferred from mineralogy (two activities). These studies have relevant surface-based and exploratory shaft tests.

8.3.1.3.2.1 Study: Mineralogy, petrology, and chemistry of transport pathways

The goals of this study are (1) to determine the three-dimensional distribution of mineral types, compositions, abundances, and petrographic textures within the potential host rock, and (2) to determine the three-dimensional distribution of mineral types, composition, and abundances in rocks beyond the host rock that provide pathways to the accessible environments. This study will provide input into the assessment of retardation by sorption (Investigations 8.3.1.3.4 and 8.3.1.3.7), the geologic framework of Yucca Mountain (Investigation 8.3.1.4.2), and the definition of the disturbed zone (Information Need 1.6.5, Section 8.3.5.12.5). The analysis of mineral types, abundances and distributions beneath Yucca Mountain is required by each of these information needs and investigations. There are three activities within this study.

8.3.1.3.2.1.1 Activity: Petrologic stratigraphy of the Topopah Spring Member

Objectives

The goal of this activity is to determine the petrologic variability within the devitrified Topopah Spring Member at Yucca Mountain and to define the stratigraphic distribution of variability.

Parameters

The data needed are as follows:

1. Geophysical logs of cored holes made through the Topopah Spring Member.

2. Descriptions of the Topopah Spring Member from core samples, from outcrop, and from the exploratory shaft.

The data gathered are as follows:

1. Modal distributions of phenocrysts and textural features in the devitrified Topopah Spring Member.
2. Quantitative x-ray diffraction (XRD) studies of the devitrified Topopah Spring Member.
3. Chemical analyses of the devitrified Topopah Spring Member.
4. Statistical interpretations of these data.

Description

Studies of the distribution of phenocrysts and rock matrix textures in this member have been shown to be useful for defining stratigraphic position within the devitrified Topopah Spring Member (Byers, 1985; Byers and Moore, 1987). Matrix textures apparently account for some of the variation in thermomechanical properties within the Topopah Spring Member (Price et al., 1985; Blacic et al., 1986). Preliminary studies using quantitative XRD data show that mineral abundances in drill core samples, particularly the distributions of silica phases, vary systematically with stratigraphic depths within the devitrified portion of the Topopah Spring Member. Chemical data for the Topopah Spring Member show little variability within the devitrified portion below the quartz-lattice caprock. However, the available chemical analyses are limited, particularly in the distribution and abundance of trace elements.

This investigation has so far used data only from the cored holes at Yucca Mountain (drillholes USW G-1, USW G-2, USW GU-3, USW G-4, and UE-25a#1). Future cored holes will also be used. Current data collected are derived from samples collected approximately every 20 m along each drill core. Samples also reflect collection sequences that closely bracketed major stratigraphic contacts, and correspond with anomalies in the drillhole geophysical logs. Sample density will be at least as frequent in future drill cores; however, the sample density may be subject to change depending on statistical requirements.

A plan to develop an integrated drilling program for acquisition of site-specific subsurface information is being developed and is described in Investigation 8.3.1.4.1. Sampling requirements for this investigation will be integrated with the drilling program. Of particular importance will be the study of samples from the exploratory shaft and from the drifts mined away from the shaft, where larger samples with well-constrained stratigraphic relations can be obtained and where lateral variability within the host rock horizon will be assessed.

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Methods and technical procedures

The methods used for Activity 8.3.1.3.2.1.1 are modal petrography, quantitative x-ray diffraction (XRD), x-ray fluorescence analyses, and electron microprobe analysis, which are summarized in the following table.

Method	Number	Technical procedure	
		Title	Date
Modal petrography	TWS-ESS-DP-03, R2	Nevada Test Site core petrography procedure	24 Nov 82
Quantitative x-ray diffraction	TWS-ESS-DP-16, R2	Siemens x-ray diffraction procedure	19 May 86
X-ray fluorescence analysis	TBD ^a	X-ray fluorescence procedure	TBD
Electron microprobe analysis	TWS-ESS-DP -07, R2	Microprobe operating procedure	5 Sep 86

^aTBD = to be determined.

8.3.1.3.2.1.2 Activity: Mineral distributions between the host rock and the accessible environment

Objectives

Using the data provided as site characterization progresses, this activity will attempt to determine the three-dimensional distribution chemistry and the total abundance of all major rock-matrix minerals, between the host rock and the accessible environment. The analysis of the three-dimensional stratigraphy will be most heavily weighted toward those units that will first be encountered along potential flow paths away from the repository (i.e., Calico Hills) as identified by Issue 1.1 (Section 8.3.5.13).

Parameters

The data needed are as follows:

1. Determination of probable flow paths between the host rock and the accessible environment.

The data gathered are as follows:

1. Quantitative x-ray diffraction (XRD) data studies of samples from deep drillholes within and around the repository block.
2. Special XRD studies (e.g., study of glycolated clay-mineral separations).
3. Statistical interpretation of these data.

Description

This activity will provide a three-dimensional model for the distributions and abundances of all major minerals and of the chemistry of these minerals and their host rocks that occur beneath Yucca Mountain, for potential flow paths between the repository and the accessible environment. Statistical evaluation of this model, such as analysis to estimate natural variability, to extrapolate between boreholes, and to determine sample density in boreholes, will be an important part of the activity. This analysis is currently coupled to the functional stratigraphy put forth by Sandia National Laboratories; and a variety of approaches including kriging will be tested. The basic data for the activity are provided from cored and drilled holes within the boundaries of the accessible environment at Yucca Mountain. These data consist of quantitative XRD determinations of mineral abundances, x-ray fluorescence (XRF) determinations of major and trace element abundances in bulk rocks, and electron microprobe analyses of mineral compositions. An ongoing part of this activity is the reevaluation and reanalysis of XRD patterns already collected and stored, as the precision and accuracy of quantitative XRD methods is improved. The current XRD data are derived from samples collected approximately every 20 m along each drill core. Samples are also collected to closely bracket major contacts. Sample density will be comparable in future drill cores. However, sample density is subject to change depending on statistical requirements. These data will ultimately be used in Investigation 8.3.1.3.4 (sorption) and as support to the performance and design issues. However, the variability of mineral paragenesis with depth and the variations in mineral structures (e.g., smectite-illite intergrowths) are important in determining the history of alteration at Yucca Mountain (see Activity 8.3.1.3.2.2.1).

Methods and technical procedures

The methods used for Activity 8.3.1.3.2.1.2 are x-ray diffraction (XRD) and XRD analysis of clay-mineral separates, x-ray fluorescence, and electron microprobe analysis, which are summarized in the following table.

Method	Number	Technical procedure	
		Title	Date
X-ray diffraction	TWS-ESS-DP-16, R2	Siemens x-ray diffraction procedure	19 May 86

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Method	Technical procedure		Date
	Number	Title	
X-ray diffraction analysis of clay-mineral separation	TWS-ESS-DP-25, R1	Clay-mineral separation and preparation for x-ray diffraction analysis	3 Apr 86
X-ray fluorescence analysis	TBD ^a	X-ray fluorescence procedure	TBD
Electron microprobe analysis	TWS-ESS-DP-07, R2	Microprobe operating procedure	5 Sep 86

^aTBD = to be determined.

8.3.1.3.2.1.3 Activity: Fracture mineralogy

Objectives

The objective of this activity is to determine the distributions of minerals within fractures at Yucca Mountain, within all significant rock masses that might provide transport pathways with some component of fracture flow.

Parameters

The data needed are as follows:

1. Model of unsaturated zone hydrologic flow.
2. Model of saturated zone hydrologic flow.

The data gathered are as follows:

1. Distribution and identity of mineral species.
2. Petrographic and chemical characteristics of fracture fillings.

Description

The minerals that occur in fractures can be very different from those that occur in the adjacent rock matrix. This difference can have important consequences for retardation by sorption (Investigation 8.3.1.3.4), particularly in situations where fracture flow becomes significant. Some potentially important sorptive minerals occur only in fractures of stratigraphic horizons where they are otherwise absent (e.g., mordenite in devitrified tuffs). Manganese minerals in fractures have potential impact as sorptive phases, and the types and distributions of manganese minerals will be determined. Hydrous minerals, including zeolites and opal, may occur in fractures

that cross the potential repository horizon; water contents and thermal evolution of water from these minerals will be determined. Fracture samples have been collected from drill cores and will be collected from future drill cores at a density of about one every 5 m and from the exploratory shaft and its lateral drifts at a comparable density. Samples from the exploratory shaft and drifts will be particularly important for determining cross-cutting vein relations and the distribution of faults and fractures with mineralogy that permits aqueous transport. Sample density in detail will depend on fracture mineral abundance and variability. Data will be collected by binocular microscope studies and petrographic thin section studies of fractures. Scanning electron microscope (SEM) studies will be made of fracture mineral morphologies and chemistries. Data will also be collected by electron microprobe where possible. Minerals scraped from fractures will be studied by x-ray diffraction (XRD). Water evolution from hydrous minerals will be evaluated by thermogravimetric analysis (TGA). The nature of mineral distributions in fractures will also provide information relevant to alteration history (Study 8.3.1.3.2.2).

Methods and technical procedures

The methods used for Activity 8.3.1.3.2.1.3 are optical microscopy, XRD, SEM, TGA and electron microprobe. If plans change and other methods are used, they will be discussed in the mineralogy-petrology study plan. The methods and procedures are given in the following table.

Method	Number	Technical procedure	
		Title	Date
Optical microscopy	TWS-ESS-DP-28, R0	Nevada Test Site fracture filling studies procedure	9 Sep 85
X-ray diffraction	TWS-ESS-DP-16, R2	Siemens x-ray diffraction procedure	19 May 86
Electron microprobe	TWS-ESS-DP-07, R2	Microprobe operating procedure	5 Sep 86
Scanning electron microscope (SEM)	TWS-ESS-DP-112 (in preparation)	SEM operating procedure	TBD ^a
Thermogravimetric analysis	TWS-ESS-DP-47 (to be prepared)	Thermogravimetric and differential scanning calorimetry analysis	TBD

^aTBD = to be determined.

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8.3.1.3.2.2 Study: History of mineralogic and geochemical alteration of Yucca Mountain

The goal of this study is to (1) determine the timing, temperatures, and hydrologic conditions of past alteration at Yucca Mountain and (2) to experimentally study the dehydration of smectite, zeolite, and glass. Processes to be studied range from deep-seated past hydrothermal alteration to shallow mineral deposition along fractures and faults. Near-surface alteration studies on trench faults can be found under Activity 8.3.1.5.2.1.5. Alteration episodes will be defined, and the constraints on times and temperatures of alteration will be used to evaluate future alteration in the natural state as opposed to alteration due to the repository's thermal load. This study will provide input for the definition of the disturbed zone (Information Need 1.6.5, Section 8.3.5.12.5), for mineral stability (Investigation 8.3.1.3.3), and for models of past hydrologic processes within Investigation 8.3.1.2.3. This study encompasses a large number of parameters that are required to integrate multiple lines of research by assessing the timing, temperatures, and processes of mineralogic alteration at Yucca Mountain.

8.3.1.3.2.2.1 Activity: History of mineralogic and geochemical alteration of Yucca Mountain

Objectives

Deep-seated alteration of a hydrothermal and epigenetic nature must be studied to constrain the timing of such activities, in order to answer the question of whether such processes pose any future threat to the repository. The temperature interpreted from the alteration mineral assemblages can also be used to estimate the long-term thermal stabilities of important sorptive phases, such as clinoptilolite, and of the silica polymorphs that can influence water composition, precipitation, and the stabilities of other silicate minerals.

Shallower alteration around the host rock is not as extensive as deep-seated alteration but is particularly important for answering questions about the timing and temperatures of past fluids that have left deposits in voids and fractures of the host rock. The fluids that have passed through the host rock can be inferred from the minerals deposited. Temperatures can be inferred from mineral assemblages, from stable isotope ratios, or from fluid inclusions. Relative timing or sequence of alteration events can be inferred from some textures (e.g., geopetal structures) and the timing may be determined by uranium-series, uranium-trend, potassium-argon, or electron spin resonance (ESR) dating.

Parameters

The data needed are as follows:

1. Stable isotope data from authigenic minerals.
2. Uranium-thorium and rubidium-strontium isotopic data for authigenic minerals.

3. Uranium-series and uranium-trend ages of authigenic minerals.
4. Model of unsaturated zone hydrologic flow.
5. Model of saturated zone hydrologic flow.

The data gathered are as follows:

1. Ages (potassium-argon, ESR), temperatures, and distributions of past hydrothermal alteration around Yucca Mountain.
2. Ages (potassium-argon, ESR), temperatures, and distributions of past hydrothermal and diagenetic alteration in and near the host rock.

Description

Several types of past alteration are being studied at Yucca Mountain. They include multiple episodes of hydrothermal and diagenetic alteration within the host rock and in surrounding units.

Study activities will include petrologic analysis of alteration sequences and structures (e.g., tilting of geopetal structures and bubble homogenization temperatures determined from fluid inclusions). Electron microprobe analyses will be made of minerals representing growth sequences; drill core, drill cutting, outcrop, and exploratory shaft samples will be used.

X-ray diffraction (XRD) data will be collected on authigenic mineral occurrences at and near Yucca Mountain. Paleotemperatures will be estimated from clay-mineral interstratifications, from fluid inclusions and from stable isotope compositions. The ages of alteration events will be estimated using two experimental techniques: (1) potassium-argon dating of clays and zeolites, and (2) ESR dating of quartz and calcite. Approximately 250 samples will be used in all petrographic and XRD studies combined under this activity.

Samples from the exploratory shaft, from its lateral drifts, and, in particular, from the portion of the shaft that passes through the bottom of the Topopah Spring Member and into the tuff of Calico Hills are particularly important to this study. These underground exposures will provide large oriented samples of alteration products.

Methods and technical procedures

The methods used in this activity are petrography, XRD, SEM, electron microprobe, fluid inclusions analysis, ESR dating, potassium-argon dating, and stable isotope studies. These methods and the technical procedures for this activity are given in the following table.

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Method	Number	Technical procedure	
		Title	Date
Core petrography	TWS-ESS-DP-03, R2	Nevada Test Site core petrography procedure	24 Nov 82
Electron microprobe	TWS-ESS-DP-07, R2	Microprobe operating procedure	5 Sep 86
Fluid inclusion methods	TBD ^a	Fluid inclusion analysis	TBD
Electron spin resonance (ESR)	TBD	ESR dating procedure	TBD
K-Ar dating of clays and zeolites	TBD	K-Ar dating procedure	TBD
X-ray diffraction	TWS-ESS-DP-16	Siemens x-ray diffraction procedure	TBD
Clay mineralogy	TWS-ESS-DP-25	Clay mineral separation and preparation for x-ray diffraction analysis	TBD
Stable isotope analyses	TBD	TBD	TBD

^aTBD = to be determined.

8.3.1.3.2.2.2 Activity: Smectite, zeolite, manganese minerals, glass dehydration, and transformation

Objectives

The goal of this activity is to determine how minerals and glasses important in the rocks at Yucca Mountain will dehydrate and transform under anticipated thermal loads and to investigate the ability of zeolites and smectites to rehydrate after the peak in temperature. These transformations and alterations will influence sorption and rock stability immediately below the host rock. The hydrous minerals clinoptilolite-heulandite and smectite are of the greatest importance because of their proximity (a few meters to tens of meters) to the potential repository horizon. Although less abundant, the hydrous manganese minerals are also important to retardation modeling. Vitrophyre glass and vitric, nonwelded glass also occur in this zone. The

hydrous minerals have well-documented rehydration properties in recovery from short-term heating, but prolonged-heating data at low temperatures (80 to 150°C) are not available. The hydrous glasses may not simply rehydrate, but may irreversibly dehydrate and collapse or transform to other phases. The nature of these transitions and the rates and amounts of water loss from unsaturated glass must be studied. This study will also provide input to the assessment of retardation by sorption (Investigation 8.3.1.3.4), and the definition of the disturbed zone (Information Need 1.6.5; Section 8.3.5.12.5).

Long-term heating experiments in unsaturated to saturated conditions will be conducted. This activity will study the dehydration and reaction behavior of long-term (minimum of 5 yr), low-temperature (50 to 250°C) heating of minerals and glasses.

Thermogravimetric and differential thermal analyses of hydrous minerals and glasses will be conducted to determine the time-temperature behavior of zeolites, smectites, and glasses relevant to a repository at Yucca Mountain.

Parameters

The data needed are as follows:

1. Literature information on dehydration, rehydration and low temperature hydrothermal reactions.

The data gathered are as follows:

1. Mineralogic characterization of reaction products from long-term saturated and unsaturated heating experiments.
2. Time-temperature data.

Description

Study of long-term dehydration and transformation reactions at low temperatures will be carried out in a series of solid-state controlled, low temperature ovens held at temperatures between 50 and 250°C. Reaction vessels for the experiments will consist of Teflon vessels and stainless steel, Teflon -lined Parr bombs. Reactions will be carried out with samples either in contact with liquid water, water-saturated air, or in room air to approximate a range of water vapor pressures. Dry, room-air experiments will be conducted in conventional porcelain dishes or on silica glass slides. Samples used will be natural vitrophyre and vitric, nonwelded glasses from Yucca Mountain, natural zeolites and smectites from Yucca Mountain, and cation-exchanged pure zeolites and smectites. The cation-exchanged minerals will provide critical information on the role of interlayer or exchangeable cations in determining dehydration or reaction behavior. Preliminary data suggest that partial loss of rehydration ability does occur in long-term dry heating of magnesium-saturated smectite and sodium-rich clinoptilolite. The experiments will be maintained for a minimum of 5 yr but can be continued longer with very little additional effort. Samples will be examined every six months to evaluate changes.

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Time-temperature data will be obtained at varied heating rates (1 to 20°C/min) and isothermally using thermogravimetric analysis (TGA). Variable water vapor pressures will be used in TGA analyses to assess the effects of P_{H_2O} on dehydration. Enthalpy effects associated with dehydration (and perhaps rehydration) and oxidation-reduction for zeolites and smectites will be studied by differential scanning calorimetry (DSC). These data will be obtained on natural glasses, zeolites, and smectites from Yucca Mountain and on cation-exchanged pure minerals. The cation-exchanged minerals will provide data for interpreting the effect of interlayer or exchangeable cations on dehydration-rehydration behavior.

Methods and technical procedures

The methods to be used in this activity are low-temperature heating and XRD analysis of reaction materials, TGA, and DSC with characterization by XRD. The methods and technical procedures for this activity are given in the following table.

Method	Number	Technical procedure	
		Title	Date
X-ray diffraction	TWS-ESS-DP-16, R2	Siemens x-ray diffraction procedure	19 May 86
Low-temperature heating of minerals and glasses	TBD ^a	Long-term, low-temperature heating procedure	TBD
Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis	TBD	TGA and DSC procedure	TBD

^aTBD = to be determined.

8.3.1.3.2.3 Application of results

The information derived from the studies and activities described above will be used in the following issues, investigations, and information needs:

Issue,
investigation, or
information need

Subject

8.3.1.3.7

Radionuclide retardation by all processes along flow paths to the accessible environment

<u>Issue, investigation, or information need</u>	<u>Subject</u>
8.3.1.3.3	Stability of minerals and glasses
8.3.1.3.4	Radionuclide retardation by sorption along flow paths to the accessible environment
8.3.1.4.2	Stratigraphy and structure necessary to locate the underground facility
1.6.3	Description of the paths from the disturbed zone to the accessible environment (Section 8.3.5.12.3)
1.6.5	Boundaries of the disturbed zone (Section 8.3.5.12.5)
1.8	NRC Siting Criteria (Section 8.3.5.17)
1.11.6	Predicted thermal and thermomechanical response of the host rock, surrounding strata, and ground-water system (Section 8.3.2.2.6)
4.2.1	Potential nonradiological hazards to personnel (Section 8.3.2.4.1)

8.3.1.3.2.4 Schedule and milestones

This investigation contains two studies: 8.3.1.3.2.1 (three-dimensional mineral distribution) and 8.3.1.3.2.2 (history of mineralogic and geochemical alteration). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

Both of the studies associated with this investigation are ongoing. Most of the activities in Study 8.3.1.3.2.1 are based upon subsurface samples. Therefore, schedules and milestones are constrained by sample availability, which is tied to the drilling schedule, exploratory shaft construction, and core library operations. A drilling schedule is being prepared and if a significant number of new holes are drilled, as has been proposed, work outlined for this study would increase. The timing of construction of the exploratory shaft will also have a major impact on schedules and milestones.

Study 8.3.1.3.2.1 is also constrained internally by the statistical work (kriging) that is part of this task. The statistical work will indicate a sampling optimization that will be applied to the exploratory shaft and any new drill core. The statistical work is a constraint to the drilling program. In other words, the results of the statistical effort will influence how ambitious the drilling program is.

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Completion of Study 8.3.1.3.2.2 is also constrained by sample availability. However, it is not apparent that a delay in the start of exploratory shaft would impact the study. The results of this study will contribute to the work needed to evaluate the calcite and opaline silica deposits in Study 8.3.1.5.2.1, specifically to the report on mineralogy of calcite-silica assemblages, and to the conceptual model of mineral evolution in Study 8.3.1.3.3.3.

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. Points shown on the timelines represent major events or important milestones associated with the studies. Solid lines represent study durations and dashed lines represent interfaces. The data input and output at the interfaces are shown by circles.

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

<u>Point number</u>	<u>Description</u>
1	Milestone M335. Summary report available on three-dimensional mineralogic variation along transport pathways.
2	Milestone R757. Report available on the comparison of fracture mineralogy between drill cores at Yucca Mountain.
3	Milestone M382. Report available on the mineralogic evaluation of transport pathways at Yucca Mountain.

Point
number

Description

- 4 Milestone Q001. Report available on the summary results defining the geochemical characteristics (mineralogy-petrology, mineral stability, and water chemistry) at Yucca Mountain. This is a higher-level report that summarizes the results of Investigations 8.3.1.3.1, 8.3.1.3.2, and 8.3.1.3.3 and completes the work to be done as part of this study. A delay in the exploratory shaft start date could impact the timely contribution of data from the studies in this investigation to this summary report. This could result in the report being too late to contribute to the draft environmental impact statement (DEIS).
- 5 Milestone M336. Report available on the history of chemical alteration at Yucca Mountain.
- 6 Milestone Q030. Issue summary report on alteration history.
- 7 Input on mineralogic and geochemical alteration contributes to Study 8.3.1.5.2.1 for the evaluation of calcite and opaline silica deposits.

8.3.1.3.3 Investigation: Studies to provide information required on stability of minerals and glasses

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

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

<u>SCP section</u>	<u>Subject</u>
4.1.1.4	Mineral stability
4.2.2	Hydrothermal alteration of sorbing minerals and glasses
4.4.2	Potential effects of natural changes
7.4.1.7	Rock-water interactions

Parameters

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

1. Data on mineral and water compositions in natural hydrothermal systems.
2. Data on kinetics of silica phase transformations and correlation to silica phase transformations.

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3. Data to construct thermodynamic models of clinoptilolite, analcime, and albite.
4. Conceptual model for past and future mineral alteration at Yucca Mountain.

Purpose and objectives of the investigation

The goal of this investigation is to determine the stability of minerals and glasses along the flow paths to the accessible environment in order to assess impacts of waste emplacement on mineral stability and the resulting effect on radionuclide retardation. Three studies are part of this investigation: (1) Study 8.3.1.3.3.1, (natural analogs), (2) Study 8.3.1.3.3.2 (kinetics and thermodynamics of mineral evolution), and (3) Study 8.3.1.3.3.3 (conceptual model of mineral evolution).

The conceptual model of mineral evolution will integrate the results of the first two studies and will use the descriptive and experimental work on mineral alteration found in Study 8.3.1.3.2.2, the three-dimensional mineral distribution of Study 8.3.1.3.2.1, and the ground-water conceptual model of Study 8.3.1.3.1.1. The information from this investigation will be used in Issue 1.5 (Section 8.3.5.10) to understand the near-field environment of the waste package and engineered barrier system by Information Need 1.6.5 (disturbed zone, Section 8.3.5.12.5) and in Issue 1.1 (Section 8.3.5.13) to assess geochemical retardation for the total system performance calculations. Furthermore, this information is important to Issue 1.8 (NRC siting criteria, Section 8.3.5.17) and to Investigation 8.3.1.3.7 (retardation by all processes).

Technical rationale for the investigation

The minerals and glasses present in Yucca Mountain today reflect (1) the volcanic processes that originally created the primary (igneous) phases and (2) the interaction of ground waters and atmospheric gases with these phases over the past 11 million years. Construction and operation of a repository in Yucca Mountain will result in some modification of the nature and extent of ground-water-atmosphere-rock interactions. The thermal pulse resulting from waste emplacement will be particularly important in this regard. A conceptual model of mineral and glass evolution (Study 8.3.1.3.3.3) in Yucca Mountain must be developed to allow prediction of the nature and extent of the potential modification.

Active hydrothermal systems in welded ash-flow tuffs offer natural analogs to the types of rock-water interactions that are likely in the near-field of the proposed repository in Yucca Mountain. Studies of natural analogs (Study 8.3.1.3.3.1) are needed because these systems provide insight into the effects of water-rock interactions on devitrified welded ash-flow tuffs over periods of hundreds of thousands of years.

The determination of stable mineral assemblages is also needed because solid-solid transitions are slow at the temperatures of interest and metastable reaction products are common. It is difficult to determine the stable assemblages through direct experimentation; rather, thermodynamic data (for zeolites), which can be developed from solid-liquid reactions, solid-solid

reactions at higher temperatures, and calorimetric data, are needed to predict the stable assemblages (Study 8.3.1.3.3.2). These data can also be used to identify controlling reactions that determine the rate of evolution of larger mineral assemblages. Kinetic studies will be needed on rate controlling mineral reactions (evolution of silica polymorphs and relation to evolution of aqueous silica activity) (Study 8.3.1.3.2.3).

There are three studies under this investigation: analog study of hydrothermal systems in tuff, kinetics and thermodynamics of mineral evolution; and conceptual model of mineral evolution.

8.3.1.3.3.1 Study: Natural analog of hydrothermal systems in tuff

Objectives

The goals of this study are (1) to improve the reliability of long-term predictions regarding hydrothermal rock alteration in devitrified welded ash-flow tuff, (2) test the capabilities of the EQ3/6 geochemical code (Section 7.4.4) through modeling of alteration mineral assemblages in natural systems, and (3) to provide a better understanding of the origin of alteration mineral assemblages found in Yucca Mountain at present. This study will also help in development of the conceptual model for mineral evolution in Yucca Mountain and will aid substantially in guiding the laboratory studies. This study will investigate the origin and evolution of secondary mineral assemblages produced in active hydrothermal systems in rock types similar to those which compose Yucca Mountain.

Parameters

The data needed are as follows:

1. Literature Survey:
 - a. Water compositions.
 - b. Temperatures of hydrothermal systems.
 - c. Secondary mineral assemblages and paragenesis.
2. EQ3/6 computer code.

The data gathered are as follows:

1. Microprobe analyses of alteration products.
2. Mineral solid solutions.
3. Reaction path calculations.
4. Document discrepancies between predicted and observed mineral assemblages.
5. Implications of results to Yucca Mountain..

Description

This study (presently in a conceptual phase) will (1) select and describe a hydrothermal system in tuffaceous rocks in the continental United States that could be studied as a geologic analog to the near-field of the proposed repository in Yucca Mountain, (2) evaluate the paragenesis of hydrothermal minerals in this system, (3) evaluate the chemical variability of surface and subsurface ground waters in this system to derive compositions appropriate for modeling purposes, (4) carry out preliminary calculations to test the capabilities of the EQ3/6 geochemical code in modeling of alteration reactions in natural hydrothermal systems in welded ash-flow tuffs, (5) use EQ3/6 to explore the possibility that hydrothermal systems can provide useful thermodynamic constraints on the stabilities of minerals for which reliable thermodynamic constants are presently lacking (e.g., zeolites and clays), and (6) provide a preliminary evaluation of how data from natural geothermal systems could add to our predictive capabilities with regard to geochemical modeling, experimental studies, and the overall performance of the proposed repository at Yucca Mountain.

Methods and technical procedures

Technical procedures associated with methods used in this study are:

Method	Number	Technical procedure	
		Title	Date
Electron microprobe analysis	TWS-ESS-DP-07, R2	Microprobe operating procedure	5 Sep 86
X-ray diffraction (XRD)	TWS-ESS-DP-16, R2	Siemens XRD procedure	19 May 86
Clay mineral separation	TWS-ESS-DP-25, R1	Clay mineral separation for XRD procedure	3 Apr 86
EQ3/6	TBD ^a	EQ3/6 Computer Code User Manual	TBD

^aTBD = to be determined.

8.3.1.3.3.2 Study: Kinetics and thermodynamics of mineral evolution

The goals of this study are to (1) investigate the kinetics of glass and silica polymorph transitions and their relationship to aqueous silica activity and (2) provide thermodynamic data for clinoptilolite/heulandite and albite and analcime. A kinetic study of zeolite and related framework silicates is not planned; however, the technical basis for the development of experimental activities is discussed in the following text.

Silica activity has been identified as an important parameter in controlling mineral stability in Yucca Mountain. This parameter adds uncertainty to the understanding of mineral stability because the rate of evolution of silica activity is not well understood. Considerable uncertainty exists regarding the origin of alteration minerals in rock matrices and fractures in Yucca Mountain. These minerals could have formed early in the history of the Topopah Spring Member from elevated emplacement temperatures, or they could have formed from more recent, and perhaps ongoing, interaction of ground water with glassy tuffs. If the latter is true, the alteration minerals would react to changes in ground-water conditions over time (e.g., changes in pH may cause an increase in the rate of silica phase transformation; and therefore, more rapid decrease in the aqueous silica activity). These changes would then have to be documented to assess their effect on the temporal stability of sorptive minerals along potential transport pathways. However, if the minerals can be shown to have formed early after the formation of the tuff, and not to have been affected by subsequent exchange reactions, significant interaction with ground water would be ruled out. This is particularly important because mineral alteration unrelated to the repository thermal pulse could cause changes in sorptive capacity.

Understanding the mineral stability and evolution at Yucca Mountain will depend on the quality of the thermodynamic data base available; therefore, the gathering of thermodynamic data is fundamental to this study. This data will be especially important in verifying the relationship between silica activity and mineral stability, particularly that of the framework silicates such as the zeolites. Clinoptilolite-heulandite, albite and analcime, along with the silica polymorphs, are principal components of important mineral reactions observed to have taken place in Yucca Mountain. Both thermodynamic data for the end-members of these minerals and a description of solid-solution and order-disorder phenomena are needed.

Clinoptilolite and some other zeolites are thought by some to be metastable. The disappearance of clinoptilolite from the geologic column in rock more than a few hundred million years old supports this. However, clinoptilolite is thought to be stable at metastably high silica activity and its disappearance controlled by the evolution of silica activity, which is in turn probably controlled by the evolution of the silica polymorphs. This is supported by the observation that clinoptilolite generally forms from initially glassy rocks and is generally accompanied by cristobalite (or opal-c). If field and thermodynamic studies do not ultimately support this view, or if it is found that there may be rapid evolution of aqueous silica activity to quartz saturation, kinetic studies of zeolite and other mineral reactions will become important to assess the temporal stability of the sorptive minerals. Present kinetic studies being carried out by the geologic community chiefly are directed at the kinetics of dissolution. Such studies would certainly represent part of the work needed here, but there is a need to understand precipitation kinetics and the other mechanisms controlling the rates of mineral reactions.

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8.3.1.3.3.2.1 Activity: Kinetic studies of zeolite and related framework silicates

Objectives

The goal of this activity is to predict the rates of possible transformation of silica polymorphs in Yucca Mountain and the effect such transformations would have on aqueous silica activity. This information will be combined with information from other activities and studies, particularly Activities 8.3.1.3.3.2.2 and 8.3.1.3.3.2.3 and Study 8.3.1.3.2.1 to assess the effects of silica polymorph evolution on the stability of other minerals, particularly clinoptilolite, in Yucca Mountain.

Parameters

The data needed are as follows:

1. Literature survey of kinetic data.

The data gathered are as follows:

1. Aqueous silica activity as a function of reaction progress, temperature, and pH.

Description

Literature data will be used to develop a model for the kinetics of evolution of silica phases and aqueous silica activity. This model will be compared with observations at Yucca Mountain and with field data on other vitric tuffs in the literature to estimate possible changes in silica for experimental work on aqueous silica activity. Thermodynamics and solubilities of cristobalite and opal-c are similar enough that initial experimentation will focus on hydrothermal alteration of cristobalite to quartz and observation of the aqueous silica activity as a function of reaction progress. Important variables that are likely to affect the rate of reaction are temperature, pH, and composition of the ground water.

Methods and technical procedures

No procedures have been developed at this time pending completion of the literature survey.

8.3.1.3.3.2.2 Activity: Determination of end-member free energies for clinoptilolite-heulandite, albite, and analcime

Objectives

The goal of this activity is to determine end-member free energies from solubility measurements. This activity will provide enthalpy of formation data which will then be used to determine the thermodynamic stability of these silicates.

Parameters

The data needed are as follows:

1. Pure mineral samples of clinoptilolite-heulandite, albite, and analcime.

The data gathered are as follows:

1. Solubility measurements.
2. Free energy calculations.

Description

The solubilities of clinoptilolite-heulandite, albite, and analcime with known compositions, and for albite a known state of order, will be measured. The solubility measurements will be used as a means to collect data from which free energies can be calculated because a relatively rapid approach to equilibrium is more probable than with reactions among solid phases. The equilibrium solution compositions will then be combined with knowledge of the thermodynamics of the aqueous phase (primarily from the EQ3/6 data base to be consistent with other data used in the NNWSI Project) to calculate mineral free energies for the specific compositions studied.

Methods and technical procedures

To facilitate fluid sampling and pH measurement, the initial solubility work will be done at temperatures below boiling at 1 atm in specially designed inert gas stirred reaction vessels. If higher temperatures are required to promote the approach to equilibrium, experiments will be done in high pressure hydrothermal apparatus. The solution compositions will be measured by standard analytical techniques such as inductively coupled plasma spectroscopy, ion chromatography, and pH electrodes. Characterization of solids will be done by powder x-ray diffraction and electron microprobe.

Data reduction codes (from common Los Alamos mathematical software) (CLAMS) to be used in this activity:

ANALTHERMO	Data reduction code for analcime thermodynamics uses SNSQE
ABTHERMO	Code for albite thermody- namics, uses subroutine from CLAMS
SNLS1E	Nonlinear least squares
SCOV	Generates covariance matrix from output of SNLS1E

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RPQR79

Finds roots of polynomial with real coefficients from CLAMS

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Graphics

Method	Number	Technical procedure	
		Title	Date
Electron microprobe	TWS-ESS-DP-07, R1	Microprobe operating procedures	5 Sep 86
X-ray diffraction	TWS-ESS-DP-16, R2	Siemens x-ray diffraction procedure	19 May 86
Preparation for water analysis	TWS-INC-DP-26, R0	Preparation of aqueous standards for analysis of water samples	1 June 83
Trace element analysis of water samples	TWS-INC-DP-27, R0	Trace element determination for analysis of water samples	1 June 83
pH of water	TWS-INC-DP-35, R0 CR-006	pH measurements	28 May 85 and 26 Aug 86
TBD ^a	TWS-MSTQA, QP-14, R1	Research and Development (experimental procedure)	TBD
TBD		Mineral Solubility Procedure	TBD
TBD		Procedure to implement NNWSI-SOP-03-02	TBD
TBD		Hydrothermal reactions with polymorphs	TBD
TBD		Procedures on techniques for examination of reacting silica polymorphs and coexisting fluids	TBD

^aTBD = to be determined.

8.3.1.3.3.2.3 Activity: Solid solution descriptions of clinoptilolite-heulandite and analcime

Objectives

The goal of this activity is to provide descriptions of the thermodynamics of the clinoptilolite-heulandite and analcime solid solutions in support of the development of the mineral stability model. The thermodynamic descriptions developed will be tied to the thermodynamics of discrete compositions of clinoptilolite and analcime determined in Activity 8.3.1.3.3.2.2 but will extend the thermodynamic description to the entire range of possible compositions.

Parameters

The data needed are as follows:

1. Crystallographic information.
2. Pure mineral samples.

The data gathered are as follows:

1. Solubility measurements on minerals of intermediate compositions.
2. Elemental analyses.
3. Theoretical models (for configurational entropy).

Description

Solid solution descriptions will be based primarily on theoretical models for configurational entropy with support from solubility measurements. This activity will involve solubility measurements on intermediate compositions of clinoptilolite/heulandite and analcime. A theoretical approach to the entropy of mixing will be used. Configurational entropy will be linked to crystallographic information, particularly, the available cation sites, the cations that would occupy those sites, and information on the coupling between ions that occupy the sites.

Methods and technical procedures

The methods and technical procedures used are identical to those described in Activity 8.3.1.3.3.2.2.

8.3.1.3.3.3 Study: Conceptual model of mineral evolution

Objectives

A conceptual model will be produced to explain the observed distributions of minerals in Yucca Mountain. Emphasis will be placed on the evolution of framework silicates (feldspars, zeolites, and silica polymorphs). The model will address the general chemical evolution of vitric tuffs. This model will also be used to predict future mineral evolution in the mountain due to both natural processes and as a result of a repository emplacement.

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This model will be a significant contribution to Issue 1.1 (Section 8.3.5.13) in its transport calculation and for calculation over 100,000 yr and to the waste package issue (Issue 1.4, Section 8.3.5.9) and engineered barrier system issue (Issue 1.5, Section 8.3.5.10). This model is intimately tied to the ground-water chemistry model (Investigation 8.3.1.3.1) and to the three-dimensional mineralogic distribution at Yucca Mountain (Investigation 8.3.1.3.2).

Parameters

The data needed are as follows:

1. Data from Studies 8.3.1.3.3.1 and 8.3.1.3.3.2.
2. Three-dimensional model (Study 8.3.1.3.2.1) of mineral distribution.
3. Ground-water model (8.3.1.3.1).

The data gathered are as follows:

1. Conceptual model of mineral evolution.

Description

Data from Studies 8.3.1.3.3.1 (natural analogs), 8.3.1.3.3.2 (kinetics and thermodynamics), 8.3.1.3.2.1 (three-dimensional mineralogic distribution, specifically, Activity 8.3.1.3.2.2.2, alteration of zeolites), and 8.3.1.3.1.1 (ground-water chemistry model) will be used for this conceptual model. Codes will be developed as needed. These codes will be based primarily on routines from the Common Los Alamos Mathematical Software (CLAMS) as listed in Study 8.3.1.3.3.2.

8.3.1.3.3.4 Application of results

The information derived from the studies and activities described above will be used in the following issues, information needs, and investigations:

Issue, investigation, or information need

Subject

8.3.1.3.7	Radionuclide retardation by all processes along flow paths to the accessible environment
1.6.5	Disturbed zone boundaries (Section 8.3.5.12.5)
1.8	NRC siting criteria (Section 8.3.5.17)
1.1	Total system performance (Section 8.3.5.13)
1.4	Containment by waste package (Section 8.3.5.9)
1.5	Engineered barrier system release rates (Section 8.3.5.10)

8.3.1.3.3.5 Schedule and milestones

This investigation (8.3.1.3.3) contains three studies: 8.3.1.3.3.1 (natural analogs of hydrothermal systems in tuff), 8.3.1.3.3.2 (kinetics and thermodynamics of mineral evolution), and 8.3.1.3.3.3 (conceptual model of mineral evolution). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of the final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

The studies of kinetics and thermodynamics of mineral evolution and the conceptual model development in this investigation are ongoing. Although the study of natural analog hydrothermal systems (8.3.1.3.3.1) is considered ongoing, it is currently not being funded because of budget constraints.

The experimental and modeling work for this entire investigation will proceed in parallel with performance and design activities and will interact with them in an iterative fashion. The conceptual model for mineral evolution is needed to finalize predictions of radionuclide transport required by Issue 1.1 (Section 8.3.5.13). It will also provide data on mineral stability to be used by the rock characteristics program (Section 8.3.1.4) and in repository design (Section 8.3.2.2).

The studies in this investigation are not seriously constrained by other program elements. The experimental work on kinetics and thermodynamics (Study 8.3.1.3.2) is not limited by sample availability and can begin when the study plan is available.

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

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

<u>Point number</u>	<u>Description</u>
1	Milestone R501. Report available on the application of natural analogs to mineral alteration at Yucca Mountain.
2	Milestone R358. Final report available on kinetics of silica activity evolution at Yucca Mountain. This report completes the work to be done as part of this study.
3	Milestone R359. Preliminary conceptual model of mineral evolution at Yucca Mountain available.
4	Ground-water chemistry model (Study 8.3.1.3.1.1) available for integration into mineral evolution model.
5	Milestone R360. Final report available on conceptual model of mineral evolution at Yucca Mountain. This report completes the study and the investigation.
6	Conceptual model available to Issue 1.1 (Section 8.3.5.13) for use in finalizing predictions of radionuclide transport and releases.
7	Milestone Q001. Report available on the summary results defining the geochemical characteristics (mineralogy-petrology, mineral stability, and water chemistry) at Yucca Mountain. This is a higher-level report that summarizes the results of Investigations 8.3.1.3.1, 8.3.1.3.2, and 8.3.1.3.3 and will be compiled as part of Study 8.3.1.3.2.1.

8.3.1.3.4 Investigation: Studies to provide the information required on radionuclide retardation by sorption processes along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the site characterization plan data chapters and support documents provide a technical summary of existing data relevant to this investigation:

<u>SCP section</u>	<u>Subject</u>
4.1.3.3.1	Sorption data for tuff
4.1.3.3.2	Sorption data from batch experiments
4.1.3.3.3	Sorption data from crushed tuff column experiments
4.1.3.3.4	Sorption data from circulating system experiments
4.1.3.3.5	Comparison of sorption ratios from batch, circulating system, and column measurements
4.1.3.3.6	Sorptive behavior as a function of stratigraphic position and mineralogy
4.1.3.3.7	Sorptive behavior as a function of ground-water composition
4.1.3.6.1	Transport of suspended solids

Parameters

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

1. Sorption coefficients as a function of

- a. Ground-water composition.
- b. Mineralogy.
- c. Sorbing species.
- d. Waste element concentration.
- e. Atmosphere (if needed).
- f. Temperature (if needed).
- g. Colloidal material (sorption on).
- h. Organic complexation (if needed).

2. Sorption kinetics.

3. Biological sorption and transport.

Data analysis is to include the following:

1. Statistical analysis to evaluate critical parameters and gaps in data.

Model development is to include the following:

1. Model for sorptive behavior.

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Data supplied from other investigations are as follows:

<u>Investigation</u>	<u>Subject</u>
8.3.1.2.2	Site unsaturated zone hydrologic system
8.3.1.2.3	Site saturated zone hydrologic system
8.3.1.2.1	Water chemistry (specifically Activity 8.3.1.2.1.3.5)
8.3.1.3.2	Mineralogy, petrology, and rock chemistry
8.3.1.3.3	Stability of minerals and glasses
8.3.1.3.6	Sorption from dynamic transport column experiments (specifically Study 8.3.1.3.6.1)

Purpose and objectives of the investigation

The goal of this investigation is to describe sorption behavior as a function of the physical and chemical variables. These parameters listed above, are needed to determine the role sorption plays in retarding the movement of radionuclides along flow paths to the accessible environment. To summarize, Issue 1.1 (Section 8.3.5.13) has required that for each key radionuclide species known to be chemically sorbing, and for each rock unit in the controlled area except for the overburden, estimates should be provided of the mean and standard deviation of the distribution coefficients $K_d(i)$, under the range of water-rock chemical conditions expected for the unit in question. The radionuclides as listed by Issue 1.1 are cesium, strontium, plutonium, americium, uranium, carbon, technetium, iodine, zirconium, neptunium, and curium.

Three studies are designed to satisfy this investigation: (1) generate laboratory sorption data as a function of the important variables just listed and to statistically establish these variables which most significantly influence sorption, (2) understand biological sorption and transport, and (3) generate a predictive model for sorption (isotherms) in the site system.

Technical rationale for the investigation

A brief summary follows on the status of sorption data for selected radionuclides listed in 40 CFR Part 191 and the key elements listed in Section 4.1.3.1, to show the logic of choosing a selected set of radionuclides for the sorption studies described in this investigation. This selection is based on the existing defensible data base and the relative importance of the radionuclides in release calculations.

The bulk of the sorption work on the simple cations cesium, barium, and strontium is complete. This work provides a baseline set of data that is useful in interpreting the behavior of more complex cations. When experimental parameters are to be changed (i.e., changing water chemistry, new tuff core, etc.) these well-characterized (sorption behavior) simple cations will be included in the sorption studies.

Carbon-14, iodine-129, and technetium-99 behave as anions. A review of the literature on carbon-14 (Liepins, 1987) indicates that little sorption is expected; therefore, the sorption task need not investigate carbon-14 sorption. Carbon-14, however, may be significant when considering the potential for gaseous transport. Iodine-129 as an anion is not found to sorb and no further sorption work will be conducted. Technetium-99, also behaving as an anion under oxidizing conditions, essentially does not sorb and will not be emphasized in the planned sorption tests.

Thorium is considered to be a difficult element to deal with experimentally because it is extremely difficult to get into solution and to keep in solution for the sorption experiments. Thorium sorption data have been generated by doing the experiments under a carbon dioxide atmosphere in order to control the pH. Thorium is not considered a high priority element on the list of key radionuclides or for Issue 1.1 and will not be emphasized in the planned sorption studies.

Radium-226 is also a difficult element to work with; however, data have been obtained. Also, barium may be used as an analog for radium. Radium then, will not be included in future sorption tests. Tin-126 also will not be emphasized in the planned sorption tests since there is a substantial amount of sorption data for tin.

Other elements that will not be investigated at this stage of the sorption task are zirconium-95 and nickel. There are sorption data on zirconium and further work on zirconium will not be emphasized. Nickel may be important depending on what the waste form will be, and development of sorption experiments on nickel may be necessary in the future. See Chapter 4 for details of the rationale for the sorption experiments.

The key radionuclides that will be emphasized and investigated in the following sorption studies will be americium, plutonium, neptunium, and uranium. Although the data base for these elements has increased, the sorptive behavior of these elements (i.e., speciation, near-neutral solutions, effects of concentration, etc.) is still technically incomplete and difficult to interpret.

The first study is a batch sorption study that will focus on the key actinides, americium, plutonium, neptunium, and uranium. If other radionuclides are to be investigated they will be specifically noted under each activity. The batch sorption activities will study sorptive behavior in the rock/ground-water system along potential flow paths as a function of sorbing element concentration, speciation, ground-water composition, and mineralogy. The batch sorption study (Study 8.3.1.3.4.1) includes five activities. They are:

<u>SCP section</u>	<u>Description</u>
8.3.1.3.4.1.1	Batch sorption measurements
8.3.1.3.4.1.2	Sorption as a function of sorbing element concentrations (isotherms)
8.3.1.3.4.1.3	Sorption as a function of ground-water compositions

<u>SCP section</u>	<u>Description</u>
8.3.1.3.4.1.4	Sorption on particulates and colloids
8.3.1.3.4.1.5	Statistical analysis of sorption data

Experiments that may be conducted at a later time if a strong technical need is recognized, are sorption experiments as a function of atmosphere (CO_2). Furthermore, work on radionuclide complexation by organics introduced by the materials and fluids used in the exploratory shaft construction might also be initiated.

This investigation includes two other studies:

Study 8.3.1.3.4.2 Biological sorption and transport

Study 8.3.1.3.4.3 Development of sorption models (isotherms)

These studies are planned to be concurrent and interactive, in that the sorption data generated will be statistically analyzed to direct future work while being integrated with the model development.

The oxidation state of the sorbing species controls their chemical and, hence, sorption behavior. Different oxidation states of the same element may very well have different sorption characteristics. Consequently, it is essential to characterize those oxidation states expected under repository conditions and to determine their sorption behavior. The concentration of the sorbing element can also affect sorption ratios. The concentration of a waste element is expected to decrease by dilution as the fluids from the repository move to the far field and mix with surrounding ground waters. To model such a change in concentration in the transport process, the variation of sorption with concentration is needed. In addition, in most transport codes, it is assumed that the sorption ratio does not depend on concentration. This is probably true for repository conditions but must be verified (Section 4.1.3.3.4).

Ground-water composition (information obtained from Investigation 8.3.1.3.1), including oxidizing potential, pH, and presence of complexing agents, determines the chemical environment along the flow paths in the saturated zone. It controls the oxidation state and speciation of the waste elements, as well as their solubility, all of which can affect sorption of the elements by tuff. In a similar vein, mineralogy determines both the ground-water chemistry and the sorption capacity of the tuff. For example, as discussed in Section 4.1.3.3.6, the presence of the zeolite clinoptilolite strongly enhances the sorption of simple cationic species.

Other sorption activities under the batch sorption study include the study of the effect of microbial activity, as well as sorption on colloidal and particulate material. If sorption of waste elements occurs on colloids or microbes, and if those colloids or microbes are able to move with ground water (Investigation 8.3.1.3.6) to the accessible environment, then the use of sorption coefficients alone will not adequately predict the transport of those radionuclides. Transport could occur on naturally occurring colloids and particulates present in the ground water, on material created by degradation of the engineered barrier system components such as container corrosion

products, or by microbes present in the ground water or introduced during construction and operation. It must be determined whether sorption occurs on such colloidal material and then if that material can be transported to the accessible environment.

For laboratory data to be defensible, they must be shown to be reproducible and statistically significant; therefore, statistical methods (in particular analysis of variance) are needed for the evaluation of the statistically significant parameters in sorptive behavior. Simple statistical models will be developed to predict sorption, and the characterization of the models will lead to an investigation of the mechanism of sorption. These models will include factors such as mineralogy, particle size, and concentration. Error estimates on the model predictions will be given. Variances and covariances and the parameter estimates of the model will point out gaps in the data. These gaps could be places where more data are needed to increase the precision of the estimated mean or instances where experiments need to be run to obtain independent estimates of the parameters.

Modeling of sorptive behavior of Yucca Mountain materials by isotherms is required for the prediction of sorption under both expected and unexpected site-specific scenarios. Depending on the isotherms found to represent sorption, it may be possible to develop contours of iso- K_d s (zones of equal average sorption behavior) and isobetas (zones of equal sorption heterogeneity). The K_d s give a measure of the average retardation of radionuclides, and the betas, when derived from the modified Freundlich isotherm, give a measure of sorption heterogeneity (see Section 8.3.1.3.4.3). This modeling effort will support the use of laboratory sorption data by performance assessment in a predictive way. Performance assessment will also use results from actual field experiments. Currently, there are plans for field tests for sorbing tracers in C-well testing (Section 8.3.1.2.3) only; however, testing may indicate the need for other field and analog studies (Study 8.3.1.3.7.2).

8.3.1.3.4.1 Study: Batch sorption studies

The goal of this study is to complete the measurement of batch sorption coefficients for key radionuclides on tuff samples representative of Yucca Mountain, as a function of mineralogy and time. This will provide the main sorption data base for the statistical analysis (Activity 8.3.1.3.4.1.5) for developing a model (Study 8.3.1.3.4.3) to predict sorption at Yucca Mountain, in order to better understand the sorption mechanism and for testing the preliminary performance allocation for the Calico Hills tuff. Experimental emphasis is now on those elements considered most important (Section 4.1)--americium, plutonium, neptunium, and uranium. Comparison of the batch sorption coefficients with those measured from crushed tuff column experiments (Activity 8.3.1.3.6.1.1) may indicate the presence of one or more chemical species of a radionuclide and help to establish if these chemical species have differing sorption ratios (other variables affecting sorption are held constant). By performing these batch measurements on pure minerals, the minerals responsible for the sorption of the waste element can also be identified. Results of initial testing will direct further testing to satisfy model development and performance assessment needs. Radionuclides showing sorption coefficients well in excess of the requirements of Issue 1.1

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(Section 8.3.5.13) may be deleted from further testing and the testing matrix reduced. Modified batch techniques will also be used to study particulate and colloid sorption behavior, and microbial sorption.

Sorption coefficients and their dependence upon the variables studied will be used in Investigation 8.3.1.3.6 (radionuclide dispersion, diffusion, and advection) to aid in predictions of flow, particularly fracture flow; in calculation of retardation by various mechanisms (Investigation 8.3.1.3.7, radionuclide retardation investigations); and in performance assessment calculations for Issue 1.1.

8.3.1.3.4.1.1 Activity: Batch sorption measurements as a function of solid phase composition

Objectives

This activity will focus primarily on determining sorption coefficients for radionuclides on tuffs of the Calico Hills zeolitic and vitric units, on devitrified units, and on pure minerals representative of the sorptive minerals in these rocks. An estimate of the mean and standard deviation of the distribution coefficients ($K_d(i)$) under expected rock-water chemistry condition will be provided. The data generated will be statistically analyzed and comparisons will be made of the sorption coefficients as a function of mineralogy. This correlation exercise will help develop a complete description of the variation of sorption coefficients with mineralogic composition. The results of the batch sorption measurements will be compared with the crushed tuff column results from Activity 8.3.1.3.6.1.1. The differences observed may indicate the presence of more than one chemical species of a radionuclide if all other variables are known to be held constant. These variables include contact time, reaction kinetics, and solid and liquid phase compositions. Elucidating chemical species may prove to be difficult.

Parameters

The data needed are as follows:

1. Mineral composition of samples from the tuffaceous beds of the Calico Hills and other tuffs of similar composition used in the tests.
2. Chemical composition of the pure minerals used.
3. Physical properties and cation exchange capacity of the solids used.
4. Ground water from well J-13.
5. Radioactive tracers (same tracers used as in Investigation 8.3.1.3.6).

The data gathered are as follows:

1. Sorption coefficients as a function of solid substrate composition.

2. Correlations of sorption coefficients with mineralogy.
3. Comparisons of batch data with crushed tuff column data (Activity 8.3.1.3.6.1.1).

Description

The test matrix will focus primarily on plutonium, neptunium, americium, and uranium because of their presence as key radionuclides and their complex aqueous chemistry. Zirconium and nickel may also be studied based on their importance in spent fuel inventories. Sorptive behavior of cesium, strontium, and barium are well characterized by existing data; however, they may be used to validate the testing procedures and to fill any existing data gaps. Zeolitic, vitric, and devitrified samples from the tuffaceous beds of Calico Hills will be the focus of the activity. Other tuffs of similar mineralogic composition will be used to supplement the limited availability of Calico Hills material. Some measurements will also be done using Topopah Spring tuff and tuffs from the saturated zone because these rocks are considered as sorptive barriers held in reserve. Sorption will also be measured on pure minerals of composition ranges bracketing those in the Yucca Mountain rocks. Clinoptilolite, mordenite, and smectite will be the primary focus, with some additional testing using calcite. Both sorption and desorption ratios will be measured, using standardized techniques. A minimum of 200 tests are anticipated for this activity, however, additional testing may be required based on the analyses of the data and on performance assessment calculations. A testing matrix is given in Table 8.3.1.3-2 summarizing the elements and solid phases addressed by this activity.

Methods and technical procedures

Method	Number	Technical procedure	Date
		Title	
Batch sorption method	TWS-CNC-DP-05, R1	Sorption, desorption ratio determinations of geologic materials by a batch method	30 Aug 82
	TWS-INC-DP-02, R3	Quality control in counting radioactive nuclides	3 Jan 84
	TWS-MSTQA-QP-15, RO	Nevada Nuclear Waste Storage Investigations calibration	1 Aug 86
	TWS-INC-DP-35, RO, CR-006	pH measurements	28 May 85 and 26 Aug 86

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Table 8.3.1.3-2. Testing matrix for batch sorption measurements as a function of solid phase composition

Elements ^{a, b}	Solid phase
U	Calico Hills tuff:
Pu	
Np	- zeolitic
Am	- vitirc
U	- devitrified
Zr	
Ni	Topopah Spring tuff ^c
Cs	
Sr	Tuff from saturated zone ^c
Ba	
Pure mineral phases:	- clinoptilolite
	- mordenite
	- smectite
	- calcite

^aSorption measurements are planned for elements in the first column on the solid phases in the second column.

^bTests will be run at only one concentration.

^cTwo samples from different locations.

Methods and technical procedures

Method	Technical procedure		
	Number	Title	Date
Batch sorption method	TWS-CNC-DP-05, R1	Sorption, desorption ratio determination of geologic materials by a batch method	30 Aug 82
	TWS-INC-DP-02, R3	Quality control in counting radioactive nuclides	3 Jan 84
	TWS-MSTQA-QP-15, RO	Nevada Nuclear Waste Storage Investigations calibration	1 Aug 86

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Method	Technical procedure		Date
	Number	Title	
	TWS-INC-DP-35, R0 CR-006	pH measurements	28 May 85 and 26 Aug 86
	TWS-MSTQA-QP-14, R1	Research and development (experimental) procedure	19 May 86
	TWS-INC-DP-62, R0	Bulk Nevada Test Site (NTS) well water samples	30 Jan 87
	TWS-INC-DP-63, R0	Preparation of NTS core samples for crushed rock experiments	20 Mar 87

Actinide tracers in known, stable, and well-characterized oxidation states are needed for use in this study and for use in Investigation 8.3.1.3.6. Most actinide elements in near-neutral solutions and at expected repository conditions can exist in more than one oxidation state, each of which may exhibit different sorption and transport behavior. To characterize these behaviors, sources of the individual species must be available. Plutonium and other actinides (key radionuclides expected to be present, Investigation 8.3.1.3.5) will be prepared in specific oxidation states in a carbonate buffer approximating the carbonate concentration of well J-13 water. The concentration prepared will be the lowest possible in which the species present can be identified (normally by spectroscopy). These solutions will be diluted and immediately used in sorption measurements. The remaining stock solution will be monitored during the course of the sorption experiments to assess the stability of the prepared oxidation state. When satisfactory techniques are developed, quality assurance technical procedures will be written and implemented.

Computer codes to be used include RAYGUN, GAMANAL, and SPECANAL, which are all standard Los Alamos gamma ray data analysis codes.

8.3.1.3.4.1.2 Activity: Sorption as a function of sorbing element concentrations (isotherms)

Objectives

The purpose of this activity is to characterize the dependence of sorption coefficients upon the concentration of the element being sorbed by

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developing isotherms for the radionuclide. These measured values of K_d will be compared with the requirements of Issue 1.1 as they are developed. This activity will develop isotherms for the radionuclides to be tested. These isotherm data will be incorporated into the sorption data base, for use in determining element concentration levels at which precipitation begins to contribute to the measured sorption ratio, and in modeling sorption (Investigation 8.3.1.3.7) to predict retardation along flow paths. Since the concentration of waste elements is expected to change along potential flow paths, accurate sorption predictions must account for these changes, if significant. Batch techniques and procedures will be used as described in Activity 8.3.1.3.4.1.1.

Parameters

The data needed are the same as Activity 8.3.1.3.4.1.1.

The data gathered are the sorption coefficients as a function of sorbing element concentration.

Description

The concentration ranges studied will try to reach an apparent concentration limit (i.e., the highest concentration the solution can maintain when all other variables are held constant) so that it can be shown that precipitation is not contributing to the sorption ratio. The primary waste elements to be studied include uranium, plutonium, neptunium, and americium, with concentrations ranging from 10^{-12} M to an apparent concentration limit approximately 10^{-4} M, if possible (Table 8.3.1.3-3). The experiments will be run with eight different concentrations within this range. The number of concentrations studied may change once the minimum number of points necessary for adequate isotherms is determined. Tuffs with mineralogy similar to Calico Hills zeolitic (T_z), vitric (T_v), and to devitrified (T_{dv}) tuffs will be used. Test procedures are as for Activity 8.3.1.3.4.1.1. A general test matrix is given below in Table 8.3.1.3-3. More elaboration is provided in the study plan on radionuclide retardation. Approximately 96 tests performed in duplicate are anticipated. This number will be adjusted based on initial testing results.

Methods and technical procedures

The methods and technical procedures are to be developed for isotherm determination.

8.3.1.3.4.1.3 Activity: Sorption as a function of ground-water composition

Objectives

The goal of this activity is to measure sorption coefficients as a function of ground-water compositions anticipated along potential travel paths and to determine if the values of K_d are above the goals set by Issue 1.1 (Section 8.3.5.13) as they are developed. Ground-water composition can control the waste radionuclide oxidation state, speciation, and solubility, and

Table 8.3.1.3-3. Sorbing element concentrations of primary waste elements^a

Elements	Solid phase ^b	Approximate concentration range ^{c,d} (M)
U	T1 T2 T3	10E-12 to 10E-4
Pu	T1 ^z T2 ^v T3 ^{dv}	10E-12 to 10E-4
Np	T1 ^z T2 ^v T3 ^{dv}	10E-12 to 10E-4
Am	T1 ^z T2 ^v T3 ^{dv}	10E-12 to 10E-4

^aExperiments run under ambient laboratory conditions. The liquid phase for all experiments was well J-13 water.

^bT1 = zeolitic tuff; T2 = vitric tuff; T3^{dv} = devitrified tuff.

^cE-12 is exponential notation (10^{-12}).

^dNumber of concentrations between given range was approximately eight.

therefore, can have a great effect on the measured sorption ratio. These data will contribute to the sorption data base and support the sorption model development and performance assessment calculations. Batch techniques and procedures will be used as described in Activity 8.3.1.3.4.1.1.

Parameters

The data needed are as follows:

1. Same parameters as for Activity 8.3.1.3.4.1.1.
2. Ground-water compositions and samples from wells at Yucca Mountain.
3. Artificially prepared ground waters.
4. Composition of unsaturated zone ground waters (Investigation 8.3.1.3.1).

The data gathered are as follows:

1. Sorption coefficients as a function of ground-water composition.

Description

Batch sorption coefficients will be measured in ground waters of varying compositions and will be compared with the results obtained using well J-13 ground water (Activity 8.3.1.3.4.1.1). Ground water from two Yucca Mountain wells, USW H-3 and UE-25p#1, will be used in these tests along with artificially prepared ground water made by spiking well J-13 water with salts to give compositions simulating and possibly bounding vadose water compositions. The actinides uranium, plutonium, neptunium, and americium will be tested with cesium, barium, strontium, tin, and europium for validation of testing

procedures and to fill gaps in the existing data base. Batch techniques and procedures will be used as described in Activity 8.3.1.3.4.1.1. A general test matrix is given in Table 8.3.1.3-4. More elaboration is provided in the radionuclide retardation study plan. A minimum of 60 tests performed in duplicate are anticipated. This number will be adjusted based on examination of the initial testing results.

Methods and technical procedures

The methods and technical procedures are to be developed for isotherm determination.

8.3.1.3.4.1.4 Activity: Sorption on particulates and colloids

Objectives

The goal of this activity is to determine if sorption of important radionuclides occurs on particulates or colloids that may be present in ground waters along potential transport pathways. This is an interactive effort with others described under Investigations 8.3.1.3.5 (solubility) and 8.3.1.3.6 (dynamic transport). Batch techniques, modified to accommodate the much smaller sample sizes, will be used to measure sorption. If any sorption is measured, then the use of sorption coefficients alone may not accurately predict the transport of sorbed radionuclides. Experiments investigating the transport of radiocolloids and particulates will be done under Investigations 8.3.1.3.6. Activity 8.3.1.3.6.1.5 (filtration) will investigate how this transport occurs through porous matrix and through fractured columns. The results of these experiments will direct the scope of this sorption activity. Data generated in this activity will not only support Investigation 8.3.1.3.6 but will contribute to the sorption data base and be used to support transport calculations by performance assessment.

Parameters

The data needed are as follows:

1. Particulates from Yucca Mountain.
2. Identification of particulate composition.
3. Size distribution of particulates.
4. Estimate of size limit for transportable particulates (Investigation 8.3.1.3.6).

The data gathered are as follows:

1. Sorption coefficients on particulates.

Table 8.3.1.3-4. General test matrix to be used in measuring batch sorption coefficients in ground waters of varying compositions^a

Element	Solid phase ^b	Sources of ground water ^c
U	T1 T2 T3 _{dv}	USW H-3 UE-25p#1 AW1,2,3
Pu	T1 _z T2 _v T3 _{dv}	USW H-3 UE-25p#1 AW1,2,3
Np	T1 _z T2 _v T3 _{dv}	USW H-3 UE-25p#1 AW1,2,3
Am	T1 _z T2 _v T3 _{dv}	USW H-3 UE-25p#1 AW1,2,3

^aAll experiments done under ambient laboratory conditions. Data to be compared with results using well J-13 water (Activity 8.3.1.3.4.1.1).

^bT1 = zeolitic tuff; T2_v = vitric tuff; T3_{dv} = devitrified tuff.

^cUSW H-3 AND UE-25p#1 are wells near Yucca Mountain; AW1, 2, 3 refers to artificially prepared ground water made by spiking well J-13 water.

Description

This activity involves the following steps: (1) collection of particulate and colloid material and its identification and (2) sorption measurements on the particulates. Particulate (and colloid) material will be obtained by filtering ground waters pumped from well J-13 and any other working wells available at the time of collection. This material will be identified by x-ray diffraction (XRD) and scanning electron microscope (SEM) analysis. Because of very limited sample availability, batch testing over the range of radionuclide concentrations and oxidation states, ground-water compositions and other variables measured in previously described batch studies, may not be practical. On the basis of the analyses of results from other batch tests, the values of these variables showing the most conservative sorption, but still consistent with site conditions, can be selected in order to set up a smaller test matrix for the particulate tests. Transport experiment results (Investigation 8.3.1.3.6) and transport calculations will also be used to limit the testing activities. The particulate-colloid sorption tests will not be initiated until preliminary testing and analysis is completed for Activities 8.3.1.3.4.1.1 through 8.3.1.3.4.1.3 and Investigation 8.3.1.3.6 to allow definition of the test matrix. More elaboration on this activity will be given in the study plan.

Methods and technical procedures

The methods and technical procedures are to be developed for sorption measurements on particulates. It is anticipated that standard batch sorption procedures can be adapted for these studies.

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8.3.1.3.4.1.5 Activity: Statistical analysis of sorption data

Objectives

The goal of this activity is to produce statistical correlations and error estimates. Various statistical approaches will be used on the sorption data base, as provided by the statistical analysis system for Los Alamos National Laboratory, to (1) determine those variables (e.g., mineralogy, ground-water composition, and atmosphere) having the most profound effect on the sorption coefficients; (2) predict sorption coefficients as a function of mineralogy and, perhaps, ground-water composition; (3) estimate errors associated with predicted sorption coefficients; and (4) identify gaps in the experimental data. The results of these analyses will be used to bound sorption coefficients to be used in Investigation 8.3.1.3.7 and for performance assessment in Issue 1.1 (Section 8.3.5.13).

Parameters

The data needed are as follows:

1. Sorption coefficients as a function of numerous variables (Activities 8.3.1.3.4.1.1 through 8.3.1.3.4.1.4 and Study 8.3.1.3.4.2).
2. Mineralogy of tuff samples (Investigation 8.3.1.3.2).
3. Ground-water composition (Investigation 8.3.1.3.1).

The data gathered are as follows:

1. Correlations of sorption with numerous variables.
2. Bounds on sorption coefficients under various conditions.
3. Estimates of errors on predicted sorption coefficients.

Description

Regression techniques will be used to investigate factors that may significantly influence sorption ratio estimates. The statistical analysis system package is being used on a trial basis for these analyses. The computer packages of SOSI; data base management (sorting) and DATATRIEVE, a data management package will also be used.

8.3.1.3.4.2 Study: Biological sorption and transport

Objectives

The objective of this study is to determine what effects microorganisms have on the movement of radioactive waste (i.e., effects on sorption) and to determine if microbial activities play a role significant enough to be included in a performance calculation for Yucca Mountain. This study will identify the quantity, location, and characteristics of past and future

organic materials used at the site and their susceptibility to microbiological degradation. The effect that these microorganisms will have on the movement of actinides will be determined through analysis of their effect on ground-water quality, colloid formation, effect on solubility, or by direct sorption of the actinides.

This study is being undertaken because (1) large amounts of biodegradable organic materials have been, or will be, introduced into or near the potential repository area, (2) microorganisms isolated from the NTS are capable of biodegrading these organic materials and have been shown to bind plutonium-239 exhibiting an R_d of 10,000, and (3) the mobility of the microorganisms through the tuff and their effect on the solubility of radioactive wastes is unknown.

Data generated will be included in the sorption data base and used to support work in Activity 8.3.1.3.6.1.5 (filtration) and to support transport calculations (Investigation 8.3.1.3.7 and Issue 1.1, Section 8.3.5.13).

Parameters

The data needed are as follows:

1. Ground-water chemistry (Investigation 8.3.1.3.1).
2. Flow rates and directions of water flows in the unsaturated and saturated zone.
3. Sorption of actinides on crushed tuff (Study 8.3.1.3.4.1).

The data gathered are as follows:

1. Sorption on microorganisms and data on steady state, v-max, actinide speciation, and cellular location.
2. Data indicating potential for the transport of radioactive wastes by microorganisms and microorganism by-products. Data on colloidal properties and mobility of microorganisms.
3. Understanding of magnitude of microbial activity on retardation and transport of radionuclides.
4. Identification of microorganisms.

Description

The following tasks are included in this study: (1) determination of the growth of microorganisms on fluid (e.g., drilling fluid), (2) evaluation of the influence of microorganism on the movement of actinides, and (3) determination of the binding constant of microorganisms to actinides. Before sorption testing can be done, bacteria must be isolated and cultured in the laboratory. To isolate the bacteria, samples are taken from soils that have received discharges of drilling fluids during the course of the drilling operations and are, therefore, considered likely to contain microorganisms capable of biodegrading drilling fluids (USW G-1 and UE-25c#2).

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The samples are placed in sterile bottles and immediately returned to the laboratory for analysis. A mineral salts medium is used to culture these microorganisms. A controlled amount of drilling fluid is added as the only energy source for microorganism growth. Solid media are inoculated with washings of the soil samples. After aerobic or anaerobic incubation at room temperature, isolated bacterial colonies growing on the medium are transferred to fresh media and incubated to obtain pure colonies. Colony morphology and microscopic characteristics and viscosity can then be determined. The growth of microorganisms indigenous to tuff from Yucca Mountain will also be studied utilizing exploratory shaft samples.

This study will determine the sorption ratio of radionuclides on bacteria. A steady-state sorption ratio for the bacteria and radionuclides will be determined. This is necessary to affix a value to bacterial sorption of radionuclides. The cellular location (internal versus external) of actinide sorption will be investigated to determine the stability of sorption. Furthermore, this study will determine if microorganisms preferentially sorb different oxidation states of a radionuclide. Sorption testing will be done primarily with plutonium, americium, and neptunium, on core samples from USW G-4 (1,501 ft) using well J-13 water. Samples from the exploratory shaft will be used when they become available.

The previously unstudied effects of microorganisms on the movement of actinides through fractured and unfractured tuff will be examined by determining the movement of plutonium, americium, and neptunium sorbed to bacteria. This work will determine if the movement is a function of the biological mobility or the colloidal dispersion of the bacteria. Furthermore, the movement of radionuclides chelated by bacterial metabolites (i.e., siderophores) through fractured and unfractured tuff will be determined.

Methods and technical procedures

Standard microbiological laboratory equipment and supplies will be used. Furthermore, standard microbiological laboratory procedures will be used using methods from the following references:

1. Manual of Methods for General Bacteriology. American Society for Microbiology (Gerhardt, 1981).
2. Standard Methods for Examination of Water and Waste Water. American Public Health Association, American Water Works Association, Water Pollution Control Federation (APHA, AWWA, WPCF, 1985).
3. Bergey's Manual of Systematic Bacteriology. Holt (1984).

Each of these references has been subjected to extensive peer review before publication; therefore, they are widely accepted among microbiologists as containing methods that will give consistent and reproducible results. Established procedures for sorption testing should be easily adapted to laboratory testing using microorganisms.

Procedures to be written include:

1. Isolation of microorganisms.

2. Growth rate of bacteria.
3. Sorption of actinides by microorganisms.
4. Chelation of actinides by microorganisms.
5. Effects of microorganisms on colloids.

Other technical procedures are given in the following table.

Method	Technical procedure		Date
	Number	Title	
Crushed Rock Column Method	TWS-CNC-DP-15, R1	Crushed rock column studies	30 Aug 82
Batch Sorp- tion Method	TWS-CNC-DP-05, R1	Sorption, desorption ratio determination of geologic materials by batch methods	30 Aug 82
	TWS-MSTQA-QP-14, R1	Research and development (experimental) procedure	19 May 86

8.3.1.3.4.3 Study: Development of sorption models (isotherms)

Objectives

The purpose of this work is to develop alternative models to predict sorption behavior of key radionuclides at Yucca Mountain using the data generated from the previously described studies and from the C-well testing activities described in Section 8.3.1.2.3. The models will describe the extent of sorption to be expected as a function of the mineralogy, ground-water composition, and radionuclide concentration expected along the potential transport paths from the repository to the accessible environment. This model will be used in Performance Issue 1.1 (Section 8.3.5.13), by Investigation 8.3.1.3.7, and by Investigation 8.3.1.3.6 as part of the description of radionuclide movement from the repository to the accessible environment.

Parameters

The data needed are as follows:

1. Suitable data gathered from the previously described studies.
2. Water composition and stratigraphy of Yucca Mountain.

The data gathered are as follows:

1. Models (isotherm) describing sorption at Yucca Mountain.

Description

After an inventory and evaluation of the quality of the raw sorption data available in the data base, attempts will be made to determine the suitability of using equilibrium models (isotherms) on the sorption data. Modeling may be done by using empirical or theoretical expressions. When data are available that do not show equilibrium conditions, kinetics models may be used to provide estimates of either pseudo-equilibrium or equilibrium sorption. Models may be used to provide estimates for a pseudo-equilibrium state if necessary. Conventional isotherm expressions (linear and nonlinear) will be evaluated as will nonconventional isotherms (e.g., modified Freundlich). The effectiveness of these isotherms will be compared by defining statistical significance of curve fitting from regression analysis techniques that are applicable to the collected data. If the use of the modified Freundlich expression is successful, the derived empirical coefficients can be used to develop maps with isobetas (curves of equal sorption heterogeneity) and iso- K_d s (curves of equal average sorption behavior). Using stratigraphic information, these maps could then be developed on the Yucca Mountain domain. Such maps would provide a convenient representation of sorption behavior for purposes of the performance assessment tasks of the Information Needs 1.1.3, 1.1.4, and perhaps 1.1.5 (Sections 8.3.5.13.3 through 8.3.5.13.5).

8.3.1.3.4.4 Application of results

The information derived from the studies and activities described above will be used in the following issues, information needs, and investigations:

<u>Issue, investigation, or information need</u>	<u>Subject</u>
1.1.1	Site information needed to calculate releases to the accessible environment (Section 8.3.5.13.1)
1.1.3	Calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release scenario classes (Section 8.3.5.13.3)
1.1.4	Determination of the radionuclide releases to the accessible environment associated with realizations of the potentially significant release scenario classes (Section 8.3.5.13.4)
1.1.5	Probabilistic estimates of the radionuclide releases to the accessible environment considering significant release scenarios (Section 8.3.5.13.5)
1.8	NRC siting criteria (Section 8.3.5.17)
8.3.1.3.5	Radionuclide retardation by precipitation processes along flow paths to the accessible environment

- 8.3.1.3.6 Radionuclide retardation by dispersive-diffusive-advective transport processes along flow paths to the accessible environment
- 8.3.1.3.7 Radionuclide retardation by all processes along the flow paths to the accessible environment

The data generated in these studies along with the model of sorption data and statistical analysis of these data, directly support the calculation of system performance described in Issue 1.1. Combined with data from Investigations 8.3.1.3.5 through 8.3.1.3.7, the retardation factors required for radionuclide transport calculations in Issue 1.1 will be provided for the range of conditions at Yucca Mountain, both expected and unexpected.

8.3.1.3.4.5 Schedule and milestones

This investigation contains three studies: 8.3.1.3.4.1 (batch sorption studies), 8.3.1.3.4.2 (biological sorption and transport), and 8.3.1.3.4.3 (development of sorption models). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

All of the studies associated with this investigation are ongoing. Availability of samples is the major constraint on completing the studies. Laboratory testing, however, can be initiated with core material presently available and will be supplemented with additional core material from the drilling program and the exploratory shaft. Sampling is required for the activities involving sorption by particulates, colloids, and microbes, but no new drillholes are needed for these activities. The modeling and statistical analyses can proceed in parallel and interact with the experimental activities. Experimental work for Investigation 8.3.1.3.6, and to a lesser degree, Investigation 8.3.1.3.5, will proceed in parallel with the batch sorption study because results are needed for proper interpretation of column experiments in Investigation 8.3.1.3.6.

The activity to determine sorption on particulates (Study 8.3.1.3.4.1) is constrained by Investigation 8.3.1.3.6, which will investigate the potential for particulate transport and define the scope of this activity. Furthermore, this activity requires particulate samples from Yucca Mountain ground water. At present, a very small amount of particulates has been recovered over long pump times from well J-13. If there is a need to reinitiate collection, it is not likely that a significant amount of particulates would be collected unless other water-producing wells show significant particulate content.

The continuation of the sorption work on actinide species (Study 8.3.1.3.4.1) is constrained by the development of the photoacoustic spectroscopy method (Study 8.3.1.3.5.1). This method allows actinide species to be

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identified and quantified at concentration less than 10^{-6} M. This is critical for interpreting batch sorption measurements on actinide species.

The study numbers and titles corresponding to the timelines are shown on the left of the preceding figure. Points shown on the timelines represent major events or important milestones associated with the studies. Solid lines represent study durations. Dashed lines represent interfaces. The data input and output at the interfaces are shown by circles.

The points on the timelines and the data input and output at the interfaces are described in the following table.

Point number	Description
1	Development and application of photoacoustic spectroscopy is completed (Study 8.3.1.3.5.1). This development constrains the sorption work on actinide species.
2	Milestone R505. Summary report available on effects of ground-water composition on sorption. A large part of the experimental work for this study assumes a ground-water composition for the unsaturated zone. However, before the experimental data are considered finalized, this ground-water composition must be confirmed by data from Investigation 8.3.1.2.2.
3	Data on the potential for particulate transport from Investigation 8.3.1.3.6.
4	Milestone R382. Report available on sorption on particulates.

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Point number

Description

- 5 Milestone M315. Final report available on sorption isotherms.
 - 6 Milestone R385. Sorption model complete.
 - 7 Report available on statistical evaluation of sorption data.
 - 8 Milestone M376. Final sorption report available. This report completes this study as well as the investigation. The data generated from this investigation will be combined with the data from Investigations 8.3.1.3.4 through 8.3.1.3.7 to provide the retardation factors required for radionuclide transport calculations for the range of conditions at Yucca Mountain, both nominal and disturbed.
 - 9 Milestone Q002. Report available on the summary of results defining radionuclide retardation at Yucca Mountain. This is a higher-level report summarizing the results of Investigations 8.3.1.3.4 through 8.3.1.3.7 and will be compiled as part of Study 8.3.1.3.7.1.
 - 10 Milestone Z484. Report available on sorption of actinides by microorganisms indigenous to Yucca Mountain.
 - 11 Milestone Z361. Final report available on the magnitude of microbial activity on retardation and transport of nuclear waste elements at Yucca Mountain.
 - 12 Milestone Z372. Final progress report available on sorption modeling. This report completes the study. The results will feed Study 8.3.1.3.4.1.
- 8.3.1.3.5 Investigation: Studies to provide the information required on radionuclide retardation by precipitation processes along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the data chapters and support documents provide a technical summary of existing data relevant to this information need:

SCP section

Subject

4.1.3.4.1	Processes affecting radionuclide concentrations and speciation in solution

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<u>SCP section</u>	<u>Subject</u>
4.1.3.4.2	Solubility and speciation data
4.1.3.4.3	Solubility modeling

Parameters

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

1. Solubility or concentration limits of important waste elements.
2. Ability of waste elements to form natural colloids.
3. Measurements of solubility as outlined by a NRC technical position "Determination of Radionuclide Solubility in Ground Water for Assessment of High-Level Waste Isolation" (NRC, 1984).
4. Sensitivity of solubility limits to variation in controlling parameters (theoretical).
5. Speciation of waste elements.
6. Models that provide theoretical framework for understanding solubility, speciation and colloid formation.

Parameters that control solubility and speciation include the following:

1. Water chemistry (dissolved constituents, pH, Eh).
2. Water temperature.
3. Radiation field.

Purpose and objectives of the investigation

The purpose of this investigation is to supply input data for calculations of radionuclide transport along potential transport pathways from the repository to the accessible environment at the Yucca Mountain site. These calculations are required to address the overall system performance objective for radionuclide release in 10 CFR 60.112 (Issue 1.1, Section 8.3.5.13) and in making findings on the postclosure system guideline and the technical guidelines for geochemistry in 10 CFR 960.4 (Issue 1.9, Section 8.3.5.18), and in the siting criteria of 10 CFR 60.122 (Issue 1.8, Section 8.3.5.17). Specifically, Issue 1.1 requires estimates of the means and standard deviations of the solubility limits of radionuclide-bearing compounds under anticipated water chemistry conditions.

There are two ways that radionuclides can be transported with water moving through the repository toward the accessible environment. Radionuclides can travel as dissolved species in the water and as particulate material carried by the water. This investigation will supply data and models that can be used to calculate concentration limits (solubilities) of dissolved waste elements in local water at the Yucca Mountain site; these concentration limits will be used directly by performance assessment models

of radionuclide transport. This investigation will also supply data and models describing the formation and stability of natural radionuclide colloids in local water. This information will be used in assessing the likelihood of colloid transport (Section 8.3.1.3.7) and by Issue 1.1 in the total systems performance calculation. Radionuclide solubility and speciation data and models will also be used to support modeling of sorptive behavior as a function of water chemistry and waste element chemistry (Section 8.3.1.3.4).

Technical rationale for the investigation

It is not practical to measure solubilities of all waste elements that may exist in radioactive waste under all conditions that may occur at the repository or along flow paths to the environment. The technical approach used to select waste elements for solubility measurements and to select the conditions of these measurements is based on three criteria:

1. Select waste elements that have radionuclides present in large quantities relative to their EPA release limits (40 CFR 191, Appendix A, Table I).
2. Select waste elements that are likely, based on present knowledge of waste element chemistry and expected repository conditions, to have solubility limits during transport.
3. Select conditions for solubility experiments that will bound expected conditions at the repository or along flow paths to the environment.

The radionuclides of primary concern are discussed in Section 4.1.3.1.1. A review of the chemistry of important waste elements is also given in Section 4.1.3.4. These sections, along with descriptions of the expected water chemistry (Section 4.1.2) and changes in water chemistry resulting from waste emplacement (Section 4.2) form the basis for the selections of solubility experiments discussed below. The initial emphasis is on americium, plutonium, and neptunium solubility and speciation; measurements are also planned for uranium, thorium, radium, zirconium, tin, and nickel. These latter elements are included in the testing program so that the concentrations can be used as upper bounds for transport assessments, since sorption work is not planned for these elements except uranium at present.

Consideration has also been given to the generic technical position entitled "Determination of Radionuclide Solubility in Ground Water for Assessment of High-Level Waste Isolation" (NRC, 1984) in the selection of these experiments. This technical position serves as guidance in the preparation of detailed plans for waste element solubility experiments. It requires that any site that elects to use solubility to limit waste element release must design experiments to determine the solubility under site-specific conditions. The experiments discussed in this section are meant to satisfy the requirements of this technical position.

The various parameters that influence solubility can be divided into three groups:

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1. Those parameters that define the conditions controlling solubility (water chemistry, temperature, and radiation field).
2. Those parameters that define element behavior (waste-element chemistry, colloid behavior, and kinetic data).
3. Those parameters necessary to understand precipitation processes (models).

The primary areas of choice in designing solubility experiments involve the conditions of the experiment and the elements chosen. For solubility conditions, five specific parameters have been considered in designing the experiments: (1) water compositions including pH and Eh (speciation of redox sensitive radionuclides), (2) temperature, (3) identity of the solid controlling solubility, (4) the presence of other solids, and (5) radiation effects such as radiolysis. Solubilities that represent upper limits on waste element concentrations are of primary concern in defining the experiments. However, solubility data without an understanding of the basic processes involved are of only limited value. Thus, the results that will aid in understanding and in solubility modeling are stressed.

An important part of this investigation is the modeling of solubility and speciation of waste elements (Section 4.1.3.4). Modeling will be used for two purposes: to assess the importance of the various parameters that influence solubility and speciation (e.g., water composition) and to calculate solubilities under conditions not directly covered by the solubility experiments. Modeling of solubility and speciation of waste elements has concentrated on equilibrium methods; this emphasis will continue. Equilibrium models require thermodynamic data for solids that are likely to precipitate and for aqueous species that may be present in the water. These data are being developed from literature sources and from the solubility and speciation data collected as part of this investigation. If nonequilibrium or kinetic models are found necessary to describe some aspects of waste element solubility, they will be used as needed.

Movement of natural radionuclide colloids represent a transport mechanism that may be active under site conditions, and may not act to limit the effectiveness of the sorption barrier in retarding migration. To assess the potential for colloid transport (Section 8.3.1.3.4), information is needed about the likelihood of colloid formation under water conditions at the Yucca Mountain site and the stability of colloids once formed. Two waste elements that may form stable colloids under these conditions have been identified; they are plutonium and americium (Section 4.1.3.4). Because these elements also contribute significant activity to the waste inventory colloid formation and stability experiments are planned with them.

8.3.1.3.5.1 Study: Dissolved species concentration limits

The goal of this study is to provide solubility or concentration limits for dissolved species of important waste elements under conditions that are characteristic of the repository and along flow paths toward the accessible environment. The importance of solubility has been highlighted by the NRC

technical position entitled "Determination of Radionuclide Solubility in Ground Water for Assessment of High-Level Waste Isolation" (NRC, 1984). The experiments described under this study are meant to satisfy the requirements of this technical position.

The results of this study will be used in the assessment of radionuclide releases to the accessible environment and to assess the existence of favorable or potentially adverse conditions at the site.

8.3.1.3.5.1.1 Activity: Solubility measurements

Objectives

The goal of this activity is first to specify the conditions under which solubility experiments will be carried out and then to measure solubilities or concentrations limits of important waste elements under these conditions.

Parameters

The data needed are as follows:

1. Water chemistry (composition, pH, Eh, oxidation-reduction).
2. Water temperature.
3. Radiation environment.

The data gathered are as follows:

1. Solubilities (concentration limits).
2. Identity of solids controlling solubility.
3. Oxidation states and speciation of the dissolved species in solution.

Description

Solubility measurements are planned in three water compositions, a neutral electrolyte, well J-13 water, and drillhole UE-25p#1 water. These compositions range from a simple system with no complexing except hydrolysis through well J-13 water (sodium bicarbonate water), which is expected to be close to water compositions in the unsaturated zone, to drillhole UE-25p#1 water (calcium bicarbonate water), which is from the carbonate aquifer and has the highest solute concentration of any water observed in the vicinity of Yucca Mountain. Table 8.3.1.3-5 shows the test conditions for water used in measuring the solubility of waste elements.

The pH of the waters will be varied for the measurements (neutral electrolyte at pH 6, 7, and 8.5; well J-13 water at pH 6, 7, and 8.5; drill-hole UE-25p#1 water at pH 6, 7, 8.5, and 9.5). Solubility experiments will be performed at 25, 60, and 90°C for well J-13 water, and at 25 and 60°C for drillhole UE-25p#1 water and the neutral electrolyte. These temperatures cover the range of expected conditions where liquid water may be present.

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All measurements will be done under oxidizing conditions (oxygen saturated) to simulate the conditions found in most waters from Yucca Mountain and vicinity; this procedure will result in solubilities that are equal to or greater than solubilities that would be measured under reducing conditions. Data from tests measuring changes in water chemistry resulting from interaction with the host rock or waste package materials indicate only minor compositional changes (Section 4.1). No solubility measurements are planned in which the water compositions are modified to account for these effects. If future data from experiments involving Yucca Mountain water and local minerals or waste package material show significant water composition changes, this decision will be reviewed.

An attempt will be made to approach steady state in the solubility measurements from both undersaturation and oversaturation. Tests approaching steady state from oversaturation will be done first and the solids that precipitate will be characterized. Where possible, these solids will be prepared and used for experiments that approach steady state from undersaturation. This procedure has the advantage of not specifying the solid that controls solubility, but of allowing the system under investigation to determine the solid that will precipitate.

There are no plans to include other solids such as tuff from Yucca Mountain in the solubility experiments. These solids are not needed to control water composition and would only complicate interpretation of the experiments. The presence of other solids will not increase the solubility of waste elements as long as these solids do not alter the water composition. The potential effects of solids on solubility will be addressed in Study 8.3.1.3.6.1.

There are no plans to perform solubility experiments in the presence of gamma radiation. The effects of gamma radiation should not be significant by the end of the containment period. A number of the waste elements have radionuclides with high specific alpha activities. The effects of alpha-radiation will be investigated by performing solubility experiments with two isotopes of plutonium (Pu-239 and Pu-242) and americium (Am-241 and Am-243) that have different specific activities.

The choices of waste elements for the solubility experiments are based on the importance of each waste element (Section 4.1.3.1.1) and the likelihood of solubility having an influence on transport (Section 4.1.3.4). Solubility measurements will first be done for americium, plutonium, and neptunium. At a later date, measurements will begin for uranium, thorium, radium, zirconium, tin, and nickel. Solubility measurements are not planned for technetium, cesium, iodine, or strontium. Although radionuclides of these elements make important contributions to the activity of waste, they may have high solubilities under conditions at the Yucca Mountain site; thus solubility might not limit their transport.

Methods and technical procedures

Concentration limits of waste elements in solution will be determined by analysis of solutions that have reached steady state from oversaturation.

Table 8.3.1.3-5. Test conditions for water used in solubility measurements^a

<u>Water</u>	<u>pH</u>	<u>Temperature</u>
J-13	6, 7, 8.5	25, 60, 90°C
UE-25p#1	6, 7, 8.5, 9.5	25, 60°C
Neutral electrolyte	6, 7, 8.5	25, 60°C

^aWaters will be oxygen saturated.

The identity of solids controlling solubility will be determined by x-ray diffraction analysis (XRD), neutron activation analysis (NAA), and/or conventional chemical analysis of solids separated from the solutions. The identity of the oxidation states of dissolved species will be determined by spectroscopy or by separation and analysis of the different oxidation states. The technical procedures for this activity are in preparation.

8.3.1.3.5.1.2 Activity: Speciation measurements

Objectives

The goal of this activity is to identify important aqueous species of waste elements under conditions described in Activity 8.3.1.3.5.1.1 and determine their formation constants. This will be done when important data are unavailable from any other source outside the NNWSI Project. This activity is concurrent with the measurement of concentration limits in Study 8.3.1.3.5.1, and is intended to fill any data gaps so that this solubility data can be explained by the thermodynamic modeling (Activity 8.3.1.3.5.1.3).

Parameters

The data needed are as follows:

1. Important waste elements for which speciation measurements are needed (Activity 8.3.1.3.5.1.3).
2. Experimental conditions (Activity 8.3.1.3.5.1.1).
3. Water samples (Investigation 8.3.1.3.1).

The data gathered are as follows:

1. Determination of the identity and measurement of the formation constants of aqueous species of waste elements.

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Description

For this activity, experiments will be performed with waste elements in solution to determine the identity of the aqueous species formed and their concentrations under conditions that can be used to determine their formation constants. Under the conditions expected at Yucca Mountain, carbonate is expected to play an important role in plutonium and americium speciation. Initially, plutonium and americium carbonate speciation will be studied.

Methods and technical procedures

Spectroscopic methods will be used to identify aqueous species and to measure their concentrations. In addition, a new and very sensitive measurement technique, photoacoustic spectroscopy, is being developed for this activity. Technical procedures are under development for this activity.

8.3.1.3.5.1.3 Activity: Solubility modeling

Objectives

The goal of this activity is to develop the thermodynamic models and data needed to calculate waste element solubilities over the range of conditions expected at the site.

Parameters

The data needed are as follows:

1. Computer code EQ3/6.
2. Thermodynamic data from literature and from Activity 8.3.1.3.5.1.1 and Activity 8.3.1.3.5.1.2.

The data gathered are as follows:

1. Models and data to calculate waste element solubilities (both equilibrium and nonequilibrium or kinetic models).

Description

This activity will collect thermodynamic data from the literature and apply existing chemical equilibrium models to the solubility data developed in Activity 8.3.1.3.5.1.1 and to data from any other pertinent solubility experiments in order to test the applicability of the models and data. Where data on the existence of formation constants of aqueous species are found to be inadequate, recommendations for measurements will be made to Activity 8.3.1.3.5.1.2. If equilibrium models are found to be inadequate to describe any solubility data, nonequilibrium models that involve kinetic behavior (nucleation, precipitation, dissolution, or oxidation-reduction kinetic models) will be developed. These models will be used to test the consistency of experimental data and to assess the sensitivity of the solubilities to variations in controlling parameters such as water composition.

Methods and technical procedures

No specific methods are applicable to this activity. No technical procedures are applicable to this activity. The user's manual for EQ3/6 will be the technical procedure for use of the EQ3/6 code.

8.3.1.3.5.2 Study: Colloid behavior

The goal of this study is to determine the stability of waste element colloids under expected site-specific conditions that might be encountered at the repository or along flow paths toward the accessible environment. The results of this study will be used in the assessment of radionuclide releases to the accessible environment and to assess the existence of favorable or potentially adverse conditions at the site.

8.3.1.3.5.2.1 Activity: Colloid formation characterization and stability

Objectives

The objective of this activity is to determine the formation and stability of waste element colloids. Two waste elements that may form colloids have been identified; they are plutonium and americium (Section 4.1.3.4). This information will be used by performance Issue 1.1 (Section 8.3.5.13) and Investigations 8.3.1.3.4 and 8.3.1.3.6.

Parameters

The data needed are as follows:

1. Experimental conditions (Activity 8.3.1.3.5.1.1).
2. Water samples (Investigation 8.3.1.3.1).

The data gathered are as follows:

1. Waste elements that form natural colloids.
2. Specific condition under which colloids form.
3. Physical and chemical characteristics of the colloids.
4. Stability of colloids.

Description

Plutonium and americium have been reported to form natural colloids. Because these elements also contribute significant activity to the waste inventory, colloid formation and stability experiments are planned for these elements. The conditions likely to promote colloid formation, the stability of the colloids, and the disposition of the waste element species as the colloids break up will be described. Colloid breakup involves the redissolution or degradation of the colloid and the eventual fate of the component radioactive element(s).

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The conditions to be studied for colloid formation, stability, and break up will include pH, Eh, temperature, concentration of the element, etc. The effect of these conditions on colloid size, density, composition, charge, and chemical reactivity will be studied.

Methods and technical procedures

Colloid concentrations will be studied using well established phase separation techniques (filtration, centrifugation) to measure the amount of colloid present in suspension. These techniques, in addition to in situ measurements (e.g., autocorrelator photon spectrometer) will be used to characterize colloid size distribution. Colloid stability will be determined by studying these properties (quantity and size distribution) as a function of time. The technical procedures for this activity are in preparation.

8.3.1.3.5.2.2 Activity: Colloid modeling

Objectives

The objective of this activity is to develop models and model parameters to calculate natural colloid concentrations and stability and to describe the disposition of the waste element species as the colloids break up. Data collected for plutonium colloids indicate that true equilibrium is not obtained in solutions with colloids present because of alpha radiolysis products. A preliminary kinetic model involving oxidation and reduction of soluble plutonium species and plutonium colloids has been partially successful in describing this behavior, but further model development is needed. An americium colloid model will also be required.

Parameters

The data needed are as follows:

1. Experimental data on colloid behavior (Activity 8.3.1.3.5.2.1).

The data gathered are as follows:

1. Models and model parameters to calculate natural colloid concentrations and stability.

Description

This activity will use techniques for modeling chemical and physical systems to describe the data collected in Activity 8.3.1.3.5.2.1).

Methods and technical procedures

No specific methods or technical procedures are applicable to this activity.

8.3.1.3.5.3 Application of results

The information derived from the studies and activities just described will be used to calculate concentration limits of dissolved waste elements, speciation of waste elements, and concentrations of natural colloids of waste elements in water passing through the repository and along flow paths toward the environment. These data will be used in a number of analyses and assessments concerning radionuclide release to the accessible environment (Issues 1.1, 1.2, and 1.3, Sections 8.3.5.13 through 8.3.5.15), higher level findings involving geochemistry (Issue 1.9, Section 8.3.5.18), and NRC Siting Criteria (Issue 1.8, Section 8.3.5.17). Specifically, these data will be implicitly used by Issue 1.1 in the formulation of transport phenomenology.

Waste element concentration limits and, possibly, natural colloid concentrations will be used as input to calculate releases from the engineered barrier system (Information Need 1.5.4, Section 8.3.5.10.4) and cumulative releases to the accessible environment along the water pathway (Information Needs 1.1.4 and 1.1.5, Section 8.3.5.13.4 and 8.3.5.13.5). Speciation of waste elements will be used in assessing retardation by sorption (Investigation 8.3.1.3.4).

Evaluation of favorable and potentially adverse conditions requires a knowledge of how solubility can limit radionuclide concentrations, of the speciation of waste elements in local water, and of whether natural colloids will form and be stable. This information will be used to evaluate Issue 1.8 and to support certain higher level findings (qualifying and disqualifying conditions) in Issue 1.9. Solubility limits on waste elements are critical for the realistic calculation of cumulative releases to the accessible environment required by 10 CFR 960.3-1-5 (Issue 1.9).

8.3.1.3.5.4 Schedule and milestones

This investigation contains two studies: 8.3.1.3.5.1 (dissolved species concentration limits) and 8.3.1.3.5.2 (colloid behavior). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

Both studies associated with this investigation are ongoing and the only constraint on the initiation of the work described is the availability of the study plans. Laboratory testing can be done without the need for new drill-holes since existing wells can supply the ground waters needed in the experiments. The modeling work can be initiated based on data in the literature and will integrate experimental data as they become available. This integration is an iterative process between additional laboratory work and the development of models to explain the thermodynamic behavior of the radioelements, as well as nonequilibrium aspects of their behavior.

The work in this investigation is tied to Investigations 8.3.1.3.4 (radionuclide sorption) and 8.3.1.3.6 (radionuclide dispersion, diffusion,

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and advection). These data are important for interpreting the batch sorption and the column tests. The results of this investigation will provide corroborating data in support of the column experiments in Investigation 8.3.1.3.6. Currently, the concentrations of tracers used in the column experiments are much lower than the concentrations at which the solubility experiments are conducted.

The development of the photoacoustic spectroscopy method (Study 8.3.1.3.5.1) is in its infancy, but the capability will have a great impact on Investigations 8.3.1.3.4 and 8.3.1.3.6. This technique is considered critical in interpreting and validating the results of these two studies that will support total system performance assessment.

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. Points shown on the timelines represent major events or important milestones associated with the studies. Solid lines represent study durations. Dashed lines represent interfaces.

The points on the timeline are described in the following table.

<u>Point number</u>	<u>Description</u>
1	Milestone Z362. Report available on the development and application of photoacoustic spectroscopy to solubility determinations.
2	Milestone Z363. Report available on the solubility and speciation measurements using photoacoustic spectroscopy.
3	Milestone Z373. Final report available on solubility measurements.

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<u>Point number</u>	<u>Description</u>
4	Milestone R394. Final report available on speciation measurements.
5	Milestone R391. Final report available on EQ3/6 database (for solubility calculations).
6	Milestone M377. Final report available on the solubility of radionuclides in Yucca Mountain water. This report completes this study and the investigation. Completion of this investigation is needed before radionuclide transport assessments are finalized. The work in this investigation is intended to supply data for interim assessments of site performance during site characterization.
7	Milestone Q002. Report available on the summary of results defining radionuclide retardation of Yucca Mountain. This is a higher-level report that summarizes the results of Investigations 8.3.1.3.4 through 8.3.1.3.7 and will be compiled as part of Study 8.3.1.3.7.1.
8	Milestone Z224. Final report available on colloid stability and characterization. This report completes this study.

8.3.1.3.6 Investigation: Studies to provide the information required on radionuclide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

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

<u>SCP section</u>	<u>Subject</u>
4.1.3.5.2	Retardation by matrix diffusion during fracture flow
4.1.3.6	Radionuclide transport
4.1.3.6.1	Transport of suspended solids

Parameters

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

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1. Data on diffusion.
 - a. Longitudinal diffusion.
 - b. Matrix diffusion.
2. Data on diffusion without advection.
3. Data on adsorption.
4. Data on dispersion.
 - a. Hydrodynamic dispersion.
 - b. Channeling.
5. Data on anion exclusion.
6. Data on speciation.
7. Data on sorption kinetics.
8. Data on heterogeneity.
9. Data on colloidal movement.
10. Data on flow in fractured tuff.

Data needed from other investigations are as follows:

1. Hydrologic conditions.
2. Geometry of flow paths.
3. Results of radionuclide sorption in batch tests.

Purpose and objectives of the investigation

The goal of this investigation is to experimentally determine the rate of movement and effective retardation of radionuclides by dispersive, diffusive, and advective processes. Specifically, Issue 1.1 (Section 8.3.5.13) needs experimental evidence that could confirm or deny the theory of advective-diffusive coupling of solute concentrations in matrix and fracture flow. This theory is embodied in the transport model for fracture flow currently used in the transport model of TOSPAC (described in Issue 1.1). Issue 1.1 states that this information is crucial in establishing the credibility of transport phenomenology embodied in any models used to assess the consequences of the release scenarios associated with the water pathways.

This investigation will provide the effective diffusivity of radionuclide species in the matrix of each rock unit in the saturated and unsaturated zones to the total system performance Issue 1.1. The parameter called for by Issue 1.1 is an empirical parameter measuring the effective diffusivity of the matrix-fracture interface (constrictivity-tortuosity factor) for the saturated and unsaturated zones. Issue 1.6 (Section 8.3.5.12), which must determine the pre-waste-emplacement ground-water travel time is also calling for diffusion data from this investigation. Furthermore, permeabilities at the matrix-fracture interfaces are required by Issue 1.1. An

understanding of dispersion processes and the contributions of sorption to radionuclide retardation in an advective system is necessary to develop the required parameters for Issue 1.1. Issue 1.1 also requires distribution coefficients for the rock matrix in the saturated and unsaturated zone beyond the disturbed zone. The bulk of the sorption data will be gathered in Investigation 8.3.1.3.4, but if these data are to be used in a dynamic system, sorption (distribution coefficients) must be evaluated in this dynamic system. This investigation will provide that evaluation and support of the use of the sorption data by Issue 1.1. The results of this investigation, however, will first be assessed by Investigation 8.3.1.3.7 before being used in Issue 1.1. Finally, Issue 1.1 requires knowledge of whether a precipitate (colloid) can be transported through the porous and fractured rock.

Technical rationale for the investigation

This investigation is divided into two studies that have been designed to understand how radionuclides are transported (retarded) by advective, diffusive, and dispersive processes. These studies are the (1) dynamic transport column study (Study 8.3.1.3.6.1), and (2) diffusion study (Study 8.3.1.3.6.2). The dynamic transport column study includes five activities: crushed tuff column tests (Activity 8.3.1.3.6.1.1), mass transfer kinetics (Activity 8.3.1.3.6.1.2), unsaturated tuff column (Activity 8.3.1.3.6.1.3), fractured tuff column (Activity 8.3.1.3.6.1.4), and filtration (Activity 8.3.1.3.6.1.5).

The dynamic transport and diffusion study test matrix is shown in Table 8.3.1.3-6. This table represents all the tests and analyses that will be conducted as part of this investigation and presents the processes for which measured and derived data will be gathered by this task. The matrix shows which tasks will produce primary data (p) on each process listed and where effects of processes are observed but not used as a primary source of data (a).

The following text will briefly describe each test represented in the matrix. The first six tests listed represent activities and tests under the dynamic transport column study (Study 8.3.1.3.6.1). The last test listed is Study 8.3.1.3.6.2 (diffusion).

The crushed tuff column activity (Activity 8.3.1.3.6.1.1) will measure the rate of movement of radionuclides relative to tritiated water and other well-defined chemical species or colloids through crushed tuff columns. The primary data resulting from this test are sorption coefficients and evidence of speciation. Kinetic, matrix diffusion, longitudinal diffusion, and hydrodynamic dispersion effects will also be observed in these tests. These tests will be used to support the use of K_d s produced from the batch experiments (Investigation 8.3.1.3.4), by Issue 1.1. Differences between this study and the batch studies will be investigated in Study 8.3.1.3.6.1. Speciation information will be used to provide elucidation relative to other processes such as diffusion and dispersion and will be used to reinterpret batch distribution coefficients. The process of anion exclusion is significant because it could reduce the transport time of the anionic radionuclides through the zeolitic tuff. The observation of colloid breakthrough in this study will establish the need to treat colloidal movement (Activity 8.3.1.3.6.1.5 (filtration)).

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The mass transfer kinetic activity (Activity 8.3.1.3.6.1.2) will investigate the kinetics of sorption as a function of water velocity. The mass transfer kinetic activity will provide data to validate or support the use of retardation factors based on static measurements by performance Issue 1.1. The activity has two parts: tests run with crushed tuff columns and tests run with solid rock columns. The crushed column tests will evaluate sorption kinetics. The primary data from these tests will be kinetic data and data on longitudinal diffusion, which is diffusion in the direction of flow. Sorption coefficients, speciation, hydrodynamic dispersion effects and potential colloid transport will be observed. The solid tuff column tests will provide primary information on hydrodynamic dispersion and effects of heterogeneity on mass transfer kinetics. The other effects listed previously will also be observed.

Dispersion can be a factor when trying to elucidate the processes of diffusion and sorption kinetics. Dispersion is important to transport processes because high dispersivity broadens the breakthrough front of the radionuclide migration and, therefore, leads to earlier arrival times. Dispersion may also affect sorption by creating lower aqueous phase concentrations. The apparent dispersion (broadening of the elution curve) depends on such parameters as diffusivity, water velocity, kinetic rates, and hydrodynamic dispersivity including channeling (non-Fickian dispersion). The solid rock column tests will measure the dispersion for nonsorbing tracers that will be sensitive to hydrodynamic dispersion. Hydrodynamic dispersion can be defined as the velocity distribution due to laminar flow through pores combined with the effect of tortuous flow paths. The hydrodynamic dispersion of the solid rock columns is expected to be greater than the crushed tuff columns due to the solid rock heterogeneity. Sorbing tracers will be used to test the ability to predict the broadening effects of the combined processes just discussed. Dispersion in the solid rock column will be smaller than the dispersion data used in performance calculations; however, the laboratory experimental data will provide dispersion data in tuff at a small scale that may be useful in examining the scale dependent nature of dispersion.

There are no primary data being obtained from the unsaturated tuff column activities; however, all the effects of the processes listed in the test matrix will be observed except for matrix diffusion. Total system performance calculations (Section 8.3.5.13) will be determining radionuclide travel-time calculations through the unsaturated zone using data gathered from experiments performed under saturated conditions. Therefore, the unsaturated tuff column tests are critical for understanding how the geochemical-physical processes in a saturated system can be applied to an unsaturated system.

The fractured tuff column tests will provide primary data on hydrodynamic dispersion, channeling (non-Fickian dispersion), and heterogeneity. All other process effects will be observed except for longitudinal diffusion. Performance Issue 1.1 calls for an empirical measure of diffusivity to be used in a fracture flow scenario. The effective diffusivities measured in the column experiments in this investigation will be based on a limited set of tracers. Empirical diffusivities can be obtained by using the measured diffusion of these tracers to derive diffusivities for the other radioelements. The empirical diffusivities can only be useful in Issue 1.1 if the

Table 8.3.1.3-6. Dynamic and diffusion study test matrix

	R_d	Speciation	Colloids	Kinetics	Matrix diffusion	Longi- tudinal diffusion	Hydro- dynamic dispersion	Channeling	Hetero- geneity
Crushed tuff columns	p	p	a	a	n	a	a	n	n
Mass Transfer Kinetics									
Sorption kinetics	a	a	a	p	n	p	a	n	n
Solid tuff columns	a	a	a	a	a	a	p	n	p
Unsaturated tuff columns	a	a	a	a	n	a	a	a	a
Fractured tuff columns	a	a	a	a	a	n	p	p	p
Filtration	n	n	p	n	n	n	a	n	n
Diffusion studies	a	a	a	a	p	n	n	n	n

Key:

a = effect will be observed, but parameter will be fit or derived from other experiment.
n = negligible effect.
p = primary source of data.

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information is derived using knowledge of the diffusive and dispersive processes from this activity and the tests in this investigation. Specifically, channeling in fractures (non-Fickian dispersion) leads to only a small diffusive flux since channels contribute to a small proportion of the surface area of the fractures. The non-Fickian dispersion could have a velocity component that would cause the apparent dispersion to be increased by mass transfer kinetics (sorption kinetics).

The filtration activity will provide primary data on whether colloidal material can be filtered or transported through tuff. Radionuclides that may form natural colloids will be identified in Activity 8.3.1.3.5.2.1. The formation of radiocolloids, however, may reduce the transport time of affected radionuclides independent of the sorption capabilities of the zeolitic tuff.

The diffusion study will elucidate diffusive processes and provide primary data on matrix diffusion for performance Issue 1.1. Effects of sorption, speciation, colloids, and kinetics also will be observed in these tests. Diffusion data will be collected independently of advective and dispersive processes by looking at moving species in a nonadvective flow regime. Specifically, matrix diffusion associated with fracture flow is of particular importance to the performance of the repository because diffusion is one of the two mechanisms that enables radionuclides to contact and, therefore, interact with sorbing minerals beyond the surface of the fractures. Effects of matrix diffusion will also be observed in the previously described solid rock column tests under mass transfer kinetics and in the fractured tuff column tests.

8.3.1.3.6.1 Study: Dynamic transport column experiments

All the experiments in the dynamic transport column experiment study measure the breakthrough or elution curve for tracers through tuff columns. The elution curves can be characterized by (1) the time of arrival, and (2) the broadness or dispersion of the the curve.

The time of arrival depends on the retardation factor, that, in turn depends on the R_d . For flow through fractures the arrival time also depends on matrix diffusion. Significant deviations (those larger than expected based on sampling variability) in the arrival time for a radionuclide from that predicted on the basis of the batch R_d indicates one of the following problems that must be addressed in performance assessment:

1. The presence of more than one chemical species with different selectivities in the tuff minerals, which are not readily exchanged.
2. The presence of colloid or pseudo-colloid containing the tracer.
3. Extremely slow adsorption kinetics. (Note that the residence time for sorbing tracers is generally longer in the column studies than in the batch measurements.)
4. For solid tuff columns, the process of crushing tuff has altered the mineral surfaces responsible for sorption.

5. Matrix diffusion in the case of fractured tuff.
6. Solubility effects attributable to the presence of solids.

The broadness or apparent dispersion of the curve depends on the following:

1. Longitudinal diffusion.
2. Hydrodynamic dispersion due to laminar flow.
3. Sorption kinetics.
4. Channeling.
5. Heterogeneity.
6. Matrix diffusion.

The physical form of the tuff changes the sensitivity of the experiment to the above processes. For example, crushed tuff minimizes the sensitivity to channeling, heterogeneity, and differences in mineral composition and texture between batch measurement and column experiments. A series of experiments, varying a single parameter, such as water velocity, permit the measurement of a single process because the parametric dependence of the processes are different. For example, the velocity dependence of kinetics is different from the velocity dependence of hydrodynamic dispersion.

8.3.1.3.6.1.1 Activity: Crushed tuff column experiments

Objective

The purpose of this activity is to measure the rate of movement through crushed tuff columns of radionuclides relative to tritiated water and other well-defined chemical species or colloids. The observation of differences in the sorption ratios measured by the batch technique (Investigation 8.3.1.3.4) versus the column technique will indicate the presence of more than one chemical species of a radionuclide if all other factors listed previously are constant. Comparisons with well-characterized anions, cations, and colloids will determine the charge or colloidal form of the unknown species. By also performing these measurements on pure minerals, the minerals responsible for the sorption of single species can be identified.

Results of the crushed tuff column activity have several applications: (1) the observation of multiple species will be used in Investigation 8.3.1.3.4 to reinterpret batch distribution coefficients, (2) the retardation factors from column measurements will be used in performance assessment as either lower limits for distribution coefficients or to confirm the validity of the batch distribution coefficients, and (3) the observation of the movement of colloids through crushed-rock column experiments will establish the need to treat particulate movement in performance assessment. The contribution to the understanding of the mechanisms of interactions between single species and individual minerals will improve the confidence level and reduce uncertainties in the application of laboratory sorption data in performance assessment calculations.

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The probable crushed tuff columns that will be used for these experiments are

1. Two Topopah Spring Member tuffs.
2. Two Calico Hills tuffs (zeolitic and vitric).
3. One Prow Pass Member tuff.
4. Aluminum-poor clinoptilolite.
5. Aluminum-rich clinoptilolite.
6. Aluminum-poor mordenite.
7. Aluminum-rich mordenite.
8. Montmorillonite.
9. Illite.
10. Two feldspars.

The tracers that will be used for this activity and Activities 8.3.1.3.6.1.2 through 8.3.1.3.6.1.4 and Study 8.3.1.3.6.2 are

1. HTO (tritiated water).
2. Iodine-131.
3. Fluorescent polystyrene sols.
4. Dyes.

Cations with single oxidation states and with known solubilities are

1. Cesium-137.
2. Strontium-85.
3. Barium-133.

Key radionuclides include

1. Technetium.
2. Plutonium.
3. Americium.
4. Neptunium.
5. Uranium.

Nonradioactive tracers include

1. Fluoride.
2. Chloride.
3. Sulfate.
4. Nitrate.
5. Bromide.
6. Polystyrene latex.

For most of the activities, the anions will be run in a mixed batch (together). Tritium will always be run alone. The anions, tritium, and technetium column experiments will last approximately one week. The radionuclide experiment durations vary depending on the sorption capacity of the radionuclides. The cations cesium, barium, and strontium have already been done and the results are similar to the batch experimental results (Treher and Raybold, 1982).

The crushed-tuff column experiment is composed of three parts: (1) to characterize the columns, (2) to determine sorption ratios, and (3) to infer speciation.

The retention volume and intrinsic dispersivity of the crushed tuff columns that will be used for the other parts of this activity will be determined. Sorption ratios will then be determined by comparing the crushed tuff column results with the batch sorption results determined in Investigation 8.3.1.3.4. The differences observed may verify the presence of more than one chemical species of a radionuclide or other known tracers. Comparison of column and batch technique using pure minerals will also be conducted. Finally, should the presence of more than one chemical species containing the radionuclide be observed, speciation can be inferred. This is done by comparing the elution curves of well characterized cations, anions, and colloids to determine the charge or the colloidal form of the unknown species.

Parameters

The data needed are as follows:

1. Batch sorption data from Investigation 8.3.1.3.4.

The data measured are as follows:

1. Column characterization: retention volumes and intrinsic dispersivity.
2. Retardation factors and retention volumes of tracers.
3. Dispersion in shape of the breakthrough curve.
4. Elemental analysis of exchangeable cations.

The data derived are as follows:

1. Sorption ratios for cations and key radionuclides.
2. Comparison of sorption ratios between crushed tuff column studies and the batch technique.
3. Charge of unknown species.
4. Colloidal form of unknown species.
5. Significance of anion exclusion.

Description

Tuff samples from the same lot as Investigation 8.3.1.3.4 will be used for the crushed tuff columns. The tuff samples were chosen to have mineralogies and sorptive properties that are representative of minerals located along flow paths to the accessible environment. Furthermore, the actinide tracers used for this activity will be obtained from Investigation 8.3.1.3.4.

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Tritiated water (a nonsorbing tracer) is used to determine the intrinsic dispersivity of the crushed tuff columns. This requires measuring the void volume to determine the column porosity. All nonsorbing tracers are not equivalent because anions and other large molecules are excluded from the intracrystalline pore space in zeolites and clays.

Sorption ratios for cations and key radionuclides will be determined. Speciation may be observed as the listed cations and key radionuclides elute. Sorption ratios may also be determined for column experiments using pure minerals and these ratios will be compared to the equivalent batch technique results. Minerals responsible for the sorption of single species can then be identified.

Actinides have been observed to have a fraction that elutes through crushed rock columns earlier than expected (Olofsson and Allard, 1986). Subsequently, the determination of the species of the actinides is important. The species determination is extremely difficult, particularly for americium and plutonium, because of the low solubility of both the actinides in near neutral solutions. For example, the extinction coefficients for plutonium in a +6 oxidation state limit the measurement to approximately 10^{-6} molar. The tracer experiments (batch, column) are performed at lower concentrations; for this reason, indirect evidence must be used to infer the solution species. One piece of data that can be used to infer this information is the column behavior since negatively charged ions (anion exclusion) and large molecules are eluted earlier than tritiated water. Furthermore, colloidal matter can be eluted even earlier through a mechanism known as hydrodynamic chromatography. Therefore, comparing the known species (e.g., chlorine, known colloids) with the unknown species will allow inferences about the charge and/or colloidal form of the species. This information will be used in evaluating the results from the batch sorption tests of Investigation 8.3.1.3.4, including the sorption of single species on pure mineral samples. In particular, it has been observed that only minor amounts of technetium are adsorbed in a tuff column. In general, it is thought that technetium does not adsorb; however, this observation is not consistent with batch measurements where sorption is observed. Detailed work may be needed to reconcile the batch versus column results and may include redesigning the batch sorption experiments.

Methods and technical procedures

Standard column and analytical techniques will be used to measure the tracers eluted from the columns with the exception of colloid tracers. Colloids will be detected using either fluorescent particles or the autocorrelator photon spectroscopy method to be developed by Activity 8.3.1.3.6.1.5.

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Method	Technical procedure		Date
	Number	Title	
Crushed tuff column method	TWS-CNC-DP-15,R1	Crushed rock column studies	31 Aug 82
	TWS-CNC-DP-02,R3	Quality control in counting radio- nuclides	3 Jan 84
	TWS-INC-DP-45,R0	Analysis of strong acid anions by ion chromatography	25 May 85
	TWS-MSTQA-QP-14,R1	Research and development (experimental) procedures	19 May 86
	TWS-INC-DP-63, R0	Preparation of Nevada Test Site core samples for crushed rock experiments	20 Mar 87
	TWS-INC-DP-62, R0	Nevada Test Site bulk water samples	30 Jan 87
	TBD ^a	Procedure to imple- ment NNWSI-SOP-03-02	TBD

^aTBD = to be determined.

8.3.1.3.6.1.2 Activity: Mass transfer kinetics

Objectives

The goal of this activity is to determine the elution rate of radionuclides as a function of water velocity. The adsorption of radionuclides, like any chemical reaction, is a dynamic process and has a reaction rate. The reaction rate can be very rapid as in a simple ion exchange process or slowed by some intermediate step. If the residence time is short compared with the reaction rate, the apparent sorption ratio will decrease. These measurements will establish the mass transfer kinetics limitation and yield information that can elucidate the sorption mechanism. The elution rate of

cations and key radionuclides as a function of water velocity will be determined for crushed tuff columns (homogeneous system), solid rock columns (heterogeneous system), and for pure mineral samples.

Mass transfer coefficients (sorption K_d s) will be used by performance assessment as a basis for establishing the validity of retardation factors based on static measurements in scenarios involving rapid water movement such as fracture flow. Mass transfer coefficients will also be used by Investigation 8.3.1.3.7. Diffusion coefficients for cations will also result from this activity. These results along with the results from Study 8.3.1.3.6.2 will be used by Investigation 8.3.1.3.7 and Issue 1.1 (Section 8.3.5.13).

Parameters

The data needed are as follows:

1. Dispersion characteristics for crushed tuff (intrinsic dispersivity) (Activity 8.3.1.3.6.1.1)

The data measured are as follows:

1. Retardation factors and retention volume of tracers.
2. Dispersion in shape of the breakthrough curve.
3. Elemental analysis of exchangeable cations.

The data derived are as follows:

1. Sorption ratios.
2. Kinetic rate constants.
3. Velocity limit to which sorption values are valid.

Description

To establish mass transfer kinetics for a homogeneous system (crushed tuff columns), this activity will determine sorption rate constants and will establish the mass transfer kinetic limitation by determining a velocity limit to which the sorption values are valid. The dispersivity of the crushed tuff column must be well characterized to distinguish mass transfer from dispersion. The crushed tuff columns used will be the same columns used in Activity 8.3.1.3.6.1.1. The tracers used will be cesium, barium, strontium, uranium, plutonium, neptunium, americium, and technetium. The anions will not be used in these tests. For strongly sorbing cations or actinides, shorter crushed columns will be used.

To establish mass transfer kinetics in a heterogeneous system (solid rock column), this activity will determine sorption rate constants and will establish the mass transfer kinetics limitation by determining the velocity limit to which sorption values are valid. This activity will determine whether the mechanism of mass transfer exhibits a dependence on the heterogeneity of the rock column (i.e., mineral dependence). Two solid rock core samples without fractures from the Topopah Spring Member, possibly two from the Calico Hills (zeolitic and vitric), and one from the Prow Pass Member will be used. The mass transfer kinetics experiments will be done using an apparatus that produces an advective flow through the solid rock column.

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This apparatus is in a developmental stage. The tests will be conducted using the uranium, plutonium, neptunium, americium, technetium, and anion tracers.

Mass transfer kinetics limitations will similarly be established for systems of pure minerals. This test will provide information on the kinetics of adsorption on select sorbing minerals and will assist in elucidating the mass transfer kinetic data of the previous tests. The minerals to be used are clinoptilolite, mordenite, montmorillonite, and illite. An analcime column test may be conducted if it is established that the geochemical-physical retardation of radionuclides in flow paths at greater depths are important to the total system transport calculations (Section 8.3.5.13).

Methods and technical procedures

The same methods and technical procedures will be used as in Activity 8.3.1.3.6.1.1. However, the development of the solid rock columns is in an early stage and procedures are not yet available. Diffusion into zeolitic crystals may also be used for establishing kinetics for the pure zeolitic mineral phases. A technical procedure for this new technique will be written, if the alternate method is used.

8.3.1.3.6.1.3 Activity: Unsaturated tuff columns

Objectives

This activity will measure the relative migration rate of radionuclides through partially unsaturated rock columns. The present approach to modeling chemical interactions in unsaturated rock is to treat the chemistry in a way identical to that of saturated rock, except for modifying the effective porosity. Although dispersion is expected to vary with saturation state, the chemistry should not alter over the range of saturation states anticipated in Yucca Mountain. This assumption about dispersion and sorption must be verified through experiment. Most of the adsorption isotherms, as discussed in Chapter 4, show linear behavior; therefore, the rock-water ratio is not expected to cause a change in the apparent K_d . At present there is no surface area dependence exhibited by the batch sorption measurements (Chapter 4). Until the chemical composition of pore water in the unsaturated zone is determined (Section 8.3.1.2.2), there is no evidence to suggest that there would be a difference in the chemical interaction in the unsaturated rock due to pore water chemical composition.

The results of the unsaturated tuff column experiments will be used in Investigation 8.3.1.3.7 and ultimately in performance assessment to validate models used to calculate unsaturated flow and transport. Also, the retardation factors, if different from saturated tuff experiments, will be used in performance assessment calculations for unsaturated zone transport calculations.

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Parameters

Data and models based on saturated tuff are needed. Work on the development of an unsaturated column for laboratory scale testing is needed. Data measured are retardation factors or retention volumes.

The data derived are as follows:

1. Permeability as a function of pressure (matric potential).
2. Saturation as a function of pressure (matric potential).
3. Matric potential of the unsaturated tuff.
4. Sorption ratios.
5. Support or nonsupport of transport or flow models based on a saturated system.

Description

This activity will develop the unsaturated tuff column apparatus and the hydrologic properties of the column will be characterized. An unsaturated tuff column apparatus similar to that used in soil physics will have to be developed. Because the suction potential of tuff is much larger than that of soils, this apparatus will have to be designed to operate at high internal pressure. Conventional porous plates may be adapted for this apparatus, but other types may have to be tested.

The tuff samples used will be limited to a few Topopah Spring Member samples and one Calico Hills sample. The unsaturated tuff columns will be characterized, providing rock characteristics information and characteristic curves for hydrologic modeling and for the laboratory work in this investigation. Specifically, the matric potential of the unsaturated tuff will be characterized and the migration of cations and radionuclides in the unsaturated tuff columns will be studied. Sorption ratios for tritiated water, chloride, and only weakly sorbing cations will be determined; use of more highly sorbing cations would hinder completion of this activity in a timely manner. Results of these tests will ensure the applicability of sorption values of saturated flow in tuff to an unsaturated system. These tests are high risk experiments; however, it may be even more difficult to guarantee success of geochemical field tests in the unsaturated zone (Study 8.3.1.3.7.2). Alternate experimental approaches will be discussed in the study plan that will be developed for this study.

Methods and technical procedures

Standard analytical techniques for the elemental analysis of the cations and the radionuclides will be used (Activity 8.3.1.3.6.1.1). Technical procedures will have to be developed for the unsaturated tuff column experiments which are developmental in nature.

8.3.1.3.6.1.4 Activity: Fractured tuff column studies

Objectives

This activity will measure the transport and diffusion of radionuclides through naturally fractured tuff. Although there is a great body of research supporting the modeling of contaminant transport through homogeneous porous media from the column chromatography literature, such support does not exist for the transport of contaminants through fractures. The tests in this activity will examine the movement of tracers through naturally fractured Yucca Mountain cores to test the transport models. Because fracture flow may be a significant component of flow under some conditions, the movement of radionuclides along fractures in the tuffs must be understood and quantified. The quantification is particularly important so that estimates of radionuclide transport and retardation under porous and fracture flow regimes can be compared in the system assessments.

The results of fracture flow experiments will be used by Investigation 8.3.1.3.7 and performance assessment to validate models describing transport in fractures. The effective retardation and diffusivities of radionuclides will be used by performance assessment to calculate radionuclide migration in the saturated zone and in scenarios involving fracture flow. Also, the movement of nonsorbing tracers in fractures can be used as a reference to aid the interpretation of carbon-14 dates in ground water. Finally, the information on the effective retardation of nonsorbing tracers in fracture flow may be used in calculations of pre-waste-emplacement ground-water travel time (Issue 1.6, Section 8.3.5.12).

Parameters

The data needed are as follows:

1. Diffusivities (gained from diffusion Study 8.3.1.3.6.2).

The data measured are as follows:

1. Fracture permeability.
2. Porosity.
3. Fracture surface topography.
4. Retardation factors for non-sorbing tracers and retention volumes.
5. Elemental analysis of cations.

The data derived are as follows:

1. Fracture aperture.
2. Sorption ratios.
3. Effective retardation for a fracture flow system.

Description

At present six fractured-core columns are operating. They include four Topopah Spring Member tuffs, one Bullfrog Member tuff, and one Tram Member tuff. Samples are limited by the availability of fractured core. There are no good fractured cores of Calico Hills tuff available at this time. If and

when they are available, this activity will include samples from the Calico Hills in the tests. Cesium, barium, strontium, technetium, uranium, plutonium, americium, and neptunium will be used as tracers for these tests. This activity will validate sorption processes in a fractured system. The fractured tuff column will be characterized by determining the fracture characteristics such as fracture aperture and fracture permeability. Fracture apertures will be determined from permeability measurements and inferred using Darcy's Law. The surface topography of the fractured tuff also will be determined using optical techniques. The method for measuring permeability will be described in technical procedures not yet available.

The effective diffusivities measured in these experiments will be based on a limited set of tracers; therefore, empirical diffusivities for the other tracers of interest will be obtained by applying the known diffusion of the limited set of tracers.

The effective retardation for a fracture flow system factor or diffusivity will be determined by measuring the radionuclide elution curve and fitting the curve to curves generated either with the analytic solution described in reports referenced in Chapter 4 or when necessary by the TRACR3D (see Investigation 8.3.1.3.7) computer code. All chemical analyses will be done using standard analytical techniques, as in Study 8.3.1.3.6.1.

Methods and technical procedures

The methods and technical procedures for this activity are to be developed.

8.3.1.3.6.1.5 Activity: Filtration

Objectives

The tuffs of Yucca Mountain may provide a natural barrier by acting as an efficient filter for particulate matter. This study will attempt to quantify the filtration of colloids and particulates by the tuff as a function of particle or pore size. The filtration of various particle sizes will be measured using solid tuff cores and fractured cores. The results of the filtration experiments will provide an experimental basis to decide whether or not particulate transport of radionuclides needs to be considered in the final performance assessment or if colloid and particulate transport can be ruled out on the basis of filtration. The data will also be used by Investigation 8.3.1.3.7 to aid in this assessment.

Solid tuff cores will be used to determine whether Yucca Mountain tuff is an effective filter given matrix (porous) flow. The same solid core used by Activity 8.3.1.3.6.1.2 will be used in this activity. Synthetic colloids, natural colloids, and colloids from Study 8.3.1.3.5.2 will be characterized in terms of size distributions and then used in the tuff column test. This activity will also use fractured tuff core to determine whether filtration of particulates or colloids in a fractured tuff core and matrix diffusion will occur. The same fractured tuff core used for Activity 8.3.1.3.6.1.4 will be used.

Parameters

The data measured are size distribution and surface charges of particulates, and the data derived are effective pore sizes and filtration profiles.

Description

As in the activity describing the solid rock column mass transfer kinetics (Activity 8.3.1.3.6.1.2), an apparatus will be developed that produces advective flow through the solid rock column at pressures between 2,000 to 3,000 psi. For both the solid tuff core and the fractured tuff core, the same particulate tracers will be used. There are many standard particulate tracers available that require different techniques for detection. The tracers of choice have not been investigated for transport in tuff as yet. Possibly plutonium and americium polymers, a synthetic colloid, or a polystyrene sol will be used. Fluorescent particles are available that can be detected by fluorometry. Gold colloids can be detected by plasma emission spectrometry or neutron activation. In sufficiently high concentration, all particulate tracers can be analyzed by conventional light scattering (nephelometry).

The particle size distribution of tracers will be determined by dynamic light scattering. The colloids will also be determined by dynamic light scattering to ensure that relevant sizes of tracers are used. The dynamic light scattering, also known as autocorrelator photon spectroscopy, is a state-of-the-art technique. There will be a need to do some development to extract the theoretical limit of information contained in the measurement. The development is primarily one of producing a better code for inverting integral equations.

Methods and technical procedures

The technical procedures based on the description of these tests are not available as yet, because many are state-of-the-art.

8.3.1.3.6.2 Study: Diffusion

This study will measure the diffusivity and kinetics of adsorption in a purely diffusive system (i.e., no advection). This study supports Activity 8.3.1.3.6.1.4 and overlaps with Activity 8.3.1.3.6.1.2 by providing confirmatory results. The measured diffusivities will be used by Investigation 8.3.1.3.7 and Issue 1.1 (Section 8.3.5.13). Kinetic rate constants and effective diffusivities will be measured from the uptake of radionuclides on intact tuff as a function of time. Scaling studies will also be conducted to determine up to what scale the matrix diffusion model can be applied with confidence. Technetium, uranium, plutonium, americium, neptunium, cesium, barium, and strontium will be used in this study.

Three experimental techniques are developed in the following activities using beakers fabricated from tuff wafers and rock slabs.

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8.3.1.3.6.2.1 Activity: Uptake of radionuclides on rock beakers in a saturated system

Objectives

This activity will measure the uptake of radionuclides by rock beakers as function of time. By using rock beakers, extraneous components introduced from other types of vessels are removed. The geometry of the beaker requires a numerical rather than an analytic solution. These results will provide a baseline for the following activities on diffusion through a saturated tuff slab and diffusion in an unsaturated tuff block.

Parameters

The data needed are ionic diffusivities, and the data measured are elemental analysis of key radionuclides and cations.

The data derived are as follows:

1. Apparent diffusivity as a function of time.
2. Kinetic rate constants as a function of time.
3. Sorption ratios for cations and key radionuclides.

Description

The problem of sorption of actinides, particularly americium, on vessels made of plastic or glass can be eliminated by using saturated rock beakers. The procedure for making the rock beakers from Yucca Mountain tuff is not yet available; the rock beakers will initially be made of Topopah Spring Member tuff and then the experiments will be extended to Calico Hills tuff. The interior of the rock beaker will be relatively smooth. If the sorption of actinides is principally on the external surfaces of tuff, it would be expected that a lower K_d would be observed in these experiments than in batch sorption experiments.

The uptake of radionuclides as a function of time will be fit to a diffusion model with reactions (sorption) to determine the diffusivities and rate constants. For a linear reversible reaction, an analytic solution exists. In the event of a more complex reaction mechanism, higher order, irreversible reactions, or both will be added to the computer code TRACR3D (Investigation 8.3.1.3.7).

Methods and technical procedures

Technical procedures for this activity are under development but not yet available.

8.3.1.3.6.2.2 Activity: Diffusion through a saturated tuff slab

Objectives

This activity is designed to measure the diffusion of radionuclides in a purely diffusive system, no advection. The kinetic rate constant as a function of time and the effective diffusivity as a function of thickness will be measured. A scaling study will be made by varying the thickness of the tuff slab or wafer. The saturated slabs will be made of Topopah Spring Member tuff and Calico Hills zeolitic tuff. The results of Activity 8.3.1.3.6.2.1 will be used to interpret the results.

Parameters

The data needed are as follows:

1. Ionic diffusivities.

The data measured are as follows:

1. Porosity.
2. Pore tortuosity.
3. Pore constrictivity.
4. Elemental analyses of cations and key radionuclides.

The data derived are as follows:

1. Kinetic rate constants.
2. Sorption ratios for cations and key radionuclides.
3. Effective diffusivities.

Description

A saturated tuff slab or wafer will separate two solutions, one with tracers and one without. The migration of radionuclides due to pure diffusion will be studied. The scaling studies are done by varying the thickness of the wafer. A thick wafer will produce higher diffusivities. The grain orientation may affect the diffusion and this would provide some geometric information in interpreting diffusion in the field. For a thin wafer, diffusion times would be shorter, thus, the kinetics will be on a rapid time scale. Kinetics may be limited by a scaling dependence.

Methods and technical procedures

Standard analytical methods will be used to determine elemental concentrations in the two solutions (Study 8.3.1.3.6.1). Technical procedures are under development but not yet available.

8.3.1.3.6.2.3 Activity: Diffusion in an unsaturated tuff block

Objectives

This activity will determine the distribution of radioactivity in the unsaturated tuff matrix, using an unsaturated tuff block of the Topopah Spring Member or Calico Hills.

The uptake of radionuclides as a function of time will be fit to a diffusion model with reactions (sorption) to determine the diffusivities and rate constants. For a linear reversible reaction, an analytic solution exists as has been shown for the simple cations. In the event of more complex reaction mechanisms, higher order and irreversible reactions will be added to the computer code TRACR3D (Investigation 8.3.1.3.7).

Parameters

The data needed are as follows:

1. Ionic diffusivities.

The data derived are as follows:

1. Apparent diffusivity.
2. Kinetic rate constants as a function of time.
3. Sorption ratios for cations and key radionuclides.
4. Effective porosity.
5. Pore tortuosity and constrictivity.

Description

The method used for studying the distribution of radioactivity entails drilling a small hole in the unsaturated tuff block and injecting tracers. This design is used to minimize vapor phase convection. The diffusion or distribution of the radionuclides will be determined by sectioning the tuff block using cryogenic methods to minimize drying of the saturated slab and thus preventing the radionuclides from moving.

Methods and technical procedures:

Standard analytical methods will be used to determine elemental concentration. Technical procedures for studying the unsaturated tuff block (cryogenic methods) are under development but not yet available.

8.3.1.3.6.3 Application of results

The information derived from the studies and activities described above will be used in the following issues, information needs, and investigations:

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Issue,
investigation, or
information need

Subject

1.1.1	Site information needed to calculate releases to the accessible environment (Section 8.3.5.13.1)
1.1.2	Potentially significant release scenario classes (Section 8.3.5.13.2)
1.1.3	Calculational models for release scenario classes (Section 8.3.5.13.3)
1.1.4	Radionuclide releases for scenario classes (Section 8.3.5.13.4)
8.3.1.3.4	Radionuclide retardation by sorption processes along flow paths to the accessible environment
8.3.1.3.7	Radionuclide retardation by all processes along flow paths to the accessible environment
8.3.1.2.2	Description of the unsaturated zone hydrologic system at the site
8.3.1.2.3	Description of the saturated zone hydrologic system at the site
1.8	NRC siting criteria (Section 8.3.5.17)
1.9b	100,000 yr releases (Section 8.3.5.18)

8.3.1.3.6.4 Schedule and milestones

This investigation contains two studies: 8.3.1.3.6.1 (dynamic transport column experiments) and 8.3.1.3.6.2 (diffusion studies). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

Both studies associated with this investigation are ongoing, and the work described can be initiated after the study plans are available. The major constraints on the studies under this investigation are the availability of core samples from the Calico Hills unit, the availability of core samples exhibiting good fractures, and the need to develop techniques and apparatus for conducting some of the tests. Testing using crushed tuffs can proceed immediately along with the batch testing of Investigation 8.3.1.3.4 (radionuclide sorption). Some testing with existing cores can also be initiated and augmented when additional material is available from the drilling program and the exploratory shaft activities. Progress on some of the column

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and diffusion activities, because they are developmental, is constrained by the progress of developing adequate experimental techniques.

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

The points on the timelines are described in the following table.

<u>Point number</u>	<u>Description</u>
1	Milestone R375. Report available on speciation and transportation in crushed tuff columns.
2	Milestone R736. Final report available on transport of radionuclide by fracture flow under saturated conditions.
3	Milestone M320. Report available on transport and retardation in fractured tuff.
4	Milestone R341. Summary report available on the kinetics of sorption.
5	Milestone R527. Summary report available on filtration of radionuclides by Yucca Mountain tuff.
6	Milestone R340. Final report available on unsaturated flow column experiments. This report completes this study as well as the investigation.

Point
number

Description

- 7 Milestone R378. Summary report available on retardation by diffusion.
- 8 Milestone Q038. Summary report available on radionuclide retardation by diffusive, dispersive, and advective processes. This report completes this study.
- 9 Milestone Q002. Report available on the summary of results defining radionuclide retardation at Yucca Mountain. This is a higher-level report that summarizes the results of Investigations 8.3.1.3.4 through 8.3.1.3.7 and will be compiled as part of Study 8.3.1.3.7.1.

8.3.1.3.7 Investigation: Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

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

<u>SCP section</u>	<u>Subject</u>
4.1.2	Ground-water chemistry
4.1.3.3	Sorption
4.1.3.4	Processes affecting radionuclide concentrations and speciation in solution
4.1.3.5	Matrix diffusion
4.1.3.6	Radionuclide transport
4.1.3.7	Geochemical retardation in the host rock and surrounding units--anticipated conditions
4.1.3.8	Geochemical retardation in the host rock and surrounding units--unanticipated conditions
4.2.1	Anticipated thermal conditions resulting from waste emplacement
4.2.4	Effects of the thermal pulse on radionuclide migration

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Parameters

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

1. Significance and relative importance of physical and geochemical processes affecting transport.
2. Geochemical-geophysical model of Yucca Mountain.
3. Integrated transport calculations.
4. Transport models and related support.

Purpose and objectives of the investigation

The purpose of this investigation is to support the total systems performance calculations of Issue 1.1 (Section 8.3.5.13). Issue 1.1 requires calculational models of radionuclide transport in the unsaturated and saturated zone that are capable of representing the effects of flow in at least two dimensions on the transport of dissolved, reactive solutes and of testing the theory embodied in the one-dimensional systems-level model used in Issue 1.1. The goal of this investigation is to use the three-dimensional transport model and other multidimensional process codes to support Issue 1.1 and to determine, characterize, and quantify the cumulative effects of all significant processes, physical and geochemical, acting on or controlling radionuclide transport at Yucca Mountain. In using the 3-dimensional model to support the simpler system performance model in Issue 1.1, it must be demonstrated that the laboratory generated data described in previous investigations can be reliably transferred to anticipated field conditions. The second study of this investigation is intended to address this concern. This investigation must synthesize all the field characterization data and the experimental geochemistry data of this test program together with the geochemical field test data gathered in other test programs and as part of this investigation (Study 8.3.1.3.7.2).

Technical rationale for the investigation

The first study (Study 8.3.1.3.7.1) involves the following three principle activities: (1) determine the significance and importance of the geochemical and physical processes affecting transport, (2) compile a conceptual geochemical-geophysical model of Yucca Mountain and use it as a basis for integrated transport calculations (3-D), and (3) support and maintain the transport models. The second study (Study 8.3.1.3.7.2) outlines the elements of a strategy to address the question of validating the extrapolation of lab data to field conditions. As site characterization proceeds, the strategy will be evolved and presented in SCP updates, followed by reports on the results of this work.

To support Issue 1.1 and to calculate the best and most realistic estimates of radionuclide transport at Yucca Mountain, the significance and relative importance of each physical and geochemical process needs to be assessed. The assessment will include evaluating the following: (1) geochemical transport processes, (2) physical transport processes, (3) experimental

support and development, (4) particulate transport, (5) coupled phenomena, and (6) heat load effects.

If a particular process is known to impact transport generally but is found to be unimportant in controlling transport at Yucca Mountain, then it can be excluded from the integrated transport calculation and performance assessment calculations. However, this assessment must be based on the results from investigations into (1) the significance of the physical and geochemical processes and (2) the limits of applicability of the physical and geochemical models thought to affect transport. The laboratory and field data must be integrated into, and correlated with a determination of the significance and importance of transport processes and transport calculations in order to present the most realistic picture of potential transport.

8.3.1.3.7.1 Study: Retardation sensitivity analysis

As a baseline set of input data for the integrated transport calculations (information item in this investigation), a conceptual geochemical-geophysical description of Yucca Mountain is needed based on the results, data, and information generated from the geochemistry, mineralogy-petrology, hydrology, and other pertinent NNWSI Project tasks. From this compilation of baseline data, a determination can be made as to what data may be inadequate or insufficient to make the cumulative, integrated transport calculations needed to meet the NRC and EPA regulations. The calculations will be made during the fulfillment of Information Needs 1.1.4, and 1.1.5 (Sections 8.3.5.13.4 and 8.3.5.13.5).

The integrated transport calculations are to be used to determine and quantify the cumulative and individual effects of all physical and geochemical processes controlling transport. The effects that may be important in limiting or increasing the total integrated radionuclide release rates can then be identified. With a completed baseline set of integrated transport calculations the following can be assessed: (1) the potential effects of favorable and potentially adverse conditions; (2) the determination that the site is not disqualified and is not likely to be disqualified; (3) the determination that the site meets the qualifying conditions and is likely to continue to meet the qualifying conditions; and (4) probabilistic estimates of the radionuclide releases to the accessible environment considering anticipated and unanticipated scenarios.

Computer models are used to calculate transport and investigate the significant processes affecting transport. The geologic system and the transport processes at Yucca Mountain are very complex (e.g., being unsaturated and fractured media). To model such a system, the most efficient numerical tools need to be used. The models must be verified (assuring that a computer code correctly performs the operations specified in the numerical model and the computational algorithms used to solve the governing equations are accurate) and validated (assuring that the theoretical foundation of the code describes the actual system behavior). Alternative numerical approaches in computer models will be implemented wherever feasible. These alternative numerical models will include all significant transport processes and possibly increase computational efficiency and numerical stability. Identification of the important contributors to uncertainty and those parameters for

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which variation within favorable limits have little or no influence on results from retardation calculations will allow estimates of model sensitivities and uncertainties to be made. Once sensitivities are identified, unnecessary complexity in the systems models can be reduced (Information Need 1.1.3), thereby facilitating the probabilistic simulations of systems performance to be made in fulfilling Information Need 1.1.5.

The following three activities are intended to be interactive efforts with each other and with the laboratory and field programs presented in other investigations and the following study (Study 8.3.1.3.7.2).

8.3.1.3.7.1.1 Activity: Analysis of physical/chemical processes affecting transport

Objectives

This activity will analyze all the processes that may affect transport; geochemical transport processes, physical transport processes, particulate transport, heat-load effects, and coupled phenomena. Results of this study will be used to support and develop those laboratory experiments designed to examine the physical and geochemical processes affecting radionuclide transport and other experimental activities under this program and the exploratory shaft tests (i.e., diffusion experiments). A correlation and validation of results obtained from laboratory, exploratory shaft, and field experimental results with transport calculations will also be done.

The investigation of the geochemical processes affecting transport will be used to (1) interpret sorption, solubility, water chemistry, and precipitation data, (2) design future experiments, (3) examine and define the limits of the applicability of laboratory-measured sorption values to the field situation at Yucca Mountain, and (4) verify the applicability of using parameter values obtained in the laboratory under saturated conditions in calculations of transport through the unsaturated zone. The investigation of the physical processes (dispersion, matrix diffusion, and advection) affecting transport will be used to (1) interpret results obtained under Investigation 8.3.1.3.6, (2) examine and define the limits of the applicability of laboratory-measured diffusion and constrictivity values to the field situation at Yucca Mountain, (3) examine the impact that fracture versus matrix flow has on transport, (4) correlate the results obtained from the C-well field tests (Investigation 8.3.1.2.2) and other field tests (Study 8.3.1.3.7.2) with results obtained from laboratory testing and modeling activities. The investigation of particulate transport will be used by performance assessment (Issue 1.1) to establish a need to treat particulate transport, and a determination of the impact of microbiological activity on radionuclide transport will be made. The particulate transport investigations will also be used for the experimental design and interpretation of results from colloid transport experiments conducted under Investigation 8.3.1.3.6.

The investigation on the heat-load effects will be used by performance assessment to establish a need to treat all or some of the heat-load effects, and in the waste package activities to establish a need to treat all or some

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of the heat-load effects in waste package design and for calculations of radionuclide release from the engineered barrier system.

The investigation into coupled phenomena will be used to improve the integrated geochemical-geophysical description of Yucca Mountain (Activity 8.3.1.3.7.1.2), and to interpret experimental results and develop future experiments, and to develop and perform calculations under Activities 8.3.1.3.7.1.1 and 8.3.1.3.7.1.3.

Parameters

The data needed are as follows:

1. Data from investigations:

<u>Investigation</u>	<u>Subject</u>
8.3.1.2.2	Site unsaturated zone hydrologic system
8.3.1.2.3	C-well tracer tests
8.3.1.3.1	Water chemistry
8.3.1.3.2	Mineralogy-petrology information
8.3.1.3.3	Mineral-glass stability
8.3.1.3.4	Radionuclide sorption, microbial activity
8.3.1.3.5	Radionuclide precipitation, solubility, speciation
8.3.1.3.6	Physical processes: dispersion, matrix diffusion, advection (derived values), filtration/transport of particulates, evidence of speciation, kinetics of chemical processes (sorption), effects of flow processes on transport (fracture, matrix)
8.3.1.3.8	Gaseous radionuclide retardation

2. Data from Activity 8.3.1.3.7.2 (applicability of laboratory data to repository transport calculations). The data gathered are as follows:

1. Significance and importance of

- Geochemical processes.
- Physical processes.
- Particulate transport.

2. Extents of

- Microbial activity.
- Heat-load effects.

- c. Changes in stress and fractures.
- d. Gaseous transport.

3. Effects of coupled processes.

Description

This activity will involve verifying the applicability of using sorption measurements performed under saturated conditions, in calculations of transport through the unsaturated zone. This activity will also examine the limits of applicability of conceptual geochemical models (such as the distribution coefficient, Study 8.3.1.3.4.3). The limits of the applicability of laboratory-measured sorption values to field situation will also be assessed. Data on sorption (Investigation 8.3.1.3.4), speciation (Investigations 8.3.1.3.5 and 8.3.1.3.6), precipitation-solubility (Investigation 8.3.1.3.5), ground-water chemistry (Investigation 8.3.1.3.1), and thermodynamic data will be used in the assessments. Data from Investigation 8.3.1.3.6 will also provide input for this assessment by determining how the physical processes of dispersion, diffusion, and advection will affect radionuclide transport. This activity will (1) examine the limits of applicability of laboratory-measured diffusion and constrictivity values to the field situation, (2) examine the extent to which matrix versus fracture flow processes contribute to radionuclide transport, and (3) correlate the results obtained from the laboratory, field, and modeling investigations and activities.

Particulate transport (Activity 8.3.1.3.6.1.5, filtration) will be investigated using numerical models. The relative importance and significance of particulate transport to radionuclide transport, and the extent to which microbiological activity (Study 8.3.1.3.4.2, biological sorption) may also have an effect on transport will be determined. Heat-load effects on hydrology and transport near the repository will be modeled by examining changes in stress and fractures, and possibly by examining the extent of gaseous transport (Investigation 8.3.1.3.8). Furthermore, the effects of coupled processes on transport of radionuclides will be studied to determine which of the possible coupled processes should be taken into account by the total systems performance Issue 1.1 (Section 8.3.5.13).

In particular, the computer codes TRACR3D, COLLOID, TRANQL, WAFE, FEHMS, and HDOC will be used. TRACR3D is a finite difference three-dimensional flow and transport code that incorporates geochemical (sorption) and physical processes and data along with hydrologic and geologic data to do integrated transport calculations (Activity 8.3.1.3.7.1.2). The COLLOID code will investigate particulate and colloid transport and the contribution of microbial activity to this transport. The TRANQL code will specifically assess the geochemical processes (sorption, speciation, precipitation, solubility, thermodynamics effects) and how they may affect transport. The WAFE code incorporates a thermal component into the flow and transport code, and TRACR3D will assess the geochemical-physical conditions under a thermal regime similar to a repository environment. FEHMS is a finite element code that couples heat, mass, and stress changes, and assesses their effects on transport. Finally, HDOC is a code that uses the dynamics of contour methods to model flow and transport. It is a numerically efficient transport code that will be used comparatively with the other more complex and involved codes. This code could be very efficient and economical if it can be shown

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to replicate sensitivity studies presently performed by other more computationally intensive codes. This code then is quite robust and could be beneficial if used by performance assessment.

The codes all have user's manuals or referenceable procedures or NNWSI Project milestones associated with them. They are listed here.

<u>Code</u>	<u>Citation</u>
TRACR3D	Travis, Bryan J., "TRACR3D: A Model of Flow and Transport in Porous/Fractured Media," LA-9667-MS; Los Alamos National Laboratory (May, 1984).
TRANQL	Cederberg, G. A., R. L. Street, and J. O. Leckie, "A Groundwater Mass Transport and Equilibrium Chemistry Model for Multicomponent Systems," Water Resources Research, 21(8), 1095-1104 (1985).
HDOC	Travis, Bryan J., and L. Eric Greenwade, "A One-Dimensional Numerical Model of Two-Phase Flow and Transport in Porous Media using the Dynamics of Contours Methodology," NNWSI Milestone C717, Los Alamos National Laboratory (October, 1985).
FEHMS	Zyvoloski, G., and S. Kelkar, "Preliminary Investigation into Coupled Heat/Mass/Stress Effects at Yucca Mountain", NNWSI Milestone R346, Los Alamos National Laboratory, Los Alamos, NM (March 31, 1987).
COLLOID	Nuttall, H. E., "Population Balance Model for Colloid Transport," NNWSI Milestone R318, LA-UR-86-1914, Los Alamos National Laboratory (June, 1986). Submitted to Water Resources Research.
WAFE	Travis, Bryan J., "WAFE: A Model for Two-Phase, Multicomponent Mass and Heat Transport in Porous/Fractured Media," LA-10488-MS, Los Alamos National Laboratory (October, 1985).

Methods and technical procedures

Method	Technical procedure		Date
	Number	Title	
	TWS-MSTQA-QP-14, R1	Research and Development (Experimental) Procedure	19 May 86
	TBD ^a	Procedure to implement SOP-03-02 for Software Quality Assurance	TBD

^aTBD = to be determined.

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8.3.1.3.7.1.2 Activity: Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations

Objectives

The objective of this activity is to perform calculations of radionuclide transport from the repository to the accessible environment using, as a basis, an integrated, conceptual geochemical-geophysical model of Yucca Mountain. The geochemical model of Yucca Mountain and the integrated geochemical transport calculations will be used for site characterization, the environmental assessment, and to resolve Issues 1.1 and 1.8 (Sections 8.3.5.13 and 8.3.5.17). The results will also be used by the performance assessment subtask to establish the need to treat all or some of the geochemical and physical processes.

Parameters

The data needed are as follows:

1. Geohydrologic characteristics (Section 8.3.1.2). Recharge rates, location of water tables, flow paths and fluxes of water and gases in the unsaturated and saturated zones.
2. Rock characteristics (Sections 8.3.1.4 and 8.3.1.15). Stratigraphy and structural characteristics, spatial distribution of thermal conditions and mechanical properties.
3. Engineered barrier characteristics (Issue 1.5, Section 8.3.5.10). Boundaries of the reference engineered barrier system (EBS), release rates from the EBS assuming both anticipated and unanticipated processes and events.
4. Release rate from the waste forms after the contaminant barrier is breached (Issue 1.4, Section 8.3.5.9).
5. Geochemical characteristics (this program). Water chemistry (Investigations 8.3.1.3.1 and 8.3.1.2.2); mineralogy-petrology and rock chemistry (Investigation 8.3.1.3.2); sorption processes (Investigation 8.3.1.3.4); precipitation processes (Investigation 8.3.1.3.5); dispersive, diffusive, and advective processes (Investigation 8.3.1.3.6).
6. Potential effects of erosion (Section 8.3.1.6).
7. Potential effects of future climatic conditions (Section 8.3.1.5).
8. Potential effects of igneous and tectonic activity (Section 8.3.1.8).
9. Data from the C-well tracer tests.
10. Data from the field tests (geochemistry) of Study 8.3.1.3.7.2.

The data gathered are as follows:

1. Geochemical-geophysical model.
2. Integrated radionuclide transport calculations.

Description

This activity will first construct an integrated, conceptual geochemical/geophysical description of Yucca Mountain based on the results, data, and information generated from the geochemistry, mineralogy-petrology, hydrology, and other pertinent NNWSI Project tasks. From this complete description of Yucca Mountain, an assessment of the areas and specific items needing further and more intensive investigation can be made. This compilation activity should occur at regular intervals. A technical integrating committee may need to be formed to review the information in the reference information base and issue a NNWSI Project assessment of that data in the form of a geochemical-geophysical model similar to the one produced by this activity. This committee may also be the correct forum for determining the NNWSI Project positions on such things as which hydrologic flow models will be used.

Second, integrated transport calculations on radionuclides from the repository to the accessible environment will be performed using the geochemical-geophysical model as a basis for the calculation. The integrated transport calculations will be used to determine and quantify the cumulative and individual effects of all geochemical and physical processes controlling transport. The effects that may be important in limiting or increasing the total radionuclide release rates can then be identified. These calculations serve Activity 8.3.1.3.7.1.1 and are interactive with that activity. Furthermore, these calculations will support and give confidence to the assumptions made by performance assessment (Issue 1.1, Section 8.3.5.13) in its use of a one-dimensional system model for radionuclide transport and the resulting cumulative frequency distribution curves for radionuclide releases to the accessible environment.

The integrated transport calculations can be used to assess the potential effects of favorable conditions and potentially adverse conditions resulting from changes in future climatic conditions, erosion, and igneous and tectonic effects, on the transport and retardation of radionuclides from the waste package to the accessible environment. This activity primarily will use the transport codes TRACR3D, WAFE, and possibly HDOC, described in Activity 8.3.1.3.7.1.1. The WAFE code will be used as necessary based on requests by and continued cooperation with Lawrence Livermore National Laboratory. These particular codes will be improved and new models or methods may be developed or employed depending upon the specific problems requiring investigation. Specifically, stochastic methodology may be used to account for random variations in parameters along the transport paths and imperfect knowledge of parameters, and to estimate the most likely transport histories.

Methods and technical procedures

For this activity the methods and technical procedures are not applicable.

8.3.1.3.7.1.3 Activity: Transport models and related support

Objectives

The goal of this activity is to verify and validate computer codes used in this study and to identify important contributors to the uncertainties in retardation calculations (sensitivity analyses). The computer code benchmarking activities (verifying and validating the models) will be used for quality assurance and performance assessment. The sensitivity analysis will be used by Activities 8.3.1.3.7.1.1 and 8.3.1.3.7.1.2 and Investigations 8.3.1.3.1 through 8.3.1.3.6), to determine the adequacy of and interpret experimental results and to develop future experiments. The sensitivity analysis also will be used to establish which parameters to use in the total systems modeling for Issue 1.1 (Section 8.3.5.13). The sensitivity analysis will support and be available with the geochemical-geophysical parameters called for by Issue 1.1 and provided by this characterization program.

Computer models are used to investigate the physical and geochemical processes affecting transport and estimate the integrated transport of radionuclides (Activity 8.3.1.3.7.1.2). The geologic system and the transport processes at Yucca Mountain are very complex due to the unsaturated, fractured nature of the porous media. To model such a system, the best calculational tools need to be used. Computational cost and numerical efficiency are important factors to consider. For quality assurance, the models must be verified, validated, and the important contributors to model uncertainty and those parameters for which variation within favorable limits have little or no influence on model results should be identified. This activity will be closely linked to Activities 8.3.1.3.7.2.1 and 8.3.1.3.7.2.2; however, the results of this activity are critical, and therefore, this activity is recognized as being distinct.

A sensitivity analysis will identify the important contributors to uncertainty in retardation model calculations. Once model sensitivities are identified, unnecessary complexity in the total systems models can be reduced, thereby facilitating the probabilistic simulations of systems performance to be made in fulfilling Issue 1.1.

Inherent in this activity and in previous Activities 8.3.1.3.7.1.1 and 8.3.1.3.7.1.2 is the implementation of alternative numerical models. It is not necessary to call for a specific activity, but wherever feasible, alternative numerical approaches in computer models will be implemented to include all significant processes in the transport calculation. Alternative approaches that will increase computational efficiency and numerical stability will also be examined.

Parameters

The data needed are as follows:

1. Computer code results from all codes used in the NNWSI Project (codes: hydrologic and transport).
2. Results from Activity 8.3.1.3.7.1.1 and Study 8.3.1.3.1.2.

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The data gathered are as follows:

1. Verification and validation of computer codes.
2. Identification of uncertainties in parameters.

Description

To comply with the Quality Assurance procedure NNWSI-SOP-03-02: Software Quality Assurance, the codes being used and generated under this study must be verified and validated.

Verification of a code is defined as the assurance that a computer code correctly performs the mathematical operations specified in the numerical model. One way of verifying a computer code is to compare the numerical results with analytic solutions of the same problem. Documented benchmarking and other documented comparisons with independently derived results are also acceptable forms of verification (NNWSI-SOP-03-02). Validation of a code is defined as the assurance that a model correctly represents the physical processes embodied in it and the software is applicable to the problem. One way to validate a computer code is to compare numerical results with results obtained from field and laboratory investigations. Investigators working under this investigation will participate in NNWSI Project-wide benchmarking activities. The numerical accuracy, sensitivity, and computational costs of similar codes will be compared in these benchmarking activities.

The sensitivity analysis will identify the important contributors to uncertainty in retardation model calculations among parameters used in constructing the transport models and quantify the influence of these parameters on model results. Parameters for which variation within foreseeable limits has little or no influence on results of calculations will be identified. This analysis will be closely tied to Study 8.3.1.3.7.1.1. For example, if a model is very sensitive to relatively small changes in one specific parameter value, then that parameter must be well-defined with low uncertainties. These two tasks will be iterative and highly coupled.

Methods and technical procedures

Method	Number	Technical procedure	
		Title	Date
Benchmarking	TWS-MSTQA-QP-14, R1 (Experimental) Procedure	Research and Development	TBD ^a
	TBD	Procedure to implement SOP-03-02 for Software Quality Assurance	TBD

^aTBD = to be determined.

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The following codes will be used

<u>Code</u>	<u>Citation</u>
TRACR3D	Travis, Bryan J., "TRACR3D: A Model of Flow and Transport in Porous/Fractured Media," LA-9667-MS, Los Alamos National Laboratory (May, 1984).
TRANQL	Cederberg, G. A., R. L. Street, and J. O. Leckie, "A Groundwater Mass Transport and Equilibrium Chemistry Model for Multicomponent Systems," Water Resources Research, 21(8), 1095-1104 (1985).
HDOC	Travis, Bryan J., and L. Eric Greenwade, "A One-Dimensional Numerical Model of Two-Phase Flow and Transport in Porous Media using the Dynamics of Contours Methodology," NNWSI Milestone C717, Los Alamos National Laboratory (October, 1985).
FEHMS	Zyvoloski, G., and S. Kelkar, "Preliminary Investigation into Coupled Heat/Mass/Stress Effects at Yucca Mountain", NNWSI Milestone R346, Los Alamos National Laboratory (March 31, 1987).
COLLOID	Nuttall, H. E., "Population Balance Model for Colloid Transport," NNWSI Milestone R318, LA-UR-86-1914, Los Alamos National Laboratory (June, 1986). Submitted to Water Resources Research.
WAFE	Travis, Bryan J., "WAFE: A Model for Two-Phase, Multicomponent Mass and Heat Transport in Porous/Fractured Media," LA-10488-MS, Los Alamos National Laboratory (October, 1985).

8.3.1.3.7.2 Study: Demonstration of applicability of laboratory data to repository transport calculations

Objectives

The goal of this study is to outline the strategy that will be used to demonstrate that the geochemical data collected by the other investigations in this program are applicable to the calculations for total system performance described in Section 8.3.5.13. The implementation details of this strategy have not yet been fully developed and will be described in the first SCP update.

Parameters

The strategy will include modeling and a combination of large-scale laboratory experiments, field studies, consideration of natural analogs, information from processes in the soil zone, and peer review. Examples of

activities for each of these factors and its applicability to the goal of this study are briefly described below.

Description

Modeling

The integrated transport calculations being performed in Study 8.3.1.3.7.1 will be used to determine and quantify the cumulative and individual effects of all physical and geochemical processes controlling transport. The major contributing factors to uncertainty in transport calculations and factors to which the transport calculations are the most sensitive will be identified. The results of these calculations, which identify the important parameters, will be used to aid in the planning and interpretation of the larger scale experiments and other approaches described below.

Large scale laboratory experiments

The use of the data from experiments, such as those described in the following text, to establish the applicability of laboratory data to repository transport calculations will be evaluated in this study.

Experiments at a scale larger than are currently proposed in this section are necessary to investigate scaling phenomenon. One possibility is the single fracture test proposed in the exploratory shaft (Section 8.3.1.2.2.4.1). The goal of the proposed test is to evaluate fluid flow and chemical transport. The test will be performed by removing intact fractures from the shaft for laboratory tracer injection tests. Experiments may be needed for both the saturated and the unsaturated zone.

Field testing

Ultimately, field testing may be the only way to establish the applicability of laboratory data to repository transport calculations. If so, the field tests should first elucidate physical processes and then chemical processes. Ideally, field tests should be conducted in tuff that is chemically and physically similar to the repository horizon and to the important natural barrier unit (Topopah Spring unit and Calico Hills unit, respectively).

Several field-scale studies are already described in Chapter 8. Sections 8.3.1.2.3.1.5 through 8.3.1.2.3.1.8 describe testing of the C-wells with both conservative and reactive tracers. These tests are in the saturated zone and will be used to measure the physical and chemical properties of the geological media in the saturated zone that will affect radionuclide retardation in the Yucca Mountain vicinity. In addition, the results will be used to test numerical codes being used for predicting flow and transport. An exploratory shaft test is proposed (Activity 8.3.1.2.2.4.2) entitled infiltration tests in the exploratory shaft facility.

A field scale test outside of the exploratory shaft in an area where the potential host rock is near the surface, such as Fran Ridge, could provide useful information. Some possible tests could include gas flow experiments and a multiple fracture test to investigate flow in a complex fracture network.

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There is a tremendous potential for scientific study of radionuclide migration at the Nevada Test Site. Because of weapons tests, nuclide migration and particulate transport can be studied in a geomeia that is similar to the repository area. The site represents an opportunity to study migration from tests on a field scale, in situ, that in some instances are 20 years old. The possibility of using this resource should be considered:

Natural analogs

An alternate approach or concurrent approach to large scale field tests is to study natural analogs. The study of natural analogs to radionuclide migration has not been given attention in this program because these environments typically have chemistry and mineralogy radically different from the potential candidate site. It is not considered worthwhile to pursue this technical approach since the applicability of data from such natural analogs in licensing would be questionable. Some thought will, however, be given to analyzing potential uses and applicability of any analogs.

Soil zone data

There is a large and growing body of literature on the movement of contaminants in the near surface or soil zone and a substantial amount of the literature deals with the unsaturated zone. As a start, a literature search is proposed to determine availability and applicability of this type data.

Peer review

An important and critical part of establishing the credibility of the results of this study is peer review. The peer review process will be considered for use during all stages of this investigation, from conceptualization of the experiments to the review of the final results. Peer review can also become technical arbitor where no appropriate combinations of laboratory, field, and literature data can be identified to support the extension of lab data to the field.

8.3.1.3.7.3 Application of results

The information derived from the studies and activities just described will be used in the following issues and investigations:

This investigation, especially Study 8.3.1.3.7.1, will be interactive with the investigations listed below:

<u>Investigation</u>	<u>Study</u>
8.3.1.3.4	Radionuclide sorption
8.3.1.3.5	Radionuclide precipitation
8.3.1.3.6	Radionuclide dispersion, diffusion, and advection
8.3.1.3.8	Gaseous radionuclide retardation

Performance issues call for specific geochemical-geophysical parameters. This investigation assesses the parameters produced by the geochemistry test program and provides the required information to the performance issues.

This preferred data transmittal approach does not preclude that performance issues can go directly to the other investigations within this test program to obtain needed information. Furthermore, the integrated transport calculations directly support Issue 1.1 (Section 8.3.5.13).

This investigation will be interactive with the following information needs or issues:

<u>SCP section</u>	<u>Description</u>
1.1.1	Site information needed for calculations (Section 8.3.5.13.1)
1.1.2	Potentially significant release scenario classes (Section 8.3.5.13.2)
1.1.3	Calculational models for release scenario classes (Section 8.3.5.13.3)
1.1.5	Radionuclide releases for scenario classes (Section 8.3.5.13.5)
1.6.2	Calculational models to predict ground-water travel times (Section 8.3.5.12.2)
1.6.4	Identification of likely travel paths (Section 8.3.5.12.4)
1.8	NRC siting criteria (Section 8.3.5.17)
1.9b	100,000 yr releases (Section 8.3.5.18)

8.3.1.3.7.4 Schedule and milestones

This investigation contains two studies: 8.3.1.3.7.1 (retardation sensitivity analysis) and 8.3.1.3.7.2 (demonstration of applicability of laboratory data to repository transport calculations). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

The activities under this investigation, especially Study 8.3.1.3.7.1, are in part constrained by the progress of the experimental testing program, particularly the geochemistry and hydrology testing programs providing input parameters to the sensitivity analyses and transport models of this study. The exploratory shaft schedule would impact the experimental testing and furthermore, the initiation of geochemical field tests (Study 8.3.1.3.7.2) constrains final validation of the transport model developed in this study. The modeling work is constrained but interactive with the activities of Investigation 8.3.1.3.6 (radionuclide dispersion, diffusion, and advection), particularly the activities measuring dispersion and diffusion (Study 8.3.1.3.6.2). Sensitivity studies and model development, however, are ongoing

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and can be initiated with the existing information after the study plan (Study 8.3.1.3.7.1) is available. These activities are intended to be parallel interactive efforts with the testing programs. As data become available from the testing program, the model refinements and further sensitivity-uncertainty analyses will be performed on an incremental schedule. Study 8.3.1.3.7.2 will involve preparation of a field test proposal, which will take approximately 18 months to prepare. However, initiation of field tests, also part of this study, will be constrained by funding, as these tests are not reflected in current budget allocations. The field tests are needed for code validation of transport processes (Study 8.3.1.3.7.1).

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

The points on the timelines are described in the following table.

<u>Point number</u>	<u>Description</u>
1	Milestone R342. Final report available on TRACR3D.
2	Milestone R537. Final report available on the significance of physical processes affecting transport.
3	Milestone Z366. Final report available on benchmarking calculations for retardation sensitivity analysis.
4	Milestone R538. Final report available on the significance of geochemical processes affecting transport.
5	Milestone M390. Final geochemical-geophysical model complete.

Point
number

Description

6	Milestone P381. Final integrated transport calculations available.
7	Milestone Q002. Report available on the summary of results defining radionuclide retardation at Yucca Mountain. This is a higher-level report that summarizes the results of Investigations 8.3.1.3.4 through 8.3.1.3.7 and completes work performed as part of Investigation 8.3.1.3.7.
8	Geochemistry field test plan completed.
9	Initiation of field tests.
10	Preliminary field test results available.
11	Final field test results available.
- 8.3.1.3.8 Investigation: Studies to provide the required information on retardation of gaseous radionuclides along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical chapters and applicable support documents

The following sections of the site characterization plan data chapters and support documents provide a technical summary of the existing data relevant to this information need:

<u>SCP section</u>	<u>Subject</u>
4.1.3.6.2	Gaseous transport

Parameters

The parameters obtained from other investigations are

1. Identification of the gaseous species.
2. Composition of the unsaturated zone gas phase.
3. Mechanism for gaseous transport.
4. Flow paths available in unsaturated zone.
5. Water chemistry.
6. Physical state of the water in the unsaturated zone.

The parameter obtained from this investigation is gaseous radionuclide transport calculations.

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Purpose and objectives of the investigation

The purpose of this investigation is to supply input data for calculations of gaseous radionuclide transport from the repository to the accessible environment at the Yucca Mountain site. These calculations are required to address the overall system performance objective for radionuclide release in 10 CFR 60.112, Issues 1.1, 1.2, and 1.3 (Sections 8.3.5.13, 8.3.5.14, and 8.3.5.15), and in making findings on the postclosure system guideline and the technical guidelines for geochemistry in 10 CFR Part 960, Issue 1.9 (Section 8.3.5.18). Specifically, Issue 1.1 requires an estimate of the standard deviation of the residence time in the repository overburden of the C-14 nuclei released at the repository level. The objective of this investigation is to provide the data necessary for developing a chemical model that can be used to calculate this residence time. The residence time can then be used to calculate the rates of transport of gaseous radionuclide species between the repository and the accessible environment, and to verify experimentally the models of gaseous radionuclide transport and retardation that are used to assess radionuclide release.

Technical rationale for the investigation

The location of the repository in the unsaturated zone presents the possibility that radionuclides that can exist as gases can be transported toward the environment through gaseous flow paths in the unsaturated zone. Gaseous transport driven by concentration gradients (diffusion) or by convective flow is possible. Activity 8.3.1.2.2.8.1 (gaseous-phase chemical investigation) is focused on understanding the nature of the gas transport processes within the unsaturated zone. There are several mechanisms, however, that can retard the rate of radionuclide transport in the gas phase. The two most likely to be effective are isotopic exchange between the gas phase and aqueous phase, and the solubility of the gaseous species in the aqueous phase.

The initial approach to studying the retardation of gaseous species along flow paths is to do preliminary calculations of the rates of transport of gaseous radionuclide species considering the various driving forces that may exist and without consideration of possible retardation mechanisms. The mechanisms that can affect transport of gaseous species will be identified and calculated rates of interphase transport between the gas and aqueous phases will be used to evaluate the various retardation mechanisms. This analysis depends on a knowledge of the chemical nature of the gaseous radionuclides (the most important being carbon-14 as carbon dioxide and iodine-131 as iodine gas), the quantity, distribution, and chemistry of water that can contact the gas phase in the unsaturated zone, the nature of the driving force for transport (convection or diffusion), and the nature of the flow paths for gas in the unsaturated zone (porous flow or fracture flow). Information about hydrology (water quantity and distribution), gaseous flow paths, and the importance of connection in the unsaturated zone will be obtained from Investigation 8.3.1.2.2.

A program of experimental measurements of gas transport in unsaturated zone rock may be required to verify the calculational models used for this analysis. A decision to plan and initiate an experimental program will be made based on the results of the analysis described above.

Information from the activities just described will be combined to calculate the rates of gaseous species transport under expected repository conditions in the modeling in Investigation 8.3.1.3.7. From these results the contribution of gaseous releases to the total system releases will be determined.

8.3.1.3.8.1 Study: Gaseous radionuclide transport calculations and measurements

The goal of this study is to (1) calculate the rates of transport of gaseous radionuclide species (Activity 8.3.1.3.8.1.1) between the repository and the accessible environment considering the various driving forces and retardation mechanisms that may exist, and (2) experimentally verify potential existing models of gaseous radionuclide transport and retardation that are used to assess radionuclide release to the environment. The need for the second goal will depend on the results of the gaseous radionuclide transport calculation (Activity 8.3.1.3.8.1.1). The results of Activity 8.3.1.3.8.1.1 will be used to plan a series of experimental measurements (Activity 8.3.1.3.8.1.2) of radionuclide transport in unsaturated tuff if the calculations do not provide sufficient assurance of radionuclide containment. If calculated results with their associated uncertainties are adequate to assess the release of gaseous radionuclides for performance assessment calculations, Activity 8.3.1.3.8.1.2 may not be required. The results will be used to determine radionuclide releases to the accessible environment and to evaluate the existence of potentially adverse conditions.

8.3.1.3.8.1.1 Activity: Physical transport mechanisms and rates--retardation mechanisms and transport with retardation

Objectives

The goal of this activity is to determine the manner in which gaseous species are transported in the unsaturated zone and to calculate transport rates without retardation. This activity will then identify the retardation mechanisms that can affect the transport of gaseous species through the unsaturated zone and model these processes so that the effects on transport rates can be evaluated.

Parameters

The data needed are as follows:

1. Gaseous radionuclide species (Issue 1.1).
2. Gas phase composition (Investigation 8.3.1.2.2).
3. Mechanism of gaseous transport (Investigation 8.3.1.2.2 and Information Need 8.3.2.2.6).

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4. Flow paths for gaseous transport (Investigation 8.3.1.2.2).
5. Water chemistry (Investigations 8.3.1.3.1 and 8.3.1.2.2).
6. Physical state of the water (Investigation 8.3.1.2.2).

The data gathered are as follows:

1. Rates of gaseous transport without retardation.
2. Identification of retardation mechanisms that affect gaseous transport.

Description

This activity will calculate gaseous species transport in the absence of retardation mechanisms by applying gas transport models for convective flow and diffusion to the physical description of the system. These models will be obtained from the literature if they exist. This activity also will survey the literature on processes such as isotopic exchange and gas solubility to identify those processes that can affect gas transport. Processes that appear effective will be modeled to assess their influence on transport of gaseous radionuclide species in the unsaturated zone. Gas transport rates with retardation will be calculated.

Methods and technical procedures

No specific methods are applicable to this activity. No technical procedures are applicable to this activity.

8.3.1.3.8.1.2 Activity: Gas transport measurements

Objectives

The goal of this activity is to measure experimentally gas transport rates under typical unsaturated zone conditions to verify calculational models of gas transport and retardation if they exist.

Parameters

The data needed are as follows:

1. Identity of the gaseous species (Investigation 8.3.1.3.5).
2. Gas phase composition (Investigation 8.3.1.2.2).
3. Gas transport mechanism (Investigations 8.3.1.3.5 and 8.3.1.2.2 and Section 8.3.2.2.6).
4. Water chemistry (Investigation 8.3.1.3.1).
5. Physical state of the water (Investigation 8.3.1.2.2).

The data gathered are as follows:

1. Measurement of gas transport rates.
2. Verification of calculational models of gas transport and retardation.

Description

This activity will perform experimental measurements of gaseous transport rates and retardation processes in order to verify calculational models of these processes if they exist. The exact nature of the experimental measurements are not determined at this time. Examples of the kinds of measurements that may be needed are (1) measurements of isotopic exchange rates of carbon between carbon dioxide and aqueous carbonate under flow or diffusion conditions typical of the unsaturated zone or (2) measurements of interphase transport rates of carbon dioxide or iodine between the gas phase and an aqueous phase in pores or fractures.

Methods and technical procedures

Methods and technical procedures will be developed as needed.

8.3.1.3.8.2 Application of results

The information derived from the studies and activities described above will be used to calculate the rate of transport of gaseous radionuclide species toward the accessible environment. This information is needed to calculate the quantities of radionuclides released to the environment (Issues 1.1, 1.2, and 1.3, Information Need 1.1.1 and Investigation 8.3.1.3.7). The information is also needed to assess the existence of potentially adverse conditions at the site (Issue 1.8), and to estimate cumulative releases during a 100,000-yr period (Issue 1.9b). These issues and information needs are discussed in Section 8.3.5.

8.3.1.3.8.3 Schedule and milestones

This investigation contains one study, gaseous radionuclide transport calculations and measurements, consisting of two activities: 8.3.1.3.8.1.1 (transport and retardation mechanisms) and 8.3.1.3.8.1.2 (gas transport measurements). In the figure that follows, the schedule information for these activities is presented in the form of timelines. The timelines extend from the implementation of the approved study plan, at which time the first activity can begin, to the issuance of final products associated with the study.

This study is an out-year study. Completion of the study is dependent on the scope of work to be defined for Activity 8.3.1.3.8.1.2 (gas transport measurements), which will be based on the results of Activity 8.3.1.3.8.1.1 (transport and retardation mechanisms).

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The study number and title corresponding to the timelines are shown on the left of the following figure, which presents the two activities. Points on the timelines represent major events or important milestones associated with the study. Solid lines represent activity durations and dashed lines show interfaces.

The points on the timelines are described in the following table.

<u>Point number</u>	<u>Description</u>
1	Complete literature survey of gas transport models and processes that can affect gas transport.
2	Complete preliminary calculations of the rates of transport of gaseous radionuclide species considering the various driving forces and retardation mechanisms that may exist.
3	Begin assessment as to whether the calculated gas transport rates with their associated uncertainties are adequate to assess gaseous radionuclide releases for performance assessment calculations.
4	Preliminary results of assessment (point 3) available.
5	Complete assessment as to whether the calculated gas transport rates with their associated uncertainties are adequate to assess gaseous radionuclide releases for performance assessment calculations.

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Point
number

Description

6	Based on the results of Activity 8.3.1.3.8.1.1, begin planning a series of experimental measurements of radionuclide transport rates and retardation processes to verify calculational models.
7	Report available on the results of experimental measurements of gaseous transport rates and retardation rates to verify calculational models.