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Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume IV, Part B

Chapter 8, Section 8.3.1, Site Program

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

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8.3.1.1 Overview of the site program: Role of alternative conceptual models

The site program is designed to acquire the information about the site that is needed to resolve the design and performance issues in the issues hierarchy. (The issues hierarchy is described in Sections 8.1.1 and 8.2.1.) This objective will be met by the strategy that is illustrated in Figure 8.3.1.1-1. The site program is part of the overall issue resolution strategy that is described in Section 8.1.2.

As indicated in Figure 8.3.1.1-1, performance allocation is used to identify information needs and to develop the testing strategy of the site program. Performance allocation specifies the elements of the site that must be investigated to resolve the issues and indicates the relative degree of testing that must be done to reduce the uncertainties to levels consistent with resolution of the issues. For each issue, information needs are developed based on the current description of the physical characteristics of the site (the system description) and the associated uncertainties. The process of performance allocation is outlined later in this section and is described in detail in Section 8.1.2.2.

Investigations that address the information needs will be conducted and the results will be analyzed. The resulting information will be used in the resolution of issues as described in Section 8.1.2.

The site program testing strategy may evolve during site characterization. For example, if information gained during site characterization leads to a significant change in the conceptualization of the Yucca Mountain physical system, it may be appropriate to redefine the information needs and modify the associated testing strategy. Information needs may also change if it is found that information from the site program is not adequate to resolve all of the issues. For example, meeting some of the information needs as currently defined may be unfeasible because of limitations in measurement or analysis techniques or because the scientific findings differ significantly from current understanding. The testing strategy may also be modified if significantly improved investigative or analysis techniques become available, which permit reducing uncertainties previously considered to be irreducible. If the level of confidence in site information is inadequate and alternative tests cannot be identified, it will be necessary for the DOE to reevaluate site suitability.

The following subsections of this overview describe the elements of the Yucca Mountain system description and associated uncertainties, current site information and design, sources of site information, aspects of the site program that are designed to provide confidence that the needed data will be acquired, and, finally, the organization of the the major programs within the overall site program.

Elements of the system description and uncertainties

The Yucca Mountain site is a complex and dynamic natural physical system whose state is determined by (1) the external environmental setting (i.e., the boundary conditions); (2) the internal geometry of the system; and (3) the physical processes acting within the system. The external environmental setting includes the regional climatic, tectonic, geothermal, and

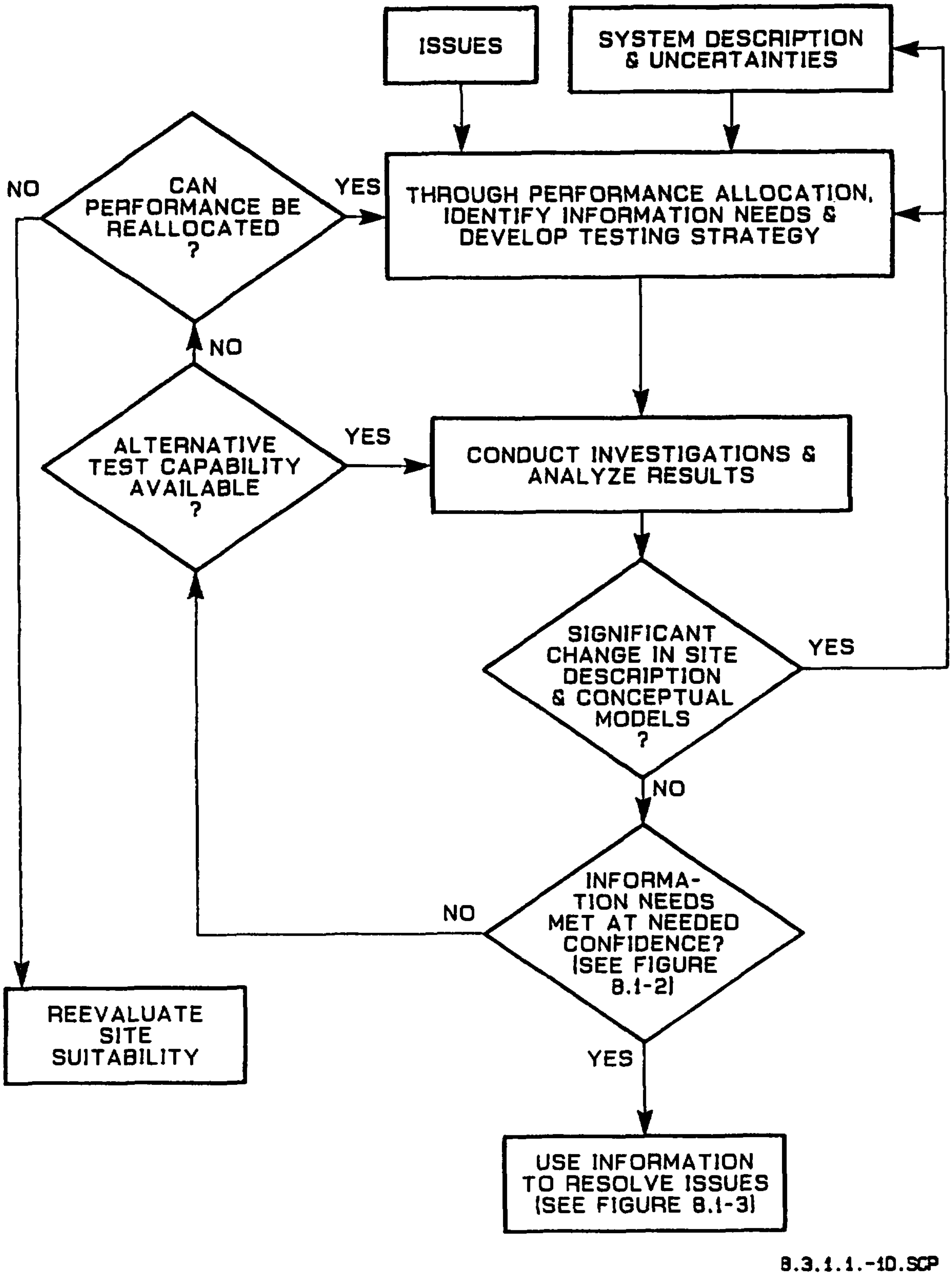

Figure 8.3.1.1-1. Strategy for the conduct of the site program.

ground-water hydrogeologic systems. The internal geometry of the site is determined by the geologic framework and is defined by local structural features and stratigraphy. The processes operating within the system include hydrologic processes controlling liquid-water storage and flow and watervapor storage and flow; geothermal heat flow; processes controlling tectonic, lithostatic, and hydrostatic stress fields; geochemical and solutional kinematics; and pore-gas storage and flow.

Conceptual models must be developed to provide a description of the site physical system and to develop numerical models that can be used to quantitatively predict the system's behavior. Each conceptual model comprises a set of hypotheses regarding the environmental setting, internal geometry, and governing internal processes that are consistent with each other and that are compatible with available data. There is uncertainty in each conceptual and numerical model and, even after site characterization, some degree of uncertainty is expected to remain. The parameterization of numerical models involves uncertainty because of data limitations. Conceptual model uncertainty is indicated by the admissibility of alternative conceptual models, that is, there may be more than one set of hypotheses that is internally consistent and compatible with the available data.

As described below, the site program is designed to reduce both parameter uncertainty and conceptual uncertainty to the degree needed to satisfy the information needs.

Current site information and design

Considerable information about the Yucca Mountain site is already available and a preliminary conceptual design of the surface and underground repository facilities has been developed. Together, the site information and preliminary design serve to constrain and guide the plans for characterizing the site.

The present state of knowledge about the site and the surrounding area is summarized in Chapters 1 through 5. Considerable data have been collected for the specific purpose of making preliminary assessments of the suitability of Yucca Mountain for a mined geologic disposal system. Data have also been collected for other purposes, most notably in support of operations at the Nevada Test Site, adjacent and east of Yucca Mountain. These data provide information on the geologic and tectonic conditions (Chapter 1), the geoengineering properties relevant to repository construction (Chapter 2), the hydrologic environment (Chapter 3), the geochemical properties relevant to repository performance (Chapter 4), and the local meteorology and long-term variations in climate (Chapter 5).

The preliminary conceptual designs of the surface and underground repository facilities are described in Chapter 6, and information on conditions that affect waste-package design and performance is presented in Chapter 7.

Sources of site information

The geology of Yucca Mountain reflects the formation and subsequent alterations of the site up to the present. The mountain was formed more than ten-million years ago and the local geologic record is about one-thousand times longer than the time frame of primary concern for waste isolation (10,000 yr). Thus, the local geologic record might be expected to contain an adequate sampling of those identifiable processes and disturbances that are reasonably likely to occur during the period important to waste isolation, as well as information on disturbances that would not be likely to occur during the geologically short period of concern.

The geologic processes that are reflected in the local geologic record, as discussed in Chapters 1 through 5, have all been observed elsewhere. These include volcanic processes, active faulting and related earthquake effects, weathering and erosional processes, and a variety of geochemical processes. Knowledge about ground-water processes is available from observations at many sites under a variety of conditions, including observations of earthquake- and explosion-induced effects. There are many observations elsewhere of the effects of earthquakes and explosions on engineered structures. This body of outside knowledge, a portion of which is described and referenced in Chapters 1 through 5, provides an understanding of the processes that may be acting locally and can be used to help interpret site-specific data and make site-specific predictions.

Evidence for some geologic processes that may affect the site may be apparent only outside of the immediate site area. For example, no known evidence exists for volcanic activity at Yucca Mountain since the Miocene, but the presence of cinder cones nearby to the south and west (Section 1.3.2.1.2) indicates a need to investigate the potential for volcanic activity at the site. In general, knowledge of the geologic setting constrains and provides confidence in local interpretations.

Understanding of the site is based on four sources of information: site-specific data, knowledge of the geologic setting, related global observations and associated knowledge, and generally accepted principles and concepts of science. Uncertainty and deficiencies in any of these sources can lead to uncertainty in the system description. Examples of current site-specific data deficiencies exist in regard to the potential for surface fault rupture at and near the proposed locations of surface facilities in Midway Valley, hydrologic parameters within the Yucca Mountain block, past changes in local water-table elevations, and past climatic conditions. Current knowledge about ground-water flow conditions in adjacent regions is inadequate and represents a deficiency in knowledge of the hydrogeologic setting. Uncertainty in global climate models creates uncertainty in predicting future precipitation and ground-water flux. Limited scientific ability to date geologic materials and structures contributes significantly to uncertainty about the geologic history of the site area. A conceptual understanding of the potential for ground-water fluctuations due to coupled igneous and tectonic effects is another area of current uncertainty.

Uncertainties of all types in the present system description were considered in defining the information needs that the site program is designed to satisfy.

Confidence building

The site program embodies a number of approaches for building confidence that the necessary data will be acquired. These include a flexible, iterative strategy for issue resolution, the use of performance allocation to ensure that site investigations acquire the most important information for resolution of performance and design issues, explicit testing of hypotheses associated with alternative conceptual models, studies that focus on particular phenomena of concern, the use of probabilistic as well as deterministic evaluations of site performance, and extensive internal and external technical review.

Flexible strategy

The flexibility in the strategy for conducting the site program, illustrated in Figure 8.3.1.1-1, was discussed earlier. Any changes in the defined information needs will be documented in semiannual progress reports on site characterization activities. The testing strategy will be reevaluated on the basis of any such changes and modified, as necessary, to acquire the needed information. Modifications to the testing strategy will also be documented in the semiannual reports.

Performance allocation

The first steps in performance allocation (Section 8.1.2.2) lead to the identification of information needs--those categories or types of information that are needed to resolve each performance and design issue. Performance allocation starts with the formulation of a licensing strategy for each issue. This step uses available information to develop a statement of the site features, engineered features, conceptual models, and analyses that are considered important to the resolution of the issue. The principal product of this step is the identification of the elements of the site that will be investigated to resolve the issue, that is, if these elements can be shown to perform as assumed in the licensing strategy, the issue is likely to be resolved. The next step is the establishment of performance measures for each of the elements identified in the preceding step. Tentative goals and indications of desired confidence that each goal is met are established for each performance measure. As discussed in Section 8.1.2.2, these goals are not standards that must be met for the repository to perform properly; their function is to guide the identification of information that must be provided by the site program. The performance measures are then used to develop information needs. The information needs are expressed in terms of the design and performance parameters that are needed to evaluate the performance measures. Tentative goals and indications of confidence that are consistent with the goals for the performance measures are established for the parameters.

The next step in performance allocation is to define the work that will produce the needed information. The information needs are expressed in terms of the design and performance parameters. To establish values for these parameters, more detailed characterization parameters and associated goals and levels of confidence are defined such that, in principle, they can be established by scientific investigation. The scientific investigations that compose the site program are then designed to provide the defined characterization parameters.

In the manner just described, performance allocation relates the site data being collected to the information needed to resolve the design and performance issues. It thus ensures that the information that is important to issue resolution will be obtained by the site program.

Further confidence in the site program is provided by the use of conservative goals in performance allocation--goals that, if met, would likely contribute to a finding that the site will meet the technical criteria of the regulations by a sufficient margin to address residual uncertainties in site characteristics.

Hypothesis testing

The site program is designed not only to reduce uncertainty associated with characterization parameters, but also to reduce uncertainty in the conceptualization of the site physical system. For example, reduction of uncertainty in conceptual models of moisture flow in partially saturated, fractured rock has been identified as being particularly important to the prediction of site performance, and this uncertainty is being addressed by studies described in Section 8.3.1.2.

Systematic hypothesis testing is being employed to discriminate between alternative conceptual models by eliminating untenable or nonviable hypotheses and to evaluate the likelihoods that alternative, admissible conceptual models are applicable. As with parameter uncertainty, conceptual uncertainty will be reduced to the extent necessary to satisfy the information needs.

To ensure comprehensive consideration of potentially viable alternative conceptual models and to document this consideration, hypothesis-testing tables have been developed for several particularly relevant disciplines. Specifically, hypothesis-testing tables have been developed for investigations related to geohydrology (Section 8.3.1.2), geochemistry (8.3.1.3), rock characteristics (8.3.1.4), climate (8.3.1.5), preclosure and postclosure tectonics (8.3.1.17 and 8.3.1.8), natural resources that could lead to future human disruption of the site (8.3.1.9), and thermal and mechanical rock properties (8.3.1.15).

These tables summarize information in five categories: (1) the current representation of the system, (2) the uncertainty and rationale in current hypothesis, (3) alternative hypotheses, (4) the significance of the alternatives, and (5) the studies or activities needed to reduce the uncertainties.

The first category, the current representation, identifies the elements of the system being evaluated and describes the current or preferred hypotheses regarding these elements. Typically, the elements of the system include its physical domain and geometry, key features and properties of the system, processes and events that may be important, and boundary conditions. The current hypotheses describe the assumptions made regarding these elements from the available information about the site.

The second category specifies the uncertainty in each current hypothesis and gives a rationale for this specification. A qualitative judgment (high, medium, or low) of ambiguity in the current conceptual understanding is presented, based on the available data and information. For example, a high specification is indicated when a particular hypothesis could be very uncertain because data are lacking or because large uncertainties arise in the interpretation of measured parameters. In other cases, when the level of uncertainty is more constrained, a medium or low rating is specified, depending on the degree and reliability of the constraints.

The third category presents possible alternative hypotheses that might also explain the available data. Where the uncertainties are judged to be very low, no alternative hypothesis may be listed. An alternative hypothesis may also be omitted when the alternative is simply that the preferred hypothesis is false.

The fourth category provides judgments of the significance of the uncertainties based on the identified information needs and the sensitivity of the information needs to the uncertainties. Specifically, the performance measures and design or performance parameters that were defined through performance allocation are listed in each table, along with the needed confidence in the measure or parameter, a judgment of the sensitivity of this information to the uncertainty in the hypothesis, and, based on the preceding elements, a judgment about the ultimate need to reduce the uncertainty. The role of the fourth category is to link the alternative conceptual models to resolution of performance and design issues. Alternative conceptual models will be considered primarily as they affect information needs associated with performance and design issues. Thus, the significance of each conceptual model is dependent on how sensitive the information needs are to the model assumptions.

The fifth category identifies the activities that are planned to discriminate between competing hypotheses or to otherwise reduce the estimated uncertainty. These activities cut across disciplines and program lines, where necessary. For example, the hypothesis-testing table for unsaturated-zone hydrology (Table 8.3.1.2-2a) lists activities being conducted under the postclosure tectonics program to assess the effects of tectonic processes and events on local fracture permeability and effective porosity, activities in the geochemistry program to provide information on water chemistry, and activities in the thermal and mechanical rock properties program to determine ambient thermal conditions.

The hypothesis-testing tables are necessarily preliminary and, therefore, list not only uncertainties known to be important, but also uncertainties that are probably inconsequential. Even so, there are undoubtedly more hypotheses that could be listed. The tables list modeling uncertainties that appear, now, to be possibly relevant.

Focus on phenomena

Another approach to building confidence that the needed information will be gathered is the phenomenological focus of many of the site characterization investigations and studies, that is, many investigations and studies have as an explicit objective an improved understanding of a physical process that may affect or occur at the site. These investigations and studies typically involve different types of activities to gain the necessary information about the process. Examples are the geohydrology investigation

(8.3.1.2.2) of water movement in the unsaturated zone, the geochemistry study (8.3.1.3.2.2) of the history of mineralogic and geochemical alteration of Yucca Mountain, and the postclosure tectonics study (8.3.1.8.3.2) of the potential effects of tectonic processes and events on the water-table elevation. With an understanding of phenomena as the basis for the system description, potentially important uncertainties are less likely to be overlooked.

Studies that focus on phenomena are often interdisciplinary and, therefore, require programmatic integration. As discussed previously, the linkage between information that is being provided by one program and that is being used by another program is documented in the hypothesis-testing tables. This linkage is also documented in performance-allocation tables for each site program (e.g., Table 8.3.1.2-1) which illustrate the connection between the design and performance issues and the information being provided by each activity. Logic diagrams for each site program (e.g., Figure 8.3.1.2-2) also indicate linkages between the various site programs. Integration across disciplines and programs during the course of site characterization will be facilitated by meetings and workshops in which the responsible investigators in different disciplines will participate.

Deterministic and probabilistic evaluations

Both deterministic and probabilistic evaluations of site performance will be performed. The deterministic evaluations include bounding analyses as well as representative estimates using point values for performance and design parameters. Probabilistic analyses will be used where appropriate to quantify and determine the importance of uncertainty in the parameters. In some cases probabilistic analysis is used as an adjunct to deterministic design-basis analysis; an example is the development of a seismic design basis for preclosure facilities that are important to safety (Section 8.3.1.17.3).

The support of probabilistic analyses provides added confidence that the data needed to adequately characterize the site will be collected. Probabilistic evaluations typically treat scenarios over a wide range of occurrence likelihoods and quantitatively consider the impact of both conceptual and parametric uncertainty. Probabilistic analyses, therefore, often require more information than deterministic analyses. Probabilistic analysis also provides an excellent framework for testing the sensitivity of modeling results to various modeling assumptions. The identification of critical assumptions will be used to help keep the site program focused on obtaining the most important information.

Technical review

The site characterization plan has been developed under a DOE quality assurance program and has been subject to an extensive review and a documented comment-resolution process before its completion and issuance, lending further confidence that the site program will acquire all information needed to resolve the design and performance issues. In addition, all technical reports produced by Yucca Mountain Project participants are reviewed according to the DOE quality assurance program.

Organization of the investigations

The subsections of Section 8.3.1 are organized according to the major topics of investigation within the site program. Following this overview, Sections 8.3.1.2 through 8.3.1.9 address topics generally associated with the postclosure performance and design issues; Sections 8.3.1.10 through 8.3.1.17 treat topics generally associated with preclosure design and safety issues. As shown in Table 8.3-1, Section 8.3.1.2 describes the investigations making up the geohydrology program. 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 and the investigations to determine the three-dimensional distribution of rock properties at Yucca Mountain. Investigations planned to predict the range of possible future climatic conditions and their effects are described in Section 8.3.1.5. Section 8.3.1.6 covers the investigations related to present and future erosion rates. Section 8.3.1.7 addresses rates of rock dissolution. Section 8.3.1.8 describes the plans for investigation of tectonic processes and events that could occur during the postclosure period. Section 8.3.1.9 considers the investigations to establish the potential for human interference at the site. Preliminary site-related data needs for preclosure radiological safety assessments 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, respectively). Section 8.3.1.14 describes the investigations to establish the surface characteristics at the site for purposes of siting repository surface facilities. 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 hydrologic conditions and processes important during the preclosure period. Finally, Section 8.3.1.17 describes the investigations to provide information on the potential for preclosure igneous activity, ground motion, and surface faulting at the Yucca Mountain site.

The site investigations described in each section are divided into studies and activities. The studies will be described in further detail in study plans; a list of study plan topics is provided in Section 8.5.1.

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Site Characterization Plan

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Office of Civilian Radioactive Waste Management

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 Yucca Mountain Project (formerly the Nevada Nuclear Waste Storage Investigations (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 transuranic 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 transuranic radioactive wastes shall be designed to provide a reasonable expectation, that for 1,000 yr after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed:
>
> (1) 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/day 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)(1)(ii)(A), and 10 CFR 60.113(a)(1)(ii)(B) are associated with the existence of ground water around the repository; in particular, 10 CFR 60.113(a)(1)(ii)(A) and 10 CFR 60.113(a)(1)(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 Yucca Mountain 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 Yucca Mountain Project.

The logic diagrams of Figures 8.3.1.2-2 through 8.3.1.2-4 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 through 8.3.1.2-4 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 (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.

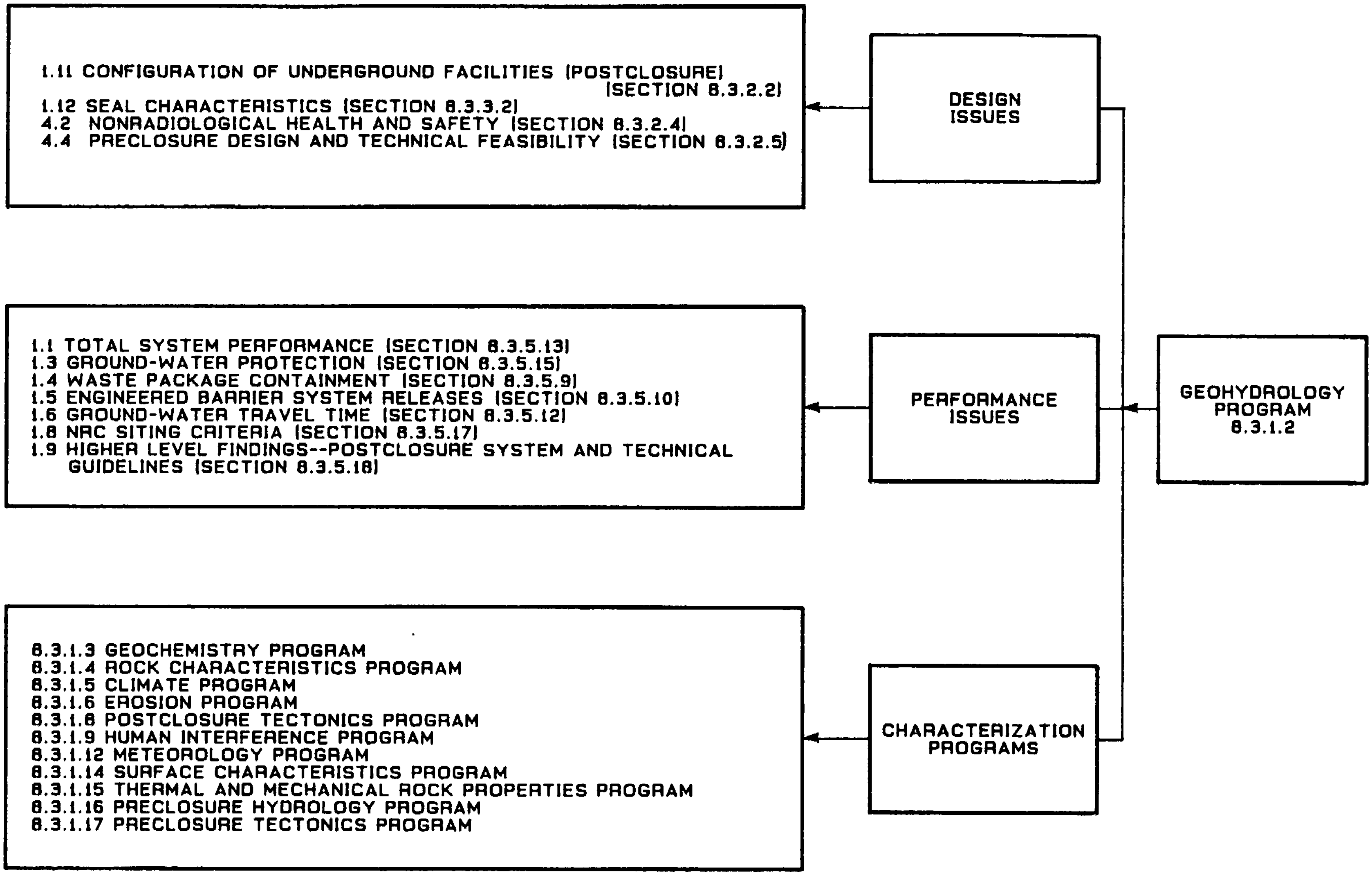
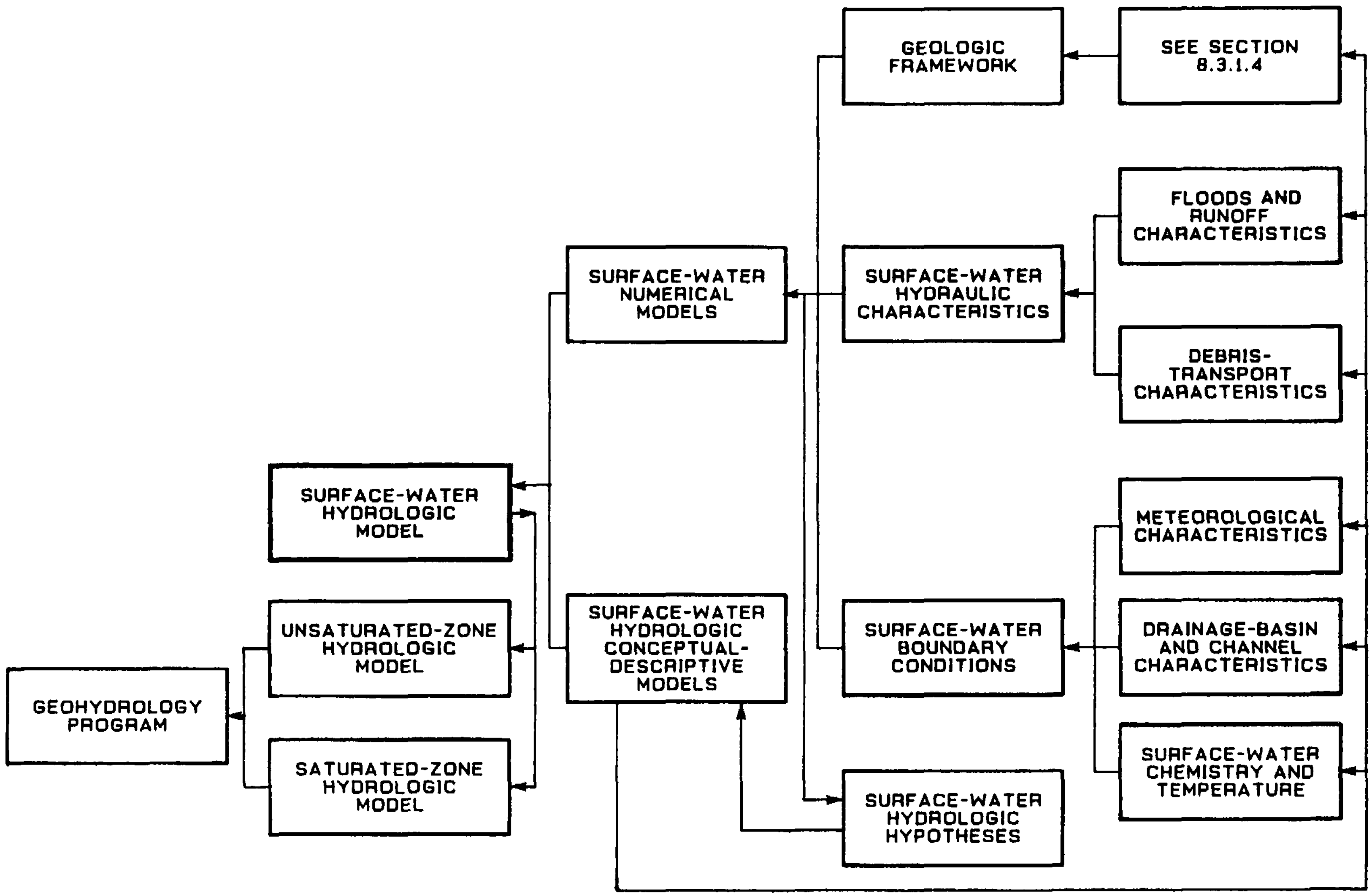
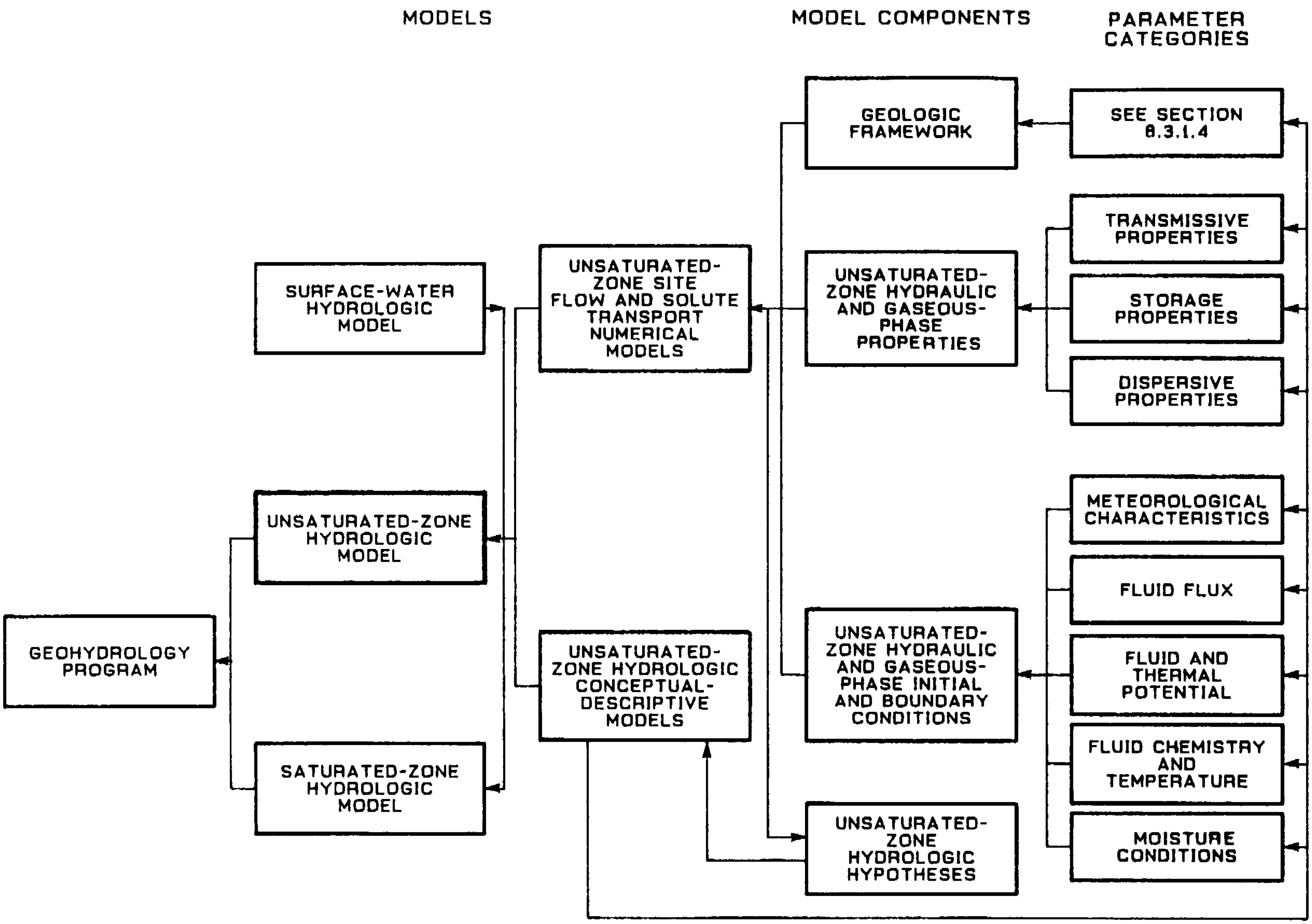


Figure 8.3.1.2-1. Interface of the geohydrology program with design and performance issue and other characterization programs.



8.3.1.2-2

Figure 8.3.1.2-2. Logic diagram of the surface-water hydrology component of the geohydrology program.



8.3.1.2-3

Figure 8.3.1.2-3. Logic diagram of the unsaturated-zone hydrology component of the geohydrology program.

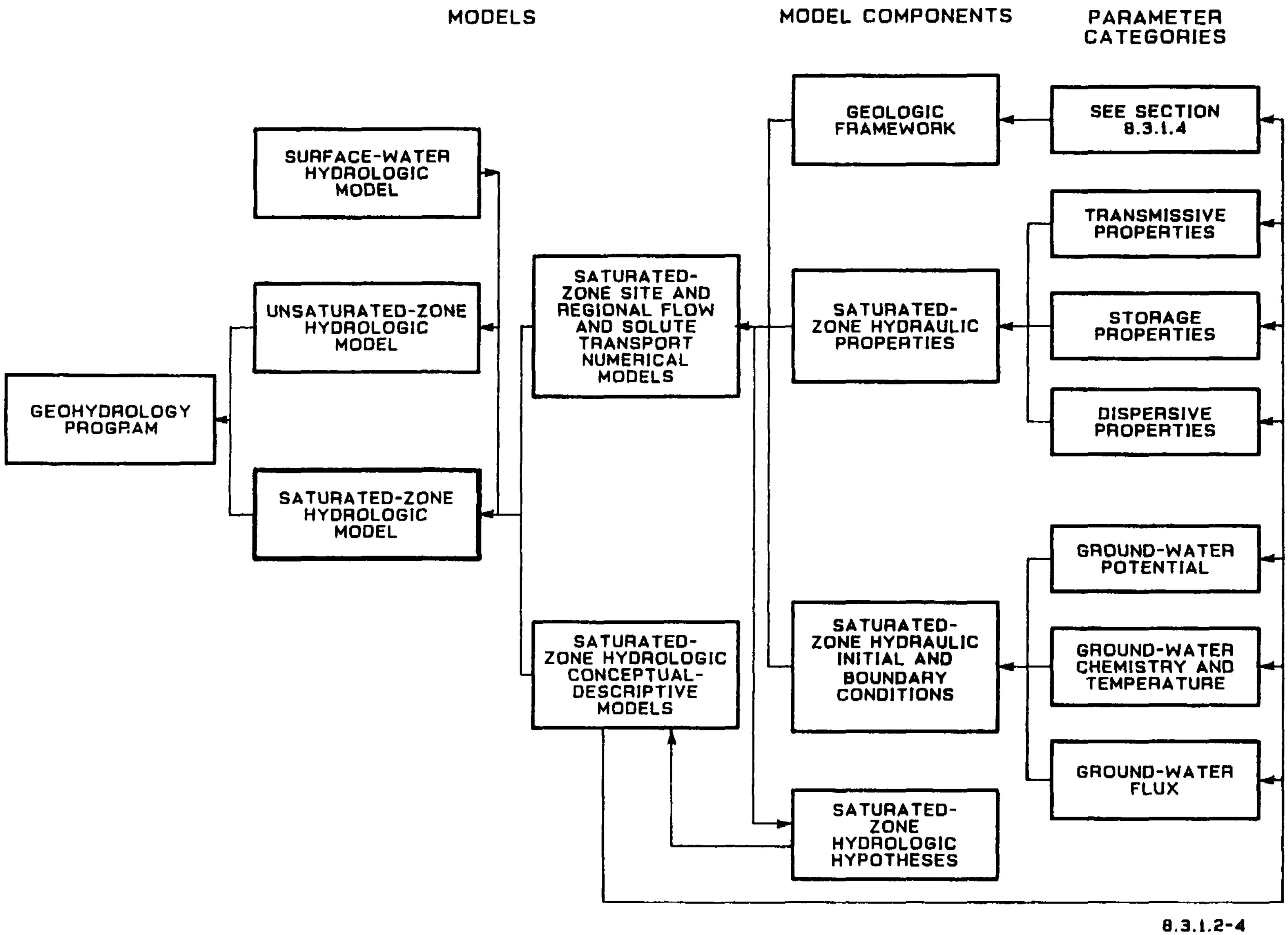


Figure 8.3.1.2-4. Logic diagram of the saturated-zone hydrology component of the geohydrology program.

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.

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 through 8.3.1.2-4.

The parameter categories in Figures 8.3.1.2-2 through 8.3.1.2-4 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 hydraulic and gaseous phase properties") and subcategories (such as unsaturated-zone transmissive properties) 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, number, 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 through 8.3.1.2-4). 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.

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 1 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		METEOROLOGICAL CHARACTERISTICS		
1.12 2.1 2.2 2.3 2.7 4.4	8.3.3.2 8.3.5.3 8.3.5.4 8.3.5.5 8.3.2.3 8.3.2.5	Meteorological characteristics	Storm movement and intensity; meteorological input to unsaturated-zone infiltration and gas-phase circulation studies; (with integrated meteorological network)	8.3.1.2.1.1
			Atmospheric pressure and pressure variability	8.3.1.2.1.1.1
			Atmospheric stability; relations to storms	8.3.1.2.1.1.1
			Atmospheric temperature	8.3.1.2.1.1.1
			Humidity, relative; diurnal and seasonal variability	8.3.1.2.1.1.1
			Precipitation chemistry	8.3.1.2.1.1.1
			Precipitation, intensity and duration (monthly and seasonal variability)	8.3.1.2.1.1.1
			Radiation and irradiation, infrared (diurnal and seasonal variability)	8.3.1.2.1.1.1
			Wind, speed, and direction (diurnal, seasonal, and storm-specific variability)	8.3.1.2.1.1.1
			Air temperature	8.3.1.2.1.2.1
			Precipitation, quantity and timing	8.3.1.2.1.2.1
			Air temperature	8.3.1.2.1.3.3
			Precipitation, quantities and frequency	8.3.1.2.1.3.3
			Precipitation	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 2 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		METEOROLOGICAL CHARACTERISTICS (continued)		
		Meteorological characteristics (continued)	Rainfall, experimentally induced	8.3.1.2.2.1.3
			Air temperature	8.3.1.2.2.6.1
			Barometric pressure	8.3.1.2.2.6.1
			Relative humidity	8.3.1.2.2.6.1
		SURFACE-WATER HYDRAULIC CHARACTERISTICS		
1.1	8.3.5.13	Surface-water flood and runoff characteristics	Runoff and streamflow, hydrologic characteristics	8.3.1.2.1.2
1.12	8.3.3.2		Durations of individual runoff events	8.3.1.2.1.2.1
2.1	8.3.5.3		Occurrences and geographics extent of runoff	8.3.1.2.1.2.1
2.3	8.3.5.5		Runoff quantities, at specific site for specific events	8.3.1.2.1.2.1
2.7	8.3.2.3		Runoff rates at specific sites	8.3.1.2.1.2.1
4.4	8.3.2.5		Runoff durations	8.3.1.2.1.3.3
			Runoff frequencies	8.3.1.2.1.3.3
			Runoff quantities	8.3.1.2.1.3.3
			Runoff rates	8.3.1.2.2.1.1
			Runoff	8.3.1.2.2.1.2
			Runoff; experimentally induced	8.3.1.2.2.1.3

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 3 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SURFACE-WATER HYDRAULIC CHARACTERISTICS (continued)		
1.1	8.3.5.13	Surface-water debris-transport characteristics	Sediment component of runoff	8.3.1.2.1.2.1
1.12	8.3.3.2		Flood debris, physical characteristics	8.3.1.2.1.2.2
2.7	8.3.2.3		Hillslope and channel erosion, location and areal extent	8.3.1.2.1.2.2
			Sediment deposits, location and areal extent	8.3.1.2.1.2.2
		SURFACE-WATER BOUNDARY CONDITIONS		
1.2	8.3.5.13	Surface-water drainage-basin and channel characteristics	Hillslope and channel erosion, timing	8.3.1.2.1.2.2
1.12	8.3.3.2		Drainage-basin and channel geometry (aspect, area, configuration, slope, Manning coefficient)	8.3.1.2.1.3.3
			Surficial deposits, distribution, and characteristics	8.3.1.2.1.3.3
1.1	8.3.5.13	Surface-water chemistry and temperature	Hydrochemistry, surface water	8.3.1.2.1.3.3
1.12	8.3.3.2			

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 4 of 38)

SURFACE-WATER HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
1.1 1.12 2.7	8.3.5.13 8.3.3.2 8.3.2.3	Surface-water hydrologic conceptual/ descriptive models	Precipitation and its relation to surface runoff with particular emphasis on the Fortymile Wash drainage basin; rainfall-runoff model	8.3.1.2.1.1
			Flood and fluvial-debris hazards (8.3.1.16.1.1)	8.3.1.2.1.2
			Runoff and streamflow, relation to amounts and processes of ground-water recharge	8.3.1.2.1.2
			Runoff and streamflow, relation to precipitation	8.3.1.2.1.2
			Relations of runoff to weather conditions	8.3.1.2.1.2.1
			Runoff frequencies in specific and general areas	8.3.1.2.1.2.1

UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
1.1 1.6 1.10 1.12 4.4	8.3.5.13 8.3.5.12 8.3.4.2 8.3.3.2 8.3.2.5	Unsaturated-zone transmissive properties	Recharge locations, rates, and history	8.3.1.2.1.3.3
			Hydraulic conductivity	8.3.1.2.2.1.3
			Flux-related, matrix hydrologic properties (transmissive) of geologic samples	8.3.1.2.2.3
			Permeability, effective, hydraulic, matrix; subsurface geologic samples	8.3.1.2.2.3.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 5 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
		Unsaturated-zone transmissive properties	Permeability, relative, hydraulic, matrix, subsurface geologic samples	8.3.1.2.2.3.1
			Effective matrix porosity	8.3.1.2.2.3.2
			Hydraulic conductivity	8.3.1.2.2.3.2
			Permeability, in situ, hydraulic, bulk	8.3.1.2.2.3.2
			Permeability, in situ, pneumatic, bulk	8.3.1.2.2.3.2
			Permeability, matrix, as a function of saturation and matric potential, laboratory	8.3.1.2.2.3.2
			Effective porosity	8.3.1.2.2.3.3
			Fracture connectiveness	8.3.1.2.2.3.3
			Permeability, in situ, hydraulic, bulk	8.3.1.2.2.3.3
			Permeability, in situ, pneumatic, bulk	8.3.1.2.2.3.3
			Effective permeability to air as a function of saturation, water potential, and applied stress	8.3.1.2.2.4.1
			Effective permeability to water as a function of saturation, water potential, and applied stress	8.3.1.2.2.4.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 6 of 38)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program	
Issue	SCP section		Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES		
1.1 1.6 1.10 1.12 4.4	8.3.5.13 8.3.5.12 8.3.4.2 8.3.3.2 8.3.2.5	Unsaturated-zone transmissive properties	Effective porosity for single fracture	8.3.1.2.2.4.1
			Permeability, effective, single fractures	8.3.1.2.2.4.1
			Effective porosities of the matrix and fractures	8.3.1.2.2.4.2
			Effective porosity, matrix and fractures	8.3.1.2.2.4.2
			Fracture connectiveness	8.3.1.2.2.4.2
			Hydraulic conductivity	8.3.1.2.2.4.2
			Hydraulic conductivity; unsaturated to air and water as functions of water saturation and matric potential	8.3.1.2.2.4.2
			Pneumatic conductivity, fracture networks	8.3.1.2.2.4.2
			Unsaturated hydraulic conductivity to air as a function of bulk water saturation and matric potential (including determination of critical saturation)	8.3.1.2.2.4.2
			Unsaturated hydraulic conductivity to water as a function of bulk water saturation and matric potential (including determination of critical saturation)	8.3.1.2.2.4.2
			Effective porosity of matrix and fractures (including pore-size distribution of matrix)	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 7 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
		Unsaturated-zone transmissive properties (continued)	Effective porosity, bulk; fracture-matrix networks	8.3.1.2.2.4.3
			Fracture and fracture-set spacing and density	8.3.1.2.2.4.3
			Hydraulic conductivity, unsaturated relative to air and water as a function of saturation and matric potential	8.3.1.2.2.4.3
			Permeability; (air) before and after excavation; hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Permeability; (pneumatic) bulk, fracture/matrix networks; hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Pneumatic conductivity; directional and saturation dependence; hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Unsaturated hydraulic conductivities relative to air as a function of saturation and matric potential	8.3.1.2.2.4.3
			Bulk permeability	8.3.1.2.2.4.4
			Bulk permeability, pneumatic	8.3.1.2.2.4.4
			Bulk porosity	8.3.1.2.2.4.4
			Fracture permeability	8.3.1.2.2.4.4
			Gas permeability, excavation effects	8.3.1.2.2.4.4
			Permeability (pneumatic) bulk, fractured rock	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 8 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
		Unsaturated-zone transmissive properties (continued)	Permeability (relative), gas; rock matrix	8.3.1.2.2.4.4
			Permeability (relative), water; rock matrix	8.3.1.2.2.4.4
			Permeability (saturated), gas; rock matrix	8.3.1.2.2.4.4
			Air-permeability profiles	8.3.1.2.2.4.5
			Permeability profiles	8.3.1.2.2.4.5
			Hydraulic conductivity, perched-water zones	8.3.1.2.2.4.7
			Transmissivity, perched-water zones	8.3.1.2.2.4.7
			Bulk permeability (pneumatic)	8.3.1.2.2.4.9
			Effective porosity	8.3.1.2.2.4.9
			Hydraulic conductivity (perched-water zones)	8.3.1.2.2.4.9
			Transmissivity (perched-water zones)	8.3.1.2.2.4.9
			Air permeability, matrix	8.3.1.2.2.4.10
			Water permeability, matrix	8.3.1.2.2.4.10
			Conductive properties, gas flow	8.3.1.2.2.6
			Effective porosity	8.3.1.2.2.6.1
			Fracture connectivity	8.3.1.2.2.6.1
			Fracture permeability, anisotropic	8.3.1.2.2.6.1
			Permeability, pneumatic, bulk	8.3.1.2.2.6.1
			Porosity, fracture, effective	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 9 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
1.1	8.3.5.13	Unsaturated-zone storage properties	Matrix porosity	8.3.1.2.2.1.1
1.6	8.3.5.12		Moisture retention curves	8.3.1.2.2.1.1
			Flux-related, matrix hydrologic properties (storage) of geologic samples	8.3.1.2.2.3
			Matrix pore-size distribution, subsurface geologic samples	8.3.1.2.2.3.1
			Moisture retention curves, subsurface geologic samples	8.3.1.2.2.3.1
			Porosity; subsurface geologic samples	8.3.1.2.2.3.1
			Matrix pore-size distribution	8.3.1.2.2.3.2
			Porosity, total, laboratory	8.3.1.2.2.3.3
			Moisture retention, rock matrix	8.3.1.2.2.4.4
			Porosity pore-size distribution, matrix	8.3.1.2.2.4.4
			Porosity, bulk, fractured rock	8.3.1.2.2.4.4
			Porosity, matrix	8.3.1.2.2.4.4
			Storage coefficient, perched-water zones	8.3.1.2.2.4.7
			Storage coefficient (perched-water zones)	8.3.1.2.2.4.9
			Storage properties, gas phase	8.3.1.2.2.6
			Storativity, gas	8.3.1.2.2.6.1
1.1	8.3.5.13	Unsaturated-zone dispersive properties	Dispersivity, fractures	8.3.1.2.2.4.1
1.10	8.3.4.2		Effective dispersivity for single fracture flow	8.3.1.2.2.4.1
			Flow-path tortuosity in single fractures	8.3.1.2.2.4.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 10 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
		Unsaturated-zone dispersive properties (continued)	Tortuosity, fracture-flow paths	8.3.1.2.2.4.1
			Convective dispersivity, fracture networks	8.3.1.2.2.4.2
			Diffusive tortuosity, fractured rock and rock mass	8.3.1.2.2.4.4
			Dispersive properties, gas flow	8.3.1.2.2.6
			Convective dispersivity	8.3.1.2.2.6.1
			Fracture constrictivity	8.3.1.2.2.6.1
1.1	8.3.5.13	Unsaturated-zone diffusive properties	Matrix diffusion coefficient, fracture networks	8.3.1.2.2.4.2
			Gaseous diffusion coefficient, fractured rock units	8.3.1.2.2.4.4
			Diffusivity coefficient	8.3.1.2.2.5.1
1.1	8.3.5.13	Unsaturated-zone fault hydrologic characteristics	Air permeability, rock mass	8.3.1.2.2.4.10
1.6	8.3.5.12		Hydraulic potential, rock mass	8.3.1.2.2.4.10
1.11	8.3.2.2		Pneumatic potential, rock mass	8.3.1.2.2.4.10
1.12	8.3.3.2		Water content, rock mass	8.3.1.2.2.4.10
4.4	8.3.2.5		Water permeability, rock mass	8.3.1.2.2.4.10

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 11 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS				
1.1	8.3.5.13	Unsaturated-zone	Water potential	8.3.1.2.2.1.1
1.6	8.3.5.13	fluid potential	Flow paths, beneath experimental infiltration plots	8.3.1.2.2.1.3
			Matric potential, beneath experimental infiltration plots	8.3.1.2.2.1.3
			Flux-related, matrix hydrologic properties (fluid potential) of geologic samples	8.3.1.2.2.3
			Matric potential, subsurface geologic samples	8.3.1.2.2.3.1
			Water potential (total), subsurface geologic samples	8.3.1.2.2.3.1
			Matric potential	8.3.1.2.2.3.2
			Pneumatic potential	8.3.1.2.2.3.2
			Pressure head, profiles	8.3.1.2.2.3.2
			Water potential, total	8.3.1.2.2.3.2
			Matric potential	8.3.1.2.2.3.3
			Pneumatic potential	8.3.1.2.2.3.3
			Potential fields (ambient), lateral variation near Solitario Canyon fault zone	8.3.1.2.2.3.3
			Water potential, total	8.3.1.2.2.3.3
			Water potential (fracture), matrix networks	8.3.1.2.2.4.2
			Hydraulic potential of matrix and rock mass	8.3.1.2.2.4.3
			Water potential, matric and rock mass	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 12 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)				
		Unsaturated-zone fluid potential (continued)	Water potential (total), hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Matric potential, fractured rock and rock mass	8.3.1.2.2.4.4
			Pneumatic potential, distribution	8.3.1.2.2.4.4
			Water potential (rock matrix), total fractured rock	8.3.1.2.2.4.4
			Water potential (total), perched-water zones	8.3.1.2.2.4.7
			Hydraulic head (perched-water zones)	8.3.1.2.2.4.9
			Matric potential	8.3.1.2.2.4.9
			Water potential	8.3.1.2.2.4.9
			Pneumatic potential	8.3.1.2.2.6.1
			Vapor-pressure deficit (potential), relative, soil gas	8.3.1.2.2.6.1
1.1	8.3.5.13	Unsaturated-zone fluid chemistry, temperature, and age	Hydrochemistry, ground-water	8.3.1.2.1.3.3
1.6	8.3.5.12		Flow paths from tritium analysis	8.3.1.2.2.1.2
1.10	8.3.4.2		Tritium isotopic composition	8.3.1.2.2.1.2
1.12	8.3.3.2		Chloride; soil and tuff samples	8.3.1.2.2.2.1
4.4	8.3.2.5		Chlorine-35 to chlorine-37 ratios, soil and tuff samples	8.3.1.2.2.2.1
			Chlorine-36 to chlorine ratios, soil and tuff samples	8.3.1.2.2.2.1
			Pore gas, composition	8.3.1.2.2.4.4
			Radioactive isotopes	8.3.1.2.2.4.4
			Stable isotopes	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 13 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)				
		Unsaturated-zone fluid chemistry, temperature, and age (continued)	Temperature, fractured rock	8.3.1.2.2.4.4
			Hydrochemical properties, perched-water zones	8.3.1.2.2.4.7
			Radioactive isotopes	8.3.1.2.2.4.7
			Stable isotopes	8.3.1.2.2.4.7
			Water quality	8.3.1.2.2.4.7
			Hydrochemistry	8.3.1.2.2.4.8
			Moisture loss (water content 0-18/0-16 and D/H ratios)	8.3.1.2.2.4.8
			Pore-gas composition	8.3.1.2.2.4.8
			Radioactive-isotope activity (C-14)	8.3.1.2.2.4.8
			Radioactive-isotope activity (Ar-39)	8.3.1.2.2.4.8
			Radioactive-isotope activity (Cl-36)	8.3.1.2.2.4.8
			Radioactive-isotope activity (tritium)	8.3.1.2.2.4.8
			Stable-isotope activity	8.3.1.2.2.4.8
			Stable-isotope ratio analyses	8.3.1.2.2.4.8
			Water quality, cations and anions	8.3.1.2.2.4.8
			Composition of formation gases	8.3.1.2.2.4.9
			Composition of formation water	8.3.1.2.2.4.9
			Radioactive and stable isotope composition	8.3.1.2.2.4.9
			Thermal potential	8.3.1.2.2.4.9
			Water chemistry (perched-water zones)	8.3.1.2.2.4.9
			Carbon-14 activity	8.3.1.2.2.4.10
			Composition of formation gases	8.3.1.2.2.4.10
			Composition of formation water	8.3.1.2.2.4.10
			Stable-isotope composition (oxygen-18, deuterium)	8.3.1.2.2.4.10

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 14 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)				
		Unsaturated-zone fluid chemistry, temperature, and age (continued)	Thermal potential, rock mass	8.3.1.2.2.4.10
			Tritium activity	8.3.1.2.2.4.10
			Gas composition	8.3.1.2.2.6.1
			Soil temperature	8.3.1.2.2.6.1
			Temperature profiles	8.3.1.2.2.6.1
			Gas chemistry and age	8.3.1.2.2.7
			Water chemistry and age	8.3.1.2.2.7
			Water-rock chemical interaction and geochemical evolution of water	8.3.1.2.2.7
			Pore-gas composition	8.3.1.2.2.7.1
			Radioactive-isotope activities in gas phase (tritium and C-14)	8.3.1.2.2.7.1
			Stable-isotope activities in gas phase (tritium and C-14)	8.3.1.2.2.7.1
			Pore water hydrochemical properties	8.3.1.2.2.7.2
			Radioactive-isotope activities in liquid phase	8.3.1.2.2.7.2
			Stable-isotope activities in liquid phase	8.3.1.2.2.7.2
			Water quality, cation and anions	8.3.1.2.2.7.2
1.1	8.3.5.13	Unsaturated-zone moisture conditions	Soil moisture content	8.3.1.2.1.3.3
1.6	8.3.5.12		Moisture content	8.3.1.2.2.1.1
1.10	8.3.4.2		Water content, gravimetric	8.3.1.2.2.1.1
1.11	8.3.2.2		Water content, saturation	8.3.1.2.2.1.2
1.12	8.3.3.2		Water content, volumetric	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 15 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)		
2.7 4.4	8.3.2.3 8.3.2.5	Unsaturated-zone moisture conditions (continued)	Flux-related, matrix hydrologic properties (moisture conditions) of geologic samples	8.3.1.2.2.3
			Moisture content (volumetric), subsurface geologic samples	8.3.1.2.2.3.1
			Water content (gravimetric), subsurface geologic samples	8.3.1.2.2.3.1
			Moisture content, time dependence	8.3.1.2.2.3.2
			Water content	8.3.1.2.2.3.2
			Water content, gravimetric	8.3.1.2.2.3.2
			Water content, saturation profiles	8.3.1.2.2.3.2
			Moisture content, lateral variation	8.3.1.2.2.3.3
			Water content, gravimetric	8.3.1.2.2.3.3
			Water content, volumetric	8.3.1.2.2.3.3
			Water content	8.3.1.2.2.4.3
			Water content of matrix and rock mass	8.3.1.2.2.4.3
			Water content, matrix	8.3.1.2.2.4.3
			Water content (gravimetric), rock mass	8.3.1.2.2.4.4
			Water content (volumetric), rock mass	8.3.1.2.2.4.4
			Moisture content, in situ degree of saturation	8.3.1.2.2.4.5
			Gravimetric moisture content	8.3.1.2.2.4.9
			Volumetric moisture content	8.3.1.2.2.4.9
			Water-content profiles	8.3.1.2.2.4.9
			Water content, matrix	8.3.1.2.2.4.10
			Water-vapor content	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 16 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)				
1.1	8.3.5.13	Unsaturated-zone fluid flux	Infiltration locations	8.3.1.2.1.3.3
1.6	8.3.5.12		Infiltration rates	8.3.1.2.1.3.3
1.10	8.3.4.2		Recharge locations, rates, and history	8.3.1.2.1.3.3
1.12	8.3.3.2		Infiltration rates	8.3.1.2.2.1.1
4.4	8.3.2.5		Vegetative cover, type and density	8.3.1.2.2.1.1
			Evapotranspiration rates	8.3.1.2.2.1.2
			Flow velocities	8.3.1.2.2.1.2
			Natural infiltration	8.3.1.2.2.1.2
			Net infiltration, beneath surficial evapotranspiration zone	8.3.1.2.2.1.2
			Water flux	8.3.1.2.2.1.2
			Evapotranspiration rates, experimental conditions	8.3.1.2.2.1.3
			Flow velocities beneath experimental infiltration plots	8.3.1.2.2.1.3
			Infiltration rates (saturated and unsaturated), experimentally induced	8.3.1.2.2.1.3
			Water flux beneath experimental infiltration plots	8.3.1.2.2.1.3
			Vapor flux	8.3.1.2.2.3.1
			Water flux	8.3.1.2.2.3.1
			Hydrogeologic unit definition	8.3.1.2.2.3.2
			Flux (volumetric) through fracture-matrix networks	8.3.1.2.2.4.2
			Volumetric flux and travel time through the rock mass	8.3.1.2.2.4.2
			Water velocity (directional distributions) fracture-matrix networks	8.3.1.2.2.4.2

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 17 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)				
		Unsaturated-zone fluid flux (continued)	Directional water velocity distributions	8.3.1.2.2.4.3
			Flux, volumetric	8.3.1.2.2.4.3
			Fracture and fracture-set densities and spacings	8.3.1.2.2.4.3
			Volumetric flux and travel time through the rock mass	8.3.1.2.2.4.3
			Water velocity (directional distributions), hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Discharge, perched-water zones	8.3.1.2.2.4.7
			Flow rates, perched-water zones	8.3.1.2.2.4.7
			Flow paths, hydrochemical determination	8.3.1.2.2.4.8
			Travel times, hydrochemical determination	8.3.1.2.2.4.8
			Fluid flow, structural controls	8.3.1.2.2.6
			Gas-flow field, pre-waste emplacement	8.3.1.2.2.6
			Moisture flux, in gas phase	8.3.1.2.2.6
			Flow direction	8.3.1.2.2.6.1
			Flow velocities (air), in surface-based boreholes	8.3.1.2.2.6.1
			Flow velocity profiles	8.3.1.2.2.6.1
			Water-vapor flux	8.3.1.2.2.6.1
			Gas flow direction, flux, and travel time	8.3.1.2.2.7
			Gas transport mechanisms	8.3.1.2.2.7
			Water flow direction, flux, and travel time	8.3.1.2.2.7

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 18 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)				
		Unsaturated-zone fluid flux (continued)	Gas flow paths, hydrochemical determination	8.3.1.2.2.7.1
			Gas flux, hydrochemical determination	8.3.1.2.2.7.1
			Gas travel times, chemical determination	8.3.1.2.2.7.1
			Water flow paths of (O^{18} to O^{16}, deuterium to hydrogen) pore waters	8.3.1.2.2.7.2
			Water travel times (C-14 and tritium)	8.3.1.2.2.7.2
UNSATURATED-ZONE HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS				
1.1 1.6	8.3.5.13 8.3.5.12	Unsaturated-zone hydrologic conceptual/ descriptive models	Description of the scale dependence of pneumatic, hydrologic, and transport parameters	8.3.1.2.2.8.1
			Fluid and solute fluxes through variably saturated, fractured rock	8.3.1.2.2.8.1
			Liquid water matric potential; time-dependent spatial distribution (coupled heat and moisture-flow model)	8.3.1.2.2.8.2
			Validity of conceptual models describing flow and transport in variably saturated, fractured rock	8.3.1.2.2.8.2
			Boundary and initial conditions of the system	8.3.1.2.2.9.1
			Geologic framework of the system	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 19 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS (continued)		
		Unsaturated-zone hydrologic conceptual/ descriptive models (continued)	Hydrologic and other related physical processes that operate within the system under the constraints imposed by the geologic framework and the boundary and initial conditions	8.3.1.2.2.9.1
		UNSATURATED-ZONE FLOW AND SOLUTE-TRANSPORT NUMERICAL MODELS		
1.1 1.6	8.3.5.13 8.3.5.12	Unsaturated-zone flow and solute-transport numerical models	Ground-water travel time, fracture-matrix networks	8.3.1.2.2.4.2
			Ground-water travel time, hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Description of the scale dependence of pneumatic, hydrologic, and transport parameters	8.3.1.2.2.9.1
			Fluid and solute fluxes through variably saturated, fractured rock	8.3.1.2.2.9.1
			Validity of numerical models describing flow and transport in variably saturated, fractured rock	8.3.1.2.2.9.2
			Boundary conditions, hydrologic (Dirichlet, Neumann, mixed, evaporative, seepage-face, evapotranspiration, etc.)	8.3.1.2.2.9.2
			Code geometry (modeled parameters)	8.3.1.2.2.9.2

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 20 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE FLOW AND SOLUTE-TRANSPORT NUMERICAL MODELS (continued)				
		Unsaturated-zone flow and solute-transport numerical models (continued)	Discretization method (finite-difference, finite-element, or integrated finite-difference)	8.3.1.2.2.9.2
			Hydrologic and coupled processes (liquid-water flow, gas-phase flow, water-vapor, heat-flow, solute transport, chemical kinetics, stress-field dynamics, two-phase flow)	8.3.1.2.2.9.2
			Matrix solver (direct or iterative)	8.3.1.2.2.9.2
			Solution methodology (Picard iteration or Newton-Raphson linearization)	8.3.1.2.2.9.2
			Boundary fluxes, pressures, and potentials	8.3.1.2.2.9.3
			Hydrologic and thermomechanical properties for the component hydrogeologic units	8.3.1.2.2.9.3
			Time-dependent spatial distribution of matric potential, liquid water, saturation, pore-gas pressure, water-vapor concentration, moisture flux, and temperature	8.3.1.2.2.9.3
			Measurement errors	8.3.1.2.2.9.4
			Probable limits of uncertainty	8.3.1.2.2.9.4
			Statistical distribution functions	8.3.1.2.2.9.4
			Land-surface net infiltration to the unsaturated zone and its distribution in space and time	8.3.1.2.2.9.5

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 21 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE FLOW AND SOLUTE-TRANSPORT NUMERICAL MODELS (continued)		
		Unsaturated-zone flow and solute-transport numerical models (continued)	Site geologic framework and its change with time	8.3.1.2.2.9.5
			Site water-table configuration and its change with time	8.3.1.2.2.9.5
			Spatial distribution of moisture flux within the unsaturated zone and its change with time	8.3.1.2.2.9.5
			Spatial distribution of temperature and stress within the unsaturated zone and their change with time	8.3.1.2.2.9.5
		SATURATED-ZONE HYDRAULIC PROPERTIES		
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone transmissive properties	Hydraulic conductivity, assessment of data needs	8.3.1.2.1.3.1
			Transmissivity, assessment of data needs	8.3.1.2.1.3.1
			Hydraulic conductivity	8.3.1.2.1.3.2
			Permeability	8.3.1.2.1.3.2
			Storativity	8.3.1.2.1.3.2
			Transmissivity	8.3.1.2.1.3.2
			Hydraulic conductivity, spatial distribution, concepts in regional 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 22 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
			SATURATED-ZONE HYDRAULIC PROPERTIES	
		Saturated-zone transmissive properties (continued)	Hydraulic conductivity, spatial distribution, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Hydraulic conductivity, spatial distribution, subregional cross-sectional model	8.3.1.2.1.4.3
			Hydraulic conductivity, spatial distribution, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Hydraulic conductivity, spatial distribution, regional three-dimensional model	8.3.1.2.1.4.4
			Hydraulic conductivity, saturated zone	8.3.1.2.3.1.2
			Effective porosity (bulk), estimate from earth-tide analysis of water levels	8.3.1.2.3.1.3
			Transmissivity (bulk) estimates at multiple-well test locations	8.3.1.2.3.1.3
			Hydraulic conductivity; tensor of equivalent porous media; multiple-well test locations	8.3.1.2.3.1.4
			Average linear velocity, pore water and tracers	8.3.1.2.3.1.5
			Effective porosities	8.3.1.2.3.1.5

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 23 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
			SATURATED-ZONE HYDRAULIC PROPERTIES (continued)	
		Saturated-zone transmissive properties (continued)	Effective porosity, single-well and multiple-well tracer test locations	8.3.1.2.3.1.5
			Fracture permeability	8.3.1.2.3.1.5
			Average linear velocity, pore water and tracers	8.3.1.2.3.1.6
			Effective porosities	8.3.1.2.3.1.6
			Effective porosity (well-test locations throughout the site) conservative tracers	8.3.1.2.3.1.6
			Hydraulic conductivity (well-test locations throughout the site) conservative tracers	8.3.1.2.3.1.6
			Sensitivity, transmissive properties	8.3.1.2.3.3.1
			Hydraulic conductivity, effective, variation with fracture geometry	8.3.1.2.3.3.2
			Hydraulic conductivity, spatial distribution	8.3.1.2.3.3.3
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone storage properties	Storage coefficient, assessment of data needs	8.3.1.2.1.3.1
			Porosity	8.3.1.2.1.3.2
			Storage coefficient	8.3.1.2.1.3.2
			Effective porosity, spatial distribution, concepts in regional flow model	8.3.1.2.1.4.1
			Storage coefficient, spatial distribution, concepts in regional 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 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC PROPERTIES (continued)		
		Saturated-zone storage properties (continued)	Effective porosity, spatial distribution, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Storage coefficient, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Effective porosity, assumptions for subregional cross-sectional model	8.3.1.2.1.4.3
			Storage coefficient, assumptions for subregional cross-sectional model	8.3.1.2.1.4.3
			Effective porosity, spatial distribution, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Storage coefficient, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Aquifer compressibility	8.3.1.2.3.1.2
			Storage coefficient, estimate from water-level fluctuations, well tests	8.3.1.2.3.1.2
			Barometric efficiency	8.3.1.2.3.1.3
			Dilatational efficiency	8.3.1.2.3.1.3
			Specific storage	8.3.1.2.3.1.3
			Storage coefficient, bulk estimates from well testing data	8.3.1.2.3.1.3
			Storage coefficient, stratigraphic variations at multiple-well locations	8.3.1.2.3.1.4
			Specific storage	8.3.1.2.3.1.6

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 25 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		SATURATED-ZONE HYDRAULIC PROPERTIES (continued)		
		Saturated-zone storage properties (continued)	Effective porosity, spatial distribution, assumptions for site conceptual model	8.3.1.2.3.3.1
			Sensitivity, storage properties	8.3.1.2.3.3.1
			Storage coefficient, spatial distribution, assumptions for site conceptual model	8.3.1.2.3.3.1
			Effective porosity, spatial distribution	8.3.1.2.3.3.3
			Storage coefficient, spatial distribution	8.3.1.2.3.3.3
1.1	8.3.5.13	Saturated-zone dispersive properties	Dispersion coefficients	8.3.1.2.3.1.5
1.6	8.3.5.12		Dispersivity, conservative tracers	8.3.1.2.3.1.6
			Dispersion coefficients, single-well and multiple-well tracer test locations, reactive tracers	8.3.1.2.3.1.7
			Dispersion coefficients, well-test locations throughout the site	8.3.1.2.3.1.8
1.1	8.3.5.13	Saturated-zone diffusive properties	Hydraulic diffusivity	8.3.1.2.3.1.2
			Pneumatic diffusivity	8.3.1.2.3.1.3
			Vertical hydraulic diffusivity	8.3.1.2.3.1.3

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 26 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC PROPERTIES (continued)		
1.1	8.3.5.13	Saturated-zone fault hydrologic characteristics	Fault zone, transmissive character	8.3.1.2.3.1.1
1.6	8.3.5.12		Hydraulic gradient	8.3.1.2.3.1.1
			Saturated hydraulic conductivity, fault zone	8.3.1.2.3.1.1
			Storage coefficient, fault zone	8.3.1.2.3.1.1
			Storage coefficients, wall rocks	8.3.1.2.3.1.1
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS		
1.1	8.3.5.13	Saturated-zone water potential	Ground-water flow-path directions and gradients; assessment of data needs	8.3.1.2.1.3.1
1.6	8.3.5.12		Hydrologic initial and boundary conditions; regional and subregional ground-water models; assessment of data needs	8.3.1.2.1.3.1
			Effective saturated thickness	8.3.1.2.1.3.2
			Ground-water flow directions, rates, and velocities	8.3.1.2.1.3.2
			Hydraulic gradient	8.3.1.2.1.3.2
			Hydraulic head	8.3.1.2.1.3.2
			Depth to saturation	8.3.1.2.1.3.4
			Hydraulic head, spatial distribution	8.3.1.2.1.3.4
			Hydraulic gradient, concepts in regional flow model	8.3.1.2.1.4.1
			Potentiometric surface, concepts in regional 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 27 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS (continued)		
		Saturated-zone water potential (continued)	Hydraulic gradient, used in subregional two-dimensional areal model	8.3.1.2.1.4.2
			Potentiometric surface, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Saturated thickness distribution, effect on flux direction and magnitudes	8.3.1.2.1.4.2
			Hydraulic gradient, used in subregional cross-section model	8.3.1.2.1.4.3
			Hydraulic gradient, used in regional three-dimensional model	8.3.1.2.1.4.4
			Potentiometric surface, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Hydraulic gradients	8.3.1.2.3.1.2
			Relative hydraulic gradients	8.3.1.2.3.1.3
			Potentiometric surface, assumptions for site conceptual model	8.3.1.2.3.3.1
			Sensitivity, potentiometric surface	8.3.1.2.3.3.1
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone ground-water chemistry, temperature, and age	Hydrologic initial and boundary conditions (regional and subregional ground-water models), assessment of data needs	8.3.1.2.1.3.1
			Thermal conductivity, ambient heat flow	8.3.1.2.1.3.2

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 28 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS (continued)		
		Saturated-zone ground-water chemistry, temperature, and age (continued)	Water temperature	8.3.1.2.1.3.2
			Radioisotope activities, ground water	8.3.1.2.1.3.3
			Radiometric ages, ground water	8.3.1.2.1.3.3
			Hydrochemistry, ground-water assumptions for subregional two-dimensional area model	8.3.1.2.1.4.2
			Ground-water chemical concentration	8.3.1.2.3.2.1
			Radioisotope activity	8.3.1.2.3.2.1
			Stable-isotope ratios	8.3.1.2.3.2.1
			Ground-water chemical concentrations	8.3.1.2.3.2.2
			Radioisotope activity	8.3.1.2.3.2.2
			Stable-isotope ratios	8.3.1.2.3.2.2
			Chemical concentration	8.3.1.2.3.2.3
			Radioisotope activity	8.3.1.2.3.2.3
			Stable-isotope ratios	8.3.1.2.3.2.3
			Conservative-solute transport, scale of Yucca Mountain	8.3.1.2.3.3.3
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone ground-water flux	Discharge locations and rates, assessment of data needs	8.3.1.2.1.3.1
			Hydrologic initial and boundary conditions (regional and subregional ground-water models), assessment of data needs	8.3.1.2.1.3.1
			Recharge locations and rates, assessment of data needs	8.3.1.2.1.3.1

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 29 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS (continued)		
		Saturated-zone ground-water flux (continued)	Evapotranspiration component of ground-water discharge	8.3.1.2.1.3.4
			Evapotranspiration rates and areal distribution	8.3.1.2.1.3.4
			Discharge, locations and rates, concepts in regional flow model	8.3.1.2.1.4.1
			Ground-water flux, concepts in regional flow models	8.3.1.2.1.4.1
			Recharge, locations and rates, concepts in regional flow model	8.3.1.2.1.4.1
			Discharge, locations and rates, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Evapotranspiration, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Ground-water flux, assumptions for subregional cross-sectional model	8.3.1.2.1.4.2
			Ground-water flux, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Hydrologic boundary conditions	8.3.1.2.1.4.2
			Recharge, locations and rates, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Discharge, locations and rates, assumptions for subregional cross-sectional model	8.3.1.2.1.4.3

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 30 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS (continued)		
		Saturated-zone ground-water flux (continued)	Recharge, locations and rates, assumptions for subregional cross-sectional model	8.3.1.2.1.4.3
			Discharge, locations and rates, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Ground-water flux, regional three-dimensional model	8.3.1.2.1.4.4
			Recharge, locations and rates, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Flow rates, interborehole and intra-borehole	8.3.1.2.3.1.3
			Nature of hydraulic boundaries and conduits type of flow	8.3.1.2.3.1.3
			Average linear velocity, pore water and tracers	8.3.1.2.3.1.5
		SATURATED-ZONE HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS		
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone hydrologic conceptual/descriptive models	Ground-water flow direction and magnitude based on regional hydrologic, hydrochemical, and heat-flow data	8.3.1.2.1.3

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 31 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS (continued)		
		Saturated-zone hydrologic conceptual/descriptive models (continued)	Porosity type; matrix and fracture, regional geohydrologic units; assessment of data needs	8.3.1.2.1.3.1
			Hydraulic boundaries and conduits; scale of well tests and type of flow	8.3.1.2.3.1.3
			Aquifer heterogeneity and spatial distribution	8.3.1.2.3.1.4
			Effective porosity, spatial distribution, assumptions for site conceptual model	8.3.1.2.3.3.1
			Ground-water flux, assumptions for site conceptual model	8.3.1.2.3.3.1
			Hydraulic conductivity, spatial distribution, assumptions for site flow model	8.3.1.2.3.3.1
			Hydraulic gradient, concepts in site flow model	8.3.1.2.3.3.1
			Relations between fracture geometry characteristics and hydrologic response	8.3.1.2.3.3.2
			Relations between geophysical and hydrologic models	8.3.1.2.3.3.2

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 32 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
SATURATED-ZONE SITE AND REGIONAL-FLOW AND SOLUTE-TRANSPORT NUMERICAL MODELS				
1.1	8.3.5.13	Saturated-zone site and regional flow and solute-transport numerical models	Effective porosity	8.3.1.2.1.4
1.3	8.3.5.15		Ground-water flux	8.3.1.2.1.4
1.6	8.3.5.12		Hydraulic conductivity	8.3.1.2.1.4
			Hydraulic gradient	8.3.1.2.1.4
			Storage coefficient	8.3.1.2.1.4
			Geochemical reaction (modeling)	8.3.1.2.3.2
			Conservative-solute transport	8.3.1.2.3.3
			Effective porosity	8.3.1.2.3.3
			Ground-water flux	8.3.1.2.3.3
			Hydraulic conductivity	8.3.1.2.3.3
			Hydraulic gradient	8.3.1.2.3.3
			Storage coefficient	8.3.1.2.3.3
			Conservative-solute transport, fracture networks, steady state and transient	8.3.1.2.3.3.2
			Effective porosity, fracture networks	8.3.1.2.3.3.2
			Ground-water flux, fracture networks, steady state and transient	8.3.1.2.3.3.2
			Hydraulic conductivity, fracture networks	8.3.1.2.3.3.2
			Hydrodynamic dispersion, fracture networks	8.3.1.2.3.3.2
			Storage coefficient, fracture networks	8.3.1.2.3.3.2
			Ground-water flow paths, scale of Yucca Mountain	8.3.1.2.3.3.3

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 33 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE SITE AND REGIONAL-FLOW AND SLUITE-TRANSPORT NUMERICAL MODELS (continued)		
		Saturated-zone and regional flow and solute-transport numerical models (continued)	Ground-water flow velocities, scale of Yucca Mountain	8.3.1.2.3.3.3
			Ground-water flux, scale of Yucca Mountain	8.3.1.2.3.3.3
		SATURATED-ZONE GEOCHEMICAL PROPERTIES		
1.1	8.3.5.13	Saturated-zone sorptive properties	Adsorption rate constants	8.3.1.2.3.1.7
			Sorption equilibrium constant	8.3.1.2.3.1.7
			Adsorption rate constants	8.3.1.2.3.1.8
			Sorption equilibrium constants	8.3.1.2.3.1.8
		ROCK-UNIT GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Rock-unit contact location and configuration	Hydrostratigraphic units	8.3.1.2.1.3.2
1.6	8.3.5.12		Stratigraphic contacts, hydrogeological units	8.3.1.2.1.3.2
1.11	8.3.2.2		Contact altitude, geohydrologic units	8.3.1.2.2.3.2
1.12	8.3.3.2		Lithology from geophysical logging	8.3.1.2.2.3.2
4.4	8.3.2.5		Depth to hydrogeologic contacts	8.3.1.2.2.4.9
			Geohydrologic units, physical properties	8.3.1.2.3.1.1
1.1	8.3.5.13	Rock-unit lateral and vertical variability	Alluvium thickness	8.3.1.2.2.1.1
1.6	8.3.5.12		Rock-unit surficial slope and aspect	8.3.1.2.2.1.1
1.11	8.3.2.2		Soil texture	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 34 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		ROCK-UNIT GEOMETRY AND PROPERTIES (continued)		
1.12	8.3.3.2	Rock-unit lateral and vertical variability	Thickness of soil and alluvium	8.3.1.2.2.1.1
4.4	8.3.2.5		Stratigraphic variation of hydraulic properties inferred from hydraulic tests	8.3.1.2.3.1.1
			Geohydrologic unit physical properties	8.3.1.2.3.1.2
			Geophysical properties, geohydrologic units, structural features	8.3.1.2.3.1.2
1.1	8.3.5.13	Rock-unit mineralogy/petrology and physical properties	Bulk density	8.3.1.2.1.3.2
1.6	8.3.5.12		Depositional environment	8.3.1.2.1.3.2
1.11	8.3.2.2		Grain size distribution	8.3.1.2.1.3.2
4.4	8.3.2.5		Lithologies, hydrogeologic units; drill cuttings, water-table holes	8.3.1.2.1.3.2
			Porosity	8.3.1.2.1.3.2
			Bulk density	8.3.1.2.2.1.1
			Clay mineralogy	8.3.1.2.2.1.1
			Grain density	8.3.1.2.2.1.1
			Porosity, subsurface geologic samples	8.3.1.2.2.3.1
			Bulk density, rock matrix	8.3.1.2.2.4.4
			Grain density, rock matrix	8.3.1.2.2.4.4
			In situ rock physical properties	8.3.1.2.2.4.5
			Porosity	8.3.1.2.2.4.5
			Porosity, perched-water zones	8.3.1.2.2.4.7
			Bulk density	8.3.1.2.2.4.9
			Fracture weathering	8.3.1.2.2.4.9
			Grain density	8.3.1.2.2.4.9
			Matrix pore-size distribution	8.3.1.2.2.4.9

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 35 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		ROCK-UNIT GEOMETRY AND PROPERTIES (continued)		
		Rock-unit mineralogy/petrology and physical properties (continued)	Total density	8.3.1.2.2.4.9
			Pore-size distribution, matrix	8.3.1.2.2.4.10
			Porosity, matrix	8.3.1.2.2.4.10
			Matrix compressibility, inferred from barometric and earth-tide analysis	8.3.1.2.3.1.3
		FRACTURE GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Fracture distribution	Fractures	8.3.1.2.1.3.2
1.6	8.3.5.12		Lineaments	8.3.1.2.1.3.2
1.11	8.3.2.2		Fracture density	8.3.1.2.2.1.1
1.12	8.3.3.2		Fracture distribution	8.3.1.2.2.3.2
4.4	8.3.2.5		Fracture spacing	8.3.1.2.2.3.2
			Fracture distribution	8.3.1.2.2.3.3
			Fracture spacing	8.3.1.2.2.3.3
			Fracture distribution	8.3.1.2.2.4.4
			Fracture frequency, spacing, and distribution	8.3.1.2.2.4.9
			Fracture distribution and geometry from core and geophysical logs	8.3.1.2.3.1.1
			Fracture distribution, spacing and geometry from core and geophysical logs	8.3.1.2.3.1.2
			Fracture-system characteristics inferred from tracer tests, geophysical logs	8.3.1.2.3.1.5

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 36 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
		Fracture distribution (continued)	Fracture-system characteristics inferred from hydraulic packer and tracer tests; conservative tracers	8.3.1.2.3.1.6
			Fracture location, orientation, and density in vertical planes between wells	
1.1	8.3.5.13	Fracture orientation	Fracture orientation	8.3.1.2.2.1.1
1.6	8.3.5.12		Fracture and fracture-set orientations	8.3.1.2.2.4.3
1.11	8.3.2.2		Fracture orientation	8.3.1.2.2.4.5
4.4	8.3.2.5		Fracture orientation from core and geophysical logs	8.3.1.2.3.1.1
			Fracture orientation inferred from core and geophysical logs	8.3.1.2.3.1.2
1.1	8.3.5.13	Fracture aperture	Fracture aperture geometry	8.3.1.2.2.4.1
1.6	8.3.5.12		Fracture aperture, roughness and contact area	8.3.1.2.2.4.1
			Fracture aperture	8.3.1.2.2.4.2
			Fracture and fracture-set apertures	8.3.1.2.2.4.3
			Fracture aperture	8.3.1.2.2.4.4
			Fracture aperture distributions inferred from hydraulic tests	8.3.1.2.3.1.1
			Fracture aperture inferred from hydraulic tests, matrix properties, geophysical logs	8.3.1.2.3.1.4

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 37 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
		Fracture aperture (continued)	Fracture aperture distribution inferred from hydraulic packer and tracer tests, conservative tracers	8.3.1.2.3.1.6
1.1	8.3.5.13	Fracture length	Fracture connectivity	8.3.1.2.2.4.2
1.6	8.3.5.12		Fracture and fracture-set connectivities	8.3.1.2.2.4.3
1.11	8.3.2.2		Fracture and fracture-set length and connectiveness	8.3.1.2.2.4.3
4.4	8.3.2.5		Fracture and fracture-set lengths	
1.1	8.3.5.13	Fracture-filling mineralogy and physical properties	Fracture weathering	8.3.1.2.2.4.4
1.6	8.3.5.12		Fracture roughness	8.3.1.2.2.4.5
4.4	8.3.2.5			
		FAULT GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Fault location	Fault-zone location	8.3.1.2.2.3.3
1.6	8.3.5.12		Fault-zone location	8.3.1.2.3.1.1
1.11	8.3.2.2		Structural locations	8.3.1.2.3.1.2
1.12	8.3.3.2			
4.4	8.3.2.5			

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 38 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
1.1	8.3.5.13	Fault geometry	Fault-zone effective width	8.3.1.2.2.3.3
1.6	8.3.5.12		Fault-zone orientation, width	8.3.1.2.3.1.1
1.11	8.3.2.2		Structural orientations and widths	8.3.1.2.3.1.2
1.12	8.3.3.2			
4.4	8.3.2.5			
1.1	8.3.5.13	Fault-zone mineralogy and physical properties, site area	Fault-zone mineralogy	8.3.1.2.2.3.3
1.6	8.3.5.12		Fault-zone physical properties	8.3.1.2.2.3.3
1.11	8.3.2.2			
1.12	8.3.3.2			
4.4	8.3.2.5			
		ROCK MECHANICAL PROPERTIES		
1.11	8.3.2.2	Rock-deformation	Fracture deformation	8.3.1.2.2.4.5
4.4	8.3.2.5			
1.10	8.3.4.2	Rock in situ stress, repository area	In situ stress, magnitude and orientation	8.3.1.2.2.4.5
1.11	8.3.2.2			
1.12	8.3.3.2			
4.4	8.3.2.5			

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. 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, which 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 through 8.3.1.2-4, 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.

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. 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.

The models will be evaluated through a combination of peer review and comparison of model predictions with laboratory experiments, field experiments, and natural analogs, and by comparison with conceptual models that are based on hydrochemical data. Successful application of any of these methods will increase confidence that the encoded mathematical model adequately describes the physical processes of the flow system.

Alternative conceptual models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated, (2) the uncertainty associated with this current understanding including alternative hypotheses that are also consistent with available data and that may compose an alternative conceptual model, (3) the significance of alternative hypotheses, and (4) activities or studies designed to discriminate between alternative hypotheses or to reduce uncertainty. Tables 8.3.1.2-2a and 8.3.1.2-2b summarize current understanding in modeling the regional- and site-unsaturated zone and the site saturated zone, respectively. Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate.

To help ensure comprehensiveness of the hypotheses considered in Tables 8.3.1.2-2a and 8.3.1.2-2b, hypotheses for modeling site hydrogeology have been divided into elements or components that describe the physical domain defined by the model, the driving forces/processes that operate within the hydrogeologic systems, the boundary conditions for the systems, the system internal geometry, and the system response/dynamics in response to the driving forces, boundary conditions, and system geometry. These elements are listed in column one.

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

The third column in Tables 8.3.1.2-2a and 8.3.1.2-2b provides a judged level of uncertainty designated "high," "medium," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

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

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

The sixth column gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

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

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

The ninth column identifies that characterization studies or activities that will discriminate among alternative hypotheses or that will reduce

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 1 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DOMAIN				
Unsaturated zone (UZ) underlying Yucca Mountain	The UZ is defined as a distinct hydrgeologic regime	Low--dominant processs defining UZ occur over geologic time scales	UZ is undefinable because of strong short-term coupling with saturated-zone, tectonic, and thermal regimes	GWTT[a]; water inflow to the underground facility[b]	High	High--UZ is presumed to be principal natural barrier to water-borne radionuclide migration	High--integrity of UZ needs to be preserved for 10,000 yr	8.3.1.2.2.10.1, 8.3.1.2.2.10.5
				INTERNAL GEOMETRY				
Stratigraphy	The unsaturated zone comprises a finite number of discrete, statistically homogeneous hydrogeologic units	Low--layered tuffs and zones of alteration lend themselves to characterization as hydrogeologic units	Hydrologic properties are graded over space; discrete hydrogeologic units cannot be distinguished Lateral and ververcal heterogeneities preclude defining hydrogeologic unit	GWTT; radionuclide releases to the accessible environment	High	High--hypothesis defines approach to calculate GWTT and radionuclide releases to the accessible environment	Low--statistical methods could be used to calculate GWTT for completely random systems	8.3.1.2.2.3.1, 8.3.1.4.3, 8.3.1.3
Structural features Fractures Faults	Fractures and fracture systems are barriers to or conduits for liquid-water flow, depending on ambient matrix saturation	Medium--current evidence indicates that spontaneous longitudinal water flow in fractures is not initiated until matrix is at or near complete saturation	Water may move longitudinally within fractures even at low values of matrix saturation	GWTT; water inflow to the underground facility	High	High--hydrologic interaction between matrix and fractures will affect possible magnitudes of both parameters	High--hydrologic interaction between partially saturated fractures and matrix may have profound effect on conditions within UZ	8.3.1.2.2.4.1, 8.3.1.2.2.4.2, 8.3.1.2.2.9.1 8.3.1.2.2.9.2

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 2 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				INTERNAL GEOMETRY (continued)				
Structural features (continued)	Fractures and fracture systems are conduits for air and water-vapor flow in fractured tuffs	Low--experimental data indicate high efficacy of gas-phase transport in fractured tuffs	Fractures contain sufficient moisture that air and water-vapor flow is ineffective	GWTT; gas-phase radionuclide transport	High	High--gas-phase transport and local moisture balance could depend on presence of bulk gas flow in fractures	High--ambient moisture conditions in Topopah Spring may depend on hypothesis	8.3.1.2.2.7.1
	Faults are conduits or barriers to liquid water flow in welded tuff units, depending on ambient matrix saturation	Medium--fault hydraulics probably are similar to fracture hydraulics in welded tuffs	Faults are everywhere conduits for liquid-water flow in welded tuffs	GWTT; water inflow to the underground facility	High	High--rationale similar to that for fractures	High--faults transect entire UZ; their hydrologic significance needs to be assessed	8.3.1.2.2.3.3
	Faults are barriers to fluid flow in nonwelded tuff units for all matrix saturations	Low--faults and fault zones in ductile, nonwelded units, probably are sealed with fault gouge, clays, or mineralization	Faults are everywhere conduits for liquid-water flow in nonwelded tuff units	GWTT; water inflow to the underground facility	High	Medium--sealed faults would redirect water flow, but overall mass balance would be preserved	Medium--sealed faults could produce temporary perched water bodies under transient conditions	8.3.1.2.2.3.3
	Transient, nonequilibrium flow of water occurs in open fractures and faults	Low--direct and indirect evidence indicate viability of this effect in the Tiva Canyon unit	Water is rapidly imbibed into the rock matrix at the fracture boundaries	Water inflow to the underground facility	Medium	Low--such flow would likely occur in upper UZ with redistribution toward uniformity in deep UZ	Medium--may be principal mechanism by which water enters UZ as net infiltration	8.3.1.2.2.1.3

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 3 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				INTERNAL GEOMETRY (continued)				
Structural features (continued)	Orientation of fractures and faults influences degree of transmissiveness, thereby introducing a fundamental system anisotropy	Low--open fractures and faults tend to be aligned with principal axis of greatest horizontal stress	Fractures, regardless of orientation, tend to be closed or otherwise seald by mineralization, or tend to be open	GWTT; water inflow into the underground facility	High	Medium--anisotropy produces directionally dependent flowpaths for water and air	Medium--repository design and GWTT calculations can accommodate anisotropy if known	8.3.1.2.2.4.2, 8.3.1.2.2.4.3, 8.3.1.2.2.4.4, 8.3.1.3.2.1.3, 8.3.1.3.3.3, 8.3.1.2.2.7.1
	Hydrologically interconnected fracture systems and rock matrix define a macroscopic composite or equivalent porous medium	High--hydrologic interaction between matrix and fractures remain poorly known and unquantified	Fractures and fracture systems must be regarded as distinct hydrologic entities	GWTT	High	Medium--if hypothesis is invalid, GWTT calculations will be more difficult	Medium--site-scale modeling will depend on validity of this hypothesis	8.3.1.2.2.4.2, 8.3.1.2.2.4.3
Eastward dipping fault blocks	Downdip lateral flow of liquid water occurs under spatially (and temporally) varying conditions	Low--eastward-dipping fault blocks introduce eastward gravitational component for fluid flow	All liquid-water flow within the UZ is dominated by the vertically downward gravitation force	GWTT; water inflow into the underground facility	High	Medium--phenomenon would induce redistribution of time and spatially varying water flow in UZ	Medium--a complete description of this process probably is beyond scope of the site characterization program	8.3.1.2.2.3.2, 8.3.1.2.2.1.2

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 4 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				BOUNDARY CONDITIONS				
Lower boundary condition	The water table, defined to be that spatially and temporally variable surface on which $P_w = P_{atmos}$	Low--the surface is well defined but its spatial and temporal dependence needs to be specified	The water table changes too erratically in space and time to be specifiable as a continuously connected surface	GWTT	High	High--water-table configuration beneath the repository is critical for calculating GWTT and radionuclide transport from disturbed zone to accessible environment	Medium--water-table configuration is unlikely to change significantly over next 10,000 yr	8.3.1.2.3.1.2, 8.3.1.8.3.2
Upper boundary condition	The land surface is the flux boundary for liquid water, air, and water vapor; flux across this boundary is spatially and temporally variable	Low--there exists a distinct surface of discontinuity between the land surface and the atmosphere	Note: land surface may be a zero- or uniform-flux boundary for any or all fluid phases	GWTT; water inflow to the underground facility	High	High--rates and distribution of net infiltration are needed to predict water flux and velocity fields in UZ	High--is net infiltration occurring? Damped and redistributed with depth? Capable of transient penetration into deep UZ?	8.3.1.2.2.1.1, 8.3.1.2.2.1.2, 8.3.1.2.2.1.3, 8.3.1.5.2.2.2, 8.3.1.2.2.7.1
Lateral boundary conditions	Site UZ is surrounded by a set of vertically oriented, lateral, zero-flux hydrologic boundaries	High--may be definable by fault complexes delimiting the Yucca Mountain site	Lateral inflow/outflow boundaries enclose part or all of the site UZ hydrogeologic system	GWTT; water inflow to the underground facility	High	Low--place boundaries sufficiently distant to have no effect on repository environment	Low--but need to identify hydrologically viable boundaries	8.3.1.2.1.4.2, 8.3.1.2.1.3.3, 8.3.1.2.1.3.1

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 5 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DRIVING FORCES/PROCESSES				
Equation of motion	Darcy's Law is applicable to the nonwelded tuff units	Low--nonwelded units generally are characterized by high porosities and large values of K_{sat}	None identified	GWTT; water inflow to the underground facility	High	High--Darcy's Law forms basis for calculating liquid-water fluxes and velocities in the rock matrix	Low--nonwelded tuffs probably satisfy conditions for validity of Darcy's Law	8.3.1.2.2.3.1
	Darcy's Law is applicable to the welded tuff units	Medium--effective porosity is unknown; K_{sat} values are near lower limit pf meaningful measurement	Storage and flow of liquid water in welded tuff units is controlled by surface adsorption within sparse, interconnected pores	GWTT; water inflow to the underground facility	High	Same as above	High--pore distribution in welded tuffs may not permit Darcian flow approximation	8.3.1.2.2.3.1
	Barometrically induced forced convection across surface drives airflow in hydrologically integrated fracture systems	High--effect is only observed in boreholes that penetrate and disturb present system	Water-vapor pressure and liquid-water capillary presure are in equilibrium within fractures that don't intersect land surface	Water inflow to the underground facility	Medium	Medium--appreciable forced convection of air will affect moisture distribution in repository environment	Low--repository design does not require precise data for this possible process	8.3.1.2.2.7.1
	Existing geothermal temperature gradient induces free convection within integrated fracture systems	High--fracture tortuosity impedes free thermal convection	Moisture balance in highly fractured zones is determined by both water-vapor and liquid-water movement	Water inflow to the underground facility	Medium	Same as above	Same as above	8.3.1.2.2.7.1

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 6 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DRIVING FORCES/PROCESSES (continued)				
Equation of motion (continued)	Molecular diffusion of water vapor in fractures occurs under existing geothermal temperature gradient	Medium--geothermal gradient induces upwardly decreasing water-vapor concentrations, but diffusion flux is small	None identified	Water inflow to the underground facility	Medium	Low--phenomenon probably would induce little effect on rock-matrix moisture distribution	Low--probably of negligble consequence	8.3.1.2.2.7.1, 8.3.1.2.2.5.1
	Changes in the tectonic environment cause changes in fracture hydrologic properties	Low--e.g., fracture apertures and orientation of open fractures depend on directions of principal horizontal stress	None identified	GWTT; water inflow to the underground facility	High	Medium--changing fracture properties could affect spatial distribution of possible transient effects in deep UZ	Medium--local stress fields within UZ probably change slowly with geologic time	8.3.1.8.3.3.1, 8.3.1.8.3.3.2, 8.3.1.8.3.3.3
	Nonequilibrium saturation profiles indicate net downward vertical liquid water flow	Medium--complete saturation profiles for UZ are not yet available	Upward water-vapor migration and downward liquid-water percolation define a steady-state circulation system; $S_w(Z) < S_R(Z)$; S_w value may pertain to "capillary fringe" above the water table	GWTT; water inflow to the underground facility	High	Low--assumption of vertical liquid-water flux consistent with local saturation values and unit hydraulic gradient assumption yields upper flux boundary	Low--present S_w values will yield upper-bound values for present vertical downward liquid-water fluxes	8.3.1.2.2.3.2

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 7 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
DRIVING FORCES/PROCESSES (continued)								
Conservation of mass	Moisture storage within the rock matrix and the interstitial pore space is partitioned among (1) capillary water, (2) adsorbed water, (3) water of hydration, and (4) water vapor	Low--uncertainty arises in quantifying the spatial and temporal distributions of the partitioning	Moisture storage within the UZ consists of uncoupled processes involving capillarity, adsorption, water vapor, and water of hydration	GWTT; water inflow to the underground facility	High	High--ambient liquid-water saturations depend on moisture storage and release mechanisms	Low--there are no other known mechanisms operating within the UZ	8.3.1.2.2.3.1, 8.3.1.3.2.2.2, 8.3.1.3.3.3
	Liquid water and water-vapor tend to be in thermodynamic phase equilibrium within the rock-matrix pore space	Medium--liquid-water and water-vapor migration in pores is slow compared with time required to establish equilibrium	None identified	Water inflow to the underground facility	Medium	Low--only local, transient, temporary departures from local thermodynamic equilibrium (LTE) are likely to occur	Low--local departures would produce small, temporary effects	8.3.1.2.2.3.2, 8.3.1.2.2.7.1, 8.3.1.15.2.2.1
	Nonthermal equilibrium distributions of water vapor may occur in fracture and fault openings	Medium--bulk air flow would tend to disrupt distribution of water vapor-pressure equilibrium	None identified	Water inflow to the underground facility	Medium	Low--effects probably would be restricted to matrix near fractures	Low--phenomenon would have little effect on possible water inflows to respository	8.3.1.2.2.3.2, 8.3.1.2.2.3.3

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 8 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DRIVING FORCES/PROCESS (continued)				
Conservation of mass (continued)	Volumes containing many pores are definable such that changes in boundary fluxes are equal to changes in internal moisture content	Medium--probably true in nonwelded tuffs; depends on density and hydrologic properties of fractures in welded tuffs	Dynamic state of system precludes defining simultaneous values of flux and moisture content	GWTT; water inflow to the underground facility	High	High--hypothesis is basis for the application of Richard's equation for water flow in UZ	High--need to ensure applicability of Darcian flow in welded tuffs	8.3.1.2.2.3.1
	Volumes containing many pores and fractures are definable such that changes in boundary fluxes equal changes in internal moisture storage	High--this is the representative elementary-volume (REV) concept applied to macroscopically highly fractured (welded) tuffs	Fractures and fracture networks must be treated as distinct hydrologic entities	GWTT; water inflow to the underground facility	High	Medium--REV concept for combined fractures and matrix simplifies numerical hydrologic modeling	Medium--site-scale modeling will be difficult if hypothesis is invalid	8.3.1.2.2.4.8
	Release or absorption of crystalline water of hydration will not significantly affect UZ saturation or moisture flux distributions	Low--the phenomenon can occur but probably would involve only small volumes of water	Sufficient water release could occur locally to affect moisture-flow pathways and fluxes	GWTT; water inflow to the underground facility	High	Medium--resulting increase or decrease of saturation would affect moisture fluxes and pathways	Medium--appreciable changes in present thermal or stress fields would be required to produce significant effects	8.3.1.3.2.2.2

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 9 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DRIVING FORCES/PROCESSES (continued)				
Conservation of mass (continued)	Tectonic events are unlikely to affect rock-matrix fluid-storage properties within the UZ hydrogeologic system	Low--pore-size distributions within the UZ are largely independent of prevailing tectonic environment	Episodic or cyclic tectonic processes or events will alter rock-matrix pore-size distributions	Water inflow to the underground facility	Medium	Low--only small total quantities of water probably would be involved	Low--effects on repository environment in UZ would be small	8.3.1.8.3.3, 8.3.1.3.2.2.2, 8.3.1.3.3.3
	Perched-water bodies and capillary-barriers may be temporarily present with the UZ system	High--perched water bodies and capillary barriers are intrinsically unstable hence, can occur only under transient conditions	Localized water inflows to the UZ are sufficient to sustain a perched-water body or capillary barrier in a quasi-stable state	GWTT; water inflow to the underground facility	High	Medium--conditions to produce naturally occuring perched-water bodies in repository environment probably are lacking	Medium--perched-water bodies probably are transient phenomena and would disperse if they are formed	8.3.1.2.2.4.7
Conservation of energy	Although presence of the geothermal temperature gradient vitiglobal isothermal approximation, local thermodynamic equilibrium (LTE) can be assumed for localized regions within the system	Low--Darcy's Law, for example, remains valid locally if one refers it to the ambient temperature	System is in such a highly dynamic state that LTE is nowhere established or maintained within the system	GWTT; water inflow to the underground facility	High	High--Darcy's Law becomes invalid for highly nonisothermal fluid flow	Low--system is unlikely to be in such a thermally dynamic state	8.3.1.2.2.3.1, 8.3.1.2.2.3.2, 8.3.1.2.2.3.3

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 10 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
SYSTEM DYNAMICS/RESPONSE								
System dynamics/ response	Nonwelded Calico Hills unit (CHnw) is the principal hydrochemical barrier to water-borne radionuclide transport between disturbed zone and accessible environment	Medium--CHnw is a thick (100 to 400 m) sparsely fractured, partially zeolitized tuff of low to medium saturated hydraulic conductivity	Flowpaths and fluxes in CHnw are such that they do not significantly impede radionuclide transport from disturbed zone to accessible environment	Radionuclide releases to the accessible environment	High	High--if CHnw is not an effective barrier, then possible rapid transport from disturbed zone to accessible environment could occur	High--hydrologic and geochemical properties of CHnw need to be well understood and quantified	8.3.1.2.2.3.1, 8.3.1.2.2.3.2, 8.3.1.2.2.4.6, 8.3.1.3.2, 8.3.1.3.3, 8.3.1.4.3, 8.3.1.8.4
	Climatic changes are unlikely to produce significant large-scale effects within the UZ hydrogeologic system during the next 10,000 yr	High--paleoclimatic data indicate past occurrences of major climatic changes within 10,000-yr intervals	Climatic changes and episodic variations are likely to occur and affect UZ hydrogeologic system	GWTT; water inflow to the underground facility	High	High--climatic changes may result in increased net infiltration and subsaturation and moisture-flux distributions within the UZ hydrogeologic system	High--assessment of future repository performance depends on moisture fluxes and flowpaths within the UZ	8.3.1.5.2.2.2
	Renewed faulting at Yucca Mountain is unlikely to significant local or large-scale effect on the UZ hydrogeologic system	Low--local fault movement would produce transient, temporary, localized effects within the UZ hydrogeologic system	Episodic or cyclic faulting may cause corresponding large-scale changes in the moisture flux distribution in the UZ	GWTT; water inflow to the underground facility	High	Low--because effects would tend to be localized and temporary	Low--frequency of occurrence and magnitude of effects probably are low	8.3.1.8.3.1.3, 8.3.1.8.3.1.4, 8.3.1.8.3.1.5, 8.3.1.8.3.2.5, 8.3.1.8.3.2.6, 8.3.1.8.4.1.3

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 11 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM DYNAMICS/RESPONSE (continued)				
System dynamics/ response (continued)	Volcanism is unlikely to affect the UZ hydrogeologic system during the next 10,000 yr	Medium--frequency of occurrence and magnitude of effects are incompletely known	Episodic or cyclic volcanism may cause corresponding large-scale changes in the mositure flux distribution in the UZ	GWTT; water inflow to the underground facility	High	High--volcanism could produce significant thermal-mechanical effects on the UZ hydrogeological system	Low--event is unlikely to occur during next 10,000 yr	8.3.1.8.3.1.1, 8.3.1.8.3.1.2
	Igneous intrusions are unlikely to disrupt the UZ hydrogeologic system during the next 10,000 yr	Medium--frequency of occurrence and magnitude of effects are incompletely known	Episodic or cyclic igneous intrusions may cause corresponding large-scale change in the moisture flux distribution in the UZ	GWTT; water inflow to the underground facility	High	High--igneous intrusions could produce significant thermal-mechanical effects on the UZ hydrogeological system	Low--event is unlikely to occur during next 10,000 yr	8.3.1.8.3.2.1, 8.3.1.8.3.2.2
	Uplift or subsidence of Yucca Mountain block is unlikely to affect the UZ hydrogeologic system during the next 10,000 yr	Medium--frequency of occurence and magnitude of effects are incompletely known	Large-scale uplift or subsidence will produce corresponding effects on the UZ hydrogeologic system	GWTT	High	Medium--the degree to which flowpaths and the water-table configuration would change is not known	Low--appreciable uplift or subsidence is unlikely to occur during next 10,000 yr	8.3.1.8.3.1.7, 8.3.1.8.3.1.4

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 12 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE/DYNAMICS (continued)				
System dynamics/ response (continued)	Pore-water chemical and isotopic composition reflects pore-water source regions and mechanisms	Medium--chemical and isotopic concentrations may be altered by pore-water interaction with rock matrix	Chemical and isotopic concentrations may be nondiagnostic mixture of waters from different sources	GWTT	High	Low--isotopic concentration alone is insufficient to determine source of UZ water	Medium--isotopic and anionic concentrations could be used as supporting if not definitive evidence for source of UZ water	8.3.1.2.2.8.2, 8.3.1.3.1.1, 8.3.1.3.2.2, 8.3.1.3.3.3
	Present UZ moisture flow system is derived from present and past net infiltration from above	Medium--rates of possible net infiltration and distributions in time and space are unknown	System below the Paintbrush unit is in quasi-equilibrium due to upward water-vapor migration and downward liquid-water percolation; consequently, there is no effective net percolation of water into the Topopah Spring and lower units Moisture in the UZ is a remnant of past rises of the water table	GWTT; water inflow to the underground facility	High	High--if hypothesis is valid, it will determine spatial and temporal distribution of water flux in repository environment	High--need to establish most probable bounds on rates and areal distribution of possible net infiltration and percolation below the Paintbrush nonwelded unit	8.3.1.2.2.3.2, 8.3.1.2.2.1.2

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 13 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Data-reduction models (continued)	Liquid water flux in rock matrix can be calculated from Darcy's Law	Low for nonwelded tuffs Medium for welded tuffs where adsorption effects may dominate	Application of Darcy's law results in inaccurate calculation of flux in welded tuffs	GWTT; water inflow to the underground facility	High	High--need accurate fluxes to estimate GWTT	High--calculations of system state and performance must be consistent with actual system dynamics	8.3.1.2.2.3.1
	Dupuit-Forchheimer assumption (fluid pore velocity = Darcian flux divided by rock-matrix porosity) applies	Medium--uses volume-averaged data to calculate a localized quantity; tends to underestimate true water-particle velocity	A random-walk model is a more appropriate approach	GWTT; water inflow to the underground facility	High	High--standard but not fully validated method for calculating pore-water velocities	High--need to know the fastest modes of pore-water movement	8.3.1.2.2.3.1, 8.3.1.2.2.9.3, 8.3.1.2.2.2.1
	Discrete fractures and fracture networks can be modeled as equivalent porous media	High--intuitively plausible, but mechanisms of fluid flow in partially saturated known and unquantified	Fluid flow in fractures is inherently dynamic and cannot be treated by simple global models	GWTT; water inflow to the underground facility	High	High--hydrologic significance of fractures under partially saturated conditions remains poorly known and unquantified	High--quantified mechanisms of matrix-fracture interactions and bounding uncertainties need to be known	8.3.1.2.2.4.1, 8.3.1.2.4.1.2, 8.3.1.2.4.1.3, 8.3.1.2.2.9

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 14 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE/DYNAMICS (continued)				
System dynamics/ response (continued)	Pore water in the UZ is in local solutional equilibrium with the surrounding rock matrix	Low--water movement in the rock matrix is sufficiently slow to permit establishment of solutional equilibrium	None identified	Waste container corrosion	Medium	High--waste container design must allow for possible contact with water in UZ	Low--It is highly unlikely that pore water in deep UZ is not in equilibrium with the surrounding rock matrix	8.3.1.2.2.8.2, 8.3.1.3.2.2, 8.3.1.5.2.1.2, 8.3.1.5.2.1.5, 8.3.1.3.3.3
				DATA-REDUCTION MODELS				
Data-reduction models	Rock-matrix hydrologic properties are defined by Darcian theory of fluid flow	Low for nonwelded tuffs Medium for welded tuffs	Use random-walk models to calculate synthetic flow-path and fluid-velocity distributions	GWTT; water inflow to the underground facility	High	High--need pore-water velocities to calculate GWTT	High--definition of hydrologic properties must be consistent with actual system state and processes	8.3.1.2.2.3.1, 8.3.1.2.2.2.1, 8.3.1.2.2.8.2, 8.3.1.2.2.4.6
	Matric potential is definable and measurable in terms of capillarity/ adsorption theory (Kelvin equation)	Low--hypothesis, however, presumes local thermodynamic equilibrium	Local thermodynamic equilibrium is nowhere established within UZ; hence, standard capillary theory does not apply	GWTT; water inflow to the underground facility	High	High--fluid flux calculations require measured in situ potential gradients	Low--definition of hydrologic functions must be consistent with actual system state and processes	8.3.1.2.2.3.1, 8.3.1.2.2.3.2

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 15 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
			SYSTEM RESPONSE/DYNAMICS (continued)					
System dynamics/ response (continued)	Liquid water flux in Topopah Spring rock matrix is distributed in space but is generally directed vertically downward	Medium--moisture fluxes have yet to be reliably computed or estimated	Rate of downward liquid-water flux may be approximately equal to upward directed water-vapor flux; Calico Hills unit defines vertical extent of the capi llary fring above the water table	GWTT; water inflow to the underground facility	High	Low--if flow is otherwise, need to account for it in GWTT calculations and assessment of water flow in repository environment	High--hypothesis establishes boundary condition at base of Topopah Spring unit for GWTT calculations	8.3.1.2.2.3.2, 8.3.1.2.2.4.6
	Hydrologic system below the Paintbrush nonwelded unit is in approximate steady-state dynamic equilibrium	High--hypothesis depends on rapid damping of transient effects, (e.g., infiltration events in the upper UZ)	Transient effects penetrate deep into or through the UZ via faults and fractures	Water inflow to the underground facility	Medium	Low--assessment of moisture content and change in repository environment must allow for dynamic conditions	High--hypothesis, if approximately valid, would facilitate predictive numerical hydrologic modeling of the system	8.3.1.2.2.3.2
	Liquid-water flow in the Topopah Spring is restricted to the rock matrix	Medium--available sparse saturation data indicate that saturations in Topopah Spring unit is too low to induce spontaneous flow in fractures	Longitudinal flow of water in fractures may occur locally or episodically over a wide range of rock-matrix saturations	Water inflow to the underground facility	Medium	Medium--dynamically changing water flow in fractures probably would affect moisture content and flow near repository	High--dynamics of matrix-fracture hydrologic interactions needs to be elucidated	8.3.1.2.2.3.2, 8.3.1.2.2.3.3

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 16 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
DATA-REDUCTION MODELS (continued)								
Data-reduction models (continued)	The rock-matrix hydrologic properties within distinct hydrogeologic units can be characterized by using classical-statistical and geostatistical methods	Low--present stratigraphic data indicate that the layered tuffs within the UZ, can be subdivided into statistically characterizable hydrogeologic units	Macroscopic vertical and lateral lateral heterogeneity within the layered tuffs precludes statistical characterization within the site domain	GWTT; radionuclide transport from disturbed zone to accessible environment	High	High--GWTT and radionuclide transport calculations depend on presence of statistically characterizable hydrogeologic units and properties	High--statistical characterization of hydrogeologic units is required to (1) estimate statistics of radionuclide release to accessible environment and of GWTT distributions, and (2) estimate errors in UZ flux calculations	8.3.1.2.2.3.1, 8.3.1.2.2.1.1, 8.3.1.2.2.9.4, 8.3.1.3.4.1.5, 8.3.1.4.2
	Laboratory-scale measurements of matrix hydrologic properties can be extrapolated to evaluate field-scale problems	High--laboratory scale "point" measurements are unlikely to be representative of large-scale dynamics	Laboratory-scale measurements of matrix hydrologic properties exceed both REV dimensions and field-scale statistical correlation lengths	GWTT; radionuclide transport from disturbed zone to accessible environment	High	High--liquid-water and gas-phase fluxes depend on properly defined hydrologic properties	High--need to obtain classical statistical and geostatistical data to assess error of extrapolation to field-scale problems	8.3.1.2.2.3.1, 8.3.1.2.2.1.1, 8.3.1.3.4.1.5, 8.3.1.3.7.2

[a]GWTT refers to pre-waste-emplacement ground-water travel time.
[b]Water inflow to the underground facility includes any and all water that may enter the facility from the unsaturated zone during preclosure and postclosure conditions.

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the geohydrology program (page 1 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
DOMAIN								
Regional saturated zone (SZ) hydrogeologic system	The regional SZ system is defined approximately by the hydrogeologic study area	Medium--hydrogeologic boundaries for the regional SZ flow system are not well defined	Larger (or smaller) area should be considered in evaluating regional SZ flow system	GWTT[a], radionuclide transport in the SZ, radionuclide transport in the UZ	High	High--the SZ is the main path for radionuclide transport from the unsaturated zone (UZ) to the accessible environment; definition of regional system domain affects SZ flux and flow paths beneath Yucca Mountain; water-table elevation is sensitive to boundary conditions	Medium--based on uncertainty	8.3.1.2.1
Subregional SZ hydrogeologic system	The subregional SZ system is defined by the Alkali Flat/ Furnace Creek Ranch subbasin	Medium--hydrogeologic boundary conditions for the sub-basin are not well established	The subregional SZ is defined by the Franklin Lake playa (Alkali Flat) subbasin; discharge that occurs at Furnace Creek Ranch is from a separate deep carbonate aquifer system	GWTT[a], radionculide transport in the SZ; radionuclide transport in the UZ	HIgh	High--the SZ is the main path for radionuclide transport from UZ to the accessible environment; definition of subregional system domain affects SZ flux and flow paths beneath Yucca Mountain; water-table elevation is sensitive to boundary conditions	Medium--based on uncertainty	8.3.1.2.1, 8.3.1.2.3

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 2 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
DOMAIN (continued)								
Site SZ hydrogeologic system	The site SZ system is defined by the boundary of the accessible environment	Medium--specification of site boundaries will have a large effect on distance used for GWTT calculations	None identified	GWTT; radionuclide transport in the SZ	Low	High--the SZ is the main path for radionuclide transport from the UZ to the accessible environment; definition of site-system domain affects length of SZ flow path to accessible environment	Low--based on needed confidence	8.3.1.2.1.3.2
Hydrogeologic units	Ground-water flow occurs in a complex framework of Paleozoic, Tertiary, and Quaternary rocks and sediments within the regional flow system, among which identifiable hydrogeologic units can be defined	Medium--borehole and surface-based observations indicate the presence of multiple hydrogeologic units of various ages and hydraulic properties, but the spatial relation is poorly defined	Variations of hydraulic properties within lithologic units is as great as among them; thus, no meaningful subdivision into hydrogeologic units can be made	GWTT; radionuclide transport in the SZ; radionuclide transport in the UZ	High	High--GWTT and transport characteristics are largely dependent on hydrogeologic units; transient behavior of water-table elevation is dependent on properties of hydrogeologic units	Medium--based on uncertainty	8.3.1.2.3.1

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 3 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance: Needed confidence in parameter or performance measure	Significance: Sensitivity of parameter or performance measure to hypothesis	Significance: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DOMAIN (continued)				
Hydrogeologic units (continued)	Flow of interest at Yucca Mountain occurs primarily through fractured Tertiary volcanic rocks; this system is separated from and lies above a deeper regional carbonate aquifer system with higher hydraulic head	Medium--in one drillhole (UE-25 p#1) the hydraulic head in a carbonate-aquifer unit underlying the Tertiary volcanic units is about 20 m higher than in the overlying units; but data are few and structure complex	Paleozoic carbonate unit plays a significant role in flow system beneath the site; areas exist where the carbonate aquifer is missing, has flow system that is interconnected with overlying volcanics, or has lower hydraulic head	Same as above	High	High--SZ GWTT and transport characteristics are largely dependent on hydrogeologic units; transient behavior of water-table elevation is dependent on properties of hydrogeologic units	Medium--based on uncertainty	8.3.1.2.1.3.2, 8.3.1.2.3.1
Structural Features								
Fractures	Fractures in Tertiary volcanic rocks serve as principal pathways for ground-water flow	Low--borehole and surface-based observations indicate that most Tertiary volcanic tuff units are highly fractured, and that fracture permeability is much greater than matrix permeability	None identified	Same as above	High	High--flow in fractures has a large effect on SZ and GWTT and transport characteristics and on transient response and storage characteristics	Low--based on uncertainty	8.3.1.2.3.1.3, 8.3.1.2.3.1.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 4 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
DOMAIN (continued)								
Fractures (continued)	Fracture permeability decreases with increasing depth in tuffaceous units at Yucca Mountain	Low--observations from borehole flow surveys show a systematic decrease in fracture permeability with depth	Large fracture permeability occurs even at great depths	Same as above	High	High--GWTT; transport characteristics and transient response of water table are largely dependent on permeability of rock	Low--based on uncertainty	8.3.1.4.2.2.2, 8.3.1.4.2.2.3, 8.3.1.4.2.2.4
Faults	None selected	High--evidence indicates that some faults, such as Solitario Canyon fault, may act as barriers, whereas others, such as faults east of Yucca Mountain, may act as conduits	Faults are either barriers or conduits to ground-water flow and have a large effect on ground-water flow direction and and magnitude, and on transport characteristics	Same as above	High	High--the permeability of a fault or fault zone has a large effect on SZ GWTT and transport characteristics, and transient behavior of SZ flow system	High--response of water-table elevation to increased recharge or tectonic changes may be very sensitive to the permeability of fault zones	8.3.1.2.1.3.2, 8.3.1.2.3.1.1, 8.3.1.2.3.1.2, 8.3.1.2.3.1.4
Lineaments	None selected	Medium--lineaments may have a substantial effect on the ground-water flow system	Lineaments may act as either conduits or barriers to ground-water flow and may be associated with regional-scale fault or fracture systems	Same as above	High	High--the permeability of a lineament zone has a large effect on SZ GWTT time, transport characteristics, and transient response	Medium--based on uncertainty	8.3.1.2.1.3, 8.3.1.2.3.1.2, 8.3.1.2.3.1.3, 8.3.1.2.3.1.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 5 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				BOUNDARY CONDITIONS				
Upper boundary	The water table is the upper boundary of the SZ ground-water flow system	Low--evidence from drillhole tests shows the SZ as being unconfined and responding as if it had	None identified	Same as above	High	High--transient models of ground-water flow, used to estimate SZ GWTT, transport characteristics, and transient responses of water-table elevation are dependent on the specification of confined versus unconfined upper boundary conditions	Low--based on uncertainty	8.3.1.2.3.1.2
	Average recharge to the SZ at Yucca Mountain through the UZ is small	High--no direct evidence is available to estimate recharge directly; annual precipitation at Yucca Mountain is small, resulting in probable small amounts of recharge, but areal variations in recharge may be substantial	Localized recharge through fractures and or fault zones is substantial	GWTT; radionuclide transport in the UZ[b], radionuclide transport in the SZ	High	High--GWTT and transport in the UZ and SZ are directly affected by amount of recharge	High	8.3.1.2.1.1, 8.3.1.2.1.2, 8.3.1.2.1.3.3, 8.3.1.2.1.3.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 6 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				BOUNDARY CONDITIONS (continued)				
Upper boundary (continued)	Discharge from the subregional SZ flow system occurs primarily as evapotranspiration at Franklin Lake playa, minor evapotranspiration within the Amargosa Desert, and spring flow that occurs at Furnace Creek Ranch from Paleozoic carbonate unit	Medium--potentiometric data indicate a continuum of the flow system from Yucca Mountain to known discharge areas at Franklin Lake playa; origin of spring flow at Furnace Creek Ranch is uncertain	Discharge from the subbasin is restricted to discharge occurring as evapotranspiration at Franklin Lake playa and minor amounts elsewhere in the Amargosa Desert	Same as above	High	High--SZ GWTT and transport characteristics are directly affected by location and rate of discharge	Medium--based on uncertainty	8.3.1.2.1.3.4, 8.3.1.2.1.4
	Recharge to the regional SZ flow system occurs primarily at Rainier and Pahute mesas	Low--potentiometric and hydrochemical data show a direct source to groundwater at Yucca Mountain	Primary recharge to SZ flow system at Yucca Mountain occurs from upward leakage from underlying Paleozoic carbonate rocks, or is areally distributed, occurring beneath washes throughout the subbasin	Same as above	High	High--SZ GWTT and transport characteristics are directly affected by location and rate of recharge	Low--based on uncertainty	8.3.1.2.1.1.1, 8.3.1.2.1.2.1, 8.3.1.2.1.3.3

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 7 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
BOUNDARY CONDITIONS (continued)								
Upper boundary (continued)	A substantial amount of recharge to the SZ occurs along Fortymile Wash	High--little data exist to determine the extent and rate of recharge in Fortymile Wash	Recharge along Fortymile Wash is minor	GWTT; radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--SZ and UZ GWTT and transport characteristics are directly affected by location and rate of recharge at and near the site	High--recharge at Fortymile Wash may be one of the most critical boundary conditions affecting SZ and UZ at Yucca Mountain	8.3.1.2.1.3.3
	Water-table mounds and perched-water bodies originate primarily from water infiltrating from above	Medium--testing of perched or mounded water has not been sufficient to develop a complete understanding of the origin of this water	Water-table mounds and perched water are the result of geothermal and/or seismic pumping of deep-seated ground water	Same as above	High	Medium--upward migration of deep-seated ground water would have a large effect on GWTT and water-table altitude	Medium--based on uncertainty and sensitivity	8.3.1.2.2.4.7, 8.3.1.2.3.1.2

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 8 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
BOUNDARY CONDITIONS (continued)								
Lower boundary	Lower boundary is the base of the Tertiary units (volcanics and basin-fill sediments), across which little or no flow occurs	High--few data exist at depth to establish lower flow or no-flow boundary conditions, or lithologies therein; evidence indicates that the number of open fractures decreases with increasing depth, and potentiometric data from several drillholes indicate increasing head with increasing depth	Lower boundary is the base of the Tertiary units (volcanics and basin-fill sediments), across which substantial upward or downward leakage occurs Lower boundary is undefined; substantial circulation of flow occurs via deep-seated, thermally driven convection cells or seismic pumping through open vertically interconnected fracture networks	Same as above	High	Medium--position of boundary and amount and direction of flux across it significantly affects GWTT, transport through the SZ to the accessible environment, and the response of the water-table elevation to temporal changes	Medium--based on sensitivity	8.3.1.2.2.9.3

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 9 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
BOUNDARY CONDITIONS (continued)								
Lateral boundary								
Subregional	Subbasin lateral boundaries are no-flow boundaries, consisting of either streamlines or ground-water divides, except for flux boundaries, specified as follows: (1) throughflow from the Timber Mountain region; (2) throughflow from the western Amargosa Desert; and (3) throughflow from the Ash Meadows springline	Medium--observations of hydraulic-head distribution indicate that these probably are appropriate descriptions of the boundary conditions of the subregional ground-water flow system of Yucca Mountain and vicinity; but data are sparse and unevenly distributed	Lateral boundaries should be defined to exclude ground-water discharge at Furnace Creek Ranch in Death Valley; other lateral boundaries could be defined	Same as above	Low	Medium--exclusion of spring discharge at Furnace Creek Ranch would have a significant effect on estimates of ground-water flow direction and magnitude at Yucca Mountain; the position of other lateral boundaries probably would have minimal effect	Low--based on needed confidence	8.3.1.2.1

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 10 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				BOUNDARY CONDITIONS (continued)				
Lateral boundary (continued)								
Site	No natural lateral flow boundaries occur that would logically define the boundaries of the site, therefore, lateral site boundary conditions will be specified at the accessible environment, based on results obtained from regional ground-water flow models	Medium--boundary flux specifications will be only as reliable as the results from the regional models of ground-water flow	None identified	Same as above	Low	High--estimates of GWTT and water-table altitude will depend in large part on model results	Low--based on needed confidence	8.3.1.2.1.4
Temporal	Under present-day conditions, boundary locations and fluxes are considered invariant with time	Low--water-table altitude variations are small relative to the total effective saturated thickness	Active and expected future tectonic and thermal processes may cause substantial changes in water-table altitude	GWTT; radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--a knowledge of the temporal changes in water-table altitude is important for estimating long-term water-table altitude	Low--based on uncertainty	8.3.1.2.1, 8.3.1.2.3.1, 8.3.1.2.3.2

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 11 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				BOUNDARY CONDITIONS (continued)				
Temporal (continued)	Over the 10,000-yr isolation period, boundary positions and fluxes may change signficantly; for modeling purposes, the SZ ground-water flow system will be treated as a transient system in evaluating effects of tectonics and climate	High--water-table altitudes may change substantially, but potential magnitudes of change are unknown	None identified	Radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--substantial water-table rises could saturate respository and affect transport in UZ and SZ	High	8.3.1.2.1.4, 8.3.1.2.2.9
	Material properties are assumed to be invariant with time	Medium--within the 10,000-yr isolation period, the effect of climatic and tectonic changes on material properties (transmissivity and storage) are expected to be small, but existing modeling and analyses to demonstrate this are inadequate	Material properties are likely to change significantly during the 10,000-yr isolation period	Same as above	High	High--transport in the UZ and SZ and water-table altitudes are largely dependent on material properties	Medium--based on uncertainty	8.3.1.2.1.4, 8.3.1.5.2

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 12 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DRIVING FORCES/PROCESSES				
Equation of motion	Darcy's Law is applicable in describing ground-water flow throughout the regional and site flow systems	Low--acceptable representation of the regional and site potentiometric surface has been made using models based on Darcy's Law	Flow through fractures may be turbulent and violate Darcy's Law	GWTT; radionuclide transport in the SZ	Low	High--estimates of SZ GWTT and transport characteristics are largely dependent on applicability of Darcy's Law	Low--based on needed confidence	8.3.1.2.3.1.3, 8.3.1.2.3.1.4
Conservation of fluid mass	Changes in fluid-mass storage are negligible within the flow system because recharge is essentially equal to discharge	Medium--recharge estimates are very approximate and assume mass balance with discharge	Recharge was greater during the late Pleistocene and a recharge pulse is still propagating through the flow system	Same as above	Low	High--estimates of SZ GWTT and transport characteristics are largely dependent on recharge and discharge within the flow system	Low--based on uncertainty	8.3.1.2.1.4, 8.3.1.5.1.2
Heat energy	The coupled effects of heat energy on fluid flow in the SZ flow system do not significantly affect ground-water flow	Medium--deviations from linearity in the geothermal gradient, as measured in the SZ, generally are statistically insignificant, but data are sparse	Deep-seated geothermal waters are thermally driven vertically upward within the flow system	GWTT; radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--estimates of GWTT, water-table altitude, and transport characteristics are largely dependent on ground-water flow direction and magnitude	Medium--based on uncertainty	8.3.1.15.2.2

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 13 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DRIVING FORCES/PROCESSES (continued)				
Strain energy	The coupled effects of strain energy on fluid flow in the SZ flow system do not significantly affect ground-water flow	Medium--insufficient data exist to correlate changes in tectonically or underground nuclear explosion related strain-energy releases with substantial changes in water-table altitude	Strain energy has a large effect on water-table altitude and flow-system response	Same as above	High	High--estimates of GWTT, water-table altitude, and transport characteristics are largely dependent on understanding the coupled effect of strain energy and fluid flow	Medium--based on uncertainty	8.3.1.8.3.2.3
				SYSTEM DYNAMICS/RESPONSE				
Future climatic effects	Future climatic changes are unlikely to produce substantial large-scale effects within the SZ during the next 10,000 yr	High--paleoclimatic data indicate that major climatic changes can occur within 10,000-yr intervals	Climatic changes and episodic variations are likely to occur and significantly affect ground-water flow within the SZ during the 10,000-yr isolation time	Radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--estimates of SZ and UZ transport characteristics are largely dependent on recharge to the SZ, which is directly linked to climate	High--climatic changes to significantly wetter conditions could drastically affect radionuclide transport	8.3.1.5.2

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 14 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			DRIVING FORCES/PROCESSES (continued)					
Stress/strain effects	Renewed faulting or regional aseismic processes at Yucca Mountain are unlikely to have any local or large-scale effect on the SZ hydrologic system, during the 10,000-yr isolation period	High--few data exist related to the effects of renewed faulting or regional aseismic processes on the SZ hydrogeologic system	Changes in tectonically induced stress could substantially alter hydraulic properties, causing increased permeability, a decrease in open interconnected fractures, or a water-table rise	Same as above	High	High--radionuclide transport characteristics are largely dependent on permeability distribution within the flow system, which could be altered during an earthquake	High--neotectonics could have a large effect on radionuclide transport particularly in areas of large hydraulic gradients	8.3.1.8.3
Thermal effects	The coupled effect of heat convection and ground-water flow is likely to be minimal during the 10,000-yr isolation period	Medium--some evidence of significant thermally driven convection exists from data collected from boreholes in the vicinity of Yucca Mountain, but magnitude of potential future changes is unknown	Thermally driven convection is significant and is likely to have major effect on ground-water flow during the 10,000-yr isolation period	Same as above	High	High--transport characteristics are largely dependent on whether significant thermally driven convection is likely to occur within the flow system	Medium--thermally driven convection could significantly affect transport of radionuclides	8.3.1.8.3

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 15 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM DYNAMICS/RESPONSE (continued)				
Volcanism effects	The effect of renewed volcanism on the regional flow system would be very localized. However, changes in local ground-water flow direction and magnitude, and water-table altitude could be very large	Low--renewed volcanism during the 10,000-yr isolation period is highly unlikely	None identified	Same as above	High	High--transport characteristics are largely dependent on permeability distribution within the flow system, which could be altered during a volcanic eruption or igneous intrusion	Low--based on uncertainty	8.3.1.8.3
				DATA REDUCTION MODELS				
Porous-media versus fracture-flow models	Region: ground-water flow at the regional scale may be acceptably approximated using porous-media-equivalent models, even though flow occurs through fractured rock in much of the flow system	Low--existing models at the regional scale have acceptably approximated the flow system	None identified	GWTT; radionuclide transport in the SZ	Low	Medium--estimates of SZ GWTT and radionuclide transport are largely dependent on the choice of model used	Low--based on uncertainty	8.3.1.2.1.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 16 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
DATA-REDUCTION MODELS (continued)								
Porous media versus fracture-flow models (continued)	Site: None selected	High--large uncertainty remains whether ground-water flow at the site may be acceptably described using porous-media-equivalent models	The site SZ flow system may be acceptably represented by a fracture network model The site SZ flow system may be acceptably represented by a dual-porosity model The site SZ flow system may be acceptably represented by an equivalent-porous-media model with superimposed discrete fault zones	Same as above	Low	Medium--estimates of SZ GWTT and radionuclide transport are largely dependent on the choice of model used	Low--based on confidence	8.3.1.2.1.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 17 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
DATA-REDUCTION MODELS (continued)								
Geostatistical model	Local variations in material properties and hydraulic head are less significant at the regional scale than at the site scale. Estimates of ground-water flow direction and magnitude will be statistically based, which means that unknown local heterogeneities in material properties will probably not be predicted with geostatistical models	Low--geostatistical models have been successfully applied for characterizing material property distributions in hydrogeologic systems	None identified	Same as above	Low	High--estimates of SZ GWTT and transport characteristics are largely dependent in material properties	Low--based on uncertainty	8.3.1.2.1.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 18 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
DATA-REDUCTION MODELS (continued)								
Inverse model	Because few material property data are available to estimate transmissivity, inverse models of ground-water flow (which provide estimates of transmissivity based on model-specified flux, potentiometric distribution, and other known geohydrologic properties) are acceptable for use in characterizing the ground-water flow system at the regional and site scale	Low--inverse models have been used successfully in the past to characterize ground-water flow beneath Yucca Mountain and vicinity	Forward modeling is an acceptable alternative to inverse modeling	Same as above	Low	Medium--estimates of SZ GWTT and radionuclide transport are dependent on the type of model selected	Low--based on needed confidence	8.3.1.2.1.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 19 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Transient model	The present-day regional and site ground-water flow systems may be acceptably represented as steady-state systems, based on minimal changes in storage (see model elements listed under boundary conditions); for simulations involving potential future of climatic changes, increased pumping of ground-water, or renewed faulting transient conditions may need to be assumed	Low--steady-state models have been developed previously that successfully simulated the regional ground-water flow system	None identified	GWTT; radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	Medium--estimates of GWTT and radionuclide transport are dependent on the type of model selected	Low--based on uncertainty	8.3.1.2.1.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 20 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Coupled-effects modeling	Effects of heat- and strain-related changes on ground-water flow are expected to be small; therefore, extensive models of coupled effects of heat and strain on ground-water flow will not be needed for simulating flow system response during 10,000-yr isolation period	Medium--insufficient data exist to determine if effects will be signficant	Effects are expected to be large; therefore, coupled-effects modeling is the only way to accurately simulate combined effects of heat, strain, and fluid flow	Same as above	High	High--estimates of GWTT and radionuclide transport are largely dependent on the magnitude of the effects of heat and strain on the flow system	Medium--based uncertainty	8.3.1.2.1.4, 8.3.1.8.3

[a]GWTT = pre-waste-emplacement ground-water travel time in the saturated zone.
[b]The principal manner in which the selection of the correct saturated-zone hypothesis affects estimates of radionuclide transport in the UZ is the influence that the correct hypothesis would have on water-table altitude at the site; any rise in the water table would result in a foreshortening of the UZ and, thereby, a shortening of transport time through the UZ to the water table.

uncertainties associated with the current representation for each model element.

Interrelationships of geohydrology investigations

Three investigations are identified for the geohydrology program, namely

Investigation	Subject
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 geologic 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 ultimate source of surface water and ground water. 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 acquired 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; (3) predictions of spatial and temporal changes in the regional and site potentiometric-surface configuration; and (4) 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 developed the characterization of (1) infiltration, (2) percolation, (3) gaseous-phase movement, and (4) hydrochemistry. A fifth study is concerned with developing conceptual models for the flow of water in partially saturated fractures and the subsequent interaction between the hydrologic dynamics of fractures and the enclosing rock. This study also intends to quantify these processes and to construct and validate numerical models to simulate water flow in discrete fractures and fracture systems. A sixth study is designed to integrate data and concepts in order to develop conceptual models for the undisturbed unsaturated-zone hydrogeologic system and to construct numerical models to simulate mathematically the response of the system or its subsystems to changing boundary or internal conditions. An important product of the modeling effort will be to predict the spatial and temporal distributions of moisture flux within the system in order to provide the predictions of the moisture velocity field that are needed by performance-assessment activities for calculating ground-water travel times and total system releases to the accessible environment.

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 inferred from the potential distribution and the conductive properties of the system, or by other indirect means. From the viewpoint of nuclear waste isolation, the most significant findings will be to predict the transport of radionuclides from the repository to the water table, 200 to 400 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.

Because it can transport moisture as water vapor, gas flow in the unsaturated zone may have an important hydrologic application and, in addition, may provide a mechanism for transporting gas-phase 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 is likely to 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 for Site Program 8.3.1.2 (geohydrology) is presented in Section 8.3.1.2.4.

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:

SCP section	Subject
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

SCP section	Subject
3.6.2	Relationship among hydrogeologic units
3.6.3	Potentiometric levels
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
3.10.1	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:

Activity	Subject
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 Nevada Test Site (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.

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. Many uncertainties remain, however, that limit 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.

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 potentiometric levels, 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 recharge resulting from future climatic changes, potential increased withdrawal of ground water, and changes in hydrogeologic system properties and geometry resulting from tectonic events.

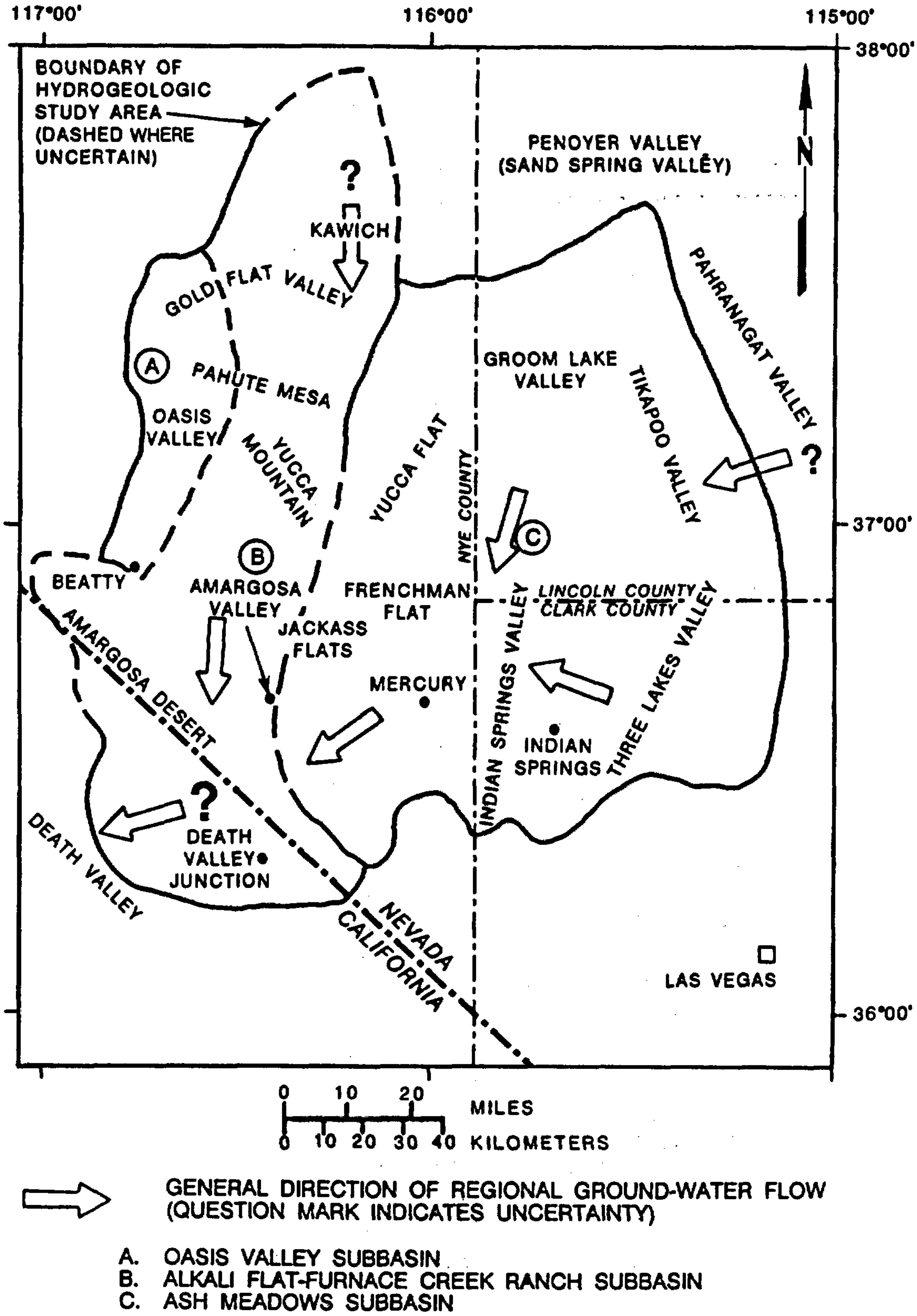


Figure 8.3.1.2-5. Hydrogeolgic study area, showing three ground- water subbasins. Modified from Rush (1970) Blankennagel and Weir (1973), Winograd and Thordarson (1975), Dudley and Larsen (1976), Waddell (1982) and Waddell, et al. (1984).

Records of existing precipitation gages at the 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. The two investigative strategies are 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 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

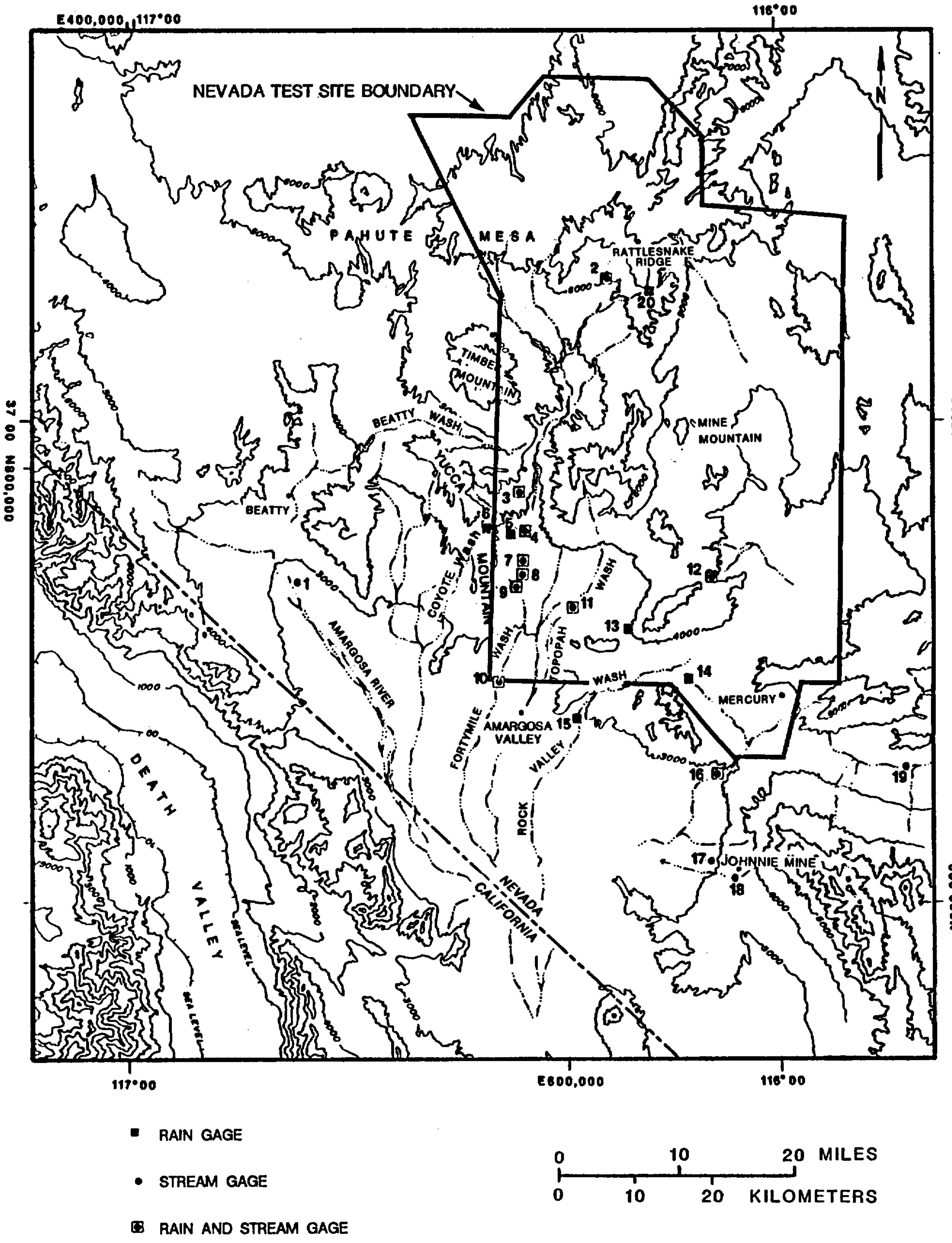


Figure 8.3.1.2-6. Regional precipitation and streamflow stations (numbers correspond to those shown in Table 8.3.1.2-3).

Table 8.3.1.2-3. Regional precipitation and streamflow stations (see Figure 8.3.1.2-6 for locations)

Map location	Location	Gage type	Nevada State coordinates North	Nevada State coordinates 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	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

[a]CSG = crest-stage stream gage.
[b]RRG = recording rain gage (tipping bucket).
[c]RSG = recording stream gage.
[d]PRG = 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 8.3.1.2.2.6.1) as well as the infiltration studies (Activity 8.3.1.2.2.1.2). The plan for the integrated precipitation network will also include a description of precipitation sampling for chemical and isotopic analyses. This program will be coordinated with other precipitation sampling efforts (Activities 8.3.1.2.1.3.3 and 8.3.1.2.2.2.1). 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 (Investigation 8.3.1.5.1). 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, quantity, and characteristics of the available data of that time; techniques will also depend on the quality and quantity of regional data and paleoclimatic 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 non-recording precipitation gages	HP-43,R1	Installation, operation, and inspection of two types of non-recording rain gages	7 Jun 88
Operate recording precipitation gages	HP-46,R1	Method of installation, operation, and inspection of recording rain gages	7 Jun 88
Operate meteorological stations	TBD[a]	Operation of meteorological stations (temperature, humidity, barometric pressure, wind speed and direction, solar radiation)	TBD
Operate Bowen-ratio stations to measure evapotranspiration	TBD	Bowen-ratio station operation to measure evapotranspiration	TBD

[a]TBD = to be determined.

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 Yucca

Mountain 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 Yucca Mountain 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-mi^2 tributary to the headwaters of Fortymile Wash near Rattlesnake Ridge.

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 mi^2 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 mi^2) and much of the runoff from Yucca Mountain that enters Fortymile Wash from the Drillhole-Sever Wash drainage (about 16 mi^2).

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.

In support of Activity 8.3.1.2.1.3.3 (Fortymile Wash) recharge study, the regional streamflow-measurement network in the Fortymile Wash basin will be expanded. Approximately six additional streamflow-measurement stations, three snow courses, six precipitation-measurement sites, and two air-temperature measurement sites will be installed and operated in the upper drainage basin of Fortymile Wash to collect data that will supplement the currently operating streamflow and precipitation networks, and thus allow precipitation-runoff model assessment for Fortymile Wash. Establishment of the meteorological stations will be coordinated with Study 8.3.1.12.1.2 (plan for synthesis of Yucca Mountain Project meteorological monitoring. The monitoring equipment for these temperature and precipitation measurement sites will include standard, continuous-recording precipitation and air-temperature gages, and the streamflow-measurement equipment will consist of continuous-recording stage recorders.

In addition, a continuously recording stream 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 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 historical streamflow data base for the area immediately surrounding and including the Yucca Mountain area and the NTS. These five incorporated sites outside of the proposed Yucca Mountain regional study area but are relatively nearby. This historical 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 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

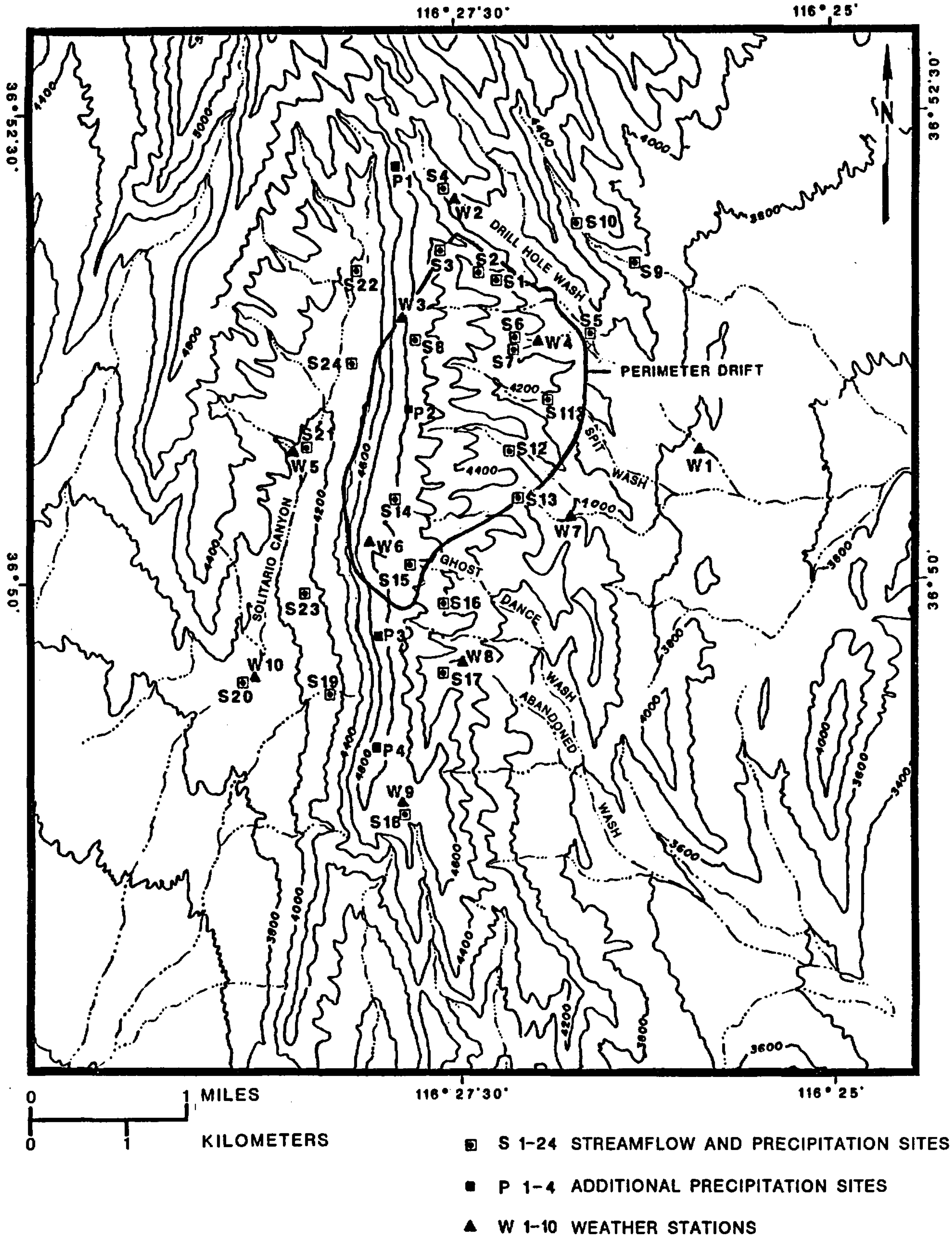


Figure 8.3.1.2-7. Site precipitation, streamflow, and proposed weather stations (refer to Table 8.3.1.2-4 for precipitation and streamflow location descriptions).

Table 8.3.1.2-4. Site precipitation and streamflow stations (see Figure 8.3.1.2-7 for locations)

Map location	Location	Gage type	Nevada State coordinates North	East
S1	Wren Wash--below USW UZN-98, just below lower confluence	TBD[a]	767,900	562,250
S2	Wren Wash--above USW 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

Table 8.3.1.2-4. Site precipitation and streamflow stations (See Figure 8.3.1.2-7 for locations) (continued)

Map location	Location	Gage type	Nevada State coordinates North	East
S17	Abandoned Wash--just below Ghost Dance fault trench	TBD	755,050	560,500
S18	Drainage south of USW UZ-13--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

[a]TBD = to be determined.

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. 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).

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.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Measure meteorological parameters	HP-43,R1	Installation, operation, and inspection of two types of nonrecording rain gages	7 Jun 88
	HP-46,R1	Method of installation, operation, and inspection of recording rain gages	7 Jun 88
	TBD[a]	Techniques of installation and operation of air-temperature gages	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Measure meteorological parameters (continued)	HP-163,R0	Meteorological monitoring of Yucca Mountain and vicinity (tentative procedure)	TBD
	HP-179,R0	Field measurement of precipitation using a tipping-bucket rain gage	20 May 88
	HP-180,R0	Field measurement of precipitation using a propane-heated, tipping-bucket rain and snow gage	15 Jun 88
	TBD	Techniques for measuring snowpack accumulation and dissipation	TBD
Measure streamflow	HP-40,R1	Determination of peak discharge by the slope-conveyance method	7 Jun 88
	HP-41,R0	Preliminary method of television recording of surface-water flow	14 Aug 84
	HP-42,R0	Field procedure for indirect measurements of stream discharge	5 Jun 88
	HP-44,R1	Installation, operation, and inspection of crest-stage streamflow gages	7 Jun 88
	HP-45,R1	Method of installation, operation, and inspection of recording streamflow gage using the bubble-gage STACOM manometer system	7 Jun 88
	HP-114,R0	Estimating streamflow discharge	7 Jun 88

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Measure streamflow (continued)	HP-115,R0	Determination of peak streamflow discharge using culverts	7 Jun 88
	HP-116,R0	Methods to install, operate, and inspect a recording-streamflow gage that uses a stilling-well system	7 Jun 88
	HP-117,R0	Installation, inspection and maintenance of scour chains at streamflow gaging sites	7 Jun 88
	HP-169,R0	Determination of peak discharge by the slope-area method	7 Jun 88
Determine relations of runoff to weather conditions	TBD	No technical procedures identified	TBD

[a]TBD = 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

This activity is closely tied to Activity 8.3.1.2.1.2.1 (surface-water runoff monitoring). If field investigations of surface runoff reveal intense and rapid movement of debris by surface runoff, data will be collected to document this movement. 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 will be used to evaluate debris hazards near the surface-facilities locations, as described in Activity 8.3.1.16.1.1.1 (site flood and debris hazards studies). The information will also increase knowledge of 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, aerial 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	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Determine quantities and characteristics of debris transport	TBD[a]	Techniques for measuring and characterizing fluvial-sediment deposits	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Determine quantities and characteristics of debris transport (continued)	HP-174,R0	Techniques for measuring severe stream-channel or hillslope erosion and (or) resultant sediment deposits	7 Jun 88
Determine sediment component of runoff	TBD	No technical procedures identified	TBD

[a]TBD = 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.

Four 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 distribution and hydrogeologic framework studies, (3) a Fortymile Wash recharge study, and (4) evapotranspiration studies.

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.

3. Potentiometric levels.

Description

A hierarchy of priorities will be assigned to data requirements for the description of regional ground-water flow description of the saturated zone. As only one of various methods that will be used, a two-dimensional ground-water flow model (Czarnecki and Waddell, 1984) will be updated to evaluate the adequacy of regional hydrogeologic 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. The effects of the positions and conditions of lateral-flow boundaries will be tested by specifying alternative configurations of model grids or meshes. 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 the updated 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.

Hydrologic data have been collected from boreholes drilled in the Amargosa Desert by a mining company (Activity 8.3.1.2.1.3.2). Preliminary assessment of these data indicated that their interpretation may result in revision of the conceptual model or regional flow.

Potentiometric and temperature data from these holes indicate a potential upward component of ground-water flow (hydraulic gradients of 0.02) from depths as great as 500 m. Upward flow of ground water was confirmed from concave-downward profiles of temperature as a function of depth. In addition, potentiometric data indicate that a ground-water divide may exist in the Greenwater Range, between the Amargosa Desert and Death Valley. Hydraulic head under the Greenwater Range is as great as 875 m, whereas in the Amargosa Desert, head is about 615 m, and in Death Valley, head is about sea level (Czarnecki, 1987).

Potentiometric and temperature data from these holes are potentially significant for characterizing the regional ground-water flow system, because they suggest that (1) upward flow from great depths may occur within the subbasin, possibly from underlying carbonate rocks, which constrains the saturated-zone flow paths from the site to occur only in the upper part of the ground-water system; (2) ground-water recharge may have occurred even in relatively low-lying arid areas, such as the Greenwater Range and the Funeral Mountains, a hypothesis that was previously not favored; (3) ground-water discharge near Furnace Creek Ranch may occur via a deeper, confined flow system, possibly through carbonate rocks; (4) the conceptual model of the ground-water flow system can be simplified by removing the ground-water discharge boundary condition at Furnace Creek Ranch; and (5) a smaller amount of ground water flows beneath Yucca Mountain than previously estimated, when discharge from this flow system was assumed to occur at Furnace Creek Ranch (Czarnecki, 1987).

Although these data support the need to revise previous conceptual models, they are not conclusive. As a result, these data will be further evaluated in the context of the regional flow system, and an assessment will be made to determine what additional data are needed to test alternative conceptual models. As described below, consideration will be given to the following efforts: (1) drill additional piezometer nests; (2) drill a deep borehole into the Paleozoic rocks beneath the Amargosa Desert; and (3) deepen proposed drillholes USW WT-21 and USW WT-22 into Paleozoic rocks (Figure 8.3.1.2-8). These tasks would be conducted as part of Activity 8.3.1.2.1.3.2. Any proposed new drilling would be integrated with drilling plans developed in Studies 8.3.1.4.1.2 and 8.3.1.4.1.3.

Piezometer nests would be constructed to determine the altitude of the potentiometric surface and changes in hydraulic head with depth along the eastern edge of the Funeral Mountains, where Paleozoic carbonate rocks outcrop. Potentiometric data from these shallow piezometer nests (150 m deep) would allow for the determination of whether the Paleozoic carbonate rocks drain ground water from the Amargosa Desert to Furnace Creek Ranch.

Although these boreholes would greatly augment existing hydrogeologic data for the regional flow system, no drillholes have been constructed to penetrate and test Paleozoic hydrogeologic units (probably carbonate rocks) underlying Tertiary basin fill at estimated depths as great as 6,000 ft (1,800 m) in the Amargosa Desert. The need to do this will be evaluated in the context of existing hydrogeologic data and conceptual models of the regional flow system. A drillhole constructed into the Paleozoic units would be used to determine the amount and direction of ground-water flow between these and overlying units, by installing multiple piezometers. Groundwater samples obtained form these Paleozoic and overlying units would be analyzed to determine the stable isotopes of oxygen and hydrogen for use in determining the source (magmatic, meteoric, etc.), based on methods presented in Barnes (1979), as part of Activity 8.3.1.2.3.2.2. Similar types of information would be obtained by deepening drillholes USW WT-21 and USW WT-22 into the underlying carbonate rocks.

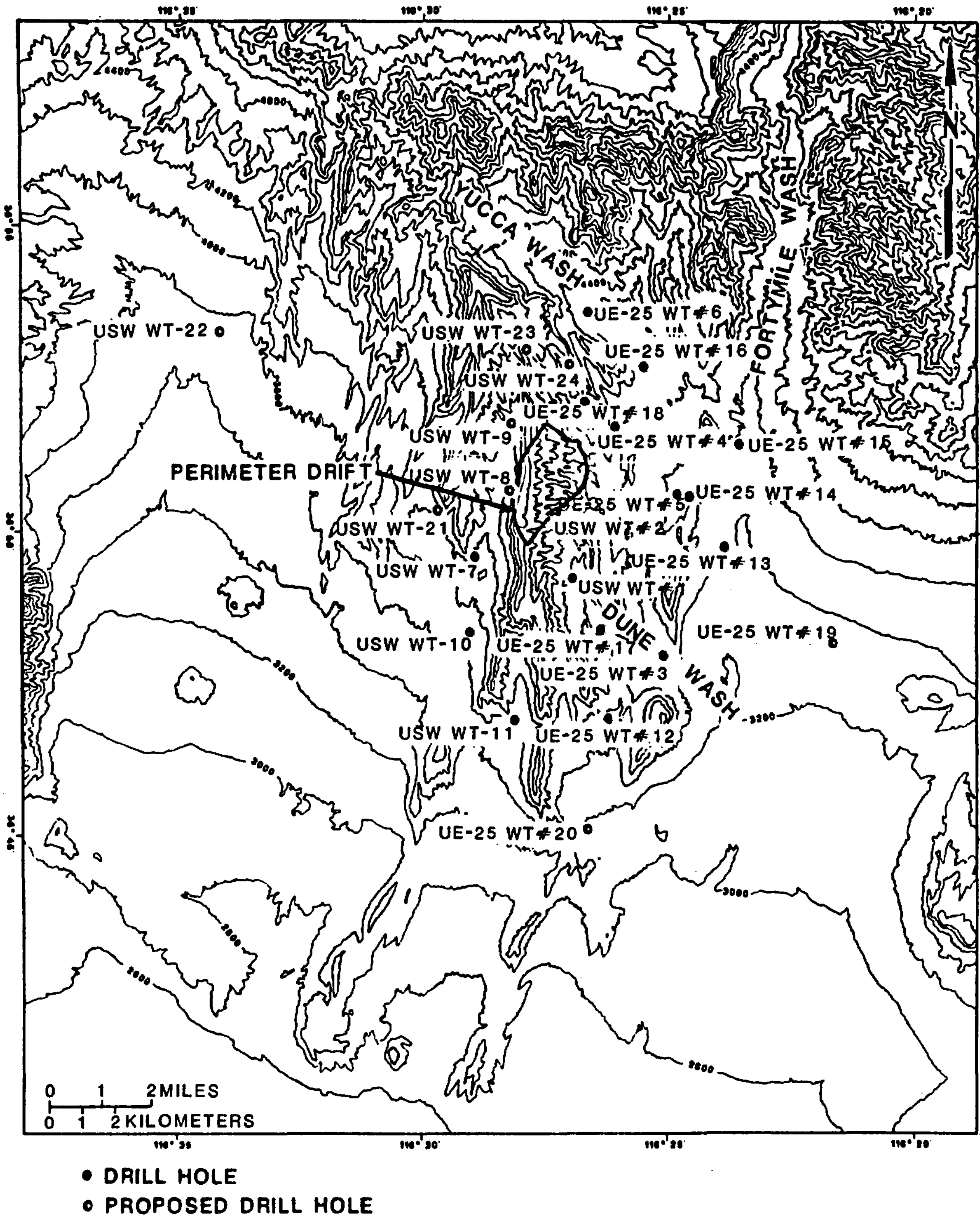


Figure 8.3.1.2-8. Location of existing and proposed water-table holes.

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
Numerical ground-water flow model parameter sensitivity analysis	TBD[a]	Reference software documentation	TBD

[a]TBD = to be determined.

8.3.1.2.1.3.2 Activity: Regional potentiometric-level distribution and hydrogeologic framework studies

Objectives

The objectives of this activity are (1) to determine the potentiometric distribution within the regional ground-water flow system, and (2) to characterize the hydrogeologic framework of the regional ground-water flow system to support reliable estimates of ground-water flow direction and magnitude within the saturated zone.

Parameters

The parameters of this activity are

1. Potentiometric-surface configuration.
2. Hydraulic gradient.
3. Heat flow.
4. Transmissivity.
5. Storativity.
6. Lineaments.
7. Fractures.
8. Hydrostratigraphic units.

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 below) will be run.

Results from regionally oriented geophysical surveys (Activities 8.3.1.4.2.1.2 and 8.3.1.17.4.3.1) will be used to (1) provide data on structural and stratigraphic controls affecting ground-water flow and (2) determine or infer the position of the water table, based on correlating known water-table altitudes with results from these surveys. These surveys will be very important for inferring the cause of the large hydraulic gradient north of the perimeter drift area and for directing the location of additional confirmatory drilling.

Because Crater Flat lacks water-level data and hydrogeologic information needed for modeling of that area, two new water-table holes, USW WT-21 and USW WT-22, will be drilled (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 as a result of Activity 8.3.1.2.1.3.1. 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.

Lithologic logs based on cuttings collected at regular intervals during the construction of USW WT-21 and USW WT-22 will be used to describe the stratigraphy as part of Activity 8.3.1.4.2.1.1. Core will be obtained near the unsaturated/saturated zone interface to extract gas and water samples for chemical analyses to determine ground-water age, origin and recharge rates in conjunction with Activities 8.3.1.3.2.2, 8.3.1.2.2.7.1, and 8.3.1.2.2.7.2.

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 Yucca Mountain 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 (Activity 8.3.1.2.3.2.2). 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 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 Morgan and Swanberg (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 (Activity 8.3.1.8.5.2.3).

A mining company is drilling boreholes to depths of 2,000 ft in valley-fill deposits of Tertiary age in the Amargosa Desert as a part of its exploration program. This commercial company has agreed to allow (1)installation of piezometers in their holes for Yucca Mountain 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.

A large gradient has been mapped in the potentiometric surface north of the site (Figure 3-28). The horizontal hydraulic gradient between wells UE-25 WT#6 and USW H-1 is about 300 m in 3,000 m, or about 0.1. This is about four orders of magnitude greater than the hydraulic gradient south of well USW H-1. Although the specific cause and nature of this large hydraulic gradient are not yet known, several hypotheses have been proposed (Czarnecki and Waddell, 1984): (1) existence or faults in the area that contain non-transmissive fault gouge or that juxtapose transmissive tuff units against nontransmissive tuff units; (2) the presence of a different type of lithology that is less subject to fracturing, such as rhyolite or argillite, or the presence of an intrusive body, such as a volcanic dike; or (3) a change in the direction of the regional stress field and a resultant change in the density, interconnectedness, and orientation of fractures on either side of the large hydraulic gradient.

Because the potential repository would be located about 200 to 400 m above the modern-day water table, and because it would be located immediately downgradient from the large hydraulic-gradient area (Figure 3-28), the stability of the low-transmissive property of this barrier to ground-water flow (fault zone, different rock type, etc.) needs to be evaluated. Neotectonics (renewed movement along faults) or alteration of stress fields could have a large effect on this stability, resulting in changed altitudes of the water table beneath the site itself. Furthermore, an understanding of this feature is needed in order to simulate accurately ground-water flow under present and changed conditions, using subregional models (Study 8.3.1.2.1.4).

This activity will analyze the cause of the large hydraulic gradient by integrating the results from several interrelated activities, including (1) analysis of existing and planned borehole fracture data (Activity 8.3.1.4.2.2.3) and data from surface fracture-network studies (Activity 8.3.1.4.2.2.2); (2) determination of in situ stress on either side of the gradient (Study 8.3.1.17.4.8); (3) refinement of the description of the potentiometric surface, using geophysical surveys (Study 8.3.1.4.2.1) and water levels from wells UE-25 WT#23 and UE-25 WT#24 (Activity 8.3.1.2.3.1.2); (4) construction of UE-25 G#5 (Activity 8.3.1.4.2.1.1) north of the gradient to provide stratigraphic, lithologic, borehole-geophysical and potentiometric data; and (5) pumping tests conducted in association with the Solitario Canyon fault study (Activity 8.3.1.2.3.1.1). In addition, existing data from large gradients elsewhere in the Nevada Test Site region will be reviewed for their applicability to understanding the feature at Yucca Mountain.

Definition of the hydrogeologic framework is an essential component of conceptual and numerical models of the regional flow system and evaluations of the impacts of potential tectonic and climatic changes on isolation (Figure 8.3.1.2-4). This activity will utilize extensively the hydrologic, geologic, geochemical, and geophysical information obtained during site characterization in order to define this framework. Data collected specifically as part of this activity will also be incorporated, including data from boreholes USW WT-21 and USW WT-22 and other drillholes that might be drilled as a result of the analyses of data needs (Activity 8.3.1.2.1.3.1).

Also, as part of this activity, major lineaments and fracture zones will be identified and characterized. Because these regional-scale features generally are distinctive high-permeability zones, they may significantly affect ground-water flow, by providing preferred regional vertical and horizontal flow paths. Preliminary lineament and linear-feature maps will be prepared from statistical analysis of digitized linear features derived from remote sensing data (Landsat Thematic Mapper and MSS imagery, passive and active radar imagery, Skylab, and aerial photographs). These maps will be compared to geologic, hydrologic, geochemical, and geophysical data (by digital, statistical, or manual correlation) to produce final lineament maps. The mapped lineaments will then be incorporated into conceptual and numerical models of regional flow (Study 8.3.1.2.1.4).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.1.3.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
General field reconnaissance	TBD[a]	No technical procedures identified	TBD
Completion of mining-company boreholes for water-level monitoring and hydrochemical sampling	TBD	Completion of regional boreholes for water-level monitoring and hydrochemical sampling	TBD
Additional water-table holes	GP-19,R0	Procedure for the identification, handling, and disposition of drill-hole core and cutting samples from the drill site to the core library	6 Mar 87
	GP-28,R2	Transfer of Project drill-hole samples and related records from the core library and data center to the sample-management facility	22 Apr 88
	TBD	Borehole drilling to water table	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole geophysical surveys	GPP-17,R0	Magnetometer borehole logging operations	27 May 88
	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 (1-139055)	15 Nov 84
Ground-water sampling for chemical and isotopic analyses	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	TBD	Water sampling for chemical and isotopic analyses	TBD
Water-level measurements and long-term monitoring	HP-181,R0	Measurement of water level and pore pressure responses in wells at Yucca Mountain during an announced nuclear explosion (tentative procedure)	20 Jun 88
	HP-01,R0	Methods for determining water level	11 Jan 82
	HP-25,R0	Methods for measuring water levels using the Dodge Logging Van (1-127410)	20 Jul 84
	HP-26,R0	Method for calibrating water-level measurement equipment using the reference steel tape	14 Aug 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Water-level measurements and long-term monitoring (continued)	HP-39,R0	Method for determining water levels using the trailer-mounted hoist (1-134719)	TBD
	HP-57,R1	Method for using graphic and digital water-level recorders	15 Jul 88
	HP-60,R0	Method for monitoring water-level changes using pressure transducers	4 May 88
	HP-71,R0	Method for monitoring water-level changes using a Campbell Scientific 21X Micrologger	1 Sept 87
	HP-75,R0	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	22 Jun 87
	HP-99,R0	Instructions for operation of a well sounder for measuring water levels	8 Jun 88
	HP-93,R0	Method for processing electronic data from a Campbell Scientific 21X Micrologger into water levels	11 May 88
	HP-85,R0	Method of monitoring water-level changes using a pressure transducer and the Fluke 2280 B Data Logger	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Hydraulic testing by drawdown-recovery methods	HP-06,R0	Hydrologic pumping test	11 Jan 82
	HP-34,R0	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	15 May 85
	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
	TBD	Hydraulic testing by drawdown-recovery methods	TBD
Estimate vertical component of ground-water flow	TBD	No technical procedures identified	TBD
Lineament analysis	HP-158,R0	Hydrology and hydraulic nature of fracture zones and lineaments determined from remote sensing and hydraulic analysis	TBD

[a]TBD = 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 significantly 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, and precipitation gages will be installed to continuously record precipitation. Maximum and minimum daily temperatures will be recorded at select sites. These stations will be established 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.

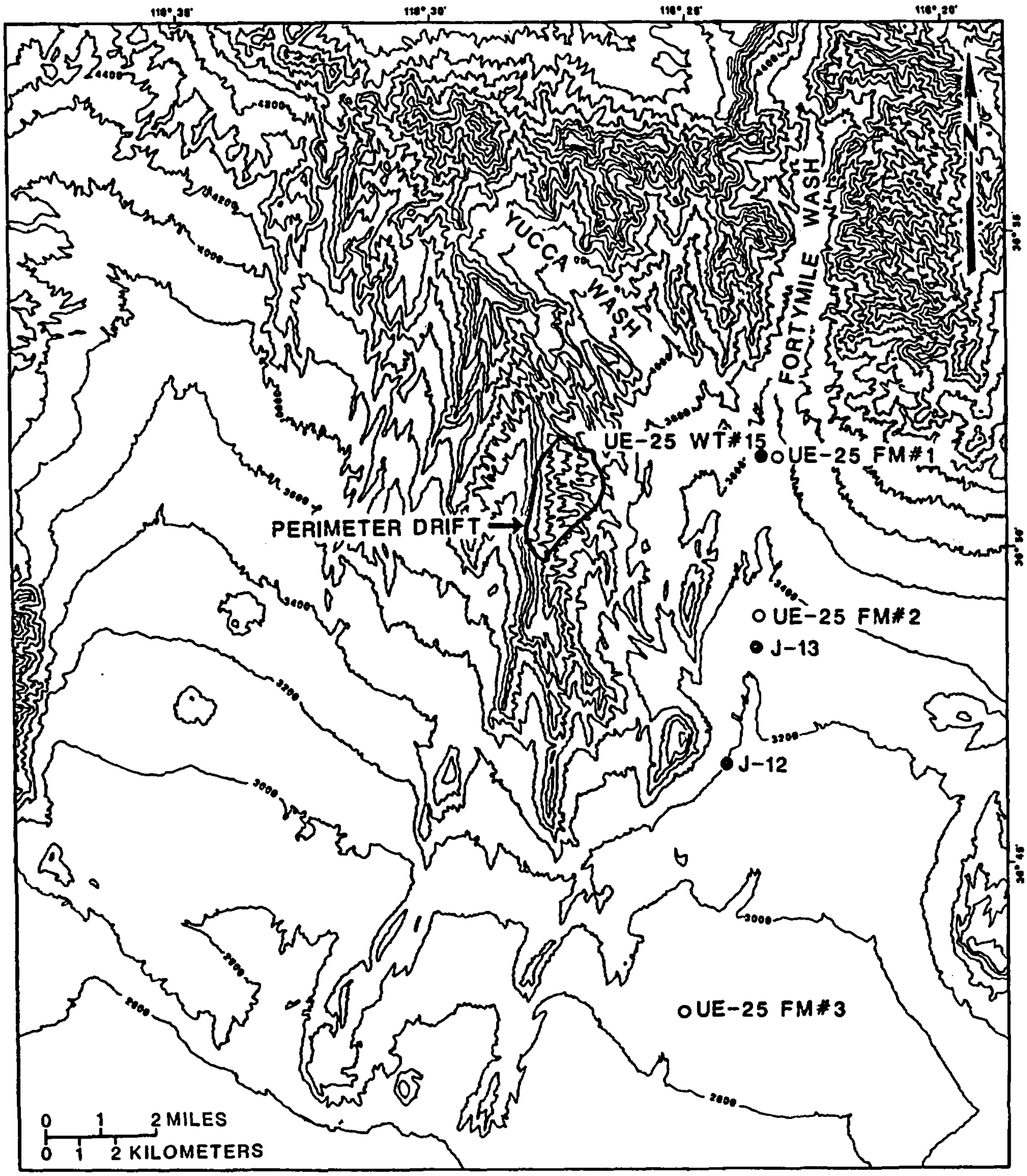
(A snowpillow consists of an inflated elastomeric bladder connected to a pressure transducer in such a way that the weight of snow falling on the bladder may be determined by changes in pressure within the bladder.)

The infiltration rate along the channel of Fortymile Wash 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.

In addition to aqueous samples collected, gas samples will be obtained from a series of piezometer nests that will be installed across Fortymile Wash, in order to help establish the extent and timing of recharge to the regional ground-water system. Gas samples will be analyzed for chemical composition and stable isotopes. Analytical results will be synthesized with other analyses of samples collected from the unsaturated zone, as described in Activities 8.3.1.2.2.7.1 and 8.3.1.2.3.2.2

Three drillholes (UE-25 FM#1, UE-25 FM#2, and UE-25 FM#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. Ponding tests conducted in Activity 8.3.1.2.2.1.3 are expected to show the relationship of thickness, texture, and porosity of unconsolidated deposits to net-infiltration rates. Results from the ponding tests may be extrapolated to Fortymile Wash, which has deposits with a similar range of properties. 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.



● EXISTING DRILL HOLE

○ PROPOSED DRILL HOLE

Figure 8.3.1.2-9. Location of existing and proposed drillholes for the Fortymile Wash recharge study.

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 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	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Streamflow and precipitation measurements	HP-16,R2	Collection and preservation of atmospheric precipitation samples for deuterium and oxygen-18 analyses	13 Jun 88
	HP-40,R1	Determination of peak discharge by the slope-conveyance method	7 Jun 88
	HP-42,R0	Field procedure for indirect measurements of stream discharge	5 Jun 88
	HP-43,R1	Installation, operation, and inspection of two types of non-recording rain gages	7 Jun 88
	HP-44,R1	Installation, operation, and inspection of crest-stage streamflow gages	7 Jun 88

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Streamflow and precipitation measurements (continued)	HP-45,R1	Method of installation, operation, and inspection of recording streamflow gage using the bubble-gage STACOM manometer system	7 Jun 88
	HP-46,R1	Method of installation, operation, and inspection of recording rain gages	7 Jun 88
	HP-91-R0	Collection and field analysis of surface-water samples	7 Oct 87
	TBD[a]	Techniques of measuring snowpack accumulation and dissipation	TBD
	HP-163,R0	Meteorological monitoring of Yucca Mountain and vicinity (tentative procedure)	TBD
	HP-179,R0	Field measurement of precipitation using a tipping-bucket rain gage	20 May 88
	HP-114,R0	Estimating streamflow discharge	7 Jun 88
	HP-115,R0	Determination of peak streamflow discharge using culverts	7 Jun 88
	HP-116,R0	Methods to install, operate, and inspect a recording-streamflow gage that uses a stilling-well system	7 Jun 88

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Streamflow and precipitation measurements (continued)	HP-117,R0	Installation, inspection, and maintenance of scour chains at streamflow gaging sites	7 Jun 88
	HP-169,R0	Determination of peak discharge by the slope-area method	7 Jun 88
	HP-180,R0	Field measurement of precipitation using a propane-heated, tipping-bucket rain and snow gage	15 Jun 88
	HP-165,R0	Method for measuring snow water content	23 Jun 88
Neutron-moisture tube tube installation and monitoring	HP-84,R0	Sealing neutron access-hole casings at the ground surface	28 Oct 85
	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88
Borehole drilling	GP-15,R0	Inventory of drill-hole core	20 Mar 87
	GP-16,R0	Procedure for the handling and storage of drill core at the core library	20 Mar 87
	GP-19,R0	Procedure for the identification, handling, and disposition of drillhole core and cutting samples from the drill site to the core library	6 Mar 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole drilling (continued)	GP-28,R2	Transfer of NNWSI Project drill-hole samples and related records from the core library and data center to the sample-management facility	22 Apr 88
	TBD	Borehole drilling to water table	TBD
	TBD	Borehole drilling and coring procedures	TBD
Soil moisture monitoring by borehole geophysics	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 84
	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88
Soil moisture measurements from drill core	HP-32,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-74,R1	Method for the operation and maintenance of the Stabil-Therm miniature batch oven in the determination of gravimetric-water content in test-hole samples	30 Sept 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Ponding and infiltration testing	TBD	Double-ring infiltrometer studies	TBD
	TBD	Ponding studies	TBD
Ground-water sampling	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-131,R0	Methods for handling and transporting usaturated-core and rubble samples for hydrochemical analysis	13 Jun 88
Chemical and isotopic analyses of water samples	HP-08,R0	Methods for determination of inorganic substances in water	6 Aug 82
	HP-11,R0	Methods for determination of radioactive substances in water	18 Jun 82
	HP-127,R0	Carbon-14 dating by tandem acceleration mass spectrometer	TBD
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
Fortymile Wash recharge analyses	TBD	No technical procedures identified	TBD

[a]TBD = to be determined.

8.3.1.2.1.3.4 Activity: Evapotranspiration studies

Objectives

The objective of this activity is to improve estimates of ground-water discharge by evapotranspiration in the Amargosa Desert, in order to provide boundary-condition data for regional ground-water flow models.

Parameters

The parameters of this activity are

1. Evapotranspiration rates and areal distribution.
2. Spatial distribution of hydraulic head.
3. Depth to saturation.

Description

A data requirement of the two-dimensional regional ground-water flow model is to specify the distribution and rate of ground-water discharge. Discharge occurs primarily as evapotranspiration and spring discharge from the regional ground-water flow system and by pumping of irrigation wells. The two principal natural 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 discharge fluxes because the area over which evapotranspiration occurs is not adequately defined. The need for improved estimates stems from the sensitivity analyses performed by Czarnecki and Waddell (1984).

The amount of ground-water discharge depends on numerous variables, including depth to the saturated zone. Evapotranspiration probably is maximum and relatively uniform at Franklin Lake playa, where depths generally are less than 5 m; probably no evapotranspiration from the saturated zone occurs where depths exceed 15 m, upgradient from Franklin Lake playa. Thus, a critical depth range (5 to 15 m) occurs beneath a large but poorly defined fringe area, within which evapotranspiration is variable and generally known.

Definition of the fringe area and its associated evapotranspiration will come from the following activities: (1) mapping of phreatophytes; (2) construction of piezometer and tensiometer nests, to determine depths to saturation and the presence or absence of upward hydraulic potentials for water flow from the shallow saturated zone to land surface; and (3) measurement of evapotranspiration using micrometeorological techniques.

Phreatophyte mapping will be used to identify the type, density, size, and areal extent of phreatophytes growing in the subregional ground-water flow system. Phreatophytes derive their water supply from the phreatic surface, or water table, and generally tap ground water at depths that exceed the threshold of bare-soil evaporation. Phreatophyte growth and evapotranspiration are limited by depth to water, soil and water salinity, and soil

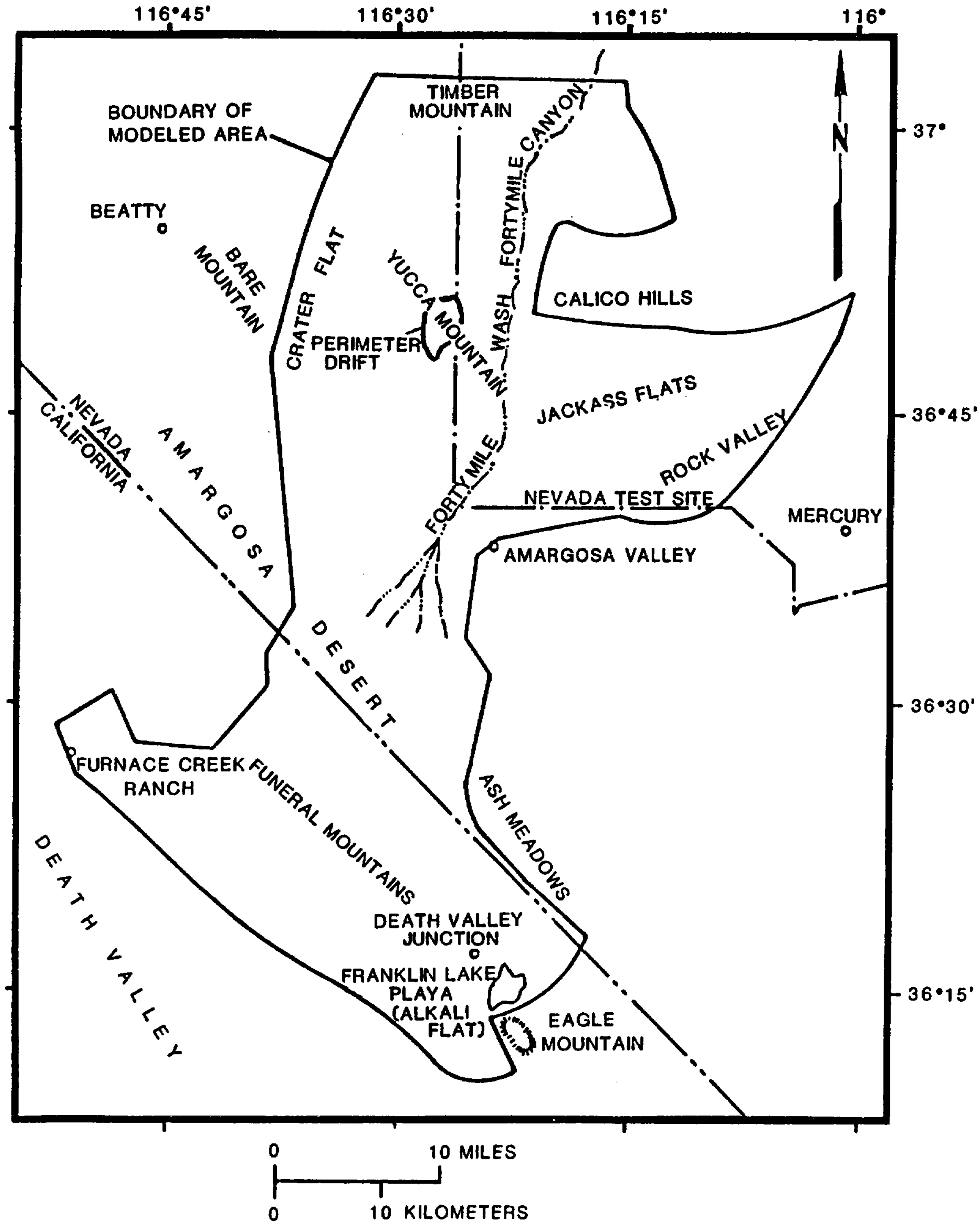


Figure 8.3.1.2-10. Subregional ground-water flow study area showing principal discharge areas at Furnace Creek Ranch and Franklin Lake Playa (Czarnecki and Waddell, 1984).

type (texture). Water salinity is high beneath Franklin Lake playa but decreases away from its margins (Czarnecki and Oatfield, 1986). Thus, phreatophytes tend to grow only in the fringe area where salinity is low and depth to saturation is less than about 15 m. It is expected, therefore, that the mapped areal extent of phreatophytes will approximately delimit the area of ground-water discharge by evapotranspiration.

In the area of evapotranspiration, an upward hydraulic gradient is expected in the saturated and unsaturated zones; elsewhere, beyond discharge areas, the gradient is expected to be downward or lateral. To determine whether an upward gradient exists, 10 to 30 nests of piezometers and tensiometers will be installed at sites in the area defined by phreatophyte mapping. Because of the large uncertainty in estimating in situ vertical hydraulic conductivity at these sites, no attempt will be made to estimate ground-water discharge using Darcy's law. However, gradient data will be used qualitatively to corroborate the location of the evapotranspiration area boundary and its associated depth to water. It is recognized that this depth varies in space and time, depending on various factors, such as soil texture, plant type and density, precipitation, temperature and runoff. These factors will be considered in locating evapotranspiration measurement sites and in evaluating evapotranspiration data.

At about 10 sites within the evapotranspiration area, total evapotranspiration will be measured using micrometeorological techniques, such as the Bowen ratio method (Stannard, 1985) or the Eddy-correlation technique (Weeks et al., 1985). These measurements will help to determine the spatial and temporal variation in net saturated-zone evapotranspiration, and provide a basis for determining the annual average saturated-zone discharge rate from the subregional flow system. Continuous measurements throughout the year will be made at two to five of these sites.

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
Estimates of evapotranspiration	TBD[a]	Evapotranspiration measurements	TBD
	TBD	Eddy-correlation techniques	TBD
	TBD	Bowen-ratio techniques	TBD

Method	Technical procedure Number	Title	Date
Estimates of evapotranspiration (continued)	TBD	Phreatophyte mapping	TBD
	TBD	Borehole drilling and coring procedures	TBD
Estimate of evapotranspiration component of discharge from saturated zone	TBD	No technical procedures identified	TBD

[a]TBD = 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 numerical model of ground-water flow. 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

1. To synthesize the available data into a model and make a qualitative analysis of how the regional hydrologic system functions.

2. To outline ground-water 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. Ground-water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated-zone rock units.
7. Potentiometric-surface configuration.

Description

All reliable data (hydrologic, geologic, and geophysical) and reasonable interpretations of it will be assimilated into a description of the regional ground-water 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
Assimilation of data and and interpretations into a conceptual description of regional flow systems	TBD[a]	No technical procedures identified	TBD

Method	Technical procedure Number	Title	Date
Use of conceptual description of flow system to update regional ground-water flow model	TBD	No technical procedures identified	TBD

[a]TBD = 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.
7. Potentiometric-surface configuration.

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.

The refined two-dimensional model will be a highly simplified representation of a complex three-dimensional system, but it is expected to be useful for various applications. These include preliminary evaluations of the effects of potential future pumping on the hydrologic system (Activities 8.3.1.9.3.2.1 and 8.3.1.16.2.1.4). The model will also be used to help guide development of more rigorous three-dimensional models (Activity 8.3.1.2.1.4.4), which will be used to test the impacts of future ground-water development, tectonic events, and climatic changes on the saturated-zone hydrologic system.

The use of a two-dimensional model for these purposes is warranted because, on a regional scale, vertical flux probably is small relative to horizontal flux. This concept will be tested as new data are obtained and by means of a two-dimensional cross-sectional model (Activity 8.3.1.2.1.4.3). If it is ascertained that significant upward or downward leakage occurs between, for example, the Paleozoic carbonate aquifer and the overlying valley-fill sediments or volcanic rocks, these fluxes will be accommodated in the two-dimensional model as source/sink terms. The model would be calibrated on the basis of estimated hydraulic properties and vertical CC-38 fluxes.

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 (Activity 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 (Activity 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.

Additional hydrogeologic data will be provided from the analyses of drillhole cuttings from exploration boreholes constructed in the Amargosa Desert in Tertiary valley-fill sediments, to depths of 2,000 ft by a commercial mining company (Study 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 (Activity 8.3.1.2.3.2.3). The need for additional information on the distribution of hydrogeologic properties will be determined as part of a regional data-needs assessment (Activity 8.3.1.2.1.3.1).

Annual average estimates of evapotranspiration were made for Franklin Lake playa, based on measurements made at various times throughout the year. These estimates (Activity 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. This sensitivity results partly because of the large magnitude of the specified discharge used in the model and because the discharge area is located directly downgradient from Yucca Mountain along the axis of the Amargosa Desert. 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 (Activities 8.3.1.2.3.2.2 and 8.3.1.2.3.2.4). 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 successfully used 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
Incorporation of new stratigraphic and structural data into two-dimensional model	TBD[a]	No technical procedures identified	TBD
Incorporation of new hydrogeologic data into two-dimensional model	TBD	No technical procedures identified	TBD
Parameter estimation and two-dimensional finite-element modeling using FEMOD program	TBD	Reference software documentation	TBD

[a]TBD = 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 test the assumption of horizontal flow.

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.
7. Potentiometric-surface configuration.

Description

A two-dimensional, steady-state, cross-sectional model of ground-water flow in the saturated zone will be constructed along an inferred ground-water flow line through Yucca Mountain (Figure 8.3.1.2-11). The model will be constructed to evaluate the lateral and vertical components of ground-water flux in the saturated zone and to examine the importance of potential structural features (such as fault-zone barriers) on the ground-water flow path. Sensitivity analyses will be performed to (1) evaluate the effect of saturated thickness distribution on ground-water flux direction and magnitude, and (2) 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 part of the basis for estimating ground-water travel time, in the saturated zone, from the site to the accessible environment. A highly simplified representation of the section will be used, with each layer being modeled as isotropic with respect to the 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. The flow line depicted in the figure enters the region at the northern boundary, passes beneath the repository perimeter drift, continues south, and is diverted to the southeast around the Funeral Mountains barrier to discharge at an altitude 606 m at the Franklin Lake playa. 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, 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.

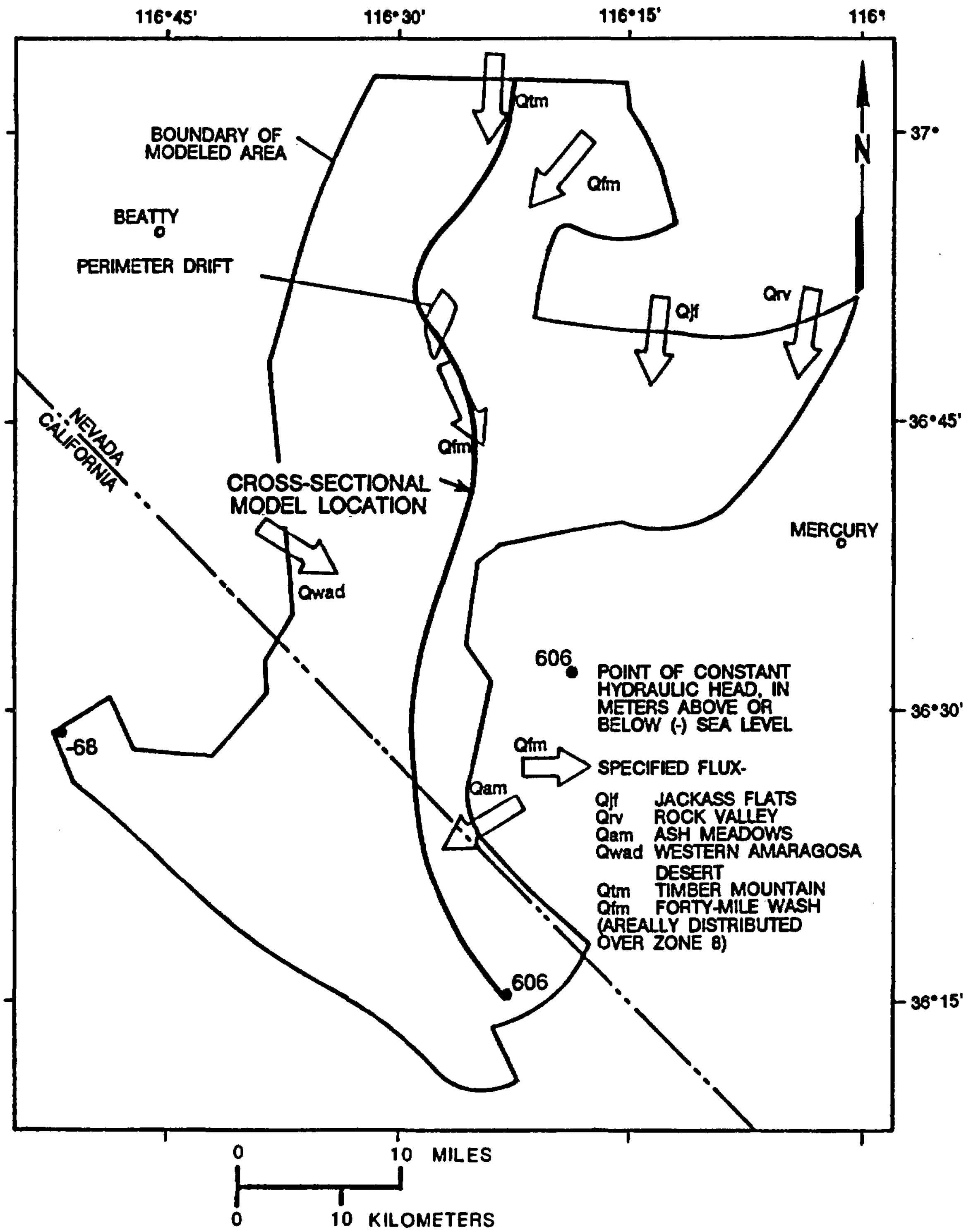


Figure 8.3.1.2-11. Location of the flow line for the subregional two-dimensional cross section of hydrologic model (modified from Czarnecki and Waddell, 1984).

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 Number	Title	Date
Construct two-dimensional, steady-state, cross-sectional model	TBD[a]	Reference software documentation	TBD
Finite-element modeling along a two-dimensional vertical cross section	TBD	Reference software documentation	TBD
Documentation, validation, and verification of model	TBD	Reference software documentation	TBD
Sensitivity analyses	TBD	Reference software documentation	TBD

[a]TBD = 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.
7. Potentiometric levels.

Description

A numerical, quasi-three-dimensional ground-water flow model of the saturated zone of the Yucca Mountain region will be constructed and calibrated. Because of the highly complex geologic structure and stratigraphy in the region, it is presently feasible to define only broad hydrogeologic units. Because of the sparseness of hydraulic-property data, particularly vertical hydraulic conductivity values for individual units, only a quasi-three-dimensional model is warranted at this time for simulation of the regional saturated-zone flow system. In this model, a leakance layer is used to simulate vertical flow between layers (see following description), and detailed knowledge of the distribution of vertical flow properties is not required. If feasible, a fully three-dimensional model will be developed for the site saturated-zone flow system (Study 8.3.1.2.3.3).

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 code (McDonald and Harbaugh, 1984) is the numerical technique that will be used to simulate the ground-water flow system in the Yucca Mountain region. The USGS three-dimensional code 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. Sensitivity analyses will be made to address uncertainties, including model boundaries, parameters, and fluxes. 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
Construction of numerical, two-layer model of Yucca Mountain saturated zone	TBD[a]	Reference software documentation	TBD
Calibration of proposed model	TBD	Reference software documentation	TBD
Refinement of proposed model	TBD	Reference software documentation	TBD

[a]TBD = 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:

SCP section	Subject
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

8.3.1.2.2 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:

SCP section	Subject
3.9.2.1	Hydraulic characteristics of the unsaturated zone
3.9.3.1	Accessible environment and credible pathways
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:

Study	Subject
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)
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 nine studies planned to be conducted under this investigation: (1) characterization of unsaturated-zone infiltration, (2) water movement tracer tests, (3) characterization of percolation in the unsaturated-zone surface-based studies, (4) characterization of percolation in the unsaturated-zone exploratory shaft facility studies, (5) diffusion tests in the exploratory shaft facility, (6) characterization of gaseous-phase movement in the unsaturated zone, (7) characterization of the unsaturated-zone hydrochemistry, (8) flow in unsaturated fractured rock, and (9) site unsaturated-zone modeling and synthesis. Of these, there are seven 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 these studies. System modeling will be conducted in the last two studies listed previously. 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 infiltration 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 studies are 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 studies and gaseous-phase studies 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 likelihood that the ambient fluid flux of water is very slow 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 transient pulses 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 poorly known. 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., Van Schilfgaarde, 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 the capability of the Yucca Mountain site to isolate nuclear waste depends upon developing valid concepts of fluid flow through such media. Therefore, many of the unsaturated-zone site characterization activities are directed at developing quantitative methodologies to assess fluid flow through unsaturated, fractured porous media.

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, seven studies have been developed: (1) infiltration characterization, (2) water-movment tracer studies, (3) percolation--surface-based, (4) percolation--exploratory shaft facility, (5) diffusion tests, (6) gaseous-phase movement, and (7) hydrochemistry. An eighth study, fluid flow in unsaturated fractured rock is designed to help design and interpret hydrologic and pneumatic tests, and to provide information about model parameters that can be incorporated into site-scale models, 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 ninth 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 to the integration of the information acquired in the first eight studies to provide a sufficient understanding of the unsaturated zone at Yucca Mountain. The last study will select, develop, and apply numerical hydrologic models of the hydrogeologic system at the site scale.

The infiltration boundary, or the surficial units, at Yucca Mountain is one of the most important boundaries that needs to be characterized. Water and air can enter and gases and water vapor can escape through this boundary from the unsaturated zone where the repository is proposed to be constructed.

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 liquid 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 8.3.1.2.2.2 through 8.3.1.2.2.7) 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 liquid-water flow in Yucca Mountain must include, for all hydrogeologic units, the determination of liquid-water flux distribution under a variety of present and future conditions. Since liquid-water 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 liquid-water flux calculations will be collected in the surface-based and exploratory shaft drilling and testing program (Studies 8.3.1.2.2.2 through 8.3.1.2.2.7).

Gas flow in the unsaturated zone has an important hydrologic rolė, 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 may be 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 8.3.1.2.2.6.1), the Solitario Canyon horizontal borehole study (Activity 8.3.1.2.2.3.3), and the simulation of the natural hydrogeologic system (Activity 8.3.1.2.2.9.3).

The hydraulic and pneumatic testing described under this investigation will provide a basis for estimating the distribution of fluid flux through the unsaturated zone. To compute travel times from the fluid 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. Integration of the percolation information with 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.

Knowledge of liquid-water flow paths (fracture or matrix) in the unsaturated zone and an understanding of factors affecting the occurrence of liquid-water flow in fractures are needed to assess current and future travel times. Many surface-based and in situ activities include an evaluation of fluid flow paths under current conditions. The intact-fracture test (Activity 8.3.1.2.2.4.1, percolation test (Activity 8.3.1.2.2.4.2), and bulk-permeability test (Activity 8.3.1.2.2.4.3) are specifically designed to evaluate liquid-water flow in fractured rocks at various scales, saturations, and fluxes.

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 8.3.1.2.2.7.1 and 8.3.1.2.2.7.2), analyses to support the various test programs include not only a suite of inorganic components but also certain organics, including freon-11 and freon-12 (which serve as tracers); lithium and bromine used to tag drillwater; SF_6 used to tag drilling air; and carbon-14 dioxide, chlorine-36, methane, HTO, 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.

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 hydrogeologic 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,

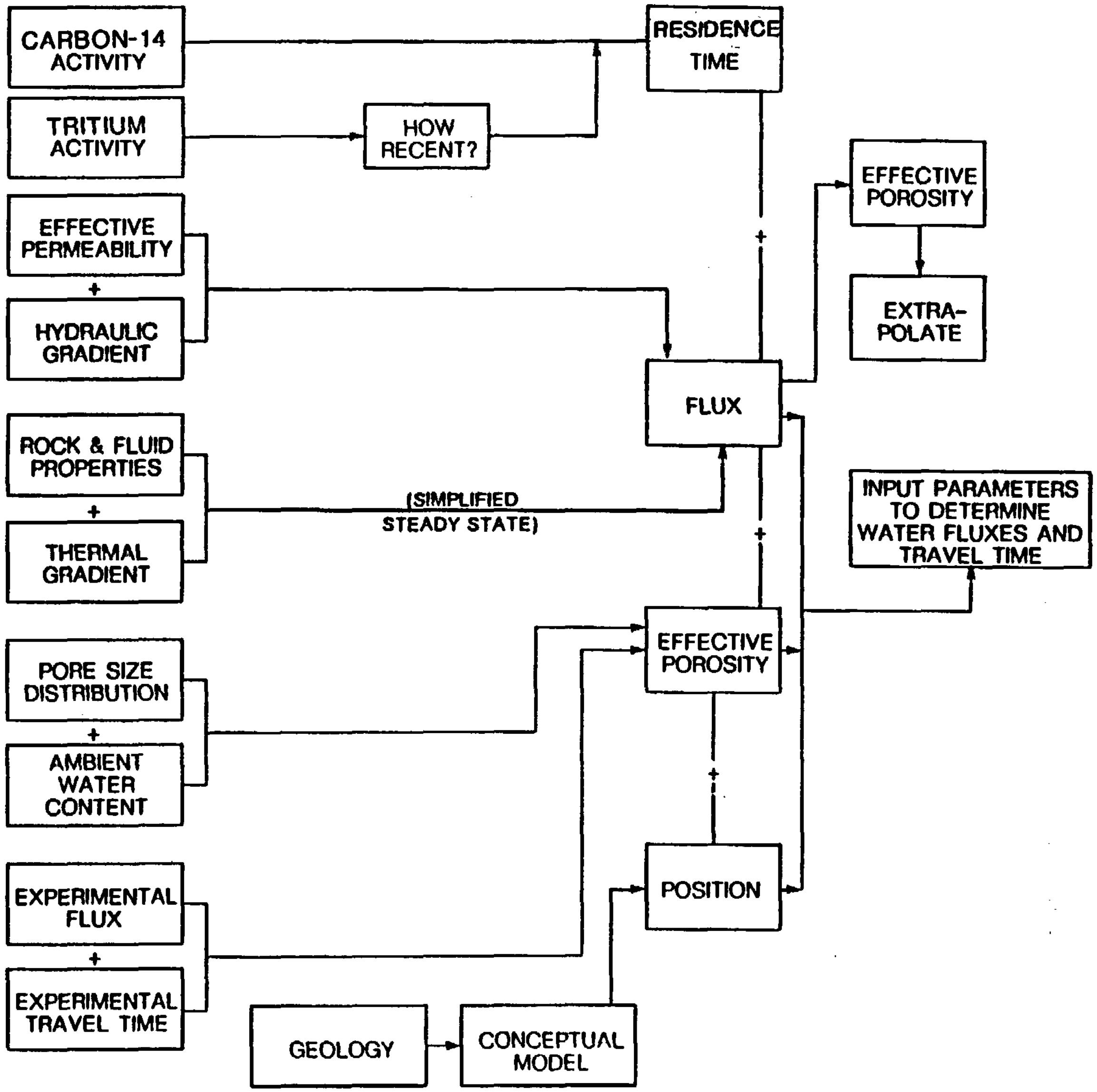


Figure 8.3.1.2-12. Process for providing parameters required by Issue 1.6 (pre-waste-emplacement ground-water travel time).

physical properties, and parameters; (3) compute fluxes, potentials, concentrations; and (4) maintain consistency with all validated data. 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 hydrogeologic system as a means of assessing coupled effects of heat, water, and gas flow for present, past, and possible future conditions. 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).

Flow model calibration will likely require redundant data to be gathered. For example, 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, fluid 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 validation 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 tests may suggest that fractures are less significant in the Paintbrush and Calico Hills nonwelded tuffs, so that matrix imbibition damps out infiltration pulses, within these nonwelded units.

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 validate 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 water vapor and liquid-water 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.

Although 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 8.3.1.5.1.4.2). 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 a 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 under steady-state conditions, 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).

<u>Methods and technical procedures</u>

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	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone bore-holes at the well site, NTS	8 Jun 88
	HP-32,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone bore-holes at the unsatu-rated-zone testing lab-oratory (Test Cell C)	30 Mar 87
	TBD[a]	Sampling, testing, and mapping studies	TBD
	TBD	See Section 8.3.1.2.2.3.1 for complete listing of matrix hydrologic-properties technical procedures	TBD
Borehole nuclear-geophysical logging	HP-50,R0	Method for neutron scatter and gamma-ray attenuation logging using the USGS Log-ging Van (I-139055)	15 Nov 84
	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88
	TBD	Borehole nuclear-geo-physical logging stud-ies and calibration procedures	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Shallow surface-seismic surveys	TBD	Shallow surface-seismic studies	TBD
Geotomography studies	TBD	Geotomography studies	TBD

[a]TBD = 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 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 constant-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

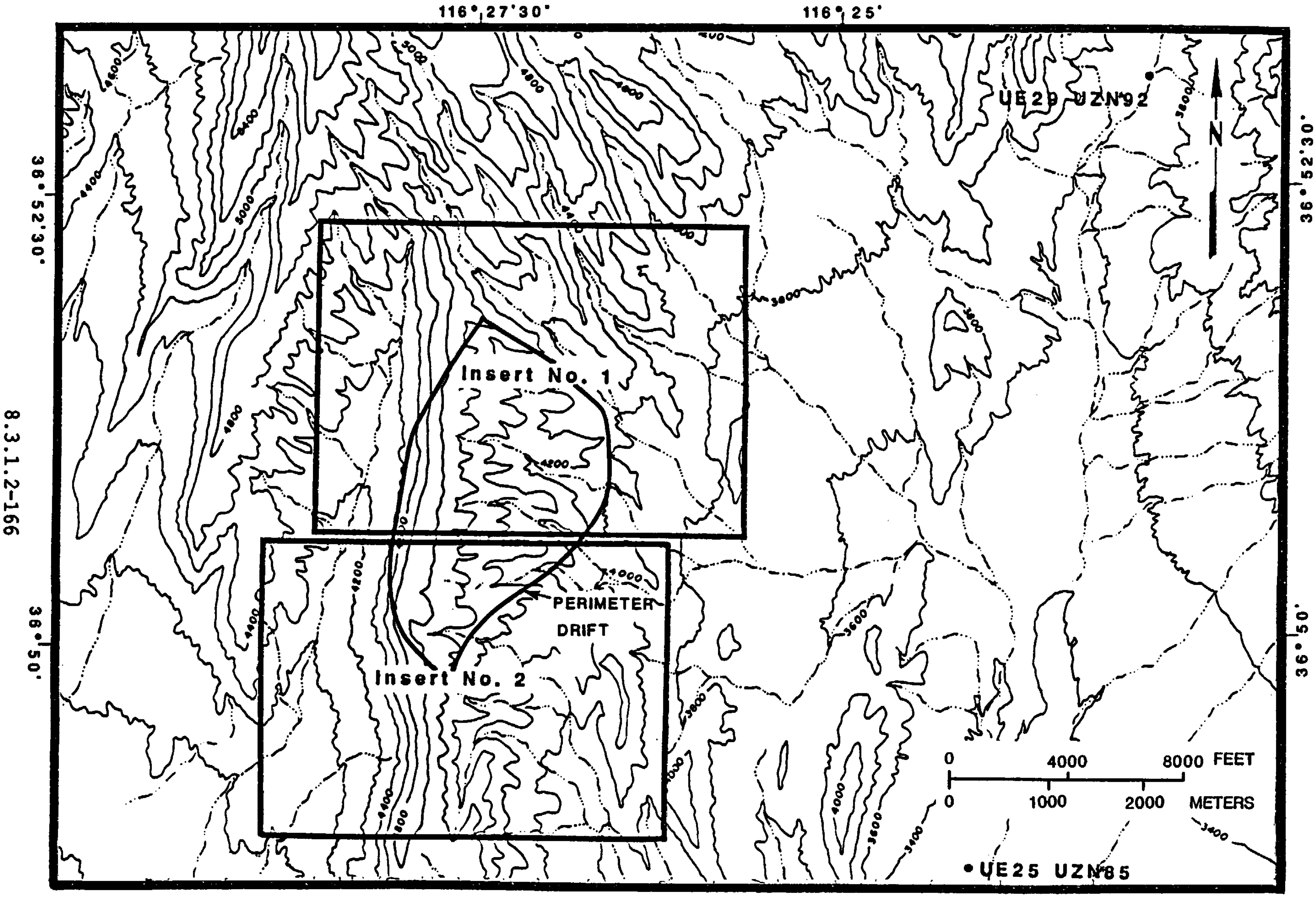


Figure 8.3.1.2-13a. Neutron access hole locations. See Figures 8.3.1.2-13b and -13c for inserts No. 1 and 2, respectively.

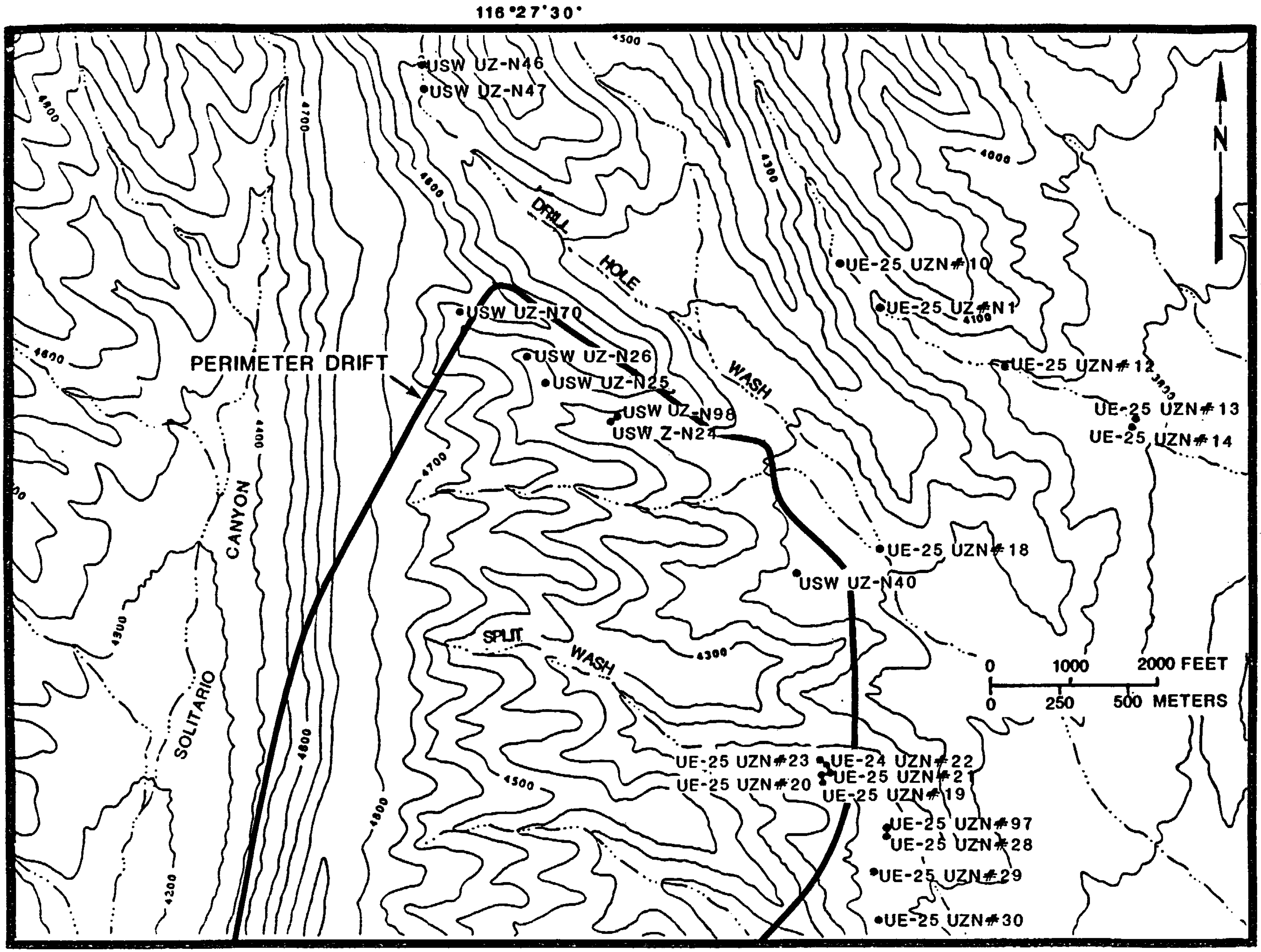


Figure 8.3.1.2-13b. Insert 1 to Figure 8.3.1.2-13a, neutron access hole locations.

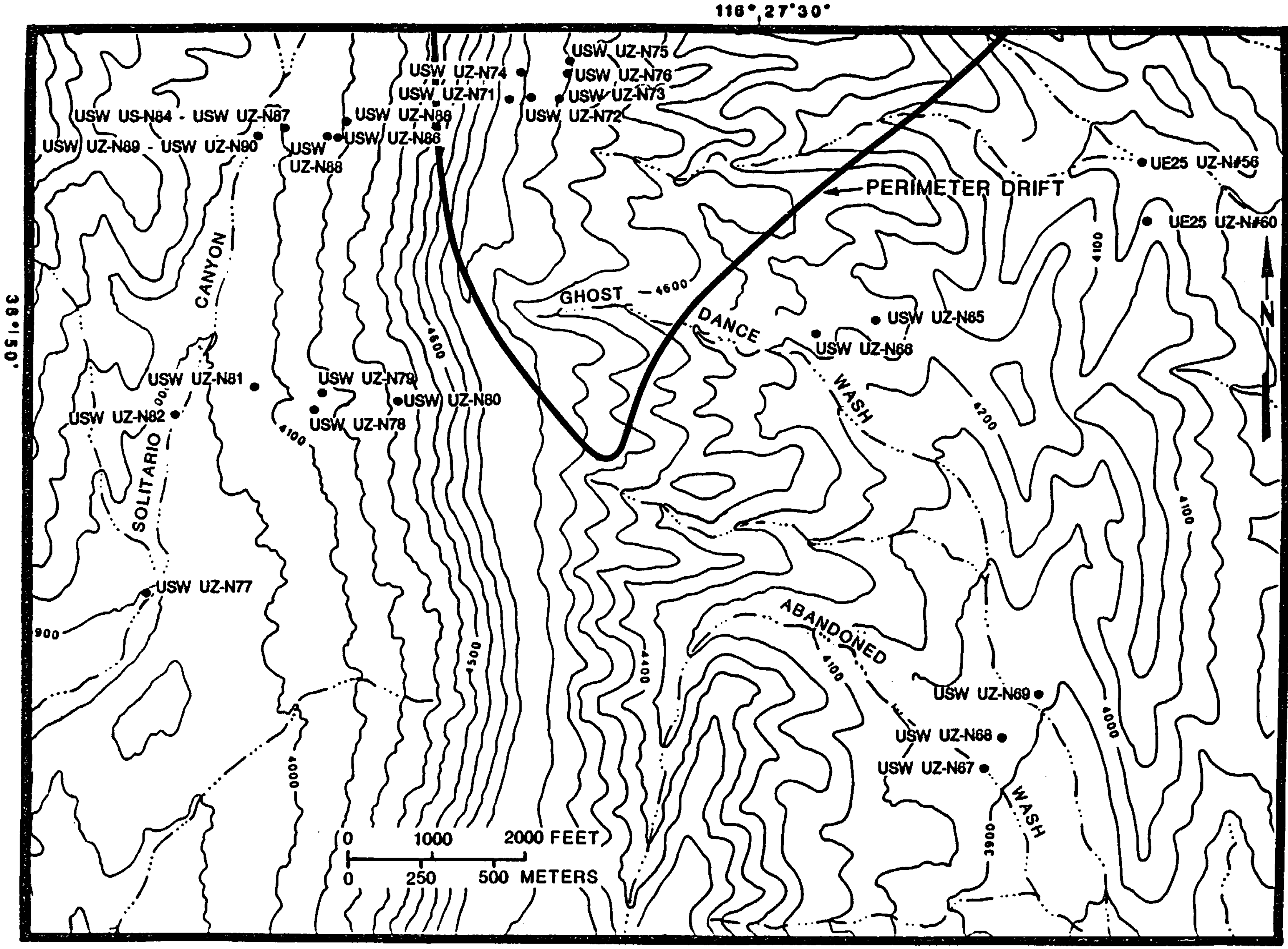


Figure 8.3.1.2-13c. Insert 2 to Figure 8.3.1.2-13a, neutron access hole locations.

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. 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 as follows:

Infiltration = (precipitation) - (runoff) - (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 Number	Title	Date
	(NWM-USGS-)		
Neutron-access borehole monitoring and analysis	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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-50,R0	Method for neutron scatter and gamma-ray attentuation logging using the USGS Logging Van (I-139055)	15 Nov 84
	HP-69,R0	Construction and operation of simple tensiometers	TBD[a]
	HP-84,R0	Sealing neutron access-hole casings at the ground surface	28 Oct 85

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Neutron-access borehole monitoring and analysis (continued)	HP-121,R0	Installing and retrieving information from a Septa pressure transducer	TBD
	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88
Artificial-infiltration control-plot studies	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 84
	HP-17,R0	Method for calibration and testing for operation of pressure transducers for air-permeability studies in the unsaturated zone	14 Aug 84
	HP-50,R0	Method for neutron scatter and gamma-ray attentuation logging using the USGS Logging Van (I-139055)	15 Nov 84
	TBD	Artificial-infiltration, control-plot studies	TBD
	HP-62,R3	Method for measuring subsurface moisture content using a neutron moisture meter	3 Jun 88
Tritium-profiling studies	TBD	Tritium-profiling methods	TBD
Water-budget studies	TBD	Water-budget studies	TBD
Remote sensing	TBD	Remote-sensing studies	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole-drilling and coring for natural-infiltration studies	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS	8 Jun 88
	TBD	Borehole drilling and for natural-infiltration studies	TBD

[a]TBD = to be determined.

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 8.3.1.2.2.1.1, 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. This procedure will help evaluate the potential for downslope flow. 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 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.

<u>Methods and technical procedures</u>

The methods and technical procedures for Activity 8.3.1.2.2.1.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Infiltrometer tests	TBD[a]	Double-ring infiltrometer studies	TBD
Ponding tests	HP-50,R0	Method for neutron scatter and gamma-ray attentuation logging using the USGS Logging Van (I-139055)	15 Nov 84
	HP-121,R0	Installing and retrieving information from a Septa pressure transducer	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Ponding tests (continued)	TBD	Ponding studies	TBD
	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88
Small-plot rainfall-simulation tests	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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-50,R0	Method for neutron scatter and gamma-ray attentuation logging using the USGS Logging Van (I-139055)	15 Nov 84
	HP-69,R0	Construction and operation of simple tensiometers	TBD
	HP-88,R0	Preliminary method of chemical/hydrological study of alluvium around Yucca Mountain using small-plot rainfall simulation devices (tentative procedure)	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Small-plot rainfall-simulation tests (continued)	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88
Large-plot rainfall-simulation tests	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 Jul 84
Large-plot rainfall-simulation tests	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 84
Large-plot rainfall-simulation tests	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-50,R0	Method for neutron scatter and gamma-ray attentuation logging using the USGS Logging Van (I-139055)	15 Nov 84
Large-plot rainfall-simulation tests	HP-69,R0	Construction and opera- of simple tensiometers	TBD
	TBD	Large-plot rainfall-simulation studies	TBD
	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole drilling and coring for artificial-infiltration studies	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS	8 Jun 88
	TBD	Borehole drilling and coring for artificial-infiltration studies	TBD

[a]TBD = 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 from isotopic measurements of soil, tuff, and water 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 yr to 2 million years. These data are part of the input for developing numerical models of ground-water flow at this site.

Chlorine-36 is just one of many natural isotopes that could be used to evaluate infiltration, mixing, ground-water sources, and alternative models of possible upwelling of deep water. In fact, various stable isotopes will be analyzed as part of Activity 8.3.1.2.2.7.2 (aqueous-phase chemical investigations). In addition, however, the natural isotope technetium-99 could be used as an alternative or as a supplement to work already planned. Laboratory methodologies regarding the analysis of technetium-99 are available. Analyses of the noble gases helium, argon, and neon could also be used as a powerful tool to evaluate the mixing of waters (i.e., source determination, upwelling). These isotopes could provide a distinct reservoir signature. If a need is established to utilize natural isotopes other than those previously identified, technical plans will be developed and included in an SCP progress report, and the study plan will be revised to include a new activity.

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 are needed for the following parameters:

1. Precipitation measurements.
2. Dry chloride fallout.
3. Fracture morphology in Paintbrush Tuff.
4. Site hydrology and hydrochemistry.

Data have 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 activity 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

The methods and technical procedures for Activity 8.3.1.2.2.2.1 are given in the following table:

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Sample analysis	ASTM standard	Chloride analyses of soil samples	TBD[a]
	HYDRO-GEO-CHEM	Isotope analyses of chloride samples	TBD
	TBD	Chloride analyses of tuff samples	TBD
Software quality assurance	TBD	Procedure to implement NNWSI-SOP-03-02, Software Quality Assurance	TBD

[a]TBD = to be determined.

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. 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. In addition, core and gas samples will be used under Study 8.3.1.2.2.7 for chemical/isotopic analyses. 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 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 Site 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. (1986).

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 the rock characteristics program (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

Table 8.3.1.2-5. Borehole information and estimates of numbers of core samples available for permeability related tests (page 1 of 2)

	Non- to partially welded and bedded tuff units				Moderately to densely welded tuff units	
Borehole	Completion date	Total depth (ft)	Continuously cored intervals (ft)	Number of samples available	Depth interval between "spot cores" (ft)	Number of samples available
SHALLOW CORED AND INSTRUMENTED HOLES						
UE-25 UZ#4	9/84	366.5	275.8	83	10	8
UE-25 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-25 UZ#9a	-	1,500.0	85.0	30	10	50
UE-25 UZ#9b	-	1,500.0	85.0	30	10	50
USW UZ-10	-	1,500.0	60.0	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						
UE-25 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
UE-25 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

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	Non- to partially welded and bedded tuff units				Moderately to densely welded tuff units	
	Completion date	Total depth (ft)	Continuously cored intervals (ft)	Number of samples available	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 -- SPRS-24	-	5.0	0 to 5	48	-	-
SPRS-25 -- SPRS-100	-	5.0	-	-	2.5	198
LARGE-PLOT ARTIFICIAL INFILTRATION MONITORING HOLE						
LPRS-1 -- LPRS-50	-	35.0	0-35	700	-	-
LPRS-50 -- LPRS-120	-	35.0	-	-	2.5	980
TOTAL				748		1,178

[a]- denotes not available.

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

[a]One 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.

[b]100 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.

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.

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 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 2 m (6 ft). 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., 1986). 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. Because oil does not interact with the matrix, 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 (Mualem, 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	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Measure gravimetric-water content	HP-32,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone	9 Sept 85
	HP-73,R0	Calibration and use of the Sartorius Electronic Toploader (balance) Model 1507 MP8	29 Mar 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated zone testing laboratory (Test Cell C) test holes	30 Mar 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Measure gravimetric-water content (continued)	HP-74,R1	Method for the operation and maintenance of the Stabil-Therm miniature batch oven in the determination of gravimetric water content in test-hole samples	30 Sept 87
Measure volumetric-water content	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85
	HP-73,R0	Calibration and use of the Sartorius Electronic Toploader (balance) Model 1507 MP8	29 Mar 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	TBD[a]	Procedures for the measurement of: (1) volumetric water content, (2) bulk density, (3) porosity, (4) saturated water and gas permeability, (5) relative permeability	TBD
Measure bulk density	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Measure bulk density (continued)	HP-73,R0	Calibration and use of the Sartorius Electronic Toploader (balance) Model 1507 MP8	29 Mar 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	TBD	Procedures for the measurement of: (1) volumetric water content, (2) bulk density, (3) porosity, (4) saturated water and gas permeability, (5) relative permeability	TBD
Measure grain density	HP-30,R0	Calibration and operation procedure for Quantachrome Stereopycnometer Model SPY-2, USGS Petrophysics Laboratory, Denver, Colorado	15 May 85
	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85
	HP-73,R0	Calibration and use of the Sartorius Electronic Toploader (balance) Model 1507 MP8	29 Mar 85

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Measure grain density (continued)	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	TBD	Procedures for the measurement of: (1) volumetric water content, (2) bulk density, (3) porosity, (4) saturated water and gas permeability, (5) relative permeability	TBD
Determine porosity	HP-47,R0	Method of operating Micrometrics Series 910 mercury penetration porosimeter, USGS Petrophysics Laboratory, Denver, Colorado	14 Aug 84
	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85
	HP-73,R0	Calibration and use of the Sartorius Electronic Toploader (balance) Model 1507 MP8	29 Mar 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated zone testing laboratory (Test Cell C)	30 Mar 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Determine porosity (continued)	TBD	Procedures for the measurement of: (1) volumetric water content, (2) bulk density, (3) porosity, (4) saturated water and gas permeability, (5) relative permeability	TBD
	HP-47,R0	Method of operating Micrometrics Series 910 mercury penetration porosimeter, USGS Petrophysics Laboratory, Denver, Colorado	14 Aug 84
	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85
	HP-73,R0	Calibration and use of the Satorius Electronic Toploader (balance) Model 1507 MP8	29 Mar 85
	HP-136,R0	Methods for handling and storage of drill-cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	TBD	Porosity meter operation	TBD
	TBD	Determination of effective porosity from core samples	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Measure water potential	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84
	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
Measure matric potential	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 83
	HP-69,R0	Construction and operation of simple tensiometers	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Measure matric potential (continued)	HP-123,R0	Development of tensiometer-transducer equipment and techniques for measuring the matric potential of minimally disturbed core from Yucca Mountain	TBD
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
Determine saturated-liquid permeability	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 87
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	TBD	Laboratory procedure for mass-flow meter calibration	TBD
	TBD	Method for calibrating gas flow meters	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Determine saturated-liquid permeability (continued)	TBD	Procedures for the measment of: (1) volumetric water content, (2) bulk density, (3) porosity, (4) saturated water and gas permeability, (5) relative permeability	TBD
Determine relative-liquid permeability	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	TBD	Relative permeability: calculate from moisture retention data	TBD
	TBD	Relative permeability: centrifuge (nonsteady state)	TBD
	TBD	Relative permeability: gas-drive (nonsteady state)	TBD
	TBD	Relative permeability: pressure plate (transient flow)	TBD
	TBD	Relative permeability: steady-state centrifuge	TBD
	TBD	Relative permeability: steady-state evaporation	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Determine relative liquid permeability (continued)	TBD	Relative permeability: steady-state flow	TBD
Determine moisture retention	HP-28,R0	Laboratory procedures for the determination of moisture-retention curves on rock core	15 May 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	TBD	Moisture retention curve: gas-drive	TBD
	TBD	Moisture retention curve: mercury porosimetry	TBD
	TBD	Moisture retention curve: pressure plate	TBD
	TBD	Moisture retention curve: pressure-plate submersible	TBD
	TBD	Moisture retention curve: psychrometer-microwave	TBD
Determination of spatial variations of matrix-hydrologic properties	TBD	Statistical approach to determine testing frequency	TBD
	TBD	Sample selection program for surface-based boreholes	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Determination of spatial variations of matrix-hydrologic properties (continued)	TBD	Sample selection program for exploratory shaft vertical excavation	TBD
	TBD	Sample selection program for exploratory shaft horizontal excavations and drilling	TBD
	TBD	Characterization of spatial variability of matrix-hydrologic properties	TBD

[a]TBD = 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 activity 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.

The locations of the unsaturated-zone vertical boreholes were selected in conjunction with the development of the integrated drilling plan (Section 8.3.1.4.1) and in consideration of the concern for representativeness of data (Section 8.4.2.1.5). The rationale used in siting the individual boreholes

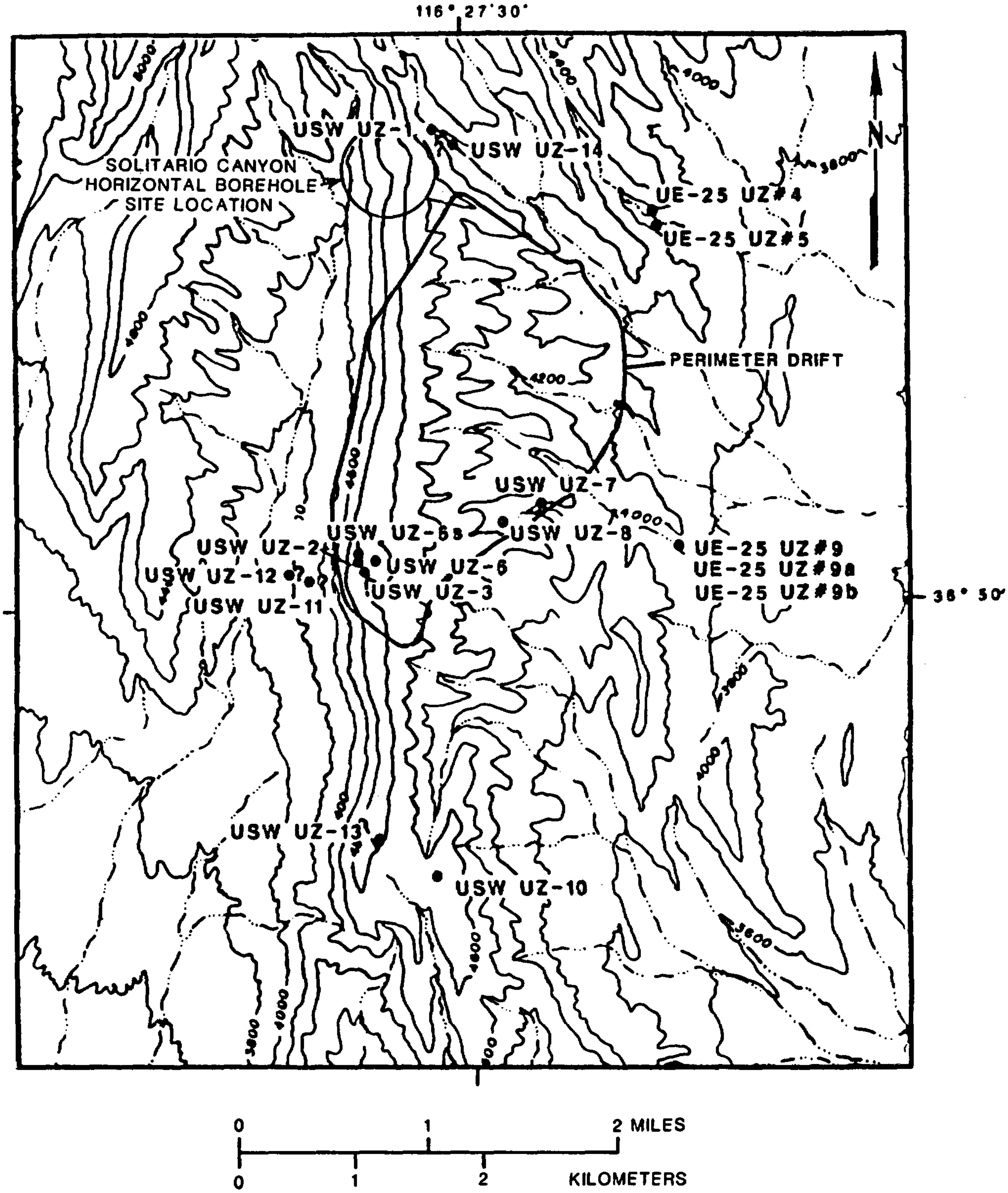


Figure 8.3.1.2-14. Map of existing and proposed unsaturated-zone borehole locations.

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 with 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 with 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 with 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 with 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 overrun of drilling time and excessive breakage of drillstring.

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-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.
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.

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-12	Planned	ODEX	±122	216	--	--	--	Topopah Spring Member of Paintbrush Tuff	In Solitario Canyon; straddles Solitario Canyon fault.
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.

was based on the need to provide areal coverage of Yucca Mountain with sufficient detail locally to examine the effects of faulting, topographic relief, and the presence of surface drainage on the hydrologic conditions at depth; and, in the case of the multiple borehole sites, to provide adequate facilities for gas tracer studies, crosshole pneumatic testing, and VSP investigations.

Locations of the deep boreholes are primarily controlled by the requirements (1) to cover Yucca Mountain areally, (2) to minimize disturbance to the main body of the proposed repository block, and (3) for a site suitable for construction of a relatively large drilling pad. The four deep drillhole sites, USW UZ-1, USW UZ-6, UE-25 UZ#9, and USW UZ-10, are located on the north, west, east, and south sides, respectively, of the proposed repository block.

Selection of the sites for the shallow unsaturated-zone (UZ) boreholes was more site specific with regard to structural and surface features than for the deep boreholes. All the shallow boreholes have been designed to penetrate the Paintbrush nonwelded unit into the Topopah Spring welded unit. In addition, each site was chosen for a specific investigative purpose. UE-25 UZ#4 and UE-25 UZ#5 were sited in and adjacent to a large drainage (Pagany Wash) to investigate infiltration related to runoff. USW UZ-7 and USW UZ-8 are located on opposite sides of the Ghost Dance fault to investigate hydrologic characteristics related to the fault. USW UZ-8 is located to penetrate the fault. USW UZ-11 and USW UZ-12 will be located on opposite sides of the Solitario Canyon fault in a similar manner. USW UZ-13 was drilled at the southern end of Yucca Mountain to provide better areal coverage as well as to investigate the Tiva Canyon welded unit, where the unit has maximum thickness. USW UZ-14 will be located near USW UZ-1 for the purpose of providing data from depths that drilling problems in USW UZ-1 precluded.

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 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

Table 8.3.1.2-8. Status of drillhole logging activities in the unsaturated zone[a,b]

Drillhole designation	Status	Depth (m)	Diam-eter (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.

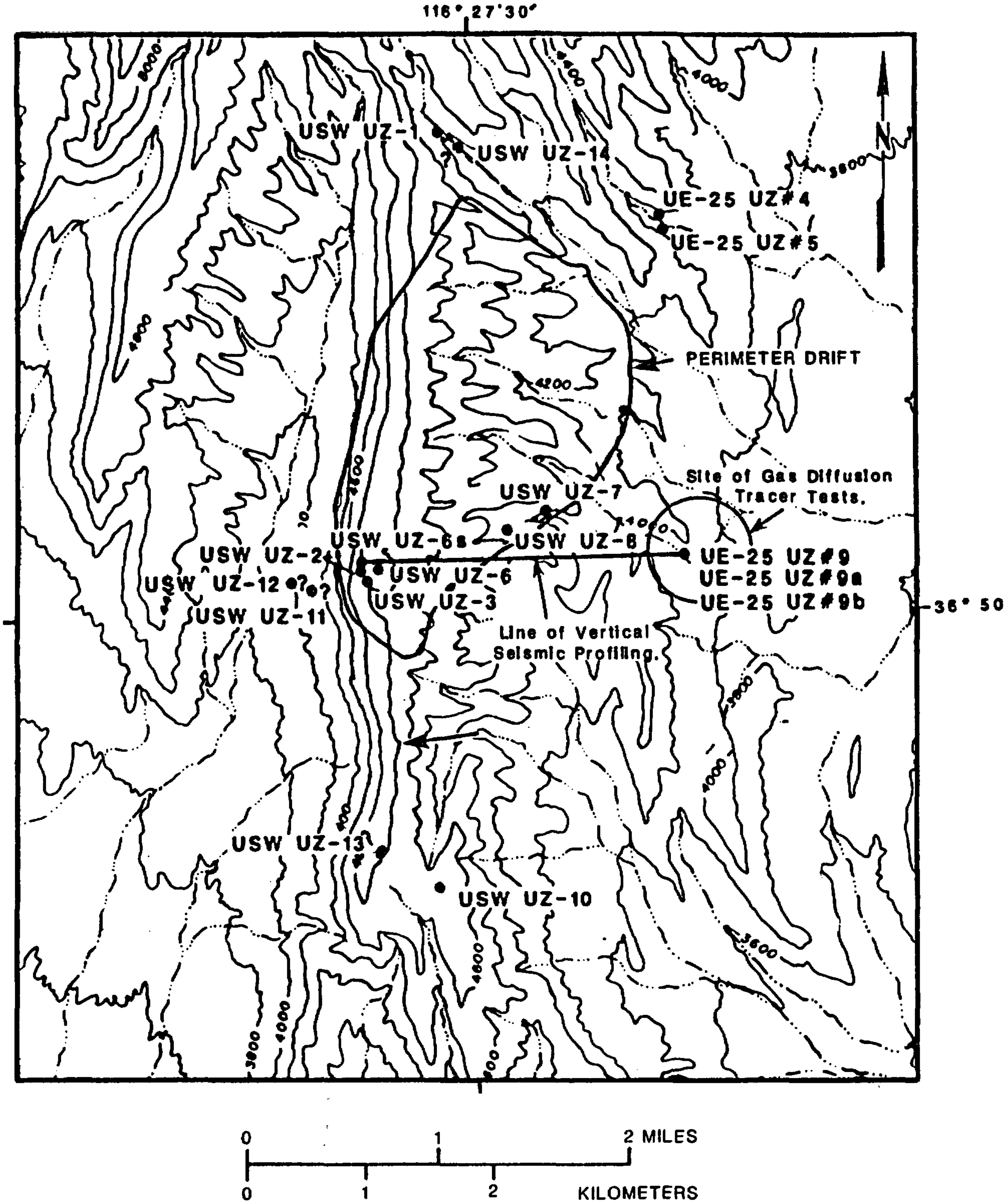


Figure 8.3.1.2-15. Map depicting location of gas tracer diffusion and vertical seismic profiling testing programs.

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 yr). 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	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Drilling and coring of vertical boreholes	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS	8 Jun 88
	HP-32,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-35,R0	Method for adding lithium bromide to a water-supply tank and monitoring its use as a tracer	7 Jan 86
	HP-38,R0	Method for measuring humidity, pressure, and temperature of intake and exhaust air during vacuum drilling	TBD[a]
	HP-131,R0	Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis	13 Jun 88

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Drilling and coring of vertical boreholes (continued)	TBD	Vadose sampling techniques	TBD
	TBD	Casing extraction procedure (Odex System)	TBD
	TBD	Borehole drilling and coring procedures	TBD
Physical-rock and matrix-hydrologic properties by laboratory analysis of samples	HP-18,R0	Frequency of equipment calibration for unsaturated-zone testing, Nevada Test Site	20 Jul 84
	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 Toploader (balance) Model 1507 MP8	29 Mar 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	HP-74,R1	Method for the operation and maintenance of the Stabil-Therm miniature batch oven in the determination of gravimetric water content in test-hole samples	30 Sept 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Physical-rock and matrix-hydrologic properties by laboratory analysis of samples (continued)	TBD	See Section 8.3.1.2.2.3.1 for a complete listing of matrix hydrologic-properties technical procedures	TBD
Borehole logging	GPP-12,R0	Borehole gravity measurement and data reduction	20 Mar 85
	GPP-14,R0	Induced-polarization borehole logging operations	27 May 86
	TBD	Data-logger internal voltmeter calibration	TBD
	TBD	Flow-test data identification, shipping, handling, and archiving	TBD
	TBD	Mass-flow meter calibration and use	TBD
	TBD	Pressure-pulse, gas injection test procedure	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Single-hole, gas-injection test procedure	TBD
	TBD	Straddle-packer-system leak detection	TBD
	TBD	Straddle-packer-system placement procedure	TBD
	TBD	Humidity sensor and sensor lead calibration	TBD
	TBD	Pressure sensor and sensor lead calibration	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole logging (continued)	TBD	Temperature sensor and sensor lead calibration	TBD
Water-injection tests	TBD	Data-acquisition system operations check	TBD
	TBD	Data-logger internal voltmeter calibration	TBD
	TBD	Flow-test data identification, shipping, handling, and archiving	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Pressure sensor and sensor lead calibration	TBD
	TBD	Temperature sensor and sensor lead calibration	TBD
	TBD	In situ recalibration of pressure sensor	TBD
	TBD	In situ recalibration of temperature sensor	TBD
	TBD	Single-hole, water-injection test procedure	TBD
	TBD	Water flow meter calibration	TBD
Field-tracer tests	HP-56,R1	Gas and water vapor sampling from unsaturated-zone test holes	15 Apr 88
	TBD	Procedure for determining test location	TBD
	TBD	Procedure for introducing gas tracers into test interval	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Field-tracer tests (continued)	TBD	Gas-chromatograph calibration	TBD
Vertical seismic profiling	TBD	Field procedure for installation of geophone cable array in Test Hole UE-25 UZ#9	TBD
	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	Procedure for data archiving, copying, and vertical seismic profiling	TBD
	TBD	Field procedure for seismic data acquisition (vertical seismic profiling)	TBD
Stemming, and in situ instrumentation and monitoring	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Stemming, and in situ instrumentation and monitoring (continued)	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-19,R0	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at the NTS	20 Jul 84
	HP-21,R0	Preliminary cable-assembly and probe-connection instruction for instrument packages, Test Hole UZ-1, NTS	15 Nov 84
	HP-24,R0	Preliminary plan for final checkout and acceptance of instrumentation packages for emplacement into Test Hole UZ-1, NTS	20 Jul 84
	HP-29,R0	Preliminary cable-assembly and probe connection instruction for instrumentation of Test Hole USW UZ-6, NTS	15 Apr 88
	HP-36,R0	Preliminary plan for probe installation and stemming of Test Hole USW UZ-6, NTS	4 Mar 86

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Stemming and in situ instrumentation and monitoring (continued)	HP-51,R0	Preliminary instructions for cable-assembly and probe-connections for instrumentation packages in Test Holes USW UZ-4 and -5, NTS	22 Aug 85
	HP-52,R0	Preliminary probe installation and stemming plan for Test Holes USW UZ-4 and -5	TBD
	TBD	Field procedure for connection of sensor leads and initializing data-acquisition system	TBD
	TBD	Field procedure for in situ calibration of pressure transducers	TBD
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	HP-22,R0	Preliminary probe installation and stemming plan for Test Hole USW UZ-1, NTS	20 Jul 84
	TBD	Field procedure for in situ evaluation of thermal sensor performance	TBD
	TBD	Field procedure for stemming and instrumenting vertical boreholes	TBD
	TBD	Field procedure for logging stemmed boreholes	TBD
Geostatistical analysis	TBD	Geostatistical analysis	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Data recording, processing, transmission, and archiving	HP-18,R0	Frequency of equipment calibration for unsaturated-zone testing, NTS	20 Jul 84
	HP-19,R0	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at the NTS	20 Jul 84
	HP-113,R0	Procedure for instrument shelter design	TBD
	HP-132,R0	Method for stabilizing air temperature inside instrument shelters used for monitoring down-hole sensors	TBD
	HP-135,R0	Procedure for IDAS development - writing, controlling, testing, implementing, and documenting IDAS software and control files	TBD
	HP-140,R0	Procedure for entry and identification to computer room and instrument shelter	TBD
	HP-142,R1	Procedure for using menu-driven routines to define master control files, specify and maintain equipment, and event history files	TBD
	HP-145,R0	Procedure for transmission of raw and reduced data from ARC-2	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Data recording, processing, transmission, and archiving (continued)	HP-146,R0	Procedure for transmission of data from field sites to ARC-1	TBD
	HP-147,R0	Procedure for network operation at the NTS	TBD
	HP-148,R0	Procedure for the receipt, screening, and archiving of data from the field sites (ARC-1)	TBD
	HP-149,R1	Procedure for questionable-data review and disposition of the data (ARC-2)	TBD
	HP-150,R0	Procedure for data reduction after DOE-NRC archiving	TBD
	HP-139,R0	Procedure to support interactive experiments during installation, testing, and calibration of downhole sensors	TBD
	HP-151,R0	Procedure for software installation, operation, and maintenance	TBD
	HP-152,R0	Procedure for IDAS domain control, operation of environmental control equipment at instrument shelters and at the archiving computer room	TBD
	HP-141,R0	Procedure for general IDAS operation: A master control and indexing procedure	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Data recording, processing, transmission, and archiving (continued)	HP-154,R0	Procedure for Hewlett-Packard multimeter installation, testing, and replacement (HP 3457A, Keithley 181)	TBD
	HP-155,R0	Procedure for GEMlink installation, testing, and operation	TBD
	HP-156,R0	Procedure for installation, testing, and maintenance of power supplies (solar-voltaic panels, batteries, charging controllers, and testing equipment)	TBD
	HP-144,R0	Procedure for installation, testing, and handling of DEC computer and equipment	TBD
	HP-157,R0	Procedure for installation and testing of field-site data-backup system: Data retrieval, identification, and handling	TBD
	HP-138,R0	Procedure for calibration, installation, and use of environmental sensors in the instrumentation shelters	TBD
	HP-137,R0	Preliminary procedure for instrument shelter design: Methods for implementing and testing environmental control systems	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Data recording, processing, transmission, and archiving (continued)	HP-134,R0	Preliminary procedure for computer room design, specifications for archiving, computer room, operator's room, user's room (tentative procedure)	TBD
	HP-153,R0	Procedure for Hewlett-Packard and Keithley data logger installation, testing, and replacement (HP 3497A, HP 3498A, Keithley 706)	TBD
	HP-133,R0	Procedure for O&A response and operation of alarm and warning system	TBD
	HP-161,R0	Field procedures for collection, retrieval, and transmission of USW UZ-1 data	TBD

[a]TBD = 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 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.

<u>Methods and technical procedures</u>

The methods and procedures for Activity 8.3.1.2.2.3.3 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Drilling and coring of horizontal boreholes	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS	8 Jun 88
	HP-32,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-38,R0	Method for measuring humidity pressure, and temperature of intake and exhaust air during vacuum drilling	TBD
	HP-131,R0	Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis	13 Jun 88
	TBD	Vadose sampling techniques	TBD
	TBD	Casing extraction procedure (Odex System)	TBD
	TBD	Borehole drilling and coring procedures	TBD
Physical-rock and matrix-hydrologic properties by laboratory analysis of samples	HP-18,R0	Frequency of equipment calibration for unsaturated-zone testing, Nevada Test Site	20 Jul 84
	HP-32,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Physical-rock and matrix-hydrologic properties by laboratory analysis of samples (continued)	HP-73,R0	Calibration and use of the Sartorius Electronic Toploader (balance) Model 1507 MP8	29 Mar 85
	HP-136,R0	Methods for handling and storage of drill cuttings and core from unsaturated-zone boreholes at the unsaturated-zone testing laboratory (Test Cell C)	30 Mar 87
	HP-75,R1	Method for the operation and maintenance of the Stabil-Therm miniature batch oven in the determination of gravimetric water content in test-hole samples	30 Sept 87
	Not applicable	See Section 8.3.1.2.2.3.1 for a complete listing of matrix hydrologic-properties technical procedures	Not applicable
Borehole logging	GPP-12,R0	Borehole gravity measurement and data reduction	20 Mar 85
	GPP-14,R0	Induced-polarization borehole logging operations	27 May 86
	GPP-17,R0	Magnetometer borehole logging operations	27 May 86
	TBD	Borehole video and logging survey procedure: Horizontal and vertical holes (F&S)	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Determine lithology, geohydrologic contacts and fracture frequency, spacing and orientation	TBD	No technical procedures identified	TBD
In situ pneumatic tests	TBD	Cross-hole, gas-injection test procedure	TBD
	TBD	Data-acquisition system operations check	TBD
	TBD	Data-logger internal voltmeter calibration	TBD
	TBD	Flow-test data identification, shipping, handling, and archiving	TBD
	TBD	Mass-flow meter calibration and use	TBD
	TBD	Pressure-pulse, gas-injection test procedure	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Single-hole, gas-injection test procedure	TBD
	TBD	Straddle-packer-system leak detection	TBD
	TBD	Straddle-packer-system placement procedure	TBD
	TBD	Humidity sensor and sensor-lead calibration	TBD
	TBD	Pressure sensor and sensor-lead calibration	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
In situ pneumatic tests (continued)	TBD	Temperature sensor and sensor-lead calibration	TBD
Water-injection tests	TBD	Data-acquisition system operations check	TBD
	TBD	Data-logger internal voltmeter calibration	TBD
	TBD	Flow-test data identification shipping, handling, and archiving	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Pressure sensor and sensor lead calibration	TBD
	TBD	Temperature sensor and sensor lead calibration	TBD
	TBD	In situ recalibration of pressure sensor	TBD
	TBD	In situ recalibration of temperature sensor	TBD
	TBD	Single-hole, water-injection test procedure	TBD
	TBD	Water-flow meter calibration	TBD
Stemming, and in situ instrumentation and monitoring	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Stemming, and in situ instrumentation and monitoring (continued)	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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-19,R0	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at the NTS	20 Jul 84
	TBD	Field procedure for connection of sensor leads and initializing data-acquisition system	TBD
	TBD	Field procedure for in situ calibration of pressure transducers	TBD
	TBD	Field procedure for stemming and instrumenting horizontal boreholes	TBD
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Field procedure for in situ evaluation of thermal sensor performance	TBD
	TBD	Field procedure for logging stemmed boreholes	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Data recording, processing, transmission, and archiving	HP-18,R0	Frequency of equipment calibration for unsaturated-zone testing, Nevada Test Site	20 Jul 84
	HP-19,R0	Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at the NTS	20 Jul 84
	HP-113,R0	Procedure for instrument shelter design	TBD
	HP-132,R0	Method for stabilizing air temperature inside instrument shelters used for monitoring down-hole sensors	TBD
	HP-135,R0	Procedure for IDAS development - writing, controlling, testing, implementing, and documenting IDAS software and control files	TBD
	HP-140,R0	Procedure for entry and identification to computer room and instrument shelter	TBD
	HP-142,R1	Procedure for using menu-driven routines to define master control files, specify and maintain equipment, and event history files	TBD
	HP-145,R0	Procedure for transmission of raw and reduced data from ARC-2	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Data recording, processing, transmission, and archiving (continued)	HP-146,R0	Procedure for transmission of data from field sites to ARC-1	TBD
	HP-147,R0	Procedure for network operation at the NTS	TBD
	HP-148,R0	Procedure for the receipt, screening, and archiving of data from the field sites (ARC-1)	TBD
	HP-149,R1	Procedure for questionable-data review and disposition of the data (ARC-2)	TBD
	HP-150,R0	Procedure for data reduction after DOE-NRC archiving	TBD
	HP-139,R0	Procedure to support interactive experiments during installation, testing, and calibration of downhole sensors	TBD
	HP-151,R0	Procedure for software installation, operation, and maintenance	TBD
	HP-152,R0	Procedure for IDAS domain control, operation of environmental control equipment at instrument shelters and at the archiving computer room	TBD
	HP-141,R0	Procedure for general IDAS operation: A master control and indexing procedure	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Data recording, processing, transmission, and archiving (continued)	HP-154,R0	Procedure for Hewlett-Packard multimeter installation, testing, and replacement (HP 3457A, Keithley 181)	TBD
	HP-155,R0	Procedure for GEMlink installation, testing, and operation	TBD
	HP-156,R0	Procedure for installation, testing, and maintenance of power supplies (solar-voltaic panels, batteries, charging controllers, and testing equipment)	TBD
	HP-144,R0	Procedure for installation, testing, and handling of DEC computer and equipment	TBD
	HP-157,R0	Procedure for installation and testing of field-site data-backup system: Data retrieval, identification, and handling	TBD
	HP-138,R0	Procedure for calibration, installation, and use of environmental sensors in the instrumentation shelters	TBD
	HP-137,R0	Preliminary procedure for instrument shelter design: Methods for implementing and testing environmental control systems	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Data recording, processing, transmission, and archiving (continued)	HP-134,R0	Preliminary procedure for computer room design, specifications for archiving, computer room, operator's room, user's room (tentative procedure)	TBD
	HP-153,R0	Procedure for Hewlett-Packard and Keithley data logger installation, testing, and replacement (HP 3497A, HP 3498A, Keithley 706)	TBD
	HP-133,R0	Procedure for O&A response and operation of alarm and warning system	TBD

[a]TBD = 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 nine 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 phenomenological 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. Percolation 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) percolation test, (3) bulk permeability test, (4) radial boreholes test, (5) excavation effects test, (6) Calico Hills test, (7) perched water test, (8) hydrochemistry tests, (9) multipurpose-borehole testing near the exploratory shaft, and (10) hydrologic properties testing of major faults encountered in the ESF main test level. These ESF tests are described in detail in the following activities.

The intact fracture test will evaluate the fluid-flow and chemical-transport properties of individual fractures to assess the in situ behavior of fracture systems. Meteoric 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 sample containing a candidate fracture. Fracture specimens, instrumented with low-voltage displacement transducers to register aperture changes, will be tested in the laboratory with 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 numerical model development for fractured, porous media will be included in several activities, especially in the percolation 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 percolation rates. Tracer-tagged water will be supplied uniformly on a sand bed overlying a block of 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 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 percolation pulses via fracture. 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 degrees 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 obtain the average conductivity of a much larger mass 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 fluid flux within individual fractures depends on the cube of the apertures, whereas the bulk permeability depends on ill-defined continuity, homogeneity, and interconnectivity relations within the fracture system. Models must regard as discrete features all conduit sizes, such as large aperture fractures or faults, outside the range appropriate to the bulk system. The application of continuum theory to microscopically discontinuous properties entails the 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 large aperture faults.

The bulk permeability test will be conducted at four sites within the lower breakout zone of exploratory shaft 1 (ES-1). Single-hole packer air-injection tests, cross-hole tests, frustum tests, and tracer tests will be conducted at each site to assess flood transport properties. Borehole arrangements will be used to test a variety of scales.

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 eight 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 eater 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 18 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 6 of the 18 boreholes. Neutron logging will be used to measure moisture content. Directional deformation will be measured in the other 12 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 processes, conditions, and properties under both present and expected future conditions for the Calico Hills nonwelded unit will be determined from the Calico Hills test. The Calico Hills nonwelded unit is expected to be a principal barrier to the flow of ground water and transport of radionuclides. It is possible, in some circumstances, that penetration of the unit within the repository block for site characterization testing could affect the performance of the site. Therefore, the testing program designed for the Calico Hills nonwelded unit represents a trade-off between the need to acquire data directly from the Calico Hills unit and the need to preserve site performance.

The perched-water test is designed to detect and estimate properties of any perched-water zones in the part of the unsaturated zone penetrated by ES-1. This evaluation is needed to understand the geohydrologic conditions causing accumulation of perched water; the implication of such a zone on flux, flow paths, and travel time; and whether perched water is a transient or permanent feature.

No perched water is expected in the host rock, except, perhaps, immediately above the Calico Hills nonwelded unit. The presence or potential for future perching of water in the host rock, however, might interfere with construction, operation, and ultimate performance of a repository at Yucca Mountain. In addition, perched water could cause substantial modification of geochemical interactions, transport processes, flow paths, and travel times. For example, inflow of perched water during construction of the ESF or repository might substantially affect construction techniques, schedules, and safety concerns because of the potential for flooding. Perched water in the Paintbrush nonwelded unit, above the host rock, could affect the spatial and temporal distribution of flow in the host rock by modulating pulses of infiltration and by diverting flow laterally to faults. Perching of water beneath the host rock in the Calico Hills nonwelded unit could affect travel times and flow paths to the accessible environment. Perched-water zones could result from barriers to flow, which would thereby increase travel time, or from short-circuits, which would decrease travel time.

The perched-water test will be conducted only if perched water is encountered during construction of ES-1. After each excavation round, prior to the walls being prepared for geologic mapping, seeps or saturated zones will be looked for in conjunction with mapping activities. If miners report inflow of appreciable quantities of water, hydraulic tests will be initiated immediately. If perched water or fracture flow is observed, boreholes will be drilled laterally into the ES-1 wall to test and sample the zone. A pumping test will precede the borehole drilling if the flow rate into the shaft is sufficiently large.

The hydrochemistry tests in the ESF are designed to collect gas and uncontaminated pore and fracture water and perched water during the construction of ES-1. Near-fracture matrix samples will be centrifuged to collect Uncontaminated water. These gas and water samples will be analyzed for their major compositions and stable and radioactive isotopes.

Two multipurpose boreholes are planned near exploratory shafts ES-1 and ES-2 and to approximately the same depth. The principal purposes of the boreholes would be (1) to determine the ambient in situ conditions (hydrologic, chemical, thermal, and mechanical) before the shafts are constructed; and (2) to evaluate the changes in these conditions as a result of the excavations and subsurface structures. If the multipurpose boreholes are not drilled as currently planned and if the information is still considered necessary, then equivalent information will be acquired by alternative testing strategies or thorough analyses of available information. A full suite of matrix and rock mass properties would be determined from core samples. Geophysical logs and hydrologic tests would be conducted before, during, and after the shaft construction to evaluate in situ changes. Perched water, if encountered, would be sampled for chemical and isotopic testing and hydrologic tests performed. Neither of the two holes will be permanently instrumented.

Multipurpose borehole testing would provide hydrologic and engineering reference information to be used with similar results obtained from the exploratory-shaft radial boreholes and excavation effects tests. The testing would also provide an opportunity to further confirm subsurface conditions before the shaft construction begins.

The hydrologic properties of major faults encountered in the main test level of the ESF will be evaluated. Principal faults to be studied include the Ghost Dance fault, a suspected fault in Drill Hole Wash, and the imbricate fault zone. Evaluations will determine the matrix and rock mass characteristics of these areas. Tests will be conducted in boreholes drilled from the underground drifts through the fault zones. Matrix properties of fault zone samples and core will be determined and geophysical logs obtained. Pneumatic and hydraulic testing (packer-injection and cross-hole) will be conducted in the boreholes to estimate the storage and transmissive characteristic of zones that may be significant pathways for ground-water movement.

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.

Parameters

The parameters of this activity are

1. Effective fracture permeabilities to air and water as functions of fracture saturation, water potential, and applied stress.

2. Effective porosity and dispersivity for fluid flow in single fractures.

3. Flow-path tortuosity in single fractures.

4. Fracture aperture geometry.

Description

The intact fracture test is comprised of a detailed laboratory analysis of the hydraulic and transport properties of single, variably saturated natural fractures collected from the exploratory shaft facility. Minimally disturbed core samples of fractures will be collected from different rock types, locations, and orientations in the facility to provide samples that represent natural, rough-walled fractures in the unsaturated zone. Laboratory analyses under controlled conditions will provide hydraulic and transport parameters and an opportunity to directly observe fluid-flow processes over a range of hydraulic and mechanical conditions.

Neither the samples nor the parameter values are considered to be directly representative of the site in a statistical sense, due to the inherent biases in sampling locations, sampling method limitations, and the insufficient number of samples. However, it is anticipated that the opportunity to observe flow processes in a controlled laboratory environment will provide the necessary understanding required to test conceptual models of fracture flow and, based on the measured parameters, the corresponding numerical models.

The sample collection methods will be evaluated initially during a prototype testing phase. A variety of methods will be used to determine the suitability of the sampling techniques for the anticipated conditions of the exploratory shaft facility. In particular, methods must be developed both to ensure that the fracture samples are obtained with as little disturbance as possible and to describe the extent of the fracture disturbance caused by the sampling process. The required methods and procedures will be developed during the prototype testing program.

Photographs of all exposed surfaces in the exploratory shaft, main underground drifts, and the major breakout horizons and the associated mapping activities (Activity 8.3.1.4.2.2.4) will provide the information necessary to select sample locations for the intact fracture test. Suitable fracture sampling locations will be determined from the three-dimensional projections obtained from localized detailed fracture maps. Fracture fillings and pieces of intact fractures will be collected and analyzed. The results are expected to allow determination of fracture origin, whether artificial (induced due to excavation) or natural.

Two coring methods will be used for fracture sampling: (1) a bolting and overcore technique, and (2) a clamp-core technique. The bolting and overcore method will be used to collect fractures that are approximately perpendicular to the core axis for subsequent radial flow studies. These samples are collected by first drilling a pilot hole perpendicular to the fracture; the fracture is then secured by a mechanical rock bolt, which holds the fracture together during core extraction, minimizing damage to the fracture plane. The sample is overcored, and then broken off with a coring shovel and removed. Approximately twelve fracture samples will be collected from each of four general areas where drift-wall mapping has indicated there are suitable locations for coring. The three hydrogeologic units to be sampled are the Tiva Canyon, Pah Canyon, and Topopah Spring members of the Paintbrush Tuff stratigraphic unit. Both welded and nonwelded samples will be collected. The pilot hole will be 1.9 cm (0.75 in.) in diameter and will be drilled approximately 15 cm (5.9 in.) beyond the fracture. Before seating the rock bolt anchors, a groove will be cut down the wall of the pilot hole to determine if the core has rotated during overcoring.

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, using the clamp-core method for subsequent axial flow studies. These samples will be obtained by first drilling two HQ-sized boreholes that are relatively parallel to the fracture and are diametrically opposed to each other on the periphery of where the sample will be cored. The fracture will then be cored (with the HQ boreholes on the periphery of the borehole cut). Circumferential clamps will be placed around the core (placing the union of the clamp in one of the HQ boreholes so that it can be tightened), starting at the farthest end of the core with each subsequent clamp closer to the mined surface. Before the core is broken off with a coring shovel, plaster will be placed across the fracture aperture. Any change in the plaster (i.e., cracking or spalling when the core is removed) will indicate if the fracture has been disturbed.

Onsite and offsite laboratory determinations will be made of the hydraulic properties of the rock matrix in each core sample. Gravimetric water content analyses will be performed locally to ensure water content does not change as a result of handling, shipment, or exposure to air. The matrix parameters to be determined offsite include matrix 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), unconfined compressive strength, Young's modulus, and porosity (Boyle's Law using helium and/or mercury intrusion). The samples for matrix testing will be collected from portions of the core that break off when a coreshovel is used to separate the fracture sample from the remaining overcore and from material remaining after the core is trimmed to fit a laboratory confining vessel.

Two principal tests will be conducted in the laboratory. First, stress-permeability tests will be performed, which will provide hydraulic transport parameter measurements under a range of mechanical conditions. Also, flow-channelization tests will be conducted, which will provide information on the geometrical properties of fluid-phase distributions and fracture apertures.

The stress-permeability tests will be conducted in the laboratory by injecting liquids and gases into the core sample under varying applied stress conditions using a hydrostatic test machine (axial fractures) or a loading frame apparatus (radial fractures). The single- and two-phase permeability tests will also be conducted in the laboratory.

The single-phase liquid permeability test is similar to methods cited in both the soil physics and petroleum literature. A specimen will be dewatered through porous water-wet plates. The plates are used to establish a constant unit hydraulic gradient that can be incrementally increased or decreased over a desired suction range. The flow regime will be controlled by using a Mariotte reservoir system to obtain differential head values in the wetter range and positive gas pressures for the drier portion of the permeability curves. In situ water-potential measurements will be made to determine when steady-state conditions are achieved or approached. Electrical resistivity measurements will also be used to evaluate in situ moisture redistribution in the sample. Unit-gradient conditions and steady one-dimensional flow conditions will allow the permeability to be set equal to the volumetric flux, simplifying the determination of the permeability at various water potentials. A series of unsaturated permeability determinations will be made over the full range of imposed suctions during both the wetting and drying cycles to evaluate the magnitude of hysteresis effects in the fracture sample. A conservative tracer (bromide or chloride) will be injected into the flow system at various steady state intervals and breakthrough curves will be constructed from the tracer concentration measured from the outflow collected. Once a value for the liquid permeability is obtained (i.e., steady state), gas flow will be initiated to determine a gas permeability for the particular saturation. Tests will be conducted on approximately four fracture samples from each of the four hydrogeologic units to be sampled and both radial and axial orientations.

Flow rates of injected liquids and gases will be held constant to indicate how permeability is affected by stress-induced aperture variations for both the single- and two-phase permeability tests. Flow rates and fracture displacement 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 fracture samples of each fracture orientation and each rock type. Loading-unloading cycles will be repeated so that permeability hysteresis attributed to asperity deformation can be evaluated.

Laboratory injection tests will also evaluate simultaneous 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. Saturations will be changed during simultaneous flow by changing the ratio of the gas and liquid flow rates. Tests will be conducted on approximately four fracture samples from each of the hydrogeologic units to be sampled and both fracture orientations.

Tracers will be injected into the fracture samples and their concentrations will be monitored during the steady-state flow tests. The data collected will be used to construct breakthrough curves and to obtain values for effective porosities and dispersivities. Small sample sizes and anticipated uncertainties in measurement accuracy may limit the direct application of the tracer test results. However, a significant gain in the understanding of the fluid flow and transport processes is expected. Some added degree of confidence probably will also be achieved for the subsequent model validation and calibration exercises.

Flow-channelization in the fracture plane of three or four intact-fracture samples from each hydrogeologic unit and orientation will be quantitatively and qualitatively described using several laboratory methods during the final phase of laboratory testing. Initially, visible dyes will be introduced in known quantities over time and the movement of dye-tagged water across the plane of the fracture will be observed. 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. Fracture-plane roughness, which is an important factor in characterizing flow channelization, will be evaluated using a projection moire technique. The moire projection equipment will be used to perform three-dimensional adjustable resolution contouring of variable-size rock-fracture surfaces using back- projection methods. The equipment will allow the optical generation of contour fringes on the specimen surface, which can be optically (still and video photography) recorded and easily interpreted.

In addition, two other methods will be used to obtain casts of the fracture plane. A low-melting-point metal will be injected into the fracture plane to obtain a cast of the flow channel. A resin impregnation method is also being considered to obtain flow channel casts. These casts will be used to determine the topography of the flow channels between the contact points.

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 model is a semi-analytical flow model for a single rough fracture that combines the equations for capillary rise and the cubic law to predict the relative permeability of a fracture at various saturations. The model accounts for the capillary-controlled distribution of the liquid phase at low saturations and high tensions and for the gravity-induced flow at higher saturations, when a continuous liquid phase has been achieved. The model assumes that the water is supplied to the fracture at the contact points between the fracture walls.

The aperture generated by computer simulation uses a digitized, real or artificial fracture wall, which is then replicated to simulate the aperture. The walls can be manipulated in a compressional or shear sense so as to create a simulated in situ fracture. The aperture is then discretized in three dimensions and coupled with the flow portion of the computer code.

The measured fracture aperture geometrical properties obtained from the flow-channelization experiments will be compared with those predicted by the aperture generator contained within the single-fracture flow model. An assessment will then be made as to the adequacy of the aperture generator that has been conditioned by the measured data (e.g., roughness profiles and mean physical apertures). The specific geometrical parameters will be compared for both measured and predicted values and uncertainties in the aperture generator estimations will be established.

The measured unsaturated permeability values will be compared and regressed against predicted values obtained from the following: (1) the model that has been conditioned by measured fracture geometry data, (2) two-dimensional analytical Navier-Stokes solutions for planar and cross sections of the fracture flow domain, and (3) semi-empirically derived estimates of the unsaturated permeability values obtained from the pore-size distribution data and/or the moisture retention data.

The experimentally determined tracer breakthrough curves will provide an opportunity to at least qualitatively evaluate the effects of tortuosity on fluid flow due to flow-channelization in the fracture plane at various saturations. It may not be possible to determine meaningful estimates of transport parameters, such as mechanical dispersion (in the more mobile fracture domain) or diffusion (in the lesser mobile matrix domain), caused by the small size of the samples and the core sampling being nonrepresentative of the rock mass as a whole. However, the curves constructed using laboratory-collected data will be compared with the predicted curves from standard numerical models with transport capabilities (based on the advection- dispersion equation) and from codes that rely on a particle-tracking approach to determining a distribution of travel times. These comparisons will be made to better understand the nature of the transport mechanisms at the microscale and to evaluate the applicability of standard transport modeling approaches in a fracture-dominated flow system.

The comparisons between measured and predicted values will determine how appropriate the various approaches are. Favorable comparisons will imply that the predictive method adequately accounts for the essential processes and controls on the variably saturated flow domain. The uncertainties of making predictions with each of the methods will be established and interpreted by comparing the results obtained from replicating the experiments under varying initial and boundary conditions or testing with samples with widely varying geometrical properties. These comparisons will also establish confidence limits with which fracture parameters (used as input to the flow model or empirical estimation methods) can be varied when attempting to predict unsaturated permeabilities with a fracture network in the larger-scale or macroscale tests.

When sufficient data have been obtained from the previously described tests (i.e., single- and two-phase permeability, and flow-channelization), the results of the laboratory tests will then be used to help develop numerical models to be used in subsequent larger-scale tests (percolation and bulk permeability tests, as described in Activity 8.3.1.2.2.4.2 and 8.3.1.2.2.4.3) where fracture flow properties will also be studied. Activity 8.3.1.2.2.8.2 (validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock) describes the relationship between the scale-based tests (i.e., the intact fracture, percolation, and bulk permeability tests) and associated conceptual and numerical models.

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	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Fracture mapping and analysis	MDP-01,R0	Identification, handling, storage, and disposition of drill-hole core and samples	15 Oct 81
	GP-02,R0	Subsurface investigations	1 Mar 83
	GP-05,R0	Geologic support activities	1 Mar 83
	TBD[a]	Geochemical procedures (LANL)	TBD
	TBD	Mapping fractures on drift and breakout surfaces procedure	TBD
	TBD	Photographing fractures on drift and breakout surfaces procedure	TBD
Fracture sampling by bolting and over-coring method	TBD	Fracture sampling by bolting and over-coring procedure	TBD
	HP-11,R0	Logging fractures in core	15 May 85
	TBD	Procedures for handling and shipment of intact fracture core samples	TBD
Fracture sampling by clamping and coring method	TBD	Fracture sampling by clamping and coring procedure	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Fracture sampling by clamping and coring method (continued)	HP-11,R0	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,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated zone test holes	9 Sept 85
	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
Offsite laboratory hydraulic properties testing of core	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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Offsite laboratory hydraulic properties testing of core (continued)	D1188-71	Determination of volumetric water content using liquid displacement procedure	TBD
	HP-55,R0	Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85
	D1188-71	Bulk density determination using liquid displacement procedure	TBD
	D2938-79	Unconfined compressive strength of intact rock core specimens	TBD
	TBD	Determination of Young's modulus of intact rock core specimens	TBD
	HP-30,R0	Calibration and operation procedure for quantachrome steropycnometer model SPY-2	15 May 85
	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,R0	Method for operating micrometrics Series 910 mercury penetration porosimeter	14 Aug 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Single phase permeability laboratory tests	TBD	Laboratory procedure for determining effective liquid permeability under constant loading: steady state (and transient) method	TBD
	TBD	Laboratory procedure for determining effective gas permeability under constant loading: steady state (and transient) methods	TBD
	TBD	Laboratory preparation of intact fracture samples for confining vessel in an applied stress apparatus	TBD
	TBD	Laboratory procedure for operation of flow meter apparatus for gas permeabilities in intact fracture samples	TBD
	TBD	Laboratory procedure for operation of flow meter apparatus for liquid permeabilities in intact fracture samples	TBD
	TBD	Laboratory calibration of linear variable differential transformers	TBD
	TBD	Laboratory calibration of pressure transducers for stress permeability tests	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Single phase permeability laboratory tests (continued)	TBD	Laboratory procedure for operation of confining vessel and applied load test 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
Two phase permeability laboratory tests	TBD	Laboratory procedure for determining stress-relative permeability relationships using an applied load test apparatus	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 operation of flow meter apparatus for gas phase injection in intact fracture samples	TBD
	TBD	Laboratory procedure for operation of flow meter apparatus for liquid injection in intact fracture samples	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Two phase permeability laboratory tests (continued)	TBD	Laboratory calibration of linear variable differential transformers	TBD
	TBD	Laboratory calibration of pressure transducers for loading frame test apparatus	TBD
	HP-14,R1	Method for calibrating Peltier type thermocouple psychrometers for measuring water potential of partially saturated media	9 Jul 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 monitoring water content of core samples using electrical resistivity techniques	TBD
	TBD	Laboratory procedure for monitoring/collecting tracers	TBD
	TBD	Laboratory procedure for using a confining vessel in an applied load test apparatus	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Two phase permeability laboratory tests (continued)	TBD	Laboratory procedure for preparation and installation of automated DAS	TBD
	TBD	Laboratory procedure for operation of automated DAS	TBD
	TBD	Procedure for analyzing data from laboratory DAS	TBD
Tracer-injection (dispersivity) laboratory tests	TBD	Laboratory procedure for tracer handling and introduction into intact fracture samples	TBD
	TBD	Laboratory procedure for operation of flow meter apparatus for liquid permeability measurements in intact fracture samples	TBD
	HP-14,R1	Method for calibrating Peltier type thermocouple psychrometers for measuring water potential of partially saturated media	9 Jul 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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Tracer-injection (dispersivity) laboratory tests (continued)	HP-95,R0 (draft)	Tensiometer calibration	TBD
	TBD	Laboratory procedure for sampling injected fluids in outflow from an intact fracture sample in an applied load apparatus	TBD
	TBD	Laboratory procedure for determination of breakthrough curves of tracer concentration in intact fracture sample	TBD
	TBD	Procedure for calculating dispersivity from breakthrough curves	TBD
	TBD	Preparation and installation of automated laboratory DAS	TBD
	TBD	Operation of laboratory DAS	TBD
	TBD	Analysis of data collected from DAS	TBD
Flow-channelization laboratory tests	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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Flow-channelization laboratory tests (continued)	TBD	Laboratory procedure for using a simple mounting frame to control fracture aperture	TBD
	TBD	Laboratory procedure for characterizing flow-channelization in intact fracture samples: impression-able polymer film method	TBD
	TBD	Laboratory procedure for characterizing flow-channelization in intact fracture samples: low-melting-point metal method	TBD
	TBD	Laboratory procedure for characterizing flow-channelization in intact fracture samples: resin impregnation method	TBD
	TBD	Preparation and instal-lation of laboratory DAS	TBD
	TBD	Operation of laboratory DAS	TBD
	TBD	Analysis of data col-lected from DAS	TBD
Intact fracture test modeling	TBD	Procedure for using a single, variably-saturated fracture model	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Intact fracture test modeling	TBD	Procedure for calibrating a computer flow model for discrete, variably-saturated fractures	TBD

[a]TBD = to be determined.

8.3.1.2.2.4.2 Activity: Percolation tests in the exploratory shaft facility

Objectives

The objectives of this activity are to determine the hydrologic conditions that control the occurrence of fluid flow within fractures and matrix and to provide experimental data against which the validity of numerical and conceptual models can be tested.

Parameters

The parameters of this activity are

1. Unsaturated hydraulic conductivities to air and water as functions of bulk water saturation and matric potential (including the determination of critical saturation).

2. Effective porosities of the matrix and fractures.

3. Volumetric flux and travel time through the rock mass.

4. Fracture spacings, orientations, connectivity, and apertures.

Description

Because the permeability of the fracture system at Yucca Mountain is expected to be both scale dependent and spatially variable, a percolation test conducted at a single scale at a single location has limited value for characterizing the overall fracture-network permeability of the hydrogeologic unit in which it is performed. The primary value of such a test is the opportunity it provides to test hypotheses concerning the nature of fluid flow in unsaturated, fractured rock systems (Activity 8.3.1.2.2.8.1). Experimental validation of numerical models that describe unsaturated flow and transport in systems containing a limited number of discrete fractures provides a tool to allow extrapolation to larger scales at which physical experiments are not feasible. In other words, numerical "experiments" can then be performed at scales at which the physical experiments are impractical because of time or financial restraints. If the model has been physically validated at some smaller scale, the numerically generated "data" for an assumed fracture network can be used to test other simpler modeling approaches such as the composite porosity approach described below.

Detailed models that consider the effects of individual fractures or other spatial heterogeneities within a rock mass can also be used to estimate bulk parameters for the rock mass, as well as evaluate the limitations of using a bulk parameter approach. The ability of these models to estimate the bulk flow and transport parameters of an unsaturated, fractured rock mass will be examined by conducting a sequence of experiments at successively increasing scales. These experiments include the intact-fracture test (Activity 8.3.1.2.2.4.1), the percolation test (this activity), and the bulk permeability test (Activity 8.3.1.2.2.4.3). The results from each experiment can then be compared with simulated results produced by models appropriate to that scale (Activity 8.3.1.2.2.9.2).

The composite conductivity-matric potential relationship for a fractured rock mass is one example of a bulk parameter approach. It ignores the spatial heterogeneity caused by the fracture system and considers the fracture and matrix domains as a composite, homogeneous continuum. The composite conductivity-matric potential relationship can be physically determined by applying a known flux to the surface of the rock and measuring the average matric potential and total hydraulic gradient across it. From Darcy's law, the equivalent conductivity of the rock mass can be calculated by dividing the flux by the total head gradient. The calculated conductivity and average matric potential at the applied flux provide one point on the characteristic curve. By successively altering the percolation rates and average matric potential, the entire composite curve can be determined. If, at each successive percolation rate, a conservative tracer is added to the inflowing water, two additional effective parameters (effective porosity and effective dispersivity) can also be determined for that rock mass. The percolation test, to be conducted on a single block of rock excavated from the Topopah Spring welded unit at the repository horizon, is intended to test the composite continuum hypothesis. The results of this experiment, in conjunction with the results of the intact-fracture test and the bulk permeability test, will be used to assess the validity of conceptual and numerical models describing fluid and solute movement in fractured, porous rock.

Two side drifts excavated perpendicular to one of the main drifts on the lower breakout horizon of the exploratory shaft will first isolate a pillar of rock composed of fractured, welded tuff. From this pillar, a diamond-impregnated wire saw will cut a block of rock approximately 2 m on a side into which tracer-tagged water will later be introduced. This volume of rock does not necessarily reflect the dimensions of the so-called "representative elementary volume" (REV), but has been chosen because it becomes increasingly difficult to induce steady-state flow in larger volumes of low-permeability rock within the time constraints of the site characterization activities.

The test block will be hydrologically and pneumatically isolated from the surrounding rock mass on all sides. This will facilitate the collection of effluent from the base of the block so that both the volume of outflow as well as areally averaged tracer concentrations may be obtained. In addition, isolation of the block and sealing of its sides with a clear, impermeable substance will enable better characterization of the fracture network geometry and will ensure that there are no lateral flow components.

The test block will be excavated from the surrounding rock by removing tapered slabs of rock immediately adjacent to it. Holes will be first drilled through the pillar at the intersections of the horizontal and vertical faces of each slab. The wire will be threaded from driving pulleys in the first drift through a borehole and into the second drift, and then returned to the first drift through a separate hole. As the wire is circulated through the drillholes in a continuous loop, it will cut the rock in the plane defined by the holes. After each slab face is cut, the slab will be pushed into the drift adjacent to the wider end where it will be broken up and removed. The drillhole orientation will produce the tapered cuts. The bottom slab will be removed first and a vertical support system installed. The top slab will be removed next, followed by the side slabs and finally the end slabs.

Before excavation of the test block, small-diameter (1.3-cm) boreholes will be drilled through the pillar and the test block and used to perform both single-hole and cross-hole packer injection tests (using nitrogen gas). Packer spacing will be designed to isolate discrete fractures or fracture zones, as determined from mapping of the sides of the block and from borehole logging. Values of pneumatic conductivity calculated for tests conducted before the excavation of the block from the pillar will be compared with the values calculated from similar tests conducted after the excavation has been completed. In this way, the effects of excavation on changes in effective fracture aperture can be quantified. The information on fracture geometry and conductivity provided by air-injection packer tests will also be used to refine and calibrate a preliminary computer model of the test block. The boreholes in which the pneumatic tests are initially conducted can also be used as conduits for rock bolt supports during excavation.

All boreholes will be drilled and cored using air. The boreholes will be surveyed for fracture locations using downhole TV cameras and by conducting single-hole packer air-injection tests.

The core from all boreholes will be logged in detail for fracture locations and geometric parameters (e.g., fracture spacing, fracture orientation, apparent aperture, trace 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 hydraulic 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 testing). The parameters to be measured include saturated hydraulic conductivity, moisture content (gravimetric and volumetric), moisture content-matric potential relationships, water and matric potential (via psychrometers, heat-dissipation probes, tensiometers), grain density, porosity, and bulk density. From these measurements, relative permeabilities of air and liquid water as a function of matric potential or water saturation will be calculated. The spatial variability of the above-mentioned quantities within the block will be described with semivariograms.

Samples of core from the boreholes will be tested to determine the effective diffusion coefficients of the matrix (and fracture coatings, should they exist) with respect to nonreactive tracers, such as potassium bromide. An attempt will also be made to measure the permeability of any fracture coatings observed in the cores.

A ventilation door will be installed near the entrance to each of the two side drifts. These doors 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.

Individual fractures, joint sets, and fracture networks will be mapped along the exposed surfaces of the drifts as part of the geologic mapping project (Activity 8.3.1.4.2.2.4). Similar fracture maps will be prepared for each face of the percolation test block. Photographs of the drift and test-block surfaces will also be taken to provide a record of the fracture trace patterns. Fracture orientations and three-dimensional projections into the test block will be determined from the fracture maps, core samples and borehole data.

The first step in the percolation test will be to saturate the block to the maximum extent possible by ponding water directly on the surface of the block. Outflow collected from the bottom of the block will then be de-aired and recirculated. Water will move through the fracture network and be imbibed from the fractures into the matrix. Small amounts of air will be trapped and compressed within each of the fracture-bounded matrix blocks as the wetting front advances from the saturated fractures toward the centers of the blocks. Based on preliminary modeling, this small amount of compressed air probably will not significantly affect the results of the test.

Steady-state conditions will be assumed to occur when the rate of inflow into the block equals the rate of outflow from the block (to within a specified tolerance). The saturated bulk-rock conductivity and the associated percolation rate will be determined in this first phase of the test.

A sand bed and flow tank apparatus will then be installed on the upper surface of the test block and a ceramic (or metal) porous plate attached to the base of the block. A suction less than the air-entry suction of the plate will be applied to the lower plate surface with a vacuum pump. The applied suction will draw percolating fluid out of the plate to where it can be collected, measured, and analyzed. A thin (1-cm-thick) sand layer placed between the block and the porous plate will ensure that good hydraulic connection is maintained between the rock and the plate, and will reduce pressure buildup near the fractures caused by plate impedance.

Water will be applied to the sand bed surface using hypodermic syringes or perforated tubing. Capillary forces within the sand will cause water to spread laterally from the application points, so that for a homogeneous sand, the matric potential within the sand at a given height above the sand-block interface will become relatively uniform. The sand bed apparatus will consist of a framed-in box filled with well-sorted sand and instrumented with heat dissipation probes, tensiometers, and thermocouple psychrometers.

At high percolation rates, water movement at the base of the sand bed will have a strong horizontal component because the water will tend to pond above the intact matrix blocks and drain into the intervening fractures. A sand with a high saturated conductivity will maintain small lateral pressure gradients and relatively uniform matric potential at the base of the sand and within the upper part of the block. The saturated hydraulic conductivity of the sand should be larger than the measured bulk-rock conductivity.

When the sand bed and porous plate are in place, water will be infiltrated into the sand bed at rates less than the saturated hydraulic conductivity of the rock mass. The block, and particularly the fractures, will have drained somewhat as the sand bed and porous plate were being installed. However, steady-state conditions will be reestablished fairly rapidly at the new percolation rate, because drainage of water from the matrix is expected to be small. Because the matrix will remain nearly completely saturated over the range of matric potentials in which liquid-water flow within the fracture is thought to be important, very little water will need to be drained from or added to the matrix to maintain pressure-potential equilibrium between the fractures and the matrix. Therefore, the system should equilibrate quite rapidly with respect to altered boundary conditions once the initial saturation phase has been established. By measuring the average matric potential and average hydraulic gradients at steady state for successively lower applied percolation rates, the composite conductivity-matric potential relationship of the block can be determined. Because it becomes increasingly difficult to reestablish steady-state flow (or for that matter to measure fluxes) when water flow is primarily through the matrix, the percolation test will focus on that portion of the composite curve above and just below the point at which the fracture and matrix contributions to total flux are equal. This is the matric potential at which the fracture and matrix contributions to the total flux are equal, and below which the fracture contribution to the total flux becomes increasingly insignificant.

After steady-state flow conditions have been established at a given percolation rate, a conservative tracer, such as potassium bromide, will be added to the inflowing water. The effective porosity (or more precisely, effective water content) of the block at that flow rate will be determined by dividing the Darcy flux by the length of the block and multiplying the result by the time required to observe an effluent concentration that is one-half of the input concentration. Effective moisture content, that is, the water-filled pore-volume available to solute moving through the rock, probably is a function of the flow rate and decreases with increasing fluid fluxes. A knowledge of the relationship between fluid flux and effective porosity is essential to the calculation of ground-water travel time.

The instruments employed in the percolation test must be capable of the following: (1) measuring water content and potential in the matrix, (2) distinguishing conducting (wet) fractures from nonflowing fractures, (3) monitoring the arrival of the wetting front or tracer pulse in the fractures, and (4) quantifying imbibition into the matrix through fracture walls.

Tracer movement will be monitored using electrical conductivity probes. Time domain reflectometry (TDR) will be used to measure bulk-rock water content in all phases of the experiment. During wetting, TDR will be used to monitor the wetting front in the matrix (and possibly fractures). Thereafter, TDR will be used to measure moisture redistribution during drying. Thermocouple psychrometers or heat dissipation probes will be used to measure the baseline (ambient) water potential in the rock before and during the initial wetting phase. If the initial matric potentials before wetting are less than -1,000.0 kPa, psychrometers will be used. If the potentials are between -80 and -1,000.0 kPa, heat dissipation probes will be used. Tensiometer-transducer systems will be used to measure matric potentials during wetting and subsequent steady-state conditions. The tensiometers will be arranged such that measurements in the vicinity of the fracture and in the center of the matrix block can be recorded simultaneously. In this way, imbibition rates into the matrix from adjacent fractures can be monitored during the transient wetting and drying phases. The tensiometer-transducer system can also verify that steady-state conditions predicted by inflow and outflow measurements have been attained.

All instruments will be emplaced horizontally within the test block with the exception of the TDR probes. Horizontal instrumentation will minimize disturbance of the percolation front and will eliminate the problem of preferential flow channeling that may occur along vertical boreholes.

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	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Test room location and excavation	TBD[a]	USGS geological procedure for mapping fractures in underground drifts and test rooms	TBD
Test block excavation and preparation	TBD	Procedure for determining the location of the test block	TBD
	TBD	Procedure for excavating a block of fractured, welded tuff	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Test block excavation and preparation (continued)	TBD	Procedure for sealing the sides of an infiltration test block with a clear, impermeable substance	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
Sampling, lithologic examination, and hydrologic analysis of bit-cutting and core samples	MDP-01,R0	Identification, handling, storage, and disposition of drillhole core and samples	15 Oct 81
	GP-05,R0	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, Nevada Test Site (NTS)	30 Mar 87
	HP-18,R0	Frequency of equipment calibration for unsaturated zone testing Nevada Test Site (NTS)	20 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Sampling, lithologic examination, and hydrologic analysis core samples (continued)	HP-28,R0	Laboratory procedures for the determination of moisture retention curves on rock core	15 May 85
	HP-32,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-55,R0	Hydrologic laboratory testing of core and drill-cutting samples from unsaturated-zone test holes	9 Sept 85
	HP-73,R0	Calibration and use of the Sartorius electronic top-loader (balance) Model 1507 MPS	29 Mar 85
	HP-74,R0	Use of the Stabil-Therm miniature batch oven	28 Oct 85
	HP-123,R0	Development of tensiometer-transducer equipment and techniques for measuring the matric potential of minimally disturbed core from Yucca Mountain	TBD
	HP-131,R0	Method for handling and transporting unsaturated core for hydrochemical analysis	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Sampling, lithologic examination, and hydrologic analysis of bit-cutting and core samples (continued)	TBD	Procedure for determining the effective diffusion coefficients of the welded tuff matrix	TBD
	TBD	Procedure for determining the effective diffusion coefficients of the fracture coatings	TBD
	TBD	Procedure for determining the hydraulic conductivity of the fracture coatings	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
	TBD	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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole geophysical surveys and logging (continued)	TBD	Procedure for determing 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 method	TBD
In situ 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 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
In situ pneumatic testing (continued)	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
	TBD	Flow test data identification, shipping, handling and archiving	TBD
	TBD	Procedure for determining aperture disturbance caused by excavation using single-hole pneumatic tests	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
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 Jul 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 a borehole test interval	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Cross-hole pneumatic testing (continued)	HP-56,R0	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	TBD
	TBD	Procedure for determining aperture disturbance caused by excavation by using cross-hole pneumatic testing	TBD
Test room preparation	HP-18,R0	Frequency of equipment calibration for unsaturated zone testing, Nevada Test Site	20 Jul 84
	HP-48,R0	Method for calibrating hand-held glass thermometers	14 Aug 84
	HP-49,R0	Method for using hand-held glass thermometers	14 Aug 84
	TBD	Method for calibration of 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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Test room preparation (continued)	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
Infiltrometer installation	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 Jul 84
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Infiltrometer installation (continued)	HP-18,R0	Frequency of equipment calibration for unsaturated zone testing, NTS	20 Jul 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 Jul 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
	TBD	Operation of pressure transducer tensiometers in an infiltrometer sand bed	TBD
	TBD	Method for constructing and instrumenting an infiltrometer sand bed	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Infiltrometer installation (continued)	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 Jul 84
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Test hole instrumentation and monitoring (continued)	HP-17,R0	Method of calibration and testing for operation of pressure transducers for air permeability studies in the unsaturated zone	14 Jul 84
	HP-18,R0	Frequency of equipment calibration for unsaturated zone testing, NTS	20 Jul 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 Jul 84
	HP-69,R0	Construction and operation of simple tensiometers	TBD
	HP-70,R0	Psychrometer calibration	TBD
	HP-95,R0	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 Number	Title	Date
	(NWM-USGS-)		
Test hole instrumentation and monitoring (continued)	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 initialization of data acquisition system	TBD
	TBD	Preliminary probe installation and stemming plan for percolation test boreholes	TBD
	TBD	Preliminary plan for final checkout and acceptance of instrumentation packages and emplacement into percolation test holes	TBD
	TBD	Procedures for in situ measuring and monitoring of tracer concentration in boreholes	TBD
	TBD	Procedure for monitoring moisture content and movement using gamma-gamma probes in horizontal and vertical holes	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Test hole instrumentation monitoring (continued)	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 a 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 operation check	TBD
	TBD	Test hole data identification, shipping, handling, and archiving	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Percolation test method	TBD	Method for conducting an underground percolation test in unsaturated, welded tuff	TBD
	TBD	Procedure for attaching a ceramic (or metal) porous plate to a block of fractured, welded tuff	TBD
	TBD	Procedure for determining steady state flow conditions	TBD
	TBD	Procedure for collecting effluent from a block of unsaturated, welded tuff	TBD

[a]TBD = 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 the scale at which the host rock behaves as an equivalent anisotropic porous medium.

2. To compare hydraulic test results against a distribution of simulated results calculated from a large number of realizations of the possible fracture networks conditioned on average fracture orientation and/or fracture density data.

3. To use a numerical fracture-flow model to establish the minimum dimensions at which other rock masses with the same fracture characteristics behave as equivalent porous media and to examine the dependence of rock-mass dimensions on changing saturation.

Parameters

The parameters of this activity are

1. Unsaturated hydraulic conductivities relative to air as a function of liquid-water 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 liquid-water 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.

Description

The bulk permeability test is closely linked with the intact-fracture test (Activity 8.3.1.2.2.4.1) and percolation test (Activity 8.3.1.2.2.4.2) in validating conceptual and numerical models of fluid flow through unsaturated fractured rock (refer to Activity 8.3.1.2.2.8.2). The bulk permeability test will be conducted at four sites within the lower breakout zone of exploratory shaft 1 (ES-1). Single-hole packer air-injection tests, cross-hole tests, frustum tests, and tracer tests will be conducted at each site to assess the fluid transport properties of the Topopah Spring welded unit. Fracture mapping at the individual sites as well as in other drifts within the lower breakout zone, will be conducted to characterize the fracture network (Activity 8.3.1.4.2.2.4). Rock-matrix lithologic and hydrologic properties will also be characterized at each site as well as within other drifts within ES-1. These fracture and rock-matrix data will be collected 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. Resulting data from this test will be incorporated in a fracture fluid-flow model that will establish the minimum dimensions at which the rock mass behaves as an equivalent porous medium. The following paragraphs describe the data-collection process in detail.

Individual fractures, joint sets, and fracture networks will be mapped 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. 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. Samples will be collected for mineralogic, petrographic, and hydrologic properties studies. The physical properties that will be determined include pore geometry, welding, grain density, bulk density, and porosity. The hydrologic 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 testing).

Following the acquisition, analysis, and evaluation of the fracture characteristics and the rock-matrix hydrologic property data, four sites within the lower breakout zone will be chosen for air permeability testing. The air permeability test sites 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 and (2) so that the experiments performed within it will remain unaffected by the other activities occurring at the lower breakout level. Modeling and prototype testing will be used to approximate the minimum distance required to avoid interference with adjacent activities.

The drilling and air permeability testing at each of the four sites will be conducted in three stages. The first stage will consist of drilling three holes into the end or sidewall of an existing drift at the main breakout level of the exploratory shaft facility (ESF). These holes will be arranged in a frustum configuration, thus maximizing the variety of scales at which permeability testing can occur; this will provide the most data possible for determining at what scale the host rock behaves as an equivalent anisotropic porous medium. The holes will be 40 m long and diverging at an angle of 20 to 25 degrees from each other.

Following drilling, fractures that are conductive and thus suitable for testing will be located in each of the boreholes by using the single-hole packer air-injection method. This method consists of injecting nitrogen gas into a 2-ft test interval while observing the injection pressure and flow rates. If open fractures are not present, then the flow rates would be expected to decline significantly while the injection pressure remains relatively high. Thus, the location of open fractures will be inferred from high flow-rate test intervals and confirmed by examining the core and video logs. The entire lengths of both injection observation boreholes will be tested in this manner.

Next, cross-hole tests will be used to evaluate the reservoir properties, such as permeability and porosity, and to evaluate the homogeneous, anisotropic conditions in the fracture rock. The cross-hole testing method consists of injecting gas into an isolated test interval within a drill hole and monitoring the formation's response to the change in fluid pressure in nearby observation drillholes. To achieve this, a straddle packer system, consisting of four inflatable packers placed in series and separated from one another by spacer rods or well screens, will be placed in the injection borehole. Nitrogen gas will be injected into the test interval isolated between the second and third packers and the pressure response will be monitored in the adjacent observation boreholes. The observation boreholes also contain a straddle-packer system, thus providing up to three observation zones per hole where the response from fluid injection can also be monitored. In addition to the test interval, the injection borehole will contain two guard zones that straddle the test interval. These zones will be used to monitor fluid leakage from the test interval past the packers straddling the test zone.

Three types of sensors will be utilized in the cross-hole testing method for monitoring in situ air pressure, air temperature, and relative humidity in the guard and test intervals. These sensors include strain gauge pressure transducers for measuring absolute pressures, resistance temperature devices (RTDs) for measuring temperature, and thermocouple psychrometers for measuring relative humidity. Electrical leads for the sensors will be routed through the packers using gas and water-tight connectors to the collar of the drillhole. The test results, namely active and observation well fluid pressures, temperatures, and injection or production flow rates, will be used to calculate permeability.

Following the cross-hole testing, a gaseous tracer will be injected into several test intervals, and its arrival time will be measured at the outflow point to determine the effective porosity of the system. Prototype testing is planned to identify the most appropriate tracer for accomplishing this task.

The second stage of drilling and air permeability testing at each site will consist of drilling a central borehole to the same depth of 40 m. This borehole will also be injection tested along its length in 2-ft increments, using nitrogen gas to locate permeable zones suitable for cross-hole testing. Then, it will be used as the injection test borehole with the other three boreholes being used as observation boreholes during the subsequent cross-hole tests. The purpose of drilling the fourth borehole is to cut the distance between boreholes in half and thus provide a smaller scale at which cross-hole testing can be repeated.

For the third stage of drilling and permeability testing, the frustum test will be conducted. This test will consist of packing off the first 5 m of each of the four boreholes and simultaneously injecting nitrogen gas into the remaining 35 m of each borehole by connecting them to the same manifold. In this way, the test will be simulating a large-diameter, single-hole injection test, whereby a zone of constant pressure is formed from the center out to the diameter of the circle created by the ring of outer holes. The first 5 m of each hole will be packed off to minimize the permeable boundary effects of the relaxed zone. By performing this frustum test, a third scale, which is larger than the first two scales, will be investigated.

Following the air permeability testing, the data will be analyzed using discrete fracture and stochastic modeling approaches, as described in Study 8.3.1.2.2.9. In the discrete fracture modeling approach, the hydraulic test results will be compared against a distribution of simulated results calculated from numerous realizations of the possible fracture networks conditioned on average fracture orientation and/or fracture density data. In the stochastic modeling approach, the hydrologic and pneumatic test data will be treated as the realization of a stochastic process defined over a continuum, thus, allowing scales smaller or larger than the scale of measurement to be studied by means of deconvolution or spatial averaging (or both) techniques. The results of the two modeling approaches will then be compared for consistency and a final evaluation made.

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: Number	Technical procedure: Title	Technical procedure: Date
	(NWM-USGS-)		
Fracture mapping and analysis	HP-17,R1	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
Packer air-injection testing	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Packer air-injection testing (continued)	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 Jul 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 Jul 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
	TBD	Method for conducting single-hole packer air-injection tests	TBD
	TBD	Method for conducting cross-hole packer air-injection tests	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Packer air-injection testing (continued)	TBD	Method for conducting frustum air-injection tests	TBD
	TBD	Method for linking packer testing instrumentation to a local data aqui-sition system (DAS)	TBD
	TBD	Method for transmitting data from local data acquisition system (DAS) to integrated data system	TBD
	TBD	Method for calculating conductivity of indi-vidual fractures, joint sets, and frac-ture networks from air-injection packer tests	TBD
	TBD	Method for determining fracture geometric parameters from air-injection packer tests	TBD
Laboratory rock-matrix lithologic and physical prop-erties testing	HP-12,R1	Method for collection, processing, and han-dling of drill cuttings and core from unsatu-rated-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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Laboratory rock-matrix lithologic and physical properties testing (continued)	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
Laboratory hydraulic properties test of core	HP-12,R2	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the wellsite, NTS	30 Mar 87
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 84
	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 Jul 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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Laboratory hydraulic properties test of core (continued)	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
Borehole drilling and coring	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
	TBD	Method for dry drilling and coring horizontal boreholes	TBD
	TBD	Method for cleaning horizontal and vertical boreholes using dry techniques	TBD
Fracture logging of core	GP-11,R0	Logging fractures in core	15 May 85
Borehole video surveys	GP-10,R0	Borehole video fractures logging	12 Apr 85
	TBD	Method for cleaning the borehole walls prior to the television camera survey	TBD
	TBD	Operation of borehole television camera	TBD
	TBD	Method for digitizing electrical signals and interfacing with a digital computer	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole deivatometer surveys	TBD	Method for deviation surveys in horizontal and vertical boreholes	TBD
Borehole geophysical surveys	TBD	Method for geophysical logging in horizontal and vertical boreholes	TBD
	TBD	Method for determining fracture geometry parameters from geophysical surveys	TBD
Gaseous-tracer testing	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
	TBD	Procedure for determination of breakthrough curves from gaseous tracer concentrations of packer air-injection strings	TBD
Bulk-permeability test modeling	TBD	Method for using a computer model that simulates three-dimensional gas flow in nondeformable porous media	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Bulk-permeability test modeling (continued)	TBD	Method for calibrating a computer model that simulates three-dimensional gas flow in nondeformable porous media	TBD

[a]TBD = 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 to

1. 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. 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, composition of radioactive and stable isotopes and time of residence.

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 8.3.1.2-16). 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. 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 8.3.1.4.2.2.4 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 ansiotropic 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 testing). Then, the samples will be sent to offsite laboratories to be tested for the following properties: gravimetric water content, volumetric

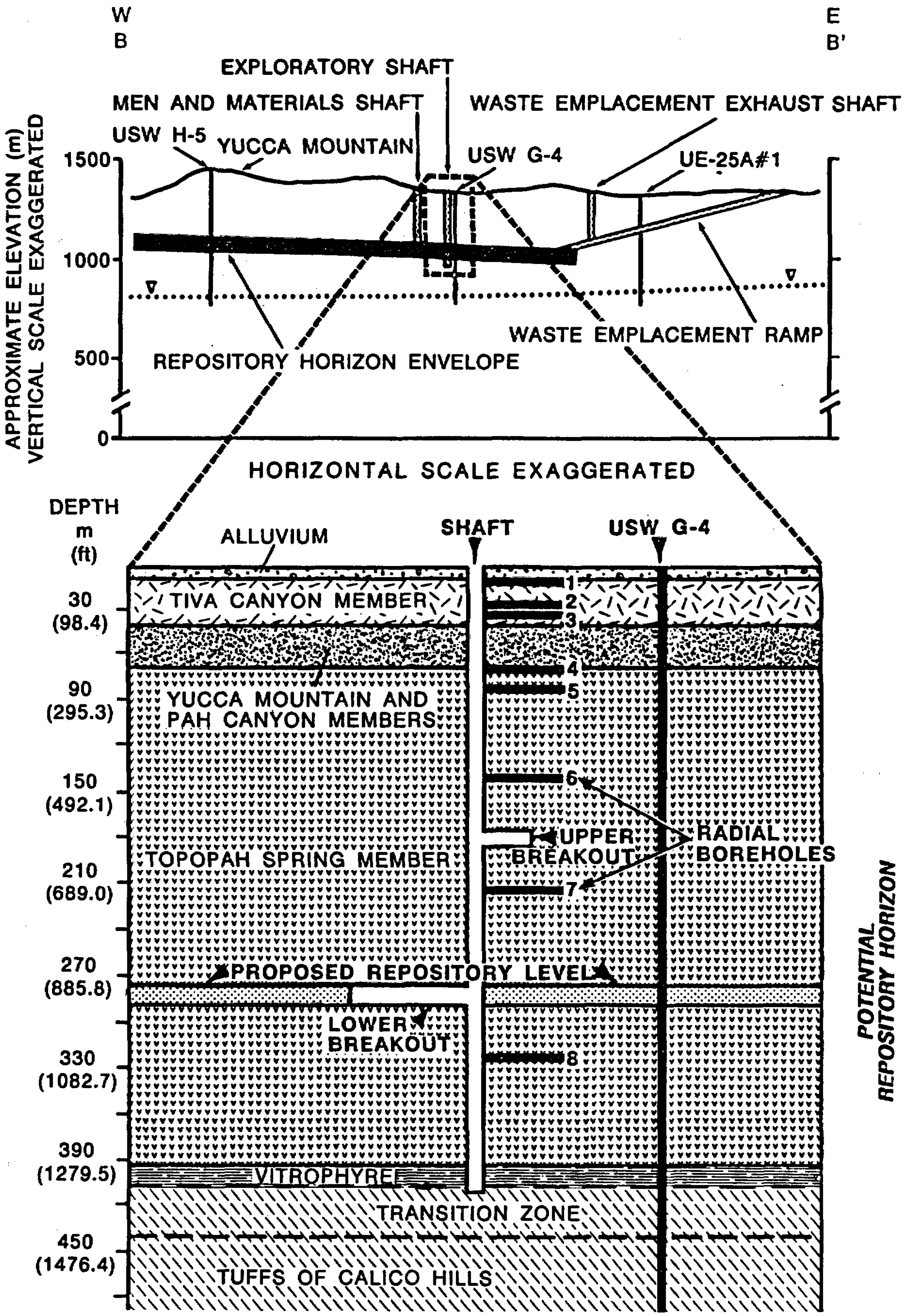


Figure 8.3.1.2-16. Schematic of the radial boreholes tests.

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 (Figure 8.3.1.2-16) 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 test; 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		
	Number	Title	Date
	(NWM-USGS-)		
Borehole drilling and coring	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS	8 Jun 88
	HP-38,R0	Method for measuring humidity, pressure, and temperature of intake and exhaust air during vacuum drilling	TBD
	TBD[a]	Borehole cleaning and verification techniques	TBD
	TBD	Drilling and coring horizontal holes dry	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole drilling and coring (continued)	TBD	Permeability-tensor calculations leading to borehole location	TBD
	TBD	Shaft-wall fracture mapping	TBD
Onsite laboratory hydraulic properties tests of core and drill cuttings	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 toploader (balance) Model 1507 MP8	29 Mar 85
Offsite laboratory hydraulic- and physical-properties tests of core	HP-28,R0	Laboratory procedure for the determination of moisture-retention curves on rock core	15 May 85
	TBD	Procedures for the measurement of: (1) volumetric water content, (2) bulk density, (3) porosity, (4) saturated water and gas permeability, (5) relative permeability	TBD
	TBD	See Section 8.3.1.2.2.3.1 for a complete listing of matrix hydrologic-properties technical procedures	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Fracture logging of core	GP-11,R0	Logging fractures in core	15 May 85
	TBD	On-site fracture logging of core	TBD
Borehole television surveys	GP-10,R0	Borehole-video fracture logging	12 Apr 85
	TBD	Borehole video logging in horizontal boreholes	TBD
	TBD	Neturon-moisture meter field calibration	TBD
	TBD	Operation of borehole television	TBD
	TBD	Procedure for measuring moisture content in a horizontal borehole using a neutron moisture meter	TBD
	TBD	Method for cleaning borehole walls prior to television camera survey	TBD
Borehole geophysical surveys	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88
In situ pneumatic tests	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
In situ pneumatic tests (continued)	HP-15-,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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
	TBD	Data acquisition system operations check	TBD
	TBD	Flow-test data identification, shipping, handling, and archiving	TBD
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Laboratory procedure for data-logger internal voltmeter	TBD
	TBD	Laboratory procedure for mass-flow meter calibration	TBD
	TBD	Pressure-pulse, gas-injection test procedure	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Single-hole, gas-injection test procedure	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
In situ pneumatic tests (continued)	TBD	Straddle packer system Leak detection	TBD
	TBD	Straddle packer system placement procedure	TBD
Borehole instrumentation and monitoring	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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-19, R0	Method for identification, transport and handling of instrumentation packages and equipment for field testing in the unsaturated zone at NTS	20 Jul 84
	TBD	Data acquisition system operations check	TBD
	TBD	Field procedure for connection of sensor leads and initializing data-acquisition system	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole instrumentation and monitoring (continued)	TBD	Field procedure for in situ calibration of pressure transducers	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	Flow test data identification, shipping, handling and archiving	TBD
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Preliminary plan for final checkout and acceptance of instrumentation packages and emplacement into radial test holes, exploratory shaft NTS	TBD
	TBD	Pressure-pulse, gas-injection test procedure	TBD
Collection and transportation of gas samples from radial boreholes	HP-56,R1	Gas and water vapor sampling from unsaturated-zone test holes	15 Apr 88
	HP-131,R0	Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis	13 Jun 88

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Collection and transportation of gas samples from radial boreholes (continued)	TBD	Procedure for shipping and handling gas samples	TBD
Cross-contact testing using cross-hole pneumatic and hydraulic tests	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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
	TBD	Cross-hole, gas-injection test procedure	TBD
	TBD	Cross-hole, water-injection test procedure	TBD
	TBD	Data-acquisition system operations check	TBD
	TBD	Data-logger internal voltmeter calibration	TBD
	TBD	Field procedure for in situ calibration of pressure transducers	TBD
	TBD	Field procedure for in situ evaluation of thermocouple psychrometer sensor performance	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Cross-contact testing using cross-hole pneumatic and hydraulic test (continued)	TBD	Gas-sample analysis	TBD
	TBD	Laboratory procedure for calibration of thermal sensors	TBD
	TBD	Mass-flow meter calibration and use	TBD
	TBD	Procedure for collecting, shipping and handling cross-hole test water samples	TBD
	TBD	Procedure for determining test location	TBD
	TBD	Procedure for introducing an aqueous tracer into a test interval	TBD
	TBD	Procedure for introducing gas tracers into test interval	TBD
	TBD	Straddle-packer-system leak detection	TBD
	TBD	Straddle-packer-system placement procedure	TBD
	TBD	Water sample analysis	TBD
	TBD	Water flow meter calibration	TBD

[a]TBD = to be determined.

8.3.1.2.2.4.5 Activity: Excavation effects test in the exploratory shaft facility

Objectives

This activity will monitor changes to both the stress state and fractured rock permeability caused by excavating and lining the shaft. The objective is to use these data, as well as other physical properties gathered during the activity, to validate and calibrate a coupled hydraulic-mechanical finite-element model. The model will be used to predict stress and ensuing permeability changes around excavation openings.

Parameters

The following parameters will be collected during the activity:

1. Air permeability profiles.
2. In situ stresses.
3. In situ rock physical properties.
4. Fracture geometry (mappings).
5. In situ degree of saturation (water).
6. Porosity.

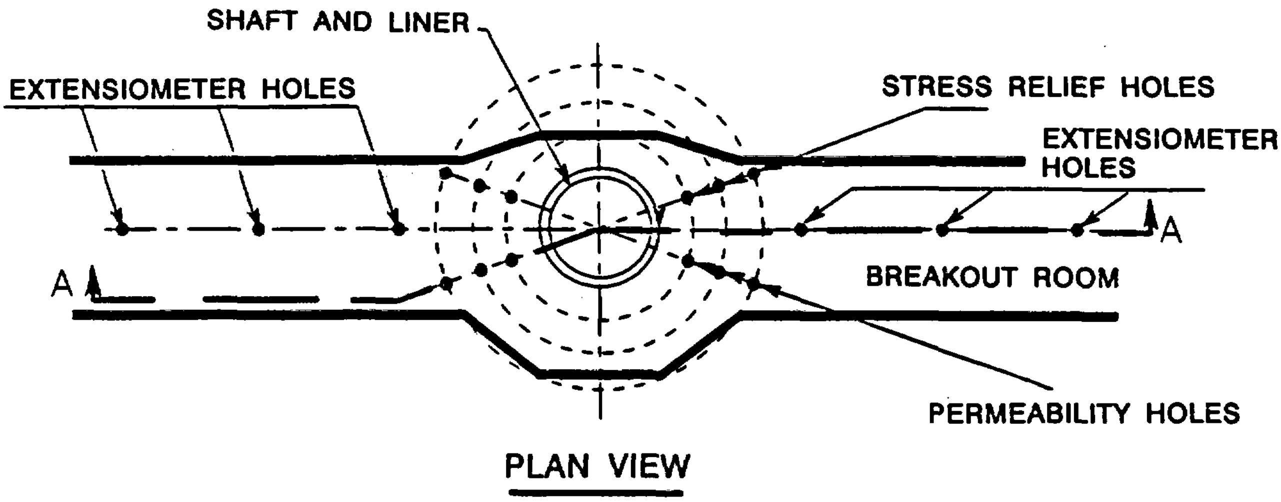
Description

This activity will be conducted at two breakout zones in the exploratory shaft (ES-1) at depths of 600 and 1,020 ft (183 and 366 m) (Figure 8.3.1.2-17). The present design (Figure 8.3.1.2-16) is preliminary and includes 18 boreholes at each breakout horizon. After completing the breakouts, two rows of three vertical holes will be air drilled for permeability measurements. These holes will be 4 to 6 in. (100 to 150 mm) in diameter (to be finalized during prototype testing) and 50 to 100 ft (15 to 30 m) in depth, depending on the ability to maintain the alignment of the holes. The holes will be located at distances of 3.9, 7.8, and 11.8 ft (1.2, 2.4, and 3.6 m) from the shaft wall.

Another set of six vertical air-drilled holes will be used for installation of deformation gages and loading cells at each breakout. These in situ-stress-measuring holes will be 3 to 4 in. (75 and 100 mm) in diameter, with the same length and distance from the shaft wall as the permeability holes. Maximum allowable deviation of both types of holes will not exceed one unit per 100 units of length. At intervals of 20 ft (6 m), the holes will be surveyed by the line-of-sight method or a borehole deviatometer.

Six placement-measuring holes, angled at approximately 45 degrees from the vertical, will be percussion drilled with air. The deviation of these holes will be surveyed by a borehole deviatometer.

The stress disturbance caused by the drill holes is expected to be very small compared to disturbance that will be caused by shaft excavation. This is based on the theory of elasticity where most of the stress redistribution takes place within two radii (one diameter) of a circular opening. Since the largest borehole is approximately 6 in. (150 mm) in diameter, the disturbed



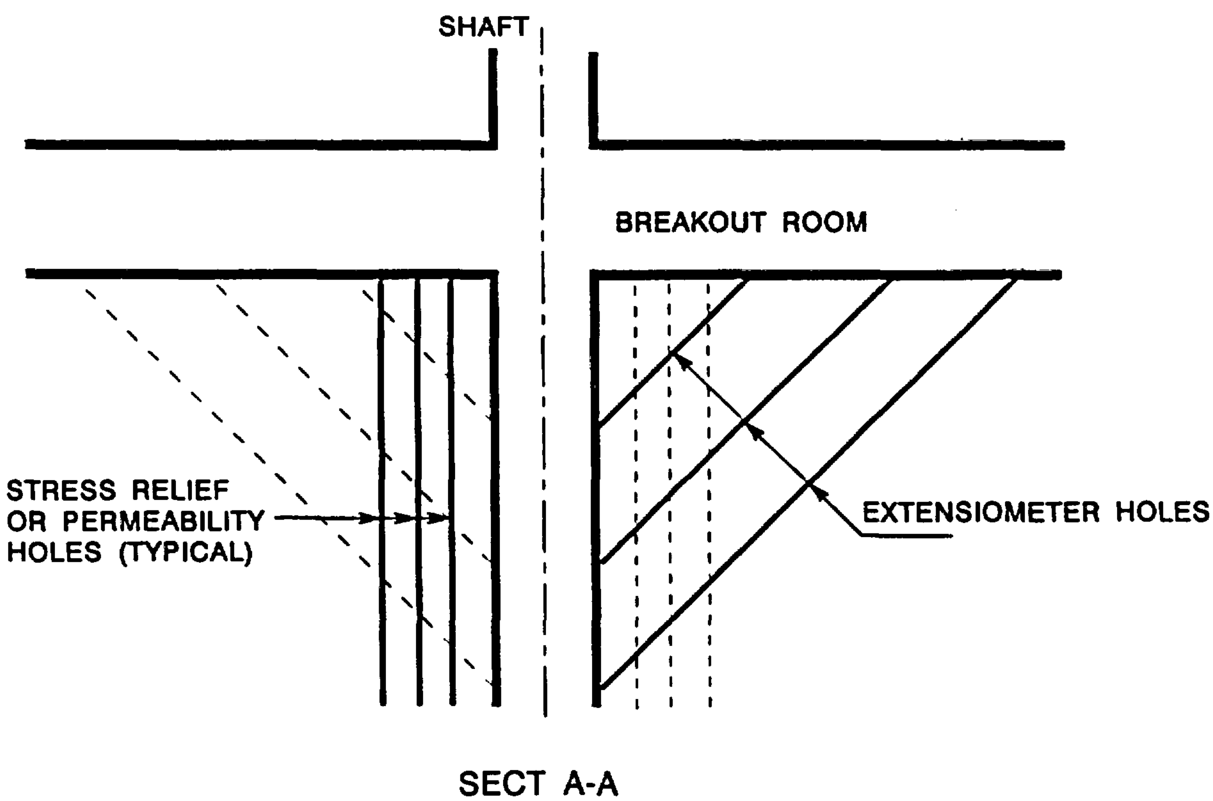


Figure 8.3.1.2-17. Conceptual plan and section of the excavation effects test showing the planned location of boreholes

zone around such a borehole is not expected to extend further than approximately 6 in. (150 mm) from the borehole wall. The surrounding rock is expected to remain in the elastic range during the stress redistribution process. This behavior will be verified during prototype testing.

In situ stress changes will be estimated using deformation gages, flatjacks, and/or loading cells. Instruments will be emplaced at 10-ft (3-m) intervals in the stress-relief holes to measure the deformation in at least two perpendicular directions prior to further shaft excavation. The change in instrument response during and after shaft excavation will be recorded. The multiposition borehole extensometers will be installed in the displacement measuring boreholes. In situ stress magnitudes and directions then will be estimated using data from these instruments, along with rock physical properties data that will be determined in the laboratory.

Television camera logs will be made 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 testing zones can be appropriately located. Borehole geophysical surveys also will be conducted 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 boreholes due to stress changes caused by the shaft excavation. These permeability tests will be performed before excavation of the shaft below the breakout levels and after every two excavation rounds until permeability changes are no longer detected. Air-injection packer strings then will be installed at certain zones to detect any long-term variations in permeability, temperature, and moisture content.

A coupled hydraulic-mechanical finite-element models will be used to analyze the basic data. Model validation and calibration will be accomplished by comparing measured and predicted in situ stress and permeability changes, given an initial state-of-stress condition. The calibrated model will be used to predict disturbances around 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 and coring	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS	8 Jun 88
	HP-38,R0	Method for measuring humidity, pressure, and temperature of intake and exhaust air during vacuum drilling	TBD[a]
	TBD	Drilling and coring (REECo)	TBD
	TBD	Borehole logging in the exploratory shaft and drifts	TBD
Borehole deviation surveys	TBD	Borehole deviation surveys	TBD
	TBD	Oriented core logging	TBD
Borehole fracture logging	GP-10,R0	Borehole-video fracture logging	12 Apr 85
	TBD	Borehole fracture logging	TBD
Borehole geophysical surveys	TBD	Gamma-gamma meter calibration	TBD
	TBD	Porosity meter calibration	TBD
	TBD	Porosity meter operation	TBD
	TBD	Method for measuring in situ porosity using porosity (epithermal neutron) logs	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole geophysical surveys (continued)	TBD	Method for measuring in situ density using gamma-gamma logs	TBD
	HP-62,R3	Method for measuring sub-surface moisture content using a neutron moisture meter	3 Jun 88
Packer air-injection tests	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 84
	HP-17,R0	Method of calibration and testing for operation of pressure transducers for air-permeability studies in the unsaturated zone	14 Sept 84
	HP-18,R0	Frequency of equipment calibration for unsaturated-zone testing, Nevada Test Site	20 Jul 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 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Packer air-injection tests (continued)	TBD	Method for calibrating gas flow meters	TBD
	TBD	Method for calibrating thermocouples	TBD
	TBD	Method for construction of air-injection packer system and air-leak detection	TBD
	TBD	Method for operation of packer air-injection string	TBD
	TBD	Method for calibrating temperature sensors	TBD
Borehole instrumentation and monitoring	GPP-04,R0	In situ stress investigation	27 Jun 83
	HP-17,R0	Method of calibration and testing for operation of pressure transducers for air-permeability studies in the unsaturated zone	14 Sept 84
	HP-18,R0	Frequency of equipment calibration for unsaturated-zone testing, Nevada Test Site	20 Jul 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 Jul 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole instrumentation and monitoring (continued)	TBD	Data-acquisition system for monitoring borehole deformation gages, flatjacks, and load cells	TBD
	TBD	Method for calibrating a coupled-hydraulic-mechanical finite-element model	TBD
	TBD	Method of calibrating flatjacks and loading cells	TBD
	TBD	Method of emplacement of borehole stress gauges	TBD
	TBD	Method of emplacement of flatjacks and loaded cells	TBD
	TBD	Method of emplacement of multiposition borehole extensometers	TBD
	TBD	Method for calibration of borehole stress gauges	TBD
	TBD	Method of calibration of multiposition borehole extensometers	TBD
Excavation-effects test modeling	TBD	Method for evaluating the correctness of a coupled-hydraulic-mechanical finite element model (bench mark problems)	TBD
	TBD	Reference software documentation	TBD

[a]TBD = to be determined.

8.3.1.2.2.4.6 Activity: Calico Hills test in the exploratory shaft facility

The Calico Hills nonwelded unit is expected to be a principal barrier to the flow of ground water and transport of radionuclides. Therefore, it is critical to have high confidence in the understanding of the unit's hydrologic processes, conditions, and properties, under both present and expected future conditions. In particular, it is important to understand the effects that fractures and faults have on flow paths and travel times, and the conditions under which fracture flow may occur. Although the need to characterize the Calico Hills is apparent, it is possible, in some circumstances, that penetration of the unit within the repository block for testing purposes could affect the performance of the site. For this reason, a test program that would be designed for the acquisition of in situ data in the Calico Hills would represent a potential trade-off between the need to acquire data and the need to preserve site-performance capability. Alternative approaches under consideration for the testing include shaft sinking and drifting in the Calico Hills unit in the vicinity of the site and various combinations of vertical and angle drillholes and underground excavation. Additional discussion of the data needs, methods of acquisition, and potential risks is presented in Section 8.4. A risk/benefit analysis and selection of appropriate test options will be prepared before the initiation of testing.

8.3.1.2.2.4.7 Activity: Perched-water test in the exploratory shaft facility

Objectives

The objectives of this activity 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 activity 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. Multipurpose testing near the exploratory shafts (Activity 8.3.1.2.2.4.9) should detect any significant amount of perched water in the vicinity of the ESF during the testing. If perched water has been detected, the activity will allow full preparation for sample collection and testing in the shaft. If perched water has not been detected in the multipurpose boreholes, it will still be necessary to visually inspect the shaft walls for indications of perched water. 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 seepage flow measurements	HP-106,R0	Sampling and field testing of a water-bearing isolated fracture in perched water zones of the exploratory shaft at Yucca Mountain, NTS	TBD[a]

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Shaft-wall seepage flow measurements (continued)	HP-107,R0	Testing and sampling wet zones and seeps in the exploratory shaft at Yucca Mountain, NTS	TBD
Perched-water sampling	HP-90,R0	Sampling and field testing of perched water in the exploratory shaft at Yucca Mountain, NTS	TBD
	HP-98,R0	Procedure for recognition of perched water in the exploratory shaft at Yucca Mountain, Nevada Test Site	TBD
	HP-104,R0	Sampling perched water for chemical and iso-topic analysis in the exploratory shaft at Yucca Mountain, Nevada Test Site	TBD
Pore-water extraction	TBD	Pore-water extraction	TBD
Borehole drilling of perched-water zones	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone bore-holes at the well site, NTS	8 Jun 88
	HP-33,R0	Preliminary method for monitoring and testing perched-water zones in a borehole drilled with the reverse-vacuum method	15 May 85
	HP-109,R0	Boreholes drilled in perched-water zones after a liner is installed in the exploratory Shaft at Yucca Mountain, NTS	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole drilling of perched-water zones (continued)	TBD	Borehole dry drilling and coring (perched-water zones)	TBD
Water flow-rate measurements of large flows	HP-06,R0	Hydrologic pumping test	11 Jan 82
	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
Testing, instrumentation, and monitoring of boreholes	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially-saturated media	9 Jul 84
	HP-15,R2	Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media	9 Jul 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-105,R0	Borehole sampling and field testing of perched-water in the exploratory shaft at Yucca Mountain, NTS	TBD
	HP-108,R0	Long-term monitoring of boreholes in perched-water zones in the exploratory shaft at Yucca Mountain, NTS	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Hydraulic tests for large flow rates	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
	HP-103,R0	Pumping tests of perched water in the exploratory shaft at Yucca Mountain, NTS	TBD
Perched-water samples analysis	TBD	Perched-water sample analysis	TBD

[a]TBD = 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 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 pressure of tritium will indicate younger water.

Additional discussions of these studies are included in Activity 8.3.1.2.2.7.2.

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 of 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-)		
Collection and transportation of gas samples from radial boreholes	HP-56,R1	Gas and water vapor sampling from unsaturated-zone test holes	15 Apr 88
	TBD[a]	Data archiving, shipping and handling procedures	TBD
Preparation of gas samples for analysis	HP-86,R0	Method for degassing carbon dioxide and water (vapor) samples from unsaturated zone test holes	16 May 88
Analysis of gas samples	HP-07,R0	Use of a trace gas for determining atmospheric contamination in a dry-drilled borehole	30 Sept 81
	HP-127,R0	Carbon-14 dating by tandem acceleration mass spectrometer	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Analysis of gas samples (continued)	TBD	Data archiving, shipping, and handling procedure	TBD
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	HP-160,R0	Methods for collection and analysis of samples for gas composition by gas chromatography	16 Jun 88
Collection and transportation of core and rubble samples	HP-12,R3	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS	8 Jun 88
	HP-131,R0	Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis	13 Jun 88
Rubble coring	TBD	Air coring of 6.35 cm cores from rubble	TBD
Extraction of water from core and rubble-core samples	HP-110,R0	Extraction of pore waters by centrifuge methods	8 Jun 88
	HP-125,R0	Method for extraction of pore water from tuff cores by triaxial compression	20 May 88
	HP-126,R0	Extraction of residual water from tuff samples by vacuum distillation	15 Jun 88
Analysis of water samples	HP-08,R0	Methods for determination of inorganic substances in water	6 Aug 82

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Analysis of water samples (continued)	HP-11,R0	Methods for determination of radioactive substances in water	18 Jul 82
	HP-127,R0	Carbon-14 dating by tandem acceleration mass spectrometer	TBD
	TBD	Data archiving, shipping, and handling procedure	TBD
	TBD	Method for analyzing water samples for Cl-36	TBD
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	TBD	Procedure for determining the presence of tracers in pore water samples	TBD

[a]TBD = to be determined.

8.3.1.2.2.4.9 Activity: Multipurpose-borehole testing near the exploratory shafts

Objectives

The planned objectives of this activity are

1. To monitor and evaluate potential hydrologic and engineering interference effects from exploratory shaft (ES) construction on ES tests and interference effects between ES tests.

2. To identify possible occurrence of perched water and, if present, sample and test.

3. To confirm engineering and hydrogeologic properties on which the ESF design is based and identify anomalous conditions in the vicinity of the ESF.

The drilling method for this application has not been selected; the selection will be based on feasibility testing of air drilling and coring methods and equipment in a prototype borehole.

The prototype borehole is planned to be drilled before drilling the first multipurpose borehole (USWMP-1) in a similar stratigraphic profile to the exploratory shaft to ensure that the dry drilling method is feasible to the planned depth. The dry coring technique will be tested to evaluate the feasibility for core sampling in the multipurpose boreholes. The technical procedures for the drilling, sampling, and testing will be developed during prototype testing. If the feasibility testing regarding dry coring techniques is successful, the Project will proceed with multipurpose borehole drilling near the exploratory shafts.

Parameters

The parameters of this activity are

1. In situ gravimetric moisture content.
2. In situ volumetric moisture content.
3. In situ water potential.
4. Water-content profiles.
5. In situ matric potential
6. Temperature profiles.
7. Matrix pore size distribution.
8. Grain density.
9. Bulk density.
10. Total porosity.
11. Matrix effective porosity.
12. Bulk permeability (pneumatic).
13. Composition of formation water.
14. Composition and stable isotope composition.
15. Radioactive and stable isotope composition.
16. Fracture frequency, orientation, spacing, distribution, and weathering.
17. Depths to hydrogeologic contacts.
18. Transmissivity (perched-water zone).

19. Hydraulic conductivity (perched-water zone).

20. Hydraulic head (perched-water zone).

21. Storage coefficient (perched-water zone).

22. Water chemistry (perched water).

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

If the prototype borehole feasibility testing is successful, two multipurpose boreholes (USW MP-1 and USW MP-2) would be constructed using dry-drilling and spot-coring techniques,to the extent practicable, to achieve the objectives listed above. Both boreholes would be located such that they do not penetrate within a distance of either two shaft or drift diameters, as appropriate, of any underground openings. USW MP-1 would be located near exploratory shaft 1 (ES-1), and USW MP-2 near exploratory shaft 2 (ES-2) (Figure 8.3.1.2-18). Each would be approximately 15 to 18 m from the corresponding shaft, USW MP-1 to the south of ES-1, and USW MP-2 to the southeast of ES-2. Both boreholes would be approximately 15 cm in diameter and would be drilled to depths approximately equal to the corresponding shafts, with walls as smooth as practical to maximize the quality of geophysical logging and provide adequate packer seats. The planned coring program in USW MP-1 is more extensive than that planned for USW MP-2. USW MP-1 would be drilled first and spot cored throughout. The amount of coring in USW MP-1 is estimated to be 128 m of the total 335 m. USW MP-2 would be spot cored or continuously cored as deemed necessary or practical based on experience from drilling of USW MP-1, or upon finding any indication of perched water. The MBPH drilling activities are planned to be completed and monitoring begun before exploratory shaft sinking.

Depth penetration of ES-1 will precede ES-2 until about 30 m is reached. At this level tests will be conducted in the radial boreholes in ES-1 (Activity 8.3.1.2.2.4.4) at the contact of the Tiva Canyon welded unit and the Paintbrush nonwelded unit. Because ES-2 is designed to provide quick access to the main test level, the construction of ES-2 will proceed ahead of ES-1 after the first few tens of meters.

USW MP-1 is planned (1) to be located to provide reference information in the vicinity of ES-1 and (2) to provide a monitoring hole once shaft construction activities begin. The pre-shaft-sinking results of the moisture-sensitive geophysical testing (e.g., neutron activation) are planned to serve as a baseline against which construction-induced variations can be assessed. If significant net amounts of water are introduced by construction, and if that water migrates outward from the shaft, the periodic logs would record the movement of the moisture front. USW MP-1 would also provide for testing and sampling of any perched water zones encountered before possible drainage and contamination from fluids introduced during the construction of ES-1. This borehole would be located outside the anticipated modified permeability zone (MPZ) caused by construction of ES-1, but within the radial distance from ES-1 covered by the radial borehole test. In conjunction with

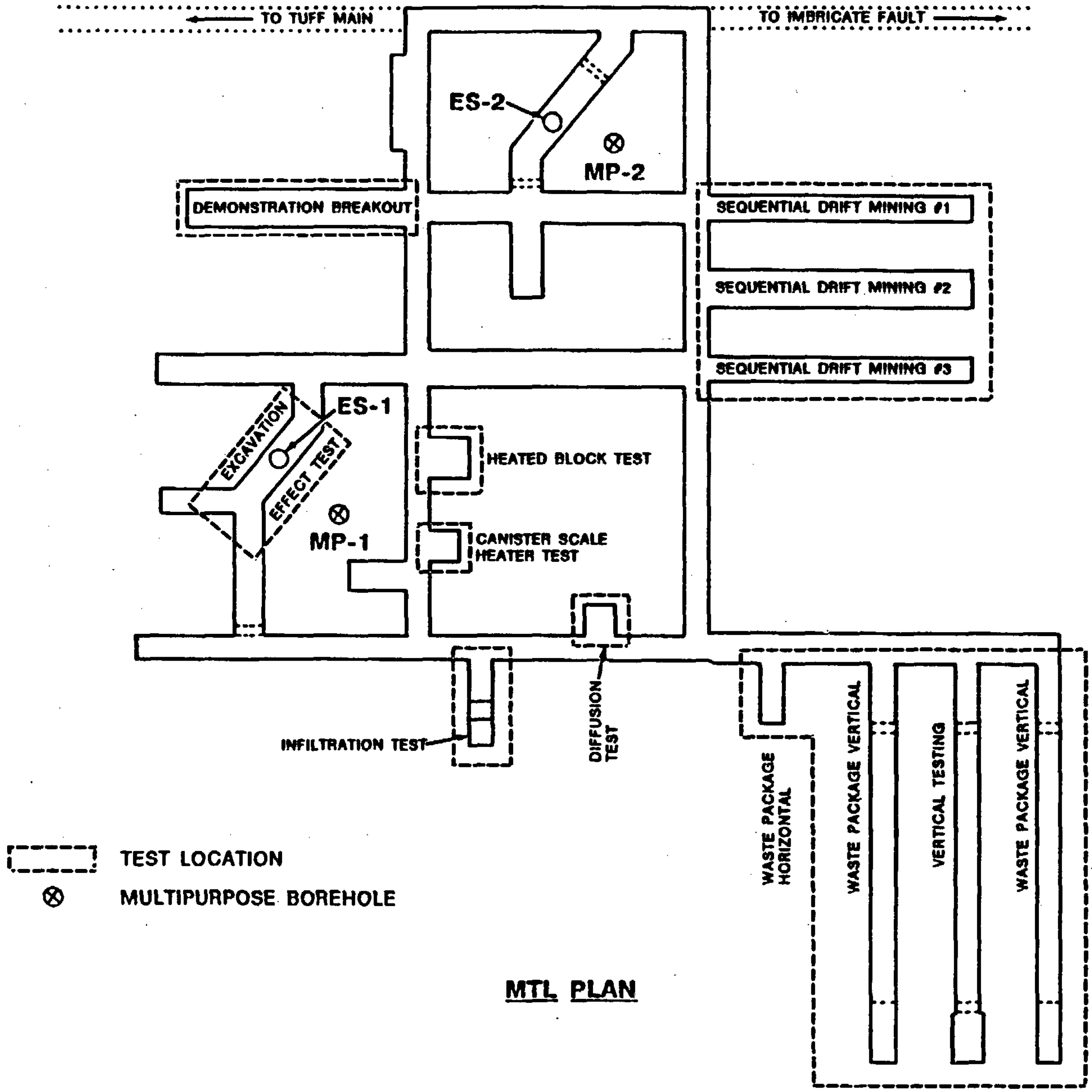


Figure 8.3.1.2-18. Location of multipurpose boreholes MP-1 and MP-2 relative to exploratory shafts at main test area of the exploratory shaft facility

monitoring performed during the radial borehole test in ES-1, periodic geophysical logging and pneumatic testing would be conducted in USW MP-1 to monitor conditions during construction of ES-1. Analysis of the core samples obtained from USW MP-1 and USW MP-2 would provide the data base for establishing pre-shaft in situ ambient conditions and would become part of the site data base compiled in Activity 8.3.1.2.2.3.1 (matrix hydrologic properties testing). Within each hydrostratigraphic unit, a sample would be analyzed for the parameters for this activity. In particular, matrix hydrologic properties and moisture conditions would be characterized to establish in situ conditions that could be correlated with the initial results of geophysical testing.

USW MP-2 is planned to be located near ES-2 in order to provide confirmation of conditions expected to be encountered during shaft construction activities. This borehole is designed to detect any anomalous conditions, including perched water, that may be present at this location. If large amounts of perched water are present in the ESF vicinity, it would probably be detected in USW MP-1. However, even if perched water has not been detected in USW MP-1, continual observations for indications of perched water would be conducted in USW MP-2.

If unexpected conditions do exist, information obtained in the two boreholes could prevent potentially costly delays in shaft construction. The responses observed in USW MP-2 caused by the construction of ES-2 would be expected to be similar to those that might be later observed in USW MP-1 caused by the construction of ES-1. Therefore, observations in USW MP-2 could provide some lead time, so that construction effects can be considered before ES-1 testing.

The models of shaft construction effects developed from observations around ES-1 (radial boreholes test and excavation effects test (Activities 8.3.1.2.2.4.4 and 8.3.1.2.2.4.5 and USW MP-1) and ES-2 (USW MP-2) can be applied to predict what these effects will be at the ESF main test level. This approach will aid in confirming whether the selected test locations at the main test level are appropriate. In addition, distinctive tracers will be included in all ESF construction fluids to help identify the sources of any fluids sampled during ESF excavation. If tracers are detected at proposed test locations, this information will also be used to help determine whether proposed test locations are suitable.

A third multipurpose borehole may be drilled midway between ES-1 and ES-2, if further study indicates a need for such a borehole. The primary purpose of this borehole would be to attempt to assess the impact of construction activities in ES-2 on investigations in ES-1. Preliminary modeling (Section 8.4) results indicate that any expected fluid loss from construction activities in ES-2 probably would not migrate in the matrix or small-aperture fractures the 30 to 45 m from the shaft to the additional borehole, and that changes in matrix saturation would be small. However, the potential exists for more extensive fluid movement along large-aperture fractures. In addition, bulk pneumatic permeability would be affected by even small changes in moisture contents of fractures. These effects could be detectable by a multipurpose borehole sited between ES-1 and ES-2. A decision on the need for a third multipurpose borehole will be made before the construction of ES-2 on the basis of additional analyses of the magnitudes and significance of expected effects.

If perched water is detected during the process of drilling either of the two multipurpose boreholes, an attempt to obtain a water sample would be made, possibly by means of a bailer or other type of downhole sampler. A water sample must be obtained with minimal delay before the possible drainage of a small perched water zone. If sufficient water is present to conduct aquifer testing, testing will be initiated, and additional water samples will be obtained.

Because drilling fluid used during construction of nearby test hole USW G-4 contained water, the occurrence of perched water in either of the two multipurpose boreholes could be the result of drilling fluids lost from USW G-4. Drilling fluids used in USW G-4 contained 20 ppm LiBr tracer; thus, analyses for this tracer will establish whether any perched water samples contain drilling fluid that has migrated laterally from USW G-4 to areas of ESF excavation.

A standard suite of borehole geophysical logs would be run in each multipurpose borehole, either during a pause in drilling or following completion of drilling. Radial-(side scan viewing) and axial-(forward viewing) oriented television video camera logs of each borehole would also be run. These would be used for mapping fracture orientations, distributions, and densities. Neutron moisture logs would be made periodically during and after the drilling period to monitor any changes in water-content profiles.

To establish a preconstruction data set for bulk pneumatic permeabilities immediately following drilling, packer nitrogen-injection tests would be performed in each of the boreholes to determine gas permeabilities of the combined fracture and rock matrix system. Multiple test zones would be selected for each hydrogeologic unit. These zones would be tested with a straddle packer system consisting of a variable length injection interval, and two observation intervals. All three intervals would be equipped with thermocouple psychrometers (or other humidity sensors), thermocouples and pressure transducers. The observation intervals would be monitored for evidence of bypass of the packers from the injection interval. The flow rate and injection pressure of the nitrogen gas would be monitored until steady-state conditions are achieved. The same procedure would be carried out at higher flow rates and pressures for each tested interval to determine the relationship of permeability versus flow rates and pressure. During construction of the exploratory shafts, additional periodic packer tests would be conducted to determine any changes in gas permeabilities due to shaft construction.

Neither of the two multipurpose boreholes would be permanently instrumented. The open boreholes would allow flexibility in terms of follow-up packer testing and continual neutron-moisture logging that a permanently instrumented borehole could not accommodate.

Drilling of the multipurpose boreholes would disturb in situ conditions in the near-field rock mass adjacent to the boreholes. In addition, nitrogen pressure injection testing could drive moisture away from the near-field environment of the borehole. However, the planned dry drilling and coring methods are expected to minimize the disturbance to the hydrologic system, and pre-injection reference information would be collected before nitrogen injection testing. This information would consist of laboratory measurements of moisture content and matric potential from core and cuttings and geophysical logging records correlated with these data. Although these data would not directly address changes in moisture in fractures, results of neutron moisture logging would provide some indication of moisture contents in fracture zones.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.9 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Borehole drilling and coring	TBD[a]	Reynolds Electrical & Engineering Co. (REECo) dry drilling and coring procedure	TBD
	TBD	Borehole cleaning and verification technique	TBD
Borehole deviatometer surveys	TBD	TBD	TBD
Drill-bit cuttings and core sampling, lithologic analysis, hydrologic measurements	HP-12,R3	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,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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Drill-bit cuttings and core sampling lithologic analysis, hydrologic measurements (continued)	HP-73,R0	Calibration and use of the Sartorius electronic top loader (balance) Model 1507 MPS	29 Mar 85
Offsite laboratory hydraulic properties testing core	HP-28,R0	Laboratory procedures for the determination of moisture-retention curves on rock core	15 May 85
	HP-55,R0	Hydrologic-laboratory testing of core and drilling-cutting samples from unsaturated-zone test holes	9 Sept 85
	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
Fracture logging of core	GP-11,R0	Logging fractures in core	15 May 85
Borehole video surveys	TBD	TBD	TBD
Borehole geophysical surveys	TBD	TBD	TBD
	HP-62,R1	Method for measuring subsurface moisture content using a neutron moisture meter	16 May 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole thermal surveys	TBD	TBD	TBD
Packer air-injection testing	TBD	TBD	TBD
Perched-water sampling	TBD	TBD	TBD
Borehole drilling (perched-water zones)	TBD	TBD	TBD
Water flow-rate measurements and pumping tests	HP-06,R0	Hydrologic pumping test	11 Jan 82
Gas sampling	HP-56,R0	General procedure for soil gas sampling in unsaturated zone test holes	15 Nov 84

[a]TBD = to be determined.

8.3.1.2.2.4.10 Activity: Hydrologic properties of major faults encountered in main test level of the exploratory shaft facility (ESF)

Objective

The objective of this activity is to investigate the permeability and flow conditions of the major faults encountered in the long drifts at the main test level of the ESF.

Parameters

The parameters of this activity are

1. Matrix parameters including water content, porosity, pore-size distribution, air permeability, and water permeability.

2. Rock-mass parameters including water content, hydraulic potential, pneumatic potential, thermal potential, and permeability to air and water.

3. Chemical parameters including composition of formation water, composition of formation gases, carbon-14 and tritium activity, and stable isotope composition (oxygen-18), deuterium) for the purpose of age dating and environmental interpretations.

Description

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

This test is designed to supplement information relative to hydrologic characteristics of faults determined under Activity 8.3.1.2.3.3 (Solitario Canyon horizontal borehole study) and in part, under Activity 8.3.1.2.2.3.2 (site vertical borehole studies). In addition, the data collected during this activity will be used to test conceptual models of the hydrologic system and will be used in the development of a model of the unsaturated-zone hydrologic system at Yucca Mountain (Studies 8.3.1.2.2.8 and 8.3.1.2.2.9).

On the basis of the identification of major faults by the geologic mapping activity, a hydrologic testing program will be implemented. This program will consist primarily of tests conducted in boreholes drilled from drifts through fault zones and tests on core collected from the coreholes. Air permeability tests will be conducted between boreholes to determine the permeability to air of the fault zones. Some boreholes will be instrumented to determine in situ conditions of the rock mass and monitored for any changes in these conditions over time. Other sets of boreholes will be used for cross-hole water-injection tests. All water used for injection will be tagged with a tracer. Potential impacts of water-injection testing are described in Section 8.4.3. Core recovered from the holes will be tested to provide a water-content profile across the fault zone. This profile may provide information relative to any recent moisture occurrence in the fault zone.

All boreholes will be drilled using air as the drilling fluid to minimize changes in ambient moisture condition. Core will be examined on the site to obtain a preliminary determination of fracture frequency, orientation, location, and characteristics, as well as indications of fault gouge. This information will be used in conjunction with geophysical and television camera logs for selecting test intervals for air permeability and water-injection testing and for selecting monitoring intervals. The core and cutting samples will be sealed in wax or placed in air-tight canisters and transported to the surface-based field laboratories, where the moisture content of each sample will be determined. Samples will also be sent to laboratories off the site for determinating 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 (Activity 8.3.1.2.2.3.1).

The planned natural gamma, gamma-gamma, neutron-moisture, and caliper geophysical logs will be used to assist in establishing fault zone location in the boreholes, moisture content distribution, and the condition of the borehole. Periodic temperature logs will be made in some boreholes to help determine the thermal gradient across the fault zone and to override indications of variations in flux within the fault zone.

Two types of television cameras will be used for borehole surveys. The first type views downhole just ahead of 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 across the fault zones. A straddle packer system, consisting primarily of four packers, flow meters, pressure transducers, thermocouple psychrometers, and temperature sensors, will be installed at the desired test zone. The packers will then be inflated and nitrogen gas injected into or withdrawn from the central interval, while the two outer intervals are monitored for bypass of the packers. The response will be monitored for changes in pressure, temperature, relative humidity, and flow rate. Analysis of the test data will depend on flow domain boundary conditions, the type of fluid injected or withdrawn and the type of test conducted (steady state, transient, or instantaneous injection).

Cross-hole testing will be conducted using air- and water-injection. During air-injection testing straddle packers will be installed in both an injection and an observation borehole. Nitrogen gas will be injected in the one borehole and pressure changes will be monitored in the observation borehole. From the known flow rate and pressure drop between the two boreholes, the permeability to air of the fault zone will be determined. Water-injection tests will be conducted in a similar manner with tagged water being injected into one borehole and monitored for in the other borehole.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.4.10 are given in the following table.

	Technical procedure		
Method	Number	Title	Date
	(NWM-USGS-)		
Borehole drilling and coring	TBD[a]	Reynolds Electrical & Engineering Co. (REECo) dry drilling and coring procedure--horizontal and angled holes	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Onsite core sampling and lithologic analysis	HP-55,R0	Hydrologic-laboratory testing of core and drilling-cutting samples from unsaturated-zone test holes	9 Sept 85
Offsite laboratory hydraulic properties testing of core	HP-28,R0	Laboratory procedures for the determination of moisture-retention curves on rock core	15 May 85
	HP-32,R0	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone	15 May 85
	HP-55,R0	Hydrologic-laboratory testing of core and drilling-cutting samples from unsaturated-zone test holes	9 Sept 85
Fracture mapping and analysis	TBD	TBD	TBD
Borehole video surveys	TBD	TBD	TBD
Borehole geophysical surveys	TBD	TBD	TBD
Borehole thermal surveys	TBD	TBD	TBD
Packer air-injection testing	HP-10,R0	Packer-injection and shut-in tests	9 Jul 84
Cross-hole air-injection testing	TBD	TBD	TBD
Cross-hole water-injection testing	TBD	TBD	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole instrumentation and monitoring	HP-14,R1	Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media	9 Jul 84
	TBD	Pressure transducer use and calibration	TBD
	TBD	Mass flow rate meters - use and calibration	TBD
	TBD	Stemming boreholes	TBD

[a]TBD = 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 the tuffs of the Topopah Spring welded, unit which 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 the Topopah Spring tuff to model the transport of technetium-99 and iodine-129, nonreactive radionuclides, 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 the 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 emplacement locations will be chosen in borehole segments that are free from fractures that might result in water flow through the diffusion volume. A small amount of nonsorbing tracers will be introduced into the bottom of the borehole; appropriate methods of emplacement have yet to be identified, but will be evaluated prior to the test. 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. If the exploratory shaft penetrates the Calico Hills unit (evaluation made in Section 8.4), then a diffusion test also will be conducted in that unit.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.5.1 are given in the following table.

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)	12 Apr 85
Tracer-injection tests	TBD	Tracer-injection tests	TBD
Borehole overcoring	TBD	Borehole overcoring	TBD
Laboratory tracer concentration analysis of core	TBD	Laboratory tracer concentration analysis of core	TBD
Diffusivity analysis	TBD	Diffusivity analysis	TBD
Software QA	TBD	Procedure to implement NNWSI-SOP-03-02, Software Quality Assurance	TBD
Research and development	TWS-MSTQA-QP-14,R1	Research and development (experimental procedure)	TBD

[a]TBD = to be determined.

8.3.1.2.2.6 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 gaseous-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 gaseous-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 gaseous 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 determining 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, sorative, and dispersive properties of the unsaturated zone.

8.3.1.2.2.6.1 Activity: Gaseous-phase circulation study

<u>Objectives</u>

The objectives of this activity are

1. To describe and model the pre-waste-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, $CBrCl_2F$ for drilling-air contamination, CCl_2F_2, CCl_3F, and ratios of 14 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 chamgers 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 3-m 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
UZ-6 borehole complex and UZ-9 borehole complex (continued)	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 Kreamer (1982).

2. To provide the 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 8.3.1.2-19). 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

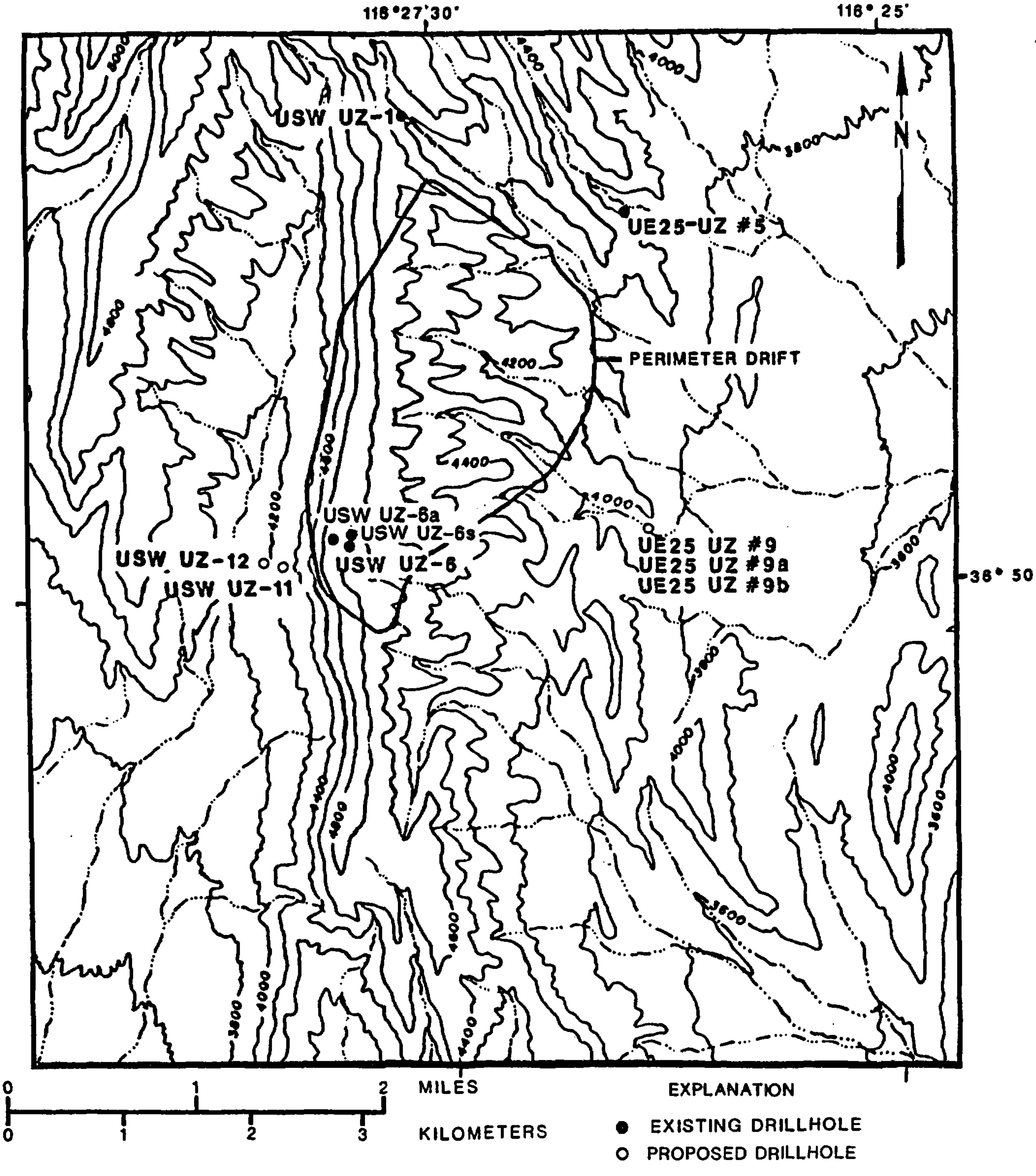


Figure 8.3.1.2-19. Gaseous-phase sampling locations.

atmosphere will be measured. In turn, each well will be opened, and the pressures will be measured in all surrounding wells to conduct interference tests. The results will be analyzed 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, $CBrCl_2F$(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 tracer tritium 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.

At some time 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, UE-25 UZ#9a, and UE-25 UZ#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 gases to the atmosphere, additional open-borehole studies may be needed at other locations on Yucca Mountain.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.6.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Total air circulation in open boreholes	HP-18,R0	Frequency of equipment calibration for unsaturated-zone testing, Nevada Test Site	20 Jul 84
	HP-129,R0	Method for investigating topographically affected convective air flow in wells	TBD[a]
	HP-175,R1	Method for surface measurements of velocity, direction, temperature and humidity of convective airflow in topographically-affected wells	27 May 88
	HP-177,R0	Operation of the Setra Model 270 barometric pressure transducer	27 May 88
	HP-178,R0	Procedure to measure temperature, humidity, differential pressure, and airflow at selected depths in UZ boreholes	3 Jun 88
Flow, temperature, and gas-composition profiles	HP-07,R0	Use of a trace gas for determining atmospheric contamination in a dry drilled borehole	30 Sept 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Flow, temperature, and gas-composition profiles (continued)	HP-56,R1	Gas and water vapor sampling from unsaturated-zone test holes	15 Apr 88
	HP-111,R0	Operating GMC Logging Truck #81890 to obtain temperature, trace-jector,and natural gamma logs	TBD
	HP-129,R0	Method for investigating topographically affected convective air flow in wells	TBD
	TBD	Data archiving, shipping, and handling procedure	TBD
	TBD	Gas-sample analysis	TBD
	TBD	Calibration of noncommercial logging tools	TBD
	TBD	Depth calibration of noncommercial logging tools	TBD
	TBD	Gas-chromatography operation	TBD
	HP-160,R0	Methods for collection and analysis of samples for gas composition by gas chromatography	16 Jun 88
	HP-176,R0	Procedure to collect gas composition samples at selected depth intervals	2 May 88

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Flow-interference tests	HP-130,R0	Procedure for performing airflow-interference tests at UZ6 and UZ6s, Yucca Mountain, NTS	TBD
	TBD	Drilling and coring horizontal holes dry	TBD
	TBD	Flow-test data identification, shipping, handling, and archiving	TBD
	TBD	Mass-flow meter calibration and use	TBD
	TBD	Humidity sensor and sensor-lead calibration	TBD
	TBD	Pressure sensor and sensor-lead calibration	TBD
	TBD	Temperature sensor and lead calibration	TBD
Gas-tracer tests	TBD	Data-acquisition system operations check	TBD
	TBD	Data archiving, shipping, and handling procedure	TBD
	TBD	Gas-sample analysis	TBD
	TBD	Procedure for introducing gas tracers into test interval	TBD
	TBD	Gas-chromatography operation	TBD
	TBD	Preliminary research procedure for conducting gas-tracer tests using boreholes	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Gas-tracer tests (continued)	TBD	Procedure for making chemical standards for tracers	TBD
Gas flow modeling	TBD	Reference software documentation	TBD

[a]TBD = to be determined.

8.3.1.2.2.7 Study: Hydrochemical characterization of the unsaturated zone

The objectives of this study are to (1) understand the gas transport mechanism, direction, flux and travel time within the unsaturated zone; (2) design and implement methods for extracting pore fluids from the tuff; (3) provide independent evidence of flow direction, flux, and travel time of water in the unsaturated zone; (4) determine the extent of the water-rock interaction, and (5) model geochemical evolution of ground water in the unsaturated zone. Two activities are planned to collect the data required to satisfy these objectives.

8.3.1.2.2.7.1 Activity: Gaseous-phase chemical investigations

Objectives

The objective of this activity is to understand the gas transport mechanism, and 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 CO_2 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 8.3.1.2-20). Gas samples will be checked for contamination caused by air coring (using SF_6 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 ratio of carbon-14 and carbon-13 to carbon-12 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 8.3.1.2.2.6.1), and data collected from the unsaturated zone just above the water table, as described in Activity 8.3.1.2.3.2.2 (hydrochemical characterization of water in the upper part of the saturated zone) in an assessment of the Yucca Mountain gas flow processes.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.7.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Collection and transportion of gas samples	HP-56,R1	Gas and water vapor sampling from unsaturated-zone test holes	15 Apr 88
	TBD[a]	Data archiving, shipping, and handling procedure	TBD

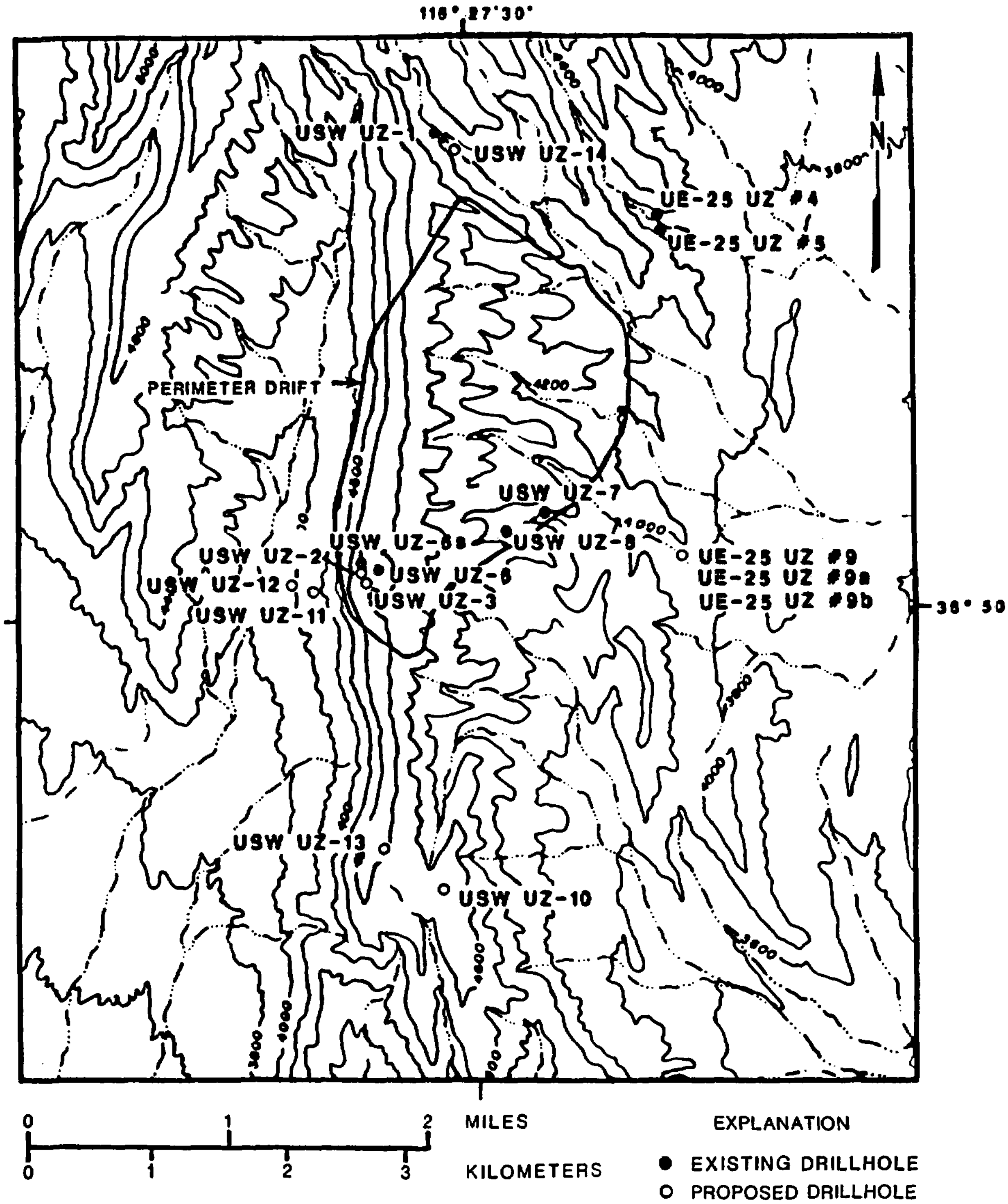


Figure 8.3.1.2-20. Gaseous and liquid-phase chemical sampling locations.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Preparation of gas samples for analysis	HP-86,R0	Method for degassing carbon dioxide and water (vapor) samples from unsaturated zone test holes	16 May 88
Analysis of gas samples	HP-07,R0	Use of a trace gas for determining atmospheric contamination in a dry-drilled bore-hole	30 Sept 87
	HP-127,R0	Carbon-14 dating by tandem acceleration mass spectrometer	TBD
	TBD	Data archiving, shipping, and handling procedure	TBD
	TBD	Procedure for analysis of of constituent stable isotopes of water	TBD
	TBD	Method for carbon-13 determination	TBD
	HP-160,R0	Methods for collection and analysis of samples for gas composition by gas chromatography	16 Jun 88

[a]TBD = to be determined.

8.3.1.2.2.7.2 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.

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 8.3.1.2-20. 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 h, 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.

Pore water in the unsaturated zone may originate from above as downward percolating water or it may originate from below as water remaining from a previous period of saturation when the water table would have been higher. These alternative concepts will be tested in part by applying, in combination, the following hydrochemical criteria:

1. Age of pore water. If pore water is derived from above, its age would generally be expected to increase with depth. Pore water derived from below would generally be expected to have similar ages throughout the stratigraphic section.

2. Composition of fluid inclusions along fracture planes. During the crystallization of minerals or during recrystallization following fracturing, small amounts of water may become trapped within mineral grains. The isotopic and chemical composition of the fluid can indicate water sources and the temperature at which the minerals precipitated. For example, in general, higher temperature would indicate an origin from below.

3. General water chemistry. Chemical composition, including trace elements and anion-cation distribution, may provide supporting evidence of the water's origin by, for example, providing signatures of distinctive water types.

4. Stable isotope compositions. The oxygen-18 to oxygen-16 and deuterium to hydrogen ratios of pore waters generally would be expected to vary with depth if pore water is derived from above. Pore water derived from below generally would be expected to have similar ratios throughout the section.

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-)		
Collection and transportation of water samples	HP-131,R0	Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis	13 Jun 88
Extraction of water from core and rubble-core samples	HP-110,R0	Extraction of pore waters by centrifuge methods	8 Jun 88
	HP-125,R0	Method for extraction of pore water from tuff cores by triaxial compression	20 May 88
	HP-126,R0	Extraction of residual water from tuff samples by vacuum distillation	15 Jun 88
Analysis of water samples	HP-08,R0	Methods for determination of inorganic substances in water	6 Aug 82
	HP-11,R0	Methods for determination of radioactive substances in water	18 Jun 82
	HP-127,R0	Carbon-14 dating by tandem acceleration mass spectrometer	TBD[a]
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Analysis of water samples (continued)	TBD	Procedure for determining the presence of tracers in pore water samples	TBD

[a]TBD = to be determined.

8.3.1.2.2.8 Study: Fluid flow in unsaturated, fractured rock

The purpose of this study is to develop and refine conceptual and numerical models describing both gas flow as well as liquid water and solute movement in unsaturated, fractured rock. The primary function of these models will be to help design and interpret hydrologic and pneumatic tests, and to provide information about model parameters that can be incorporated into site-scale models (Study 8.3.1.2.2.9). As such, the models to be developed in this study are intended for application primarily at both the laboratory and sub-REV (representative elementary volume) scales. The REV for a given parameter is that volume of rock at which the model parameter becomes relatively invariant with further increases in scale. At the scale of the REV, the true medium can be replaced conceptually with an equivalent porous medium whose behavior is described by that parameter. By definition, the real and fictitious media exhibit sufficiently similar behavior at that scale with regard to the process in question.

The validity of conceptual and numerical models describing fluid and solute movement in fractured, porous rock will be assessed through experiments conducted at various scales in both the exploratory shaft facility (ESF) and in the laboratory. In addition, different modeling approaches that consider different scales and different levels of complexity will be compared to determine the adequacy of more simplified modeling approaches. In particular, the limitations of treating the fractured rock mass as a composite, homogeneous continuum will be evaluated.

The activities associated with this study also will directly address regulatory issues that concern flow path characterization and determination of ground-water fluxes and travel times within the unsaturated zone. The activities planned for this study include (1) conceptualization and numerical modeling of the unsaturated-zone hydrogeologic system at the sub-REV scale and (2) comparison of the more detailed modeling approaches with experiments to be conducted within the laboratory and in the ESF.

8.3.1.2.2.8.1 Activity: Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock

Objectives

The objective of this activity is to develop detailed conceptual and numerical models of fluid flow and transport within unsaturated, fractured rock at Yucca Mountain. These models will be applied to volumes of fractured rock at or below the dimensions at which the rock can be replaced conceptually by an equivalent porous medium. Models that consider the system in greater detail or complexity will provide a synthetic data base against which the simulated results of more simplified modeling approaches applied at larger scales can be compared.

Parameters

The parameters for this activity are

1. Fluid and solute fluxes through variably-saturated, fractured rock.

2. Description of the scale dependence of pneumatic, hydrologic and transport parameters.

Description

Conceptual and numerical models that consider fluid flow and transport in fractured rock at various spatial scales and levels of detail will be developed to examine the appropriateness of applying different models at different scales. Sub-REV (representative elementary volume) modeling efforts will support site-scale modeling (Study 8.3.1.2.2.9) by providing information about model parameters appropriate to the larger scale. Sub-REV modeling will examine the implications of spatial heterogeneity within the smallest volume considered as homogeneous within the site-scale model. For instance, sub-REV scale modeling will address the manner in which point measurements of state variables, obtained during monitoring, may be related to volume-averaged values predicted by model simulations performed at the site scale.

The effect of spatial scale on pneumatic, hydrologic, and transport parameters for single fractures and for fracture networks will be evaluated, as will the appropriateness of replacing a fractured rock mass with a stochastic continuum. Detailed modeling approaches that consider fractures as discrete entities, or models that treat the fractured rock mass as a stochastic continuum, will be used to determine the adequacy of simplified modeling approaches that treat the fracture and matrix domains as a composite, homogeneous continuum.

The conceptual model will consider the microscopic processes that influence fluid flow and solute transport both within single fractures with spatially varying aperture, and within networks containing fractures with statistically distributed hydraulic apertures. Those aspects of fluid flow and transport to be evaluated include (1) fluid flow and transport through variably saturated, rough fractures; (2) fluid flow and transport through a network of variably-saturated fractures; (3) fluid and tracer exchange between fractures and matrix; (4) small-scale capillary barrier effects between fractures and matrix and among fractures; and (5) gas-phase movement through fractured rock, in volumes of rock at and below the scale of the REV.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.8.1 are given in the following table:

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Estimation of the hydraulic and pneumatic conductivities of a single fracture as a function of matrix potential or saturation	TBD[a]	Procedure for calculating the saturation-matric potential relationship for single fractures from a knowledge of the aperture distribution	TBD
	TBD	Procedure for generating distributions of apertures within a single fracture that are spatially correlated	TBD
	TBD	Procedure for calculating the conductivity-saturation relationship for single fractures from a knowledge of the spatial distribution of apertures along the fracture plane	TBD
	TBD	Procedure for determining the planar area at which a fracture exhibits its equivalent porous media behavior	TBD
Estimation of the transport characteristics of a single fracture as a function of saturation	TBD	Procedure estimating the dispersive characteristics of a single fracture from a knowledge of the spatially distributed apertures	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Estimation of the transport characteristics of a single fracture as a function of saturation (continued)	TBD	Procedure for calculating the effects of solute diffusion from a single fracture into the adjacent matrix	TBD
Estimation of the equivalent hydraulic conductivity of a numerically synthesized, fractured rock mass as a function of average matric potential	TBD	Procedure for numerically synthesizing a network of variable-aperture fractures	TBD
	TBD	Procedure for calculating the average hydraulic gradient across a numerically synthesized, fractured rock mass	TBD
	TBD	Procedure for calculating the average matric potential in a numerically synthesized, fractured rock mass with spatially varying matric potential	TBD
	TBD	Procedure for determining the dimensions of the representative elementary volume (REV) with regard to fluid-flow processes within a numerically synthesized, fractured rock mass	TBD
Estimation of the transport characteristics of a numerically synthesized, fractured rock mass	TBD	Procedure for estimating the dispersive characteristics of a numerically synthesized, fractured rock mass	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Estimation of the transport characteristics of a numerically synthesized, fractured rock mass (continued)	TBD	Procedure for estimating the effective porosity of a numerically synthesized, fractured rock mass	TBD
	TBD	Procedure for determining the dimensions of the REV with regard to transport processes	TBD
Stochastic continuum modeling	TBD	Procedure for generating random, spatially correlated parameter fields capable of being conditioned on available observations	TBD
	TBD	Procedure for describing the spatial variability of the model parameters	TBD
	TBD	Procedure for assigning levels of uncertainty to each value in a distribution of results predicted by Monte Carlo simulation	TBD

[a]TBD = to be determined.

8.3.1.2.2.8.2 Activity: Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock

Objectives

The objective of this activity is to evaluate the reasonableness of the concepts on which the models developed under Activity 8.3.1.2.2.8.1 are based, by using the results of laboratory tests and tests performed in the exploratory shaft facility (ESF) to access the adequacy of model performance.

Parameters

The parameter for this activity is the validity of conceptual and numerical models describing fluid flow and transport in variably saturated, fractured rock.

Description

Hypotheses that describe fluid flow and transport processes in fractured rock are preliminary in nature and will require validation through field and laboratory testing, as described in Study 8.3.1.2.2.4. The process of model validation is intended to ensure that the model can adequately describe the system to which it is being applied. As discussed in the previous activity (8.3.1.2.2.8.1), the reasonableness of a modeling approach can often be evaluated by comparing simulated results from the model with those of a more detailed, and presumably more accurate and realistic model. The limitations of a simpler model can often be exposed in this manner. However, those models determined to be compatible and internally consistent must still be tested by devising experiments that isolate and test individual components in each model. This ensures that these components adequately describe the physical processes at the temporal and spatial scales at which the model application is to be made. By comparing measured and simulated results, a determination is then made as to whether or not the model appears to be adequate for its intended application. In the context of waste repository licensing, "adequacy" may mean simply that the model is accurate enough that a clear-cut decision may be made concerning whether the proposed facility would satisfy the regulatory requirements.

The need to isolate and test the individual components of the overall model provides the rationale for conducting a series of hydrologic tests in both the laboratory and exploratory shaft facility that consider progressively increasing spatial scales. The intact-fracture test (Activity 8.3.1.2.2.4.1) will test models that predict the unsaturated hydraulic characteristics of single fractures based on measurable geometric parameters, such as aperture distribution. This test will also attempt to establish statistical relationships between fracture parameters and to estimate confidence intervals for model predictions by regressing data measured on model-predicted results.

The numerical and conceptual models examined with the intact-fracture test will be used to provide independent estimates of the hydraulic properties associated with each fracture identified in the percolation test block (Activity 8.3.1.2.2.4.2). The confidence intervals associated with these model predictions provide the limits within which estimates of the hydrologic characteristics for individual fractures may be changed when attempting to match measured fluid and solute fluxes from the percolation test block with simulated results. Statistical relationships established between fracture parameters in the intact-fracture test may also provide additional constraints when assigning fracture hydrologic characteristics to individual fractures in model simulations of the percolation test in the ESF (Activity 8.3.1.2.2.4.2).

The percolation test in the ESF itself will provide an opportunity to compare simulated results with physical measurements of fluid and solute fluxes in variably saturated, fractured rock under conditions in which the boundary conditions and flow-system geometry are reasonably well known. In particular, the percolation test in the ESF will be used to determine the ability of various fracture network or stochastic modeling approaches to estimate the bulk effective parameters of an unsaturated, fractured rock mass. The parameters to be estimated include effective bulk-rock conductivity, effective porosity and dispersivity, each as a function of the overall saturation or average matric potential of the rock mass.

The bulk-permeability test (Activity 8.3.1.2.2.4.3) will employ cross-hole, air-permeability testing methods to determine the scale at which the host rock behaves as an equivalent anisotropic, porous medium, and to determine the directional permeabilities at that scale. The measured dimensions at which porous media behavior is observed and the associated directional permeabilities will be compared against a distribution of simulated results. These results are calculated by assuming various system geometries compatible with available observations. This approach is necessary because the actual distribution of high-permeability conduits in such a large rock volume is not expected to be known except in a statistical sense, for example, in terms of average fracture orientations and/or fracture density.

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	Technical procedure Title	Technical procedure Date
Estimation of the hydraulic and pneumatic conductivities of a single fracture as a function of matric potential or saturation	TBD[a]	Procedure for calculating the saturation-matric potential relationship for single fractures from a knowledge of the aperture distribution	TBD
	TBD	Procedure for generating spatially correlated distributions of apertures within a single fracture	TBD

Method	Technical procedure Number	Title	Date
Estimation of the hydraulic and pneumatic conductivities of a single fracture as a function of matrix potential or saturation (continued)	TBD	Procedure for calculating the conductivity-saturation relationship for single fractures from a knowledge of the spatial distribution of apertures along the fracture plane	TBD
	TBD	Procedure for determining the planar area at which a fracture exhibits equivalent porous medium behavior	TBD
Estimation of the transport characteristics of a single fracture as a function of saturation	TBD	Procedure for estimating the dispersive characteristics of a single fracture from a knowledge of the spatially distributed apertures	TBD
	TBD	Procedure for calculating the effects of solute diffusion from a single fracture into the adjacent matrix	TBD
Estimation of the equivalent hydraulic conductivity of a numerically synthesized, fractured rock mass as a function of average matric potential	TBD	Procedure for numerically synthesizing a network of variable-aperture fractures	TBD
	TBD	Procedure for calculating the average hydraulic gradient across a numerically synthesized, fractured rock mass	TBD

Method	Technical procedure Number	Title	Date
Estimation of the equivalent hydraulic conductivity of a numerically synthesized, fractured rock mass as a function of average matric potential (continued)	TBD	Procedure for calculating the average matric potential in a numerically synthesized, fractured rock mass with spatially varying matric potential	TBD
	TBD	Procedure for determining the dimensions of the representative elementary volume (REV) with regard to fluid-flow processes	TBD
Estimation of the transport characteristics of a numerically synthesized, fractured rock mass	TBD	Procedure for estimating the dispersive characteristics of a numerically synthesized, fractured rock mass	TBD
	TBD	Procedure for estimating the effective porosity of a numerically synthesized, fractured rock mass	TBD
	TBD	Procedure for determining the dimensions of the REV with regard to transport processes	TBD
Stochastic continuum modeling	TBD	Procedure for generating random, spatially correlated parameter fields capable of being conditioned on available observations	TBD
	TBD	Procedure for describing the spatial variability of the model parameters	TBD

Method	Technical procedure Number	Title	Date
Stochastic continuum modeling (continued)	TBD	Procedure for assigning levels of uncertainty to each value in a distribution of results predicted by Monte Carlo simulation	TBD
Validation through comparison of simulated and measured results	TBD	Procedure for independently calibrating a numerical model	TBD
	TBD	Procedure for determining which aspects of a numerical model require validation	TBD
	TBD	Procedure for estimating the probability density function (pdf) of model parameters from measured data	TBD
	TBD	Procedure for determining the adequacy of model performance	TBD

[a]TBD = to be determined.

8.3.1.2.2.9 Study: Site unsaturated-zone modeling and synthesis

The purpose and activities of this study are to (1) develop appropriate conceptual models for the site unsaturated-zone hydrogeologic system; (2) select, modify, or develop numerical hydrologic models capable of simulating the hydrogeologic system and its component subsystems; (3) apply the models to predict the system response to changing external and internal conditions; (4) evaluate the accuracy of the models using stochastic modeling, conventional statistical analyses, and sensitivity analyses; and (5) integrate data and analyses to synthesize a comprehensive qualitative and quantitative description of the site unsaturated-zone hydrogeologic system under present as well as probable, or possible, future conditions. The ultimate goal of this synthesis is to address those information needs for the overall unsaturated-zone hydrogeologic system that pertain to demonstrating site compliance, or noncompliance, with the regulatory criteria and guidelines for the long-term storage of high-level nuclear waste in a mined geologic repository in the unsaturated zone at Yucca Mountain.

8.3.1.2.2.9.1 Activity: Conceptualization of the unsaturated-zone hydrogeologic system

Objectives

The objectives of this activity are to develop conceptual models for the overall moisture flow system within the unsaturated zone at Yucca Mountain. The conceptual models of the system and component subsystems constitute the basis both for the hydrologic testing program at the site and for numerical hydrologic modeling of the site. Conceptual-model development is an ongoing, iterative process by which hypotheses and alternative hypotheses are tested using laboratory experiments, field experiments, and numerical modeling. Hypotheses may be accepted, rejected, revised, or refined. The goal is to develop an internally consistent set of hypotheses that describe those aspects of the site hydrogeologic system that are needed to assess the capability of the site to isolate nuclear waste for a period of 10,000 yr or longer.

Parameters

The parameters of this activity are

1. Model elements that include the
   a. Geologic frame work of the system.
   b. Boundary and initial conditions for the system.
   c. Hydrologic and other related physical processes that operate within the system under the constraints imposed by the geologic framework and the boundary and initial conditions.
2. Sets of hypotheses that
   a. Describe and quantify the model elements.
   b. Are compatible with the available empirical data for the system.
   c. Are as simple as possible with respect to the system's known complexity and data.
   d. Are mutually consistent.

More than one set of hypotheses may satisfy the above requirements but differ in that one or more hypotheses of one set may conflict with hypotheses in the other sets. Such an occurrence of competing hypotheses gives rise to the notion of alternative conceptual models and the possible need to perform tests or experiments to eliminate nonviable hypotheses.

Description

Conceptual models for natural hydrogeologic systems are discussed in general terms in Section 3.9 and are particularized to the Yucca Mountain site in Section 3.9.3. The conceptual model of a system consists of a set of elements that describe the geologic framework for the system, delimit the hydrologic boundary conditions acting on the system, and identify the hydrologic and other related physical processes (e.g., moisture flow, heat flow, tectonic stresses, etc.) operating within the system. The internal system processes operating under the constraints imposed by the geologic framework and the boundary conditions determine the instantaneous state of the system. Because the model elements, in general, tend to change with time, the state of the system also tends to change with time. Consequently, the conceptual model must address the issue of system dynamics and response.

The state of an unsaturated-zone hydrogeologic system is defined, for example, by the spatial distributions of matric potential, liquid-water saturation, pore-gas pressure, temperature, and tectonic stress. The processes operating within the system, together with time-varying internal or external constraints, may cause any one or more of these state variables to change and, in turn, to alter the state of the system. The conceptual model for the system seeks to identify and quantify those principal relations between system processes and constraints that control the state of the system and, thus, that govern the performance of the system. In the present context, those elements of system performance that relate to the isolation of high-level nuclear waste are of principal concern, and thus the conceptualization of the system must be directed toward these elements.

In general, the conceptual model of a system consists of a set of empirical data obtained from the system together with sets of hypotheses corresponding to each of the model elements for the system. A viable conceptual model requires that the hypotheses fit the available data, be as simple as is compatible with the data and known system complexity, and be mutually consistent. The sets of possible hypotheses satisfying these conditions need not be unique, and the occurrence of conflicting or competing hypotheses gives rise to the notion of alternative conceptual models.

If competing hypotheses are shown to affect important aspects of system performance, then tests must be devised to select from the competing hypotheses the one hypothesis that best applies to the system. Because complete knowledge of a macroscopic system and its governing processes and constraints is not attainable, formulating a conceptual model includes attempting to develop the simplest set of mutually consistent hypotheses that accounts for the essential aspects of system performance.

Even if no ostensible internal conflicts exist, a conceptual model is by no means a fixed entity. The acquisition of new or improved data from laboratory or field measurements and tests, the results of numerical experiments, and the reconceptualization of model elements (for example, during peer review) may require that the conceptual model be revised with the addition of new hypotheses and the elimination or revision of previously accepted hypotheses. The development of a conceptual model, therefore, must be regarded as an evolving, frequently iterative process. In general, each hypothesis must be regarded as tentative and subject to continual examination and testing. Many of the field and laboratory experiments and tests of the site characterization program are directed at examining the validity of hypotheses and at quantifying tenable hypotheses.

Independent peer review will be an important aspect of conceptual-model development. Peer review will be used to examine the completeness and the consistency of the conceptual-model hypotheses, and to ensure that the physics and mathematics of process hypotheses are formulated correctly. Changes in the conceptual model also should be subjected to appropriate peer review to ensure that the changes are both necessary and sufficient with respect to obtaining a correct conceptual representation of the hydrogeologic system.

The hypotheses that constitute the current but provisional conceptual model for the site unsaturated-zone hydrogeologic system are listed in Table 8.3.1.2-2b together with viable alternative hypotheses and an assessment of their uncertainty and significance.

Methods and technical procedures

Because conceptual-model development is largely a mental exercise, it does not lend itself to the establishment of formalized procedures. The formal methods and technical procedures that will be used in Activity 8.3.1.2.2.9.1 are listed in the following table.

Method	Technical procedure		
	Number	Title	Date
Hypothesis testing	TBD[a]	TBD	TBD
Peer review	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.2.2.9.2 Activity: Selection, development, and testing of hydrologic-modeling computer codes

Objectives

The objectives of this activity are twofold: (1) to select, evaluate, and adapt existing numerical hydrologic-modeling codes for application to the site unsaturated-zone hydrogeologic system and (2) to modify existing codes or develop new codes, as needed, to simulate particular problems or aspects that are unique to the Yucca Mountain system. Code modification and development will require the additional activities of testing (e.g., code verification) and documentation.

Parameters

The parameters of this activity consist of the attributes of the numerical hydrologic computer codes that are selected or developed:

1. Code geometry: One-, two-, or three-dimensional.

2. Discretization method: Finite-differences, finite-element, or integrated finite-difference.

3. Boundary conditions: Dirichlet, Neumann, mixed, evaporate, seepage-face, evapotranspiration, etc.

4. Hydrologic and coupled processes: Variably saturated liquid-water flow, gas-phase flow, water-vapor concentration and transport, heat flow, solute transport, chemical kinetics, stress-field dynamics, two-phase flow in fractures, etc.

5. Solution methodology: Picard iteration or Newton-Raphson linearization.

6. Matrix solver: Direct or iterative.

Description

Various available computer codes are capable of performing mathematical simulations of complex multiphase, variably saturated hydrogeologic systems. These codes differ, however, in terms of (1) the physical processes they include, (2) the types of boundary conditions they allow, (3) the numerical procedures they invoke, (4) the efficiency with which they perform the various numerical and logical operations, (5) the dimensionality and geometry of the systems they can represent, (6) the computer resources they require, and (7) the ease with which they can be implemented and adapted to solve particular modeling problems. The codes under consideration here provide the physical and mathematical foundation for the construction of predictive numerical models for hydrogeologic systems. The selection of any one or more codes depends upon the problem being solved; the degree of accuracy desired; the possible limitations of available computer resources and funding; and, finally, the degree of approximation to which the physical processes and mathematical procedures embodied in the code represent the elements of the conceptual model of the system.

None of the available codes is expected to be capable of solving all the problems expected with respect to the site unsaturated-zone hydrogeologic system. Consequently, existing codes will require some modification, and new codes will need to be developed, especially for those problems unique to the Yucca Mountain site. For example, Study 8.3.1.2.2.8 is devoted both to understanding the physics of fluid flow and solute transport in partially saturated fractures that transect variably saturated tuff and to developing appropriate quantitative models and codes to simulate fluid-flow processes in variably saturated fractures and fracture networks.

Even though the application of existing documented and verified codes to some specific Yucca Mountain problems may be straightforward, code modification and code development will require that both the new and modified codes be thoroughly tested and documented before their application to site problems. Code testing will include code verification, which demonstrates that the code performs all of the mathematical and logical procedures correctly, as well as testing to demonstrate that the code is indeed applicable to the types of problems for which it is intended. Code verification will be performed by comparing the results produced by the code for a particular problem against existing known analytic or numerical solutions for the problem. Empirical testing of the model will be performed by comparing model results against data obtained from laboratory or field experiments that are analogs to the intended application of the code.

Complete documentation of the new or modified codes will include a description of the physical and mathematical basis of the code, instructions and requirements for implementing the code, and the results of at least some selected set of verification and empirical-testing exercises performed on the code (Silling, 1982). Both the documentation and the code will be subject to thorough independent peer review before any application of the code to develop a model or models for the Yucca Mountain system or any relevant subsystem.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.9.2 are listed in the following table.

Method	Technical procedure		
	Number	Title	Date
Code verification	TBD[a]	TBD	TBD
Empirical model testing	TBD	TBD	TBD
Code documentation	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.2.2.9.3 Activity: Simulation of the natural hydrogeologic system

Objectives

The objectives of this activity are to construct appropriate hydrologic models for the natural site hydrogeologic system to (1) simulate and invest gate the present existing state of the system, and (2) predict probable future and past states of the system under changes in the environmental conditions.

Parameters

The parameters of this activity are

1. Time-dependent spatial distributions of matric potential, liquid-water, saturation, pore-gas pressure, water-vapor concentration, moisture flux, and temperature.

2. Boundary fluxes, pressures, and potentials.

3. Hydrologic and thermomechanical properties for the component hydrogeologic units.

Description

A numerical hydrologic model or combination of models will be constructed to simulate mathematically the coupled, simultaneous flow of moisture, gas, and heat within the unsaturated zone underlying the primary repository area. The construction of these flow models follows directly as a continuation and an expansion of the conceptual model development for the site hydrogeologic system (Activity 8.3.1.2.2.9.1). The basic purpose of this modeling activity is to continue but enlarge that scope of identifying and testing the hydrologic conditions, concepts, and processes that control the site hydrogeologic system. It is intended, however, that 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 possible within the practical constraints imposed by finite numerical simulations of complex physical systems. A final flow model or set of models, will be used subsequently to perform baseline analyses to (1) predict possible future or past states of hydrogeologic system and (2) support the final system synthesis and integration (Activity 8.3.1.2.2.9.5).

The input and output data for the models 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 environmental conditions that determine the flux, potential, and pressure distributions on the spatial boundaries of the model. In general the land surface will define the upper system boundary, and the water table will define the lower boundary for the models; the lateral hydrogeologic boundaries must enclose the primary repository area, but their exact locations remain to be established. The material property data for the hydrogeologic units will be obtained from field and laboratory determinations and will become available as site characterization proceeds. The environmental conditions that define the present hydrogeologic boundary conditions include the present and past site climatic and tectonic settings.

The output data generated by the models 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 flux. To the extent that the mathematical formulation of the models incorporates all the significant physical processes and conditions that control the hydrogeologic system, flow models yield internally self-consistent mathematical representations of the hydrogeologic system and its evolution with time. The probable accuracy and validity of this representation is considered under Activity 8.3.1.2.2.9.4 (stochastic modeling and uncertainty analysis). The moisture- and pore-gas flux distributions computed from the flow models provide requisite input data for subsequent solute-transport and hydrochemical modeling.

Some of the specific issues to be addressed by the construction of these models are to (1) develop strategies and methodologies for constructing three-dimensional, fluid-flow models for the site hydrogeologic system; (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 the upward diffusion or advection of water vapor in fractures coupled to a corresponding downward return flow of liquid water within the rock matrix; (4) establish limiting conditions under which capillary barriers and perched water bodies zones can be expected to occur; (5) assess the effects produced by variations with space and time in assumed land-surface net-infiltration rates; and (6) investigate the impact of time-dependent stress and thermal fields on the unsaturated-zone hydrogeologic flow system (Study 8.3.1.15.2.1, characterization of the site ambient stress conditions; Study 8.3.1.15.2.2, characterization of the site ambient thermal conditions). An important task of this activity is to identify those hydrogeologic processes and concepts that are essential for a valid mathematical representation for performance assessment analyses and to eliminate those that can be shown to be of sufficiently negligible effect. The final flow model or models, thus, are intended to provide a summary numerical description of the site hydrologic flow system.

The final flow models will be used to perform a set of baseline simulations of the natural hydrogeologic system. A simulation of the presently existing natural system will be used as the initial conditions to perform a sequence of simulations to extrapolate the system both forward and backward in time. The forward extrapolation will be based on the most probable changes expected in the site climatic regime derived from Study 8.3.1.5.1.6 (characterization of the future regional climate and environment) and in the water-table configuration derived from Study 8.3.1.8.3.2 (analysis of the effect of tectonic processes and events on changes in water-table elevation). The backward extrapolations will be based on past climatic 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 will be estimated as part of Activity 8.3.1.2.2.9.4 (stochastic modeling and uncertainty analysis). These flow models will be used to define flow paths and calculate fluxes and velocities within the unsaturated zone, as described under Activity 8.3.1.2.2.9.5 (system synthesis and integration).

The site-characterization hydrogeologic modeling to be performed as part of this activity is both complementary to and essential to the modeling that will be performed as part of performance-assessment activities. The site characterization models are intended to describe site conditions and processes and to evaluate the response of the site as a whole to changes in the local and regional climatic and tectonic settings. The performance-assessment models focus on the operation of the repository with respect to its components and immediate environment. The repository and its environment, however, are embedded in and interact with the overall site hydrogeologic system. The site models will be used to predict overall site behavior and, thereby, to evaluate the interaction between the internal state of the site and the repository system and environment. For example, the site hydrogeologic models will be used to predict the spatial and temporal distributions of both liquid-water and pore-gas fluxes within and near the repository environment. These flux distributions provide boundary-condition input data for the performance-assessment models that will be used to evaluate pre-waste-emplacement ground-water travel time and to simulate solute-transport processes. Solute-transport models will be used to assess the rates and magnitudes of possible future transport of radionuclides from the repository to the accessible environment.

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		
	Number	Title	Date
Two- and 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

Method	Technical procedure Number	Title	Date
Baseline analyses	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.2.2.9.4 Activity: Stochastic modeling and uncertainty analysis

Objectives

The objective of this activity is to assess the probable limits of uncertainty of numerical-model predictions caused by uncertainties in the material-property and boundary-condition data.

Parameters

The parameters of this activity are

1. Measurement errors.
2. Statistical distribution functions.
3. Probable limits of uncertainty.

Description

An important aspect of modeling physical systems is to assess the accuracy with which the model predictions represent the real system and, thereby, to establish the validity of the model with respect to its intended application. As discussed in Section 8.3.5.20.4 (model validation), the classical approach to model validation is to compare directly the model predictions with the observed system performance. The models that will be applied to address repository postclosure issues, however, are required to predict the effects of probable or possible changing conditions over the next 10,000 to 100,000 yr. Consequently, direct model validation is infeasible. Indirect methods must be employed to establish model credibility and to provide reasonable assurance that the long-term model predictions coupled with asymptotic bounding calculations are sufficient to assess the long-term performance of the repository and its subsystems. For hydrogeologic models, uncertainty analyses can be performed to assess model accuracy, stability, and asymptotic behavior.

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 performance of the physical system that the model is intended to simulate. 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 described in Activity 8.3.1.2.2.9.3 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 empirically determined uncertainty-distribution functions. These distribution functions will be estimated by classical statistical and geostatistical analyses to be conducted as part of this activity or of Activity 8.3.1.2.2.3.1 (matrix hydrologic properties testing). 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 will 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 8.3.1.2.2.9.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Estimation of hydrologic property uncertainty distribution function	TBD[a]	TBD	TBD
Monte Carlo simulation analysis	TBD	TBD	TBD
Sensitivity analyses	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.2.2.9.5 Activity: Site unsaturated-zone integration and synthesis

Objective

The objective of this activity is to integrate all applicable site data and analyses in order to synthesize a continually updated, comprehensive representation for the site unsaturated-zone hydrogeologic system. Attention will focus both on the present state of the system as well as on the implications concerning probable, or possible, future and past states of the system.

Parameters

The significant parameters of this activity are the elements that define the state of the hydrogeologic system:

1. The site geologic framework and its change with time.

2. The site water-table configuration and its change with time.

3. Land-surface net infiltration to the unsaturated zone and its distribution in space and time.

4. The spatial distributions of temperature and stress within the unsaturated zone and their change with time.

5. The spatial distribution of moisture flux within the unsaturated zone and its change with time.

Description

As site characterization progresses, a diverse set of empirical data, quantitative analyses, and interpretations will become available for the site unsaturated-zone hydrogeologic system. These data, analyses, and interpretations will be continually integrated with the prevailing conceptual model for the system in order to synthesize overall representations of the system. These representations will be examined for internal consistency and completeness. Consequently, system integration and synthesis are envisioned to be an ongoing activity that will review the validity of the prevailing conceptual model as well as the data acquisition and experimental program to ensure that, to the extent possible, all critical hydrogeologic data are being collected, and the appropriate hypotheses are being tested.

The synthesis performed at the end of the site characterization program is intended to yield a best possible representation of the current state of the hydrogeologic system together with inferences concerning past states of the system. This information will be used to extrapolate the system forward in time to predict short-term system behavior that can be compared with observed system behavior during the performance-confirmation period. Predictions of long-term system performance will have been made before and possibly during the licensing process. Performance-confirmation monitoring will provide a partial set of confirmatory data that can be integrated into the system synthesis to provide a partial test of the validity of the synthesis. Further numerical modeling can be performed to check specific aspects of observed performance-confirmation system dynamics and response.

Assessments of the current state of system integration and synthesis are to be presented as progress and status reports to be issued periodically. Peer review will be an important aspect to ensure the integrity of the system integration and synthesis process. By issuing progress reports, not only will the process of system integration and synthesis be formalized, but implementation of the peer review process also will be facilitated.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.2.9.5 are listed in the following table.

Method	Technical procedure		
	Number	Title	Date
System integration and synthesis	TBD[a]	TBD	TBD
Peer review	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.2.2.10 Application of results

The parameters evaluated by the planned studies and activities just described will be used in the following issues, information needs, and investigations of site characterization, repository design, and performance assessment programs:

Number	Subject
1.1.1	Site information needed for calculations of releases of radionuclides 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)

Number	Subject
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 8.3.5.1.0.3)
1.6.1	Site information and design concepts needed (identification of the fastest path of likely radionclide travel and calculation of 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 ground-water travel paths (Section 8.3.5.12.3)
1.6.4	Pre-waste-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)
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)

Number	Subject
4.4.5	Reference preclosure design (potential impacts of hydrologic characteristics on design) (Section 8.3.2.5.5)
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
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
8.3.1.14.2	Soil and rock properties
8.3.1.16.3	Ground-water conditions within and above the potential host rock

8.3.1.2.3 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:

SCP section	Subject
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)
3.9.2.2.2	Transmissivity and hydraulic conductivity (saturated zone)
3.9.2.2.3	Porosity and storage coefficients (saturated zone)

Number	Subject
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. Characteristics of geohydrologic units: spatial distribution of the physical and hydraulic properties of the rock units in the saturated zone at the site.

2. Characteristics of ground-water flow: 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:

Study	Subject
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)
8.3.1.2.2.9	Unsaturated zone system analysis and integration (unsaturated zone recharge boundary condition to saturated zone)

Study	Subject
8.3.1.4.2.1	Characterization of the vertical and lateral distribution of stratigraphic units (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 units. Modeling activities will use the resulting information to calculate ground-water 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 properties of faults, 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 hydrologic boundary conditions for the site saturated-zone hydrogeologic system will be based on the results of the two-dimensional subregional model (Section 8.3.1.2.1.4.2), the subregional two-dimensional cross-sectional model (Section 8.3.1.2.1.4.3), and the regional three-dimensional model (Section 8.3.1.2.1.4.4).

Hydraulic properties of faults

The repository block is approximately defined by faults. Numerous normal, west-dipping faults occur east of the block, and the block is bounded on the west by the Solitario Canyon fault. Strike-slip faults of northwest strike probably underlie Drill Hole Wash, bounding the block on the northeastern side.

Faults may act as barriers or conduits for ground-water flow, depending on the fault properties. The Solitario Canyon fault coincides in general with a steep gradient in the potentiometric surface, and, therefore, may act as a barrier. As part of the effort to understand the cause of the steep gradient and the potential for its modification, the hydraulic properties of the Solitario Canyon fault will be specifically evaluated (Activity 8.3.1.2.3.1.1). At Solitario Canyon, stratigraphic offset of high permeability zones against zones of low permeability could create a barrier, independent of the permeability characteristics of the fault itself.

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 numerical 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.

The normal faults east of the block coincide with a nearly flat gradient in the potentiometric surface and, therefore, are assumed to act as conduits. Because these faults are expected to be hydraulically indistinguishable from the surrounding fractured tuff, no tests are designed specifically to evaluate the hydraulic properties of these faults. Rather, those evaluations are included in the general analysis of aquifer properties (see discussion following hydraulic gradients discussion). The effects on ground-water flow of faults that probably underlie Drill Hole Wash will be evaluated as part of Activities 8.3.1.2.3.1.2 and 8.3.1.2.3.1.4 of this investigation.

Hydraulic gradients

At drillhole UE-25p#1, the hydraulic head 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 8.3.1.2-21).

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 fluctuations due to barometric changes, earth tides and possibly other phenomena, although small, are greater than apparent

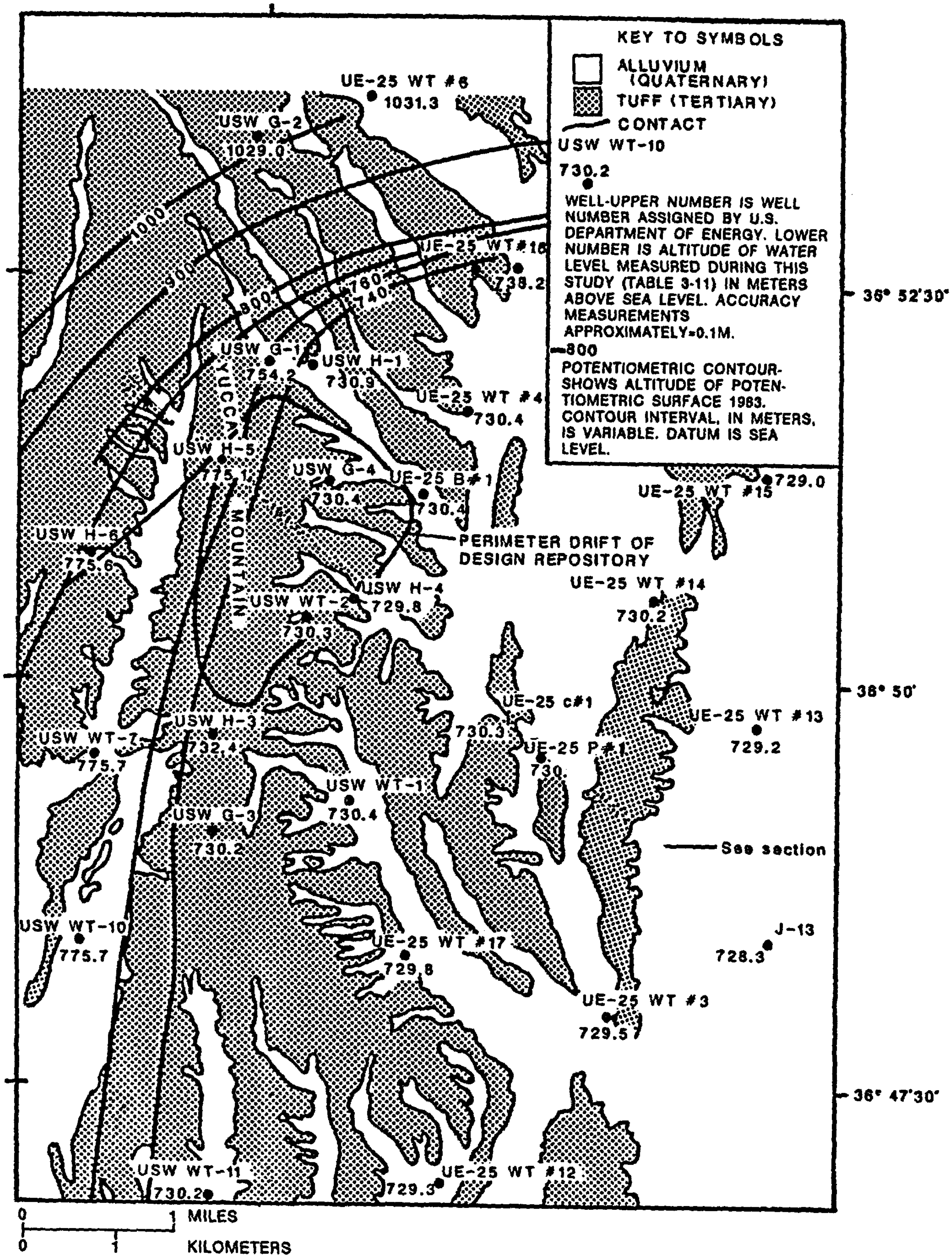


Figure 8.3.1.2-21. *Preliminary composite potentiometric-surface map of the saturated zone, Yucca Mountain (modified from Robison, 1984).*

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 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 8.3.1.2-29 in Section 8.3.1.2.3.1.4). 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 validate 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. Completion of the 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 validate 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-hydrogeologic 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 accounts realistically 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 the 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 single- and multiple-well 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 hydrogeologic 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 8.3.1.2-22. 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 8.3.1.2-22). 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.

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 Number	Title	Date
	(NWM-USGS-)		
Borehole geophysical surveys	HP-02,R0	Acoustic televiewer investigations	14 Aug 84
	TBD[a]	Drilling and coring (REECo)	TBD
Water sampling	HP-03,R0	Hydrologic trace-jector test	11 Jan 82
	HP-23,R1	Collection and field analysis of saturated zone ground-water samples	4 Nov 83
	TBD	Borehole fracture logging	TBD
Pumping tests	HP-06,R0	Hydrologic pumping test	11 Jan 82
	HP-60,R0	Method for monitoring water-level changes using pressure transducers	4 May 88

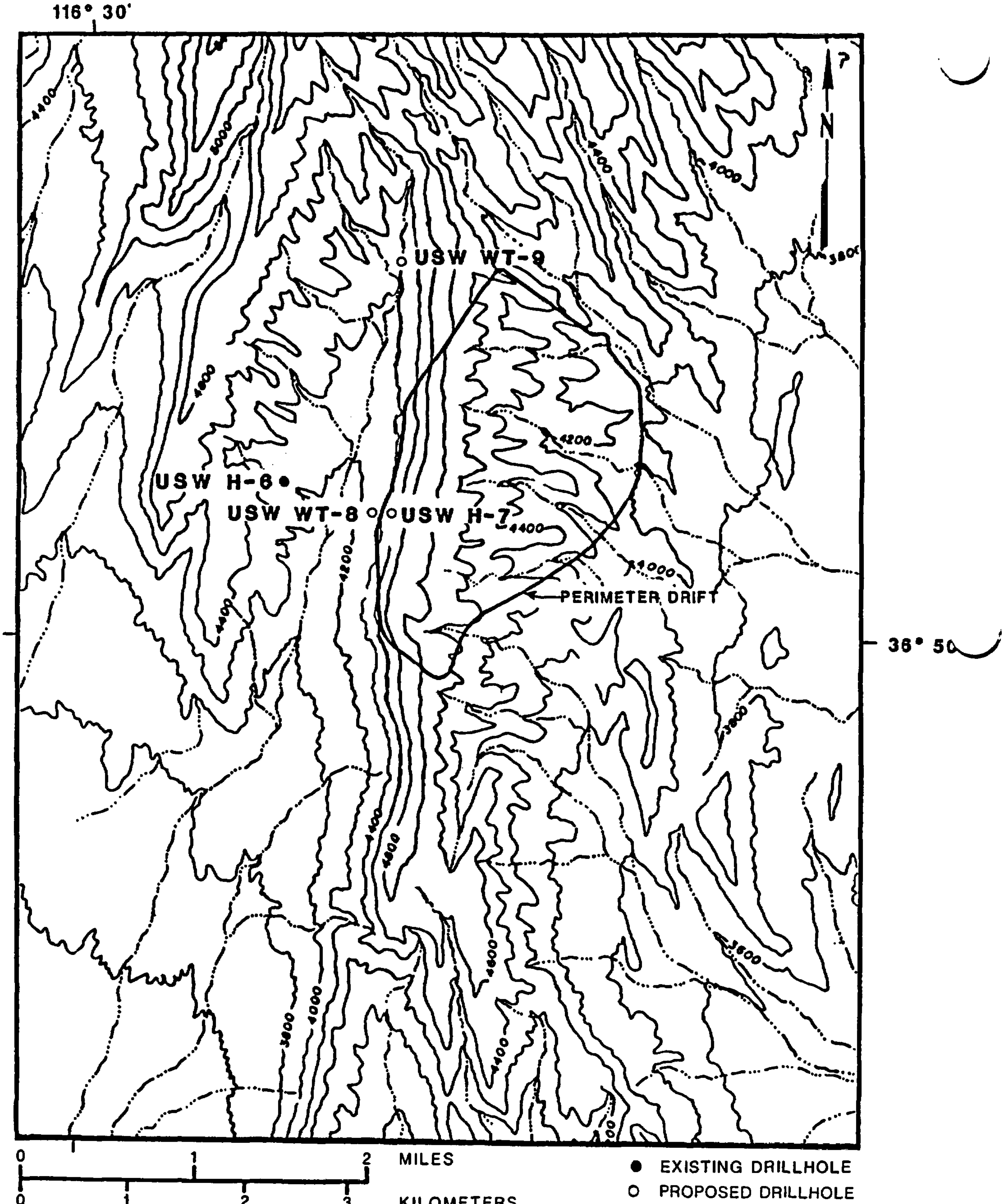


Figure 8.3.1.2-22. Location of the proposed drillholes for the Solitario Canyon fault study in the vicinity of perimeter drift.

Method	Technical Procedure Number	Title	Date
	(NWM-USGS-)		
Pumping tests (continued)	HP-93,R0	Method for processing electronic data from a Campbell Scientific 21X Micrologger into water levels	11 May 88
	HP-85,R0	Method of monitoring water-level changes using a pressure transducer and the Fluke 2280 B Data Logger	TBD

[a]TBD = to be determined.

8.3.1.2.3.1.2 Activity: Site potentiometric-level evaluation

Objectives

The objectives of this study are to

1. Refine time and configuration of the spatial dependence of the potentiometric surface.

2. Measure water-level variations with time in existing borehole and calculate average levels, as input data for hydraulic gradient calculations.

3. Analyze the character and magnitudes of water-level fluctuations to determine their causes, and, if possible, to estimate formation elastic and fluid-flow properties.

Parameters

The parameters for this activity are

1. Physical characteristics of the hydrogeologic units.

2. Hydraulic gradients.

3. Hydraulic diffusivity storage coefficients, hydraulic conductivity, aquifer compressibility.

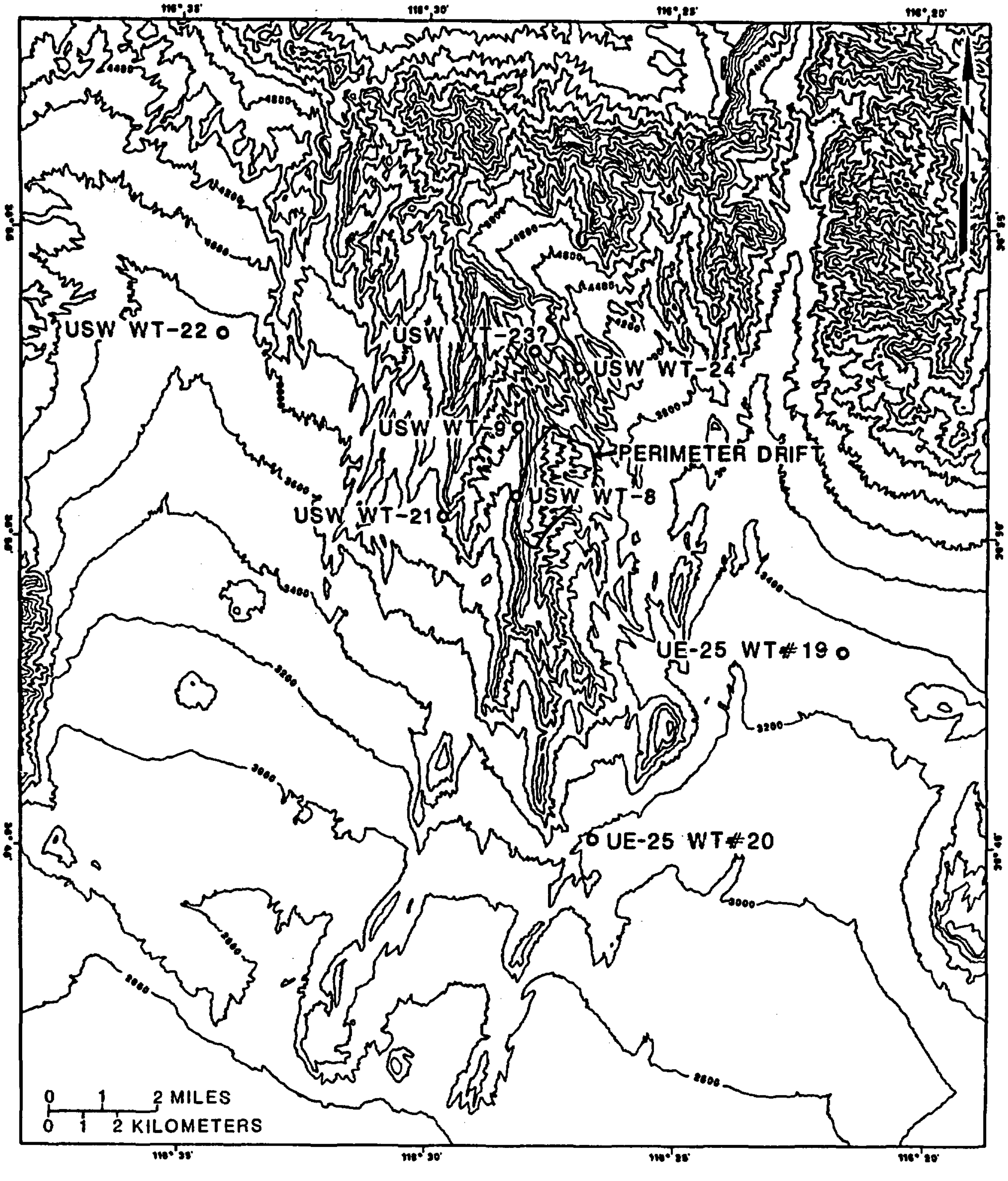
Description

About 25 geologic, hydrologic, and water-table drillholes are part of an existing 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 and connected to digital equipment at the surface; 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 holes WT-8, WT-9, WT-21, WT-22, WT-23, and WT-24; and UE-25 holes WT#19 and WT#20 (Figure 8.3.1.2-23). 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 distribution and hydrogeolgoic framework studies). The drilling of these drillholes will be coordinated with the drilling program described in 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 8.3.1.2-24) 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 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 (Figure 8.3.1.2-24), 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 8.3.1.2-23). 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.



o PROPOSED DRILL HOLE

Figure 8.3.1.2-23. Locations of the proposed water-table holes for the site potentiometric-level evaluation.

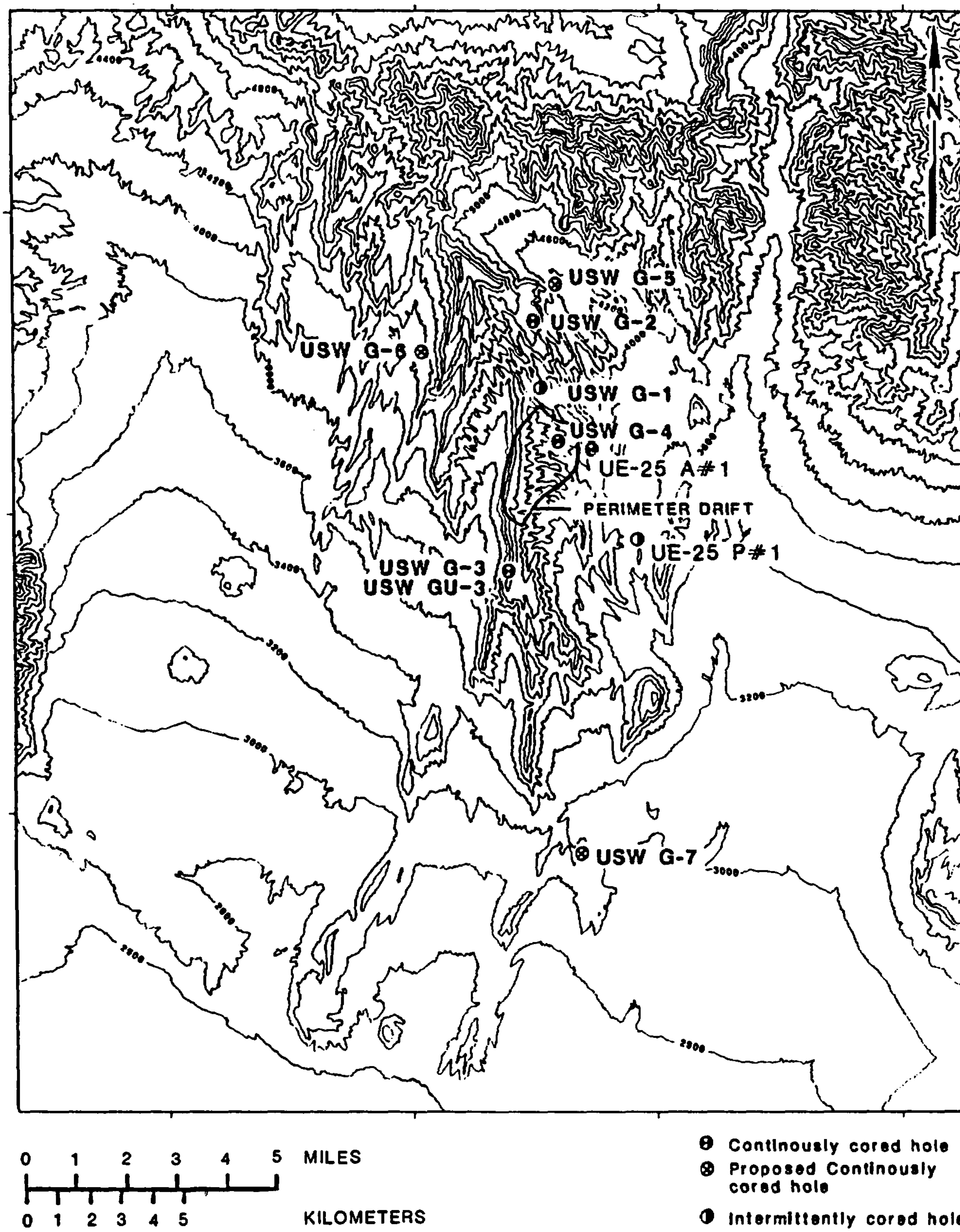


Figure 8.3.1.2-24. Location of existing and proposed geologic drillholes.

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.

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 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.

Analysis will be made of water-level fluctuations in wells that occur in response to volume/strain changes in the aquifer(s). Two broad categories of water-level response will be evaluated: dynamic and static responses. The dynamic response, due to passage of a seismic wave from earthquakes or underground nuclear explosions, will be monitored and analyzed to determine the relation between formation fluid pressure and strain, and to provide estimates of formation elastic properties. Water levels in wells may also respond to lower frequency volume/strain changes (the static response), such as those due to earth tides and atmospheric loading. These responses are readily identifiable in most wells in the potentiometric-level network, and are currently being evaluated in the UE-25c-holes and UE-25p#1 (Activity 8.3.1.2.3.1.3). Water levels may also exhibit a coseismic or aseismic low-frequency response to earthquakes. These phenomena are variously referred to as slow earthquakes or fault creep events. Concurrent measurements of strain are necessary to confirm the occurrence of aseismic fault creep. Strain measurements are also needed to improve the analysis of earth tidal effects.

To address this problem, volumetric strain meters or dilatometers will be installed in boreholes in at least three localities near Yucca Mountain. To assess the effects of terrain on the detection of horizontal tectonic displacement or strain, emplacement sites will be located on the crest, flank, and on the flat adjacent to Yucca Mountain. The array location will be coordinated to optimize the detection of explosively induced strain changes, and to complement the hydrologic studies of earth tides and apparent fault creep responses. At each locality, existing boreholes may be used or boreholes will be drilled and cored to facilitate the emplacement of strain meters. For redundancy, strain meters will be installed in two adjacent holes in at least one site. The selection of borehole sites and the criteria for well construction will be coordinated with the development of Yucca Mountain Project drilling plans (Investigation 8.3.1.4.1).

Because strain meters are temperature-sensitive, the depth of emplacement must be sufficient to minimize the effects of annual changes in surface temperature. Every effort will be made to ascertain the temperature-depth field at each locality before emplacement. Monitoring of climatic factors such as barometric pressure and rainfall will be made on a continuous basis and will be coordinated with other meteorological monitoring at the site (Study 8.3.12.1.2). The output from all strain meters at each locality will be monitored using intelligent data logging systems. Satellite (GOES) telemetry will be used to transmit the data to the office for immediate analysis so that detectable low-frequency strain changes may be observed and an appropriate response for additional field measurements may be initiated.

Currently Sacks-Evertson strainmeters, or Carnegie meters are being considered for use in this activity, because they are relatively simple and robust dilatometers that are readily available. When properly installed, they are capable of sensing strain changes of the order 10^{-10} or greater. The Carnegie meters have been used successfully by the USGS in studies on the San Andreas Fault in California.

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		
	Number	Title	Date
	(NWM-USGS-)		
Drilling of water-table observation wells	GP-02,R0	Subsurface investigations	1 Mar 83
GP-05,R0	Geologic support activities		1 Mar 83
	TBD[a]	Drilling and coring (REECo)	TBD
	TBD	Sampling, lithologic examinations and analysis of drill-cuttings and core samples	TBD
	TBD	Borehole drilling and coring procedures	TBD
Borehole geophysical survey	HP-02,R0	Acoustic televiewer investigations	14 Aug 84
	TBD	Borehole fracture logging	TBD
Water sampling	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Water-level measurements	HP-01,R0	Methods for determining water level	11 Jan 82
	HP-25,R0	Methods for measuring water levels using the Dodge Logging Van (1-127410)	20 Jul 84
	HP-26,R0	Method for calibrating water-level measurement equipment using the reference steel tape	14 Aug 84
	HP-27,R0	Instructions for operation of the Iron Horse for determining water-level measurements in wells	29 Apr 88
	HP-39,R0	Method for determining water levels using the trailer-mounted hoist (1-134719)	TBD
	HP-57,R1	Method for using graphic and digital water-level recorders	15 Jul 88
	HP-60,R0	Method for monitoring water-level changes using pressure transducers	4 May 88
	HP-71,R0	Method for monitoring water-level changes using a Campbell Scientific 21X Micrologger	1 Sept 87
	HP-75,R0	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	22 Jun 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Water-level measurements (continued)	HP-99,R0	Instructions for operation of a well sounder for measuring water levels	8 Jun 88
	HP-93,R0	Method for processing electronic data from a Campbell Scientific 21X Micrologger into water levels	11 May 88
	HP-181,R0	Measurement of water level and pore pressure responses in wells at Yucca Mountain during an announced nuclear explosion (tentative procedure)	20 Jun 88
Strain related water-level measurements	TBD	Calibrating Sacks-Evertson strain meters	TBD
	TBD	Emplacing the Sacks-Evertson strain meter in a borehole	TBD
	TBD	Monitoring the Sacks-Evertson strain meter in borehole emplacements	TBD
	TBD	Satellite (GOES) telemetry of hydrologic/strain data	TBD

[a]TBD = to be determined.

8.3.1.2.3.1.3 Activity: Analysis of single- and multiple-well 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. Determine the causes of the apparent deviant pressure transients observed in slug tests in UE-25c#1.

5. 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.

6. Determine bulk estimates of aquifer properties: transmissivity, storage coefficient, specific storage, and effective hydraulic porosity.

7. 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 8.3.1.2-21). 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 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, whereas 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 nonpumping 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 8.3.1.2-25). 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 8.3.1.2-26) and monitored in drillholes UE-25c#1 and UE-25c#3 (Figure 8.3.1.2-27). 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 8.3.1.2-25, -26, and -27).

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 fractured reservoirs, will be considered as needed. This approach, from

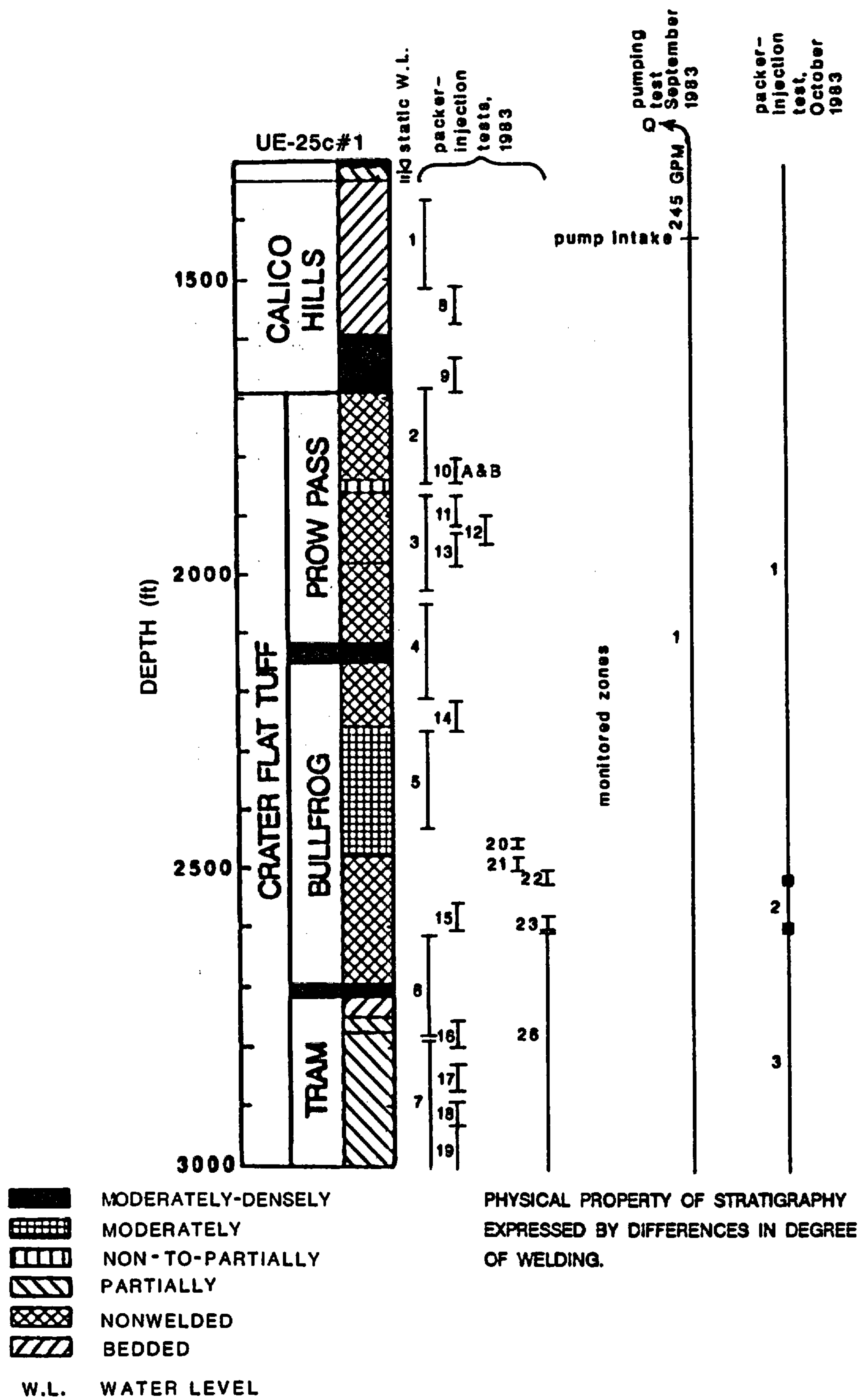


Figure 8.3.1.2-25. Test well configuration for drillhole UE-25c#1 packer-injection and open-hole pumping tests.

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.

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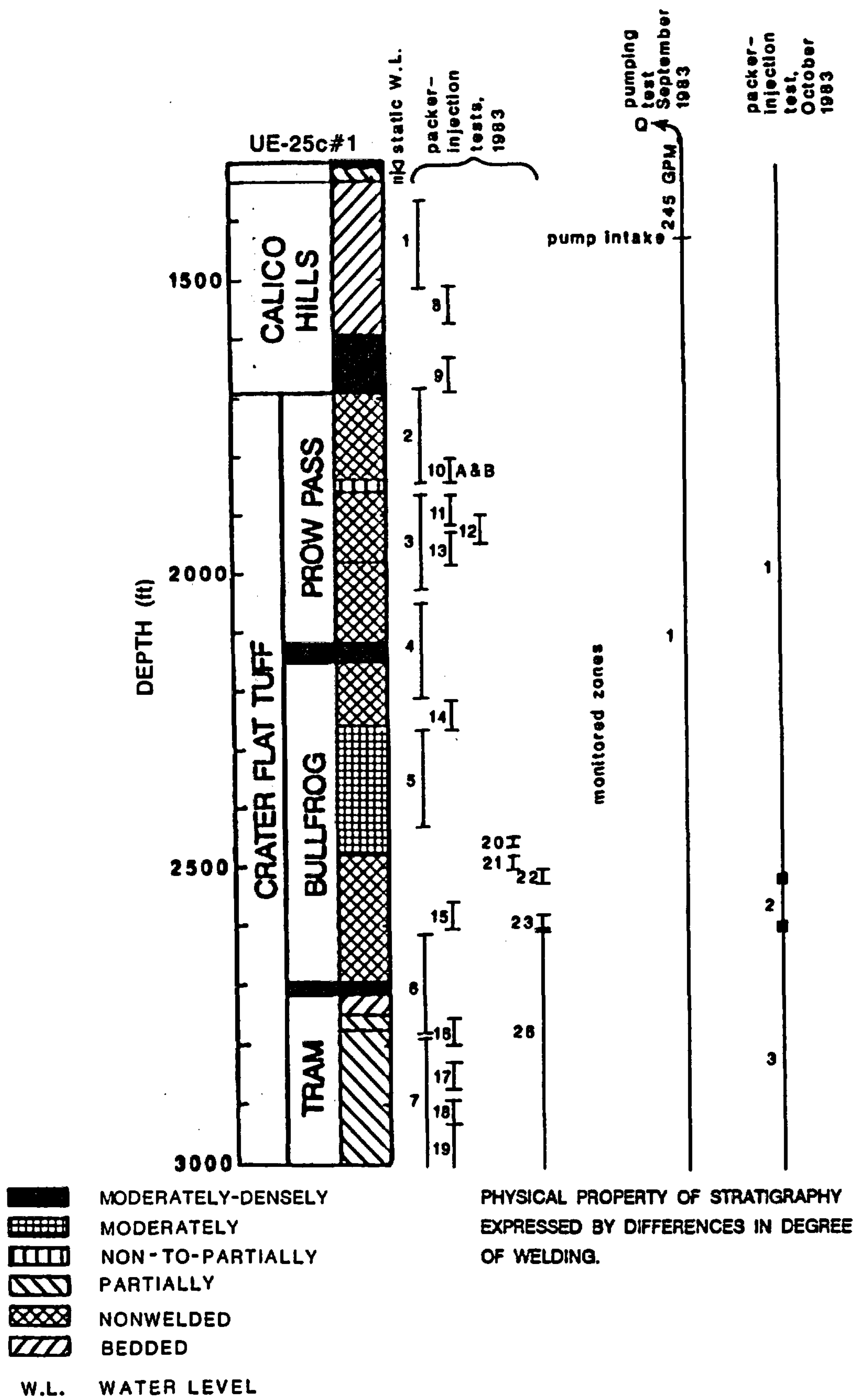

Figure 8.3.1.2-25. Test well configuration for drillhole UE-25c#1 packer-injection and open-hole pumping tests.

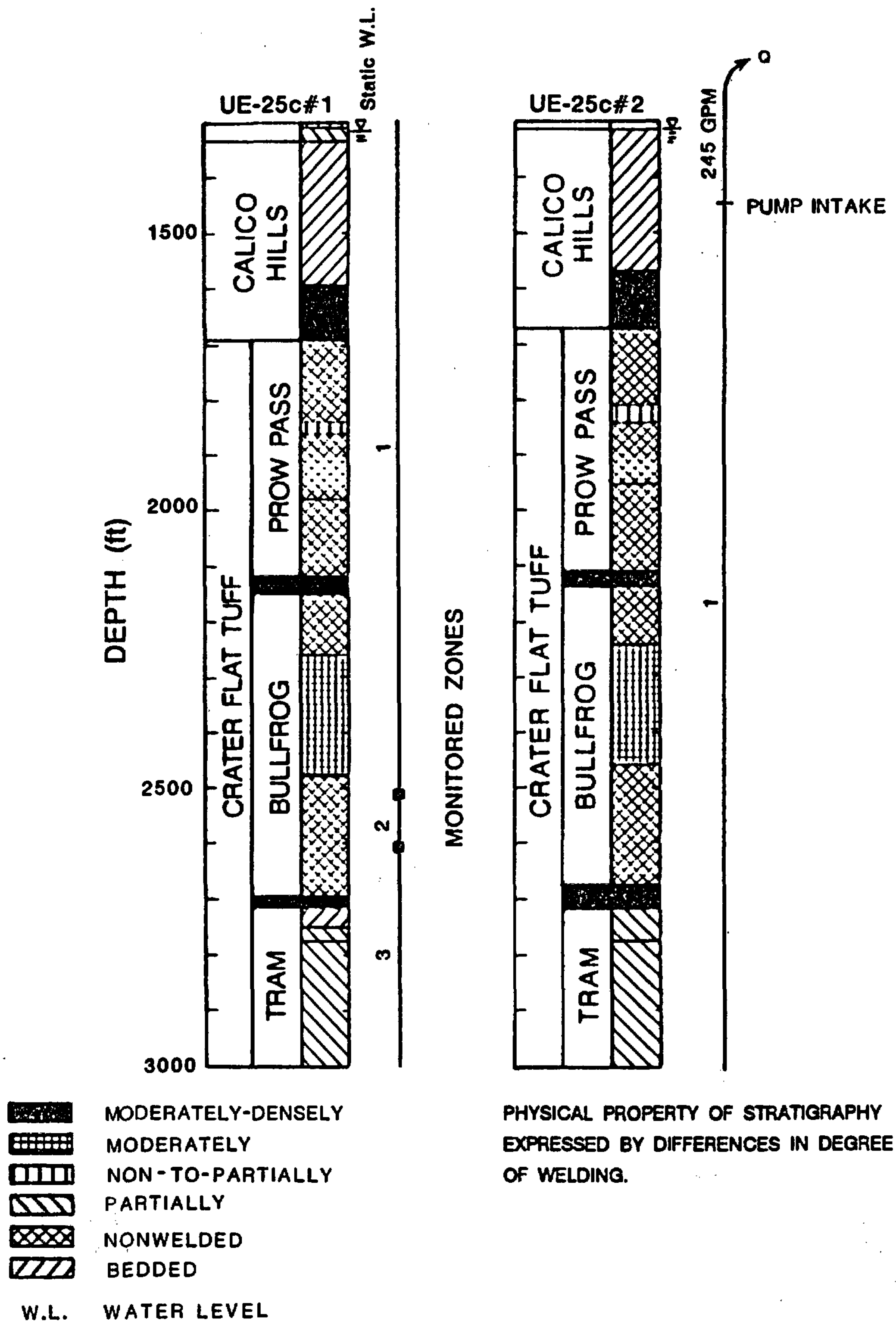

Figure 8.3.1.2-26. Test well configurations for drillhole UE-25c#2 pumping test (March 1984).

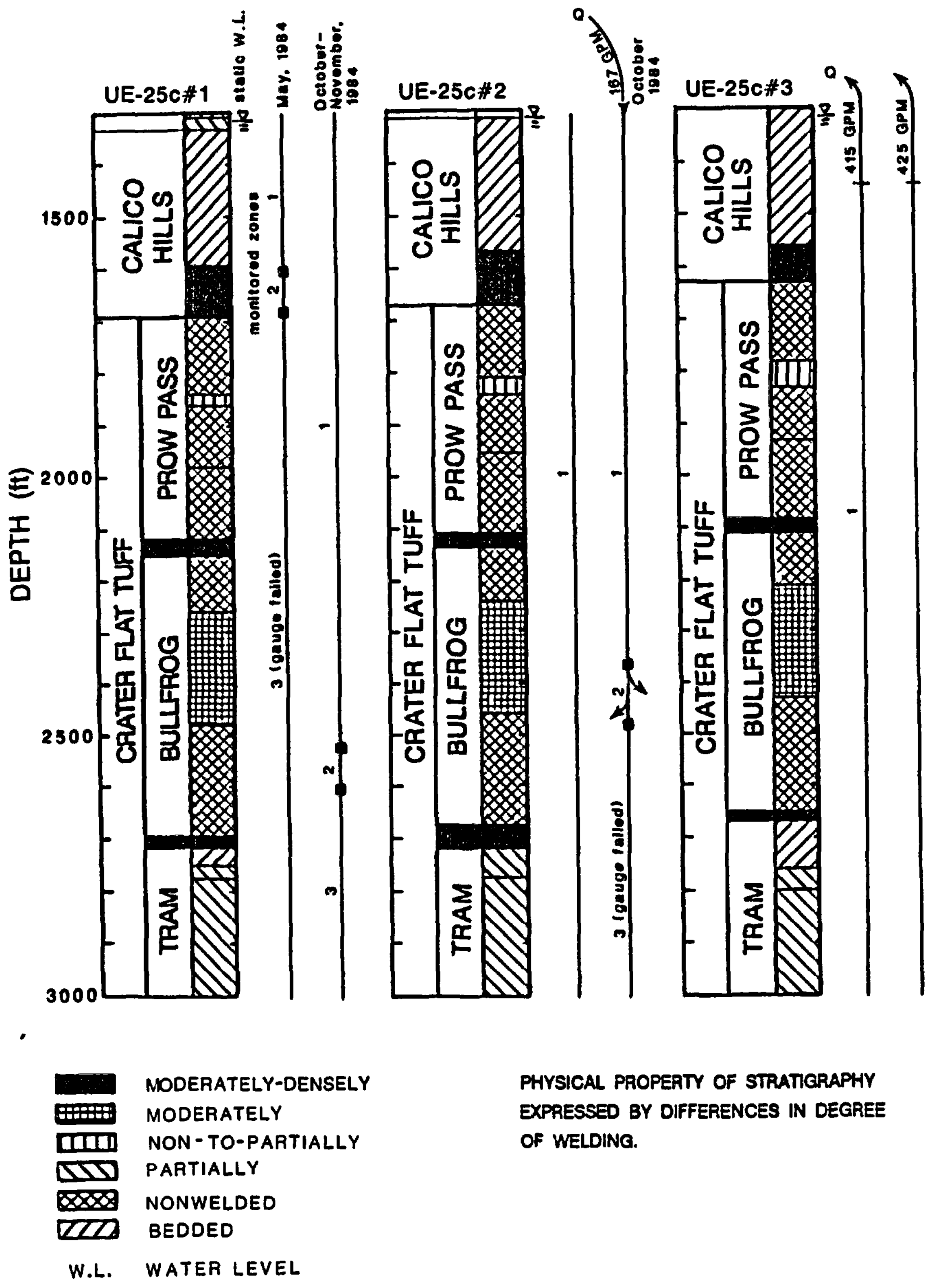

Figure 8.3.1.2-27. Test well configurations for drillhole UE-25c#3 pumping tests (May 1984, November 1984) and drillhole UE-25c#2 packer injection test (October 1984).

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 fractured 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 (Papadopulos, 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, 1987).

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, 1987).

Preliminary analysis of falling-head injection tests (slug tests) has been reported by Erickson et al. (1985) and Karasaki (1987). 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 (1987). Possible causes for deviations include: (1) large initial heads may have induced excessive pipe-friction losses, (2) large velocity may have caused non-Darcian flow in the formation near the well bore, and (3) the changing state of in situ stresses may result from high initial injection heads (750 ft above static). Results of slug tests conducted in other wells on Yucca Mountain (USW H-3 for example) indicate that existing fractures were reopened or possibly new fractures were created as a result of excessive injection heads (2,461 ft above static in USW H-3), and that the pressure-transient responses reflect the changes in the fluid flow characteristics resulting from the changing in situ stresses. Therefore, the interaction of the fluid and mechanical processes may need to be considered in the analysis of the UE-25c#1 slug tests.

Additional slug tests will be conducted in selected intervals in UE-25c#1 and possibly UE-25c#2 and UE-25c#3 for purposes of assessing the effect of the magnitude of initial injection heads on the resulting pressure transients. Lower injection heads are expected to mitigate head losses through the injection tubing, at the well/formation interface, and within fractures or faults. Lower injection heads would also decrease the effects of changing in situ stresses, thus providing test results for interpreting the fluid-flow processes relatively uncoupled from mechanical processes.

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 analyses 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 are 20 m greater than those in the tuffs and 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 insufficient 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 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 have been undertaken and reported (Galloway and Sullivan, 1986). Water levels were measured in the C-holes in five intervals (zones) (Figure 8.3.1.2-28) open to the extensively 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

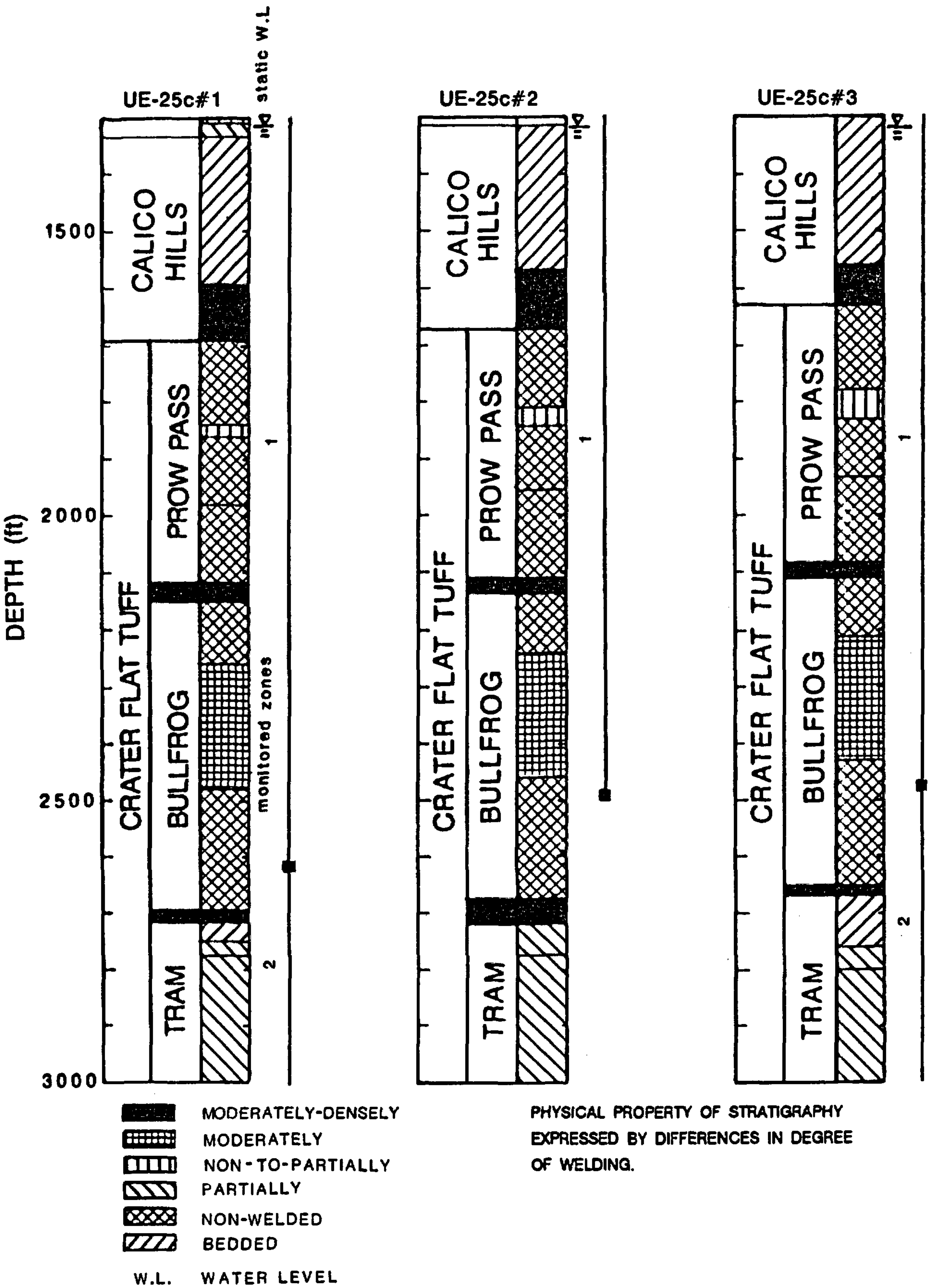

Figure 8.3.1.2-28. Test well configuration for analysis of C-hole earth-tide and barometric induced water-level fluctuations.

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, 6.0×10^{-9} 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 (1962) 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 that 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

The methods and technical procedures on Activity 8.3.1.2.3.1.3 are given in the following table.

Method	Technical procedure Number	Title	Date
Interpretation of intra-borehole flow	TBD[a]	No technical procedures identified	TBD
Interpretation of injection and withdrawal flow testing	TBD	No technical procedures identified	TBD
Barometric and earth-tide analysis	TBD	Installing and retrieving information from a Septa pressure transducer	TBD

[a]TBD = to be determined.

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 8.3.1.2-29). 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.

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.

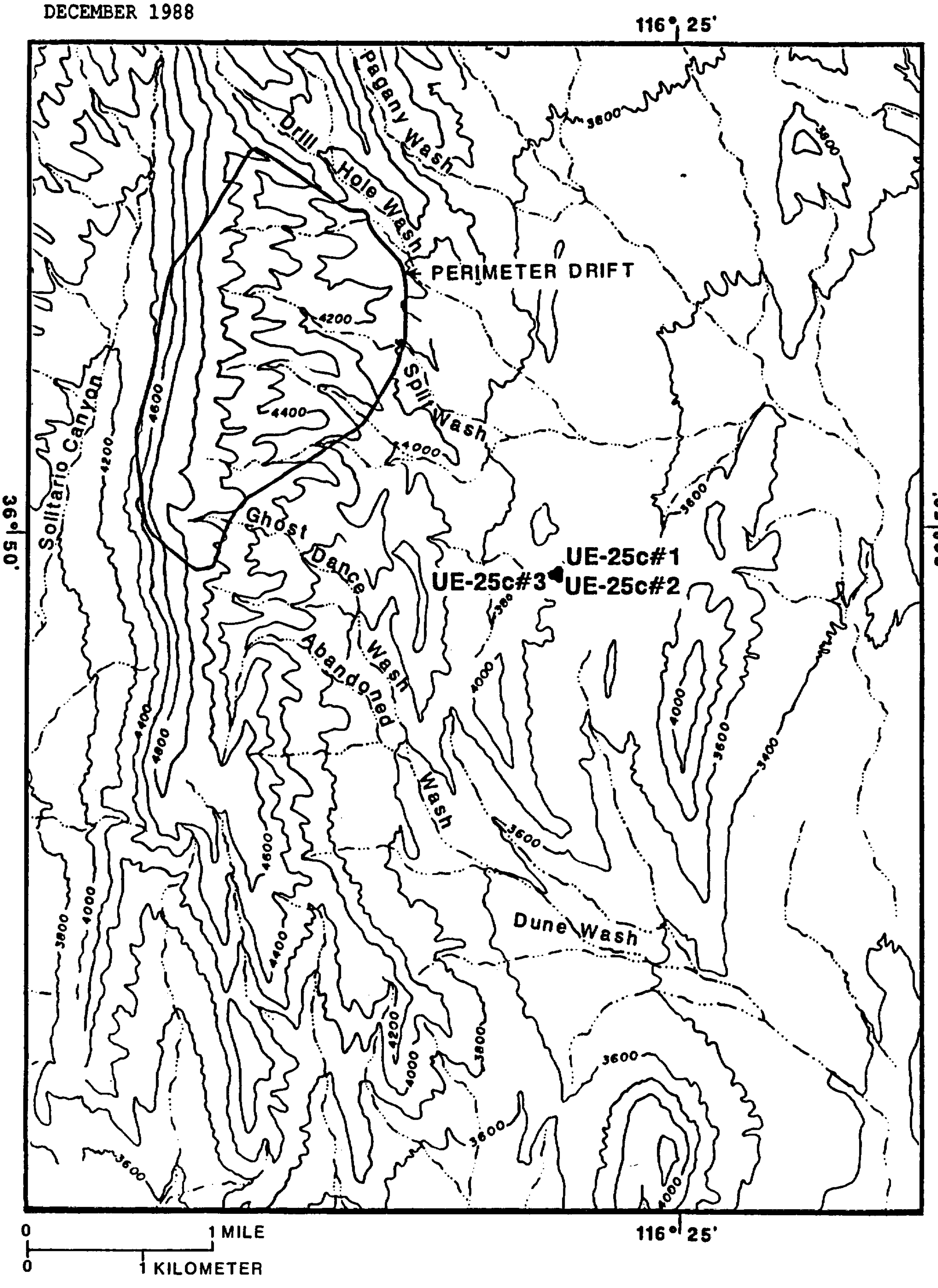

Figure 8.3.1.2-29. Location of C-hole complex.

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 Reilly (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 also will 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 tests	HP-01,R0	Methods for determining water level	11 Jan 82
	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-34,R0	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	15 May 85
	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
	HP-60,R0	Method for monitoring water-level changes using pressure transducers	4 May 88
	HP-111,R0	Operating GMC Logging Truck #81890 to obtain temperature, trace-jector, and natural gamma logs	TBD[a]
	HP-121,R0	Installing and retrieving information from a Septa pressure transducer	TBD
	TBD	Method for measuring discharge of a pumping well with an in-line flow meter	TBD
	TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
	TBD	Calibration and use of a pressure transducer in a well with a multiple-packer system	TBD
	TBD	Calibration and use of a thermister to monitor water temperature	TBD
	TBD	Method for conducting a cross-hole hydraulic test	TBD
	HP-93,R0	Method for processing electronic data from a Campbell Scientific 21X Micrologger into water levels	11 May 88
	HP-85,R0	Method of monitoring water-level changes using a pressure transducer and the Fluke 2280 B Data Logger	TBD
Large-scale pumping tests	HP-01,R0	Methods for determining water level	11 Jan 82
	HP-06,R0	Hydrologic pumping test	11 Jan 82
	HP-34,R0	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	15 May 85
	HP-39,R0	Method for determining water levels using the trailer-mounted hoist (1-134719)	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Large-scale pumping tests (continued)	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
	HP-60,R0	Method for monitoring water-level changes using pressure transducers	4 May 88
	HP-121,R0	Installing and retrieving information from a Septa pressure transducer	TBD
	TBD	Method for measuring discharge of a pumping well with an in-line flow meter	TBD
	TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	TBD
	TBD	Calibration and use of a pressure transducer in a well with a multiple-packer system	TBD
	TBD	Calibration and use of a thermister to monitor water temperature	TBD
	TBD	Method for conducting a large-scale pumping test	TBD
	HP-93,R0	Method for processing electronic data from a Campbell Scientific 21X Micrologger into water levels	11 May 88

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Large-scale pumping tests (continued)	HP-85,R0	Method of monitoring water-level changes using a pressure transducer and the Fluke 2280 B Data Logger	TBD
Analysis of multiple-well interference tests	TBD	No technical procedures identified	TBD

[a]TBD = to be determined.

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 8.3.1.2-30). 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 analyzed 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 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 will be mixed with water and injected into the aquifer. To determine the effect of matrix diffusion on the migration of tracers, colloids of various sizes will be considered for use in conjunction with conservative tracers, such as 3-trifluoromethylbenzoate. Colloidal and other tracers will be selected such that some tracers will be expected to diffuse into the rock matrix whereas others will not. The tracer will be injected as a short pulse. The steady-state recirculating flow pattern will be maintained

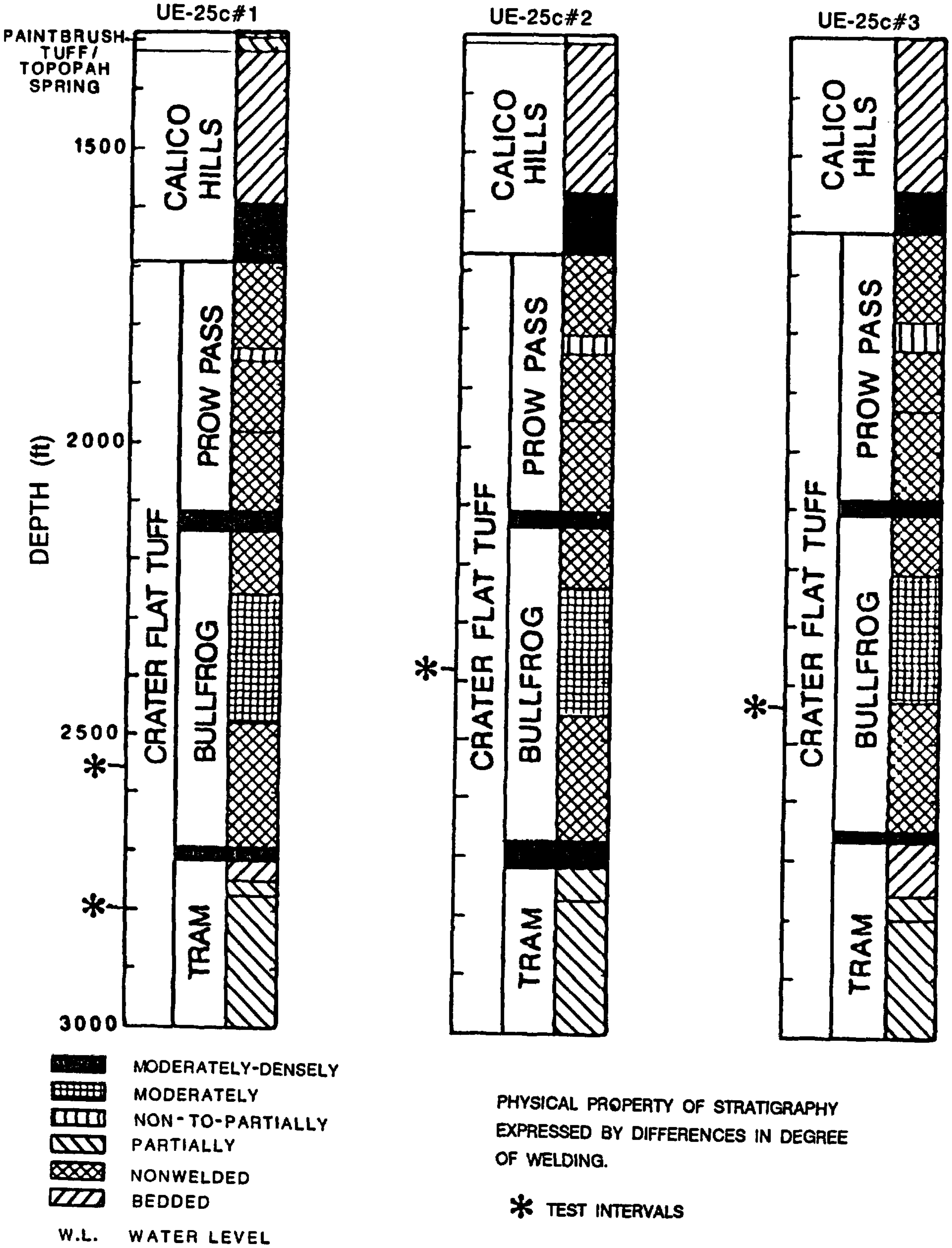

Figure 8.3.1.2-30. Location of test intervals for the drift-pumpback tests.

following tracer injection. Samples of pumped water will be collected and analyzed 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. Additional tests will be done using various combinations of pumping and injection intervals to evaluate directional characteristics of hydraulic and transport properties. Ideally one or more convergent tests would be conducted during each cross-hole hydraulic test (Activity 8.3.1.2.3.1.4). 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 analyzed 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 media. 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	HP-03,R0	Hydrologic tracejector test	11 Jun 82
	HP-06,R0	Hydrologic pumping test	11 Jun 82
	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-34,R0	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	15 May 85
	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Drift-pumpback tests (continued)	HP-111,R0	Operating GMC Logging Truck #81890 to obtain temperature, trace-jector, and natural gamma logs	TBD[a]
	TBD	Method for measuring discharge of a pumping well with an in-line flow meter	TBD
	TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	TBD
	TBD	Preparation of a tracer solution from 3-trifluoromethylbenzoate	TBD
	TBD	Method for injecting a tracer solution in selected intervals of deep wells	TBD
	TBD	Method for conducting drift-pumpback tests	TBD
	TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	TBD
Two-well recirculating tests	HP-06,R0	Hydrologic pumping test	11 Jan 82
	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Two-well recirculating tests (continued)	HP-34,R0	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	15 May 85
	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
	HP-111,R0	Operating GMC Logging Truck #81890 to obtain temperature, tracejector, and natural gamma logs	TBD
	TBD	Method for measuring discharge of a pumping well with an in-line flow meter	TBD
	TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	TBD
	TBD	Preparation of a tracer solution from 3-trifluoromethylbenzoate	TBD
	TBD	Method for injecting a tracer solution in selected intervals of deep wells	TBD
	TBD	Analysis of water samples by HPLC	TBD
	TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	TBD
	TBD	Long-term storage of of water samples	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Two-well recirculating tests (continued)	TBD	Method for conducting a two-well recirculating tracer test	TBD
Two-well convergent tests	HP-03,R0	Hydrologic tracejector test	11 Jan 82
	HP-06,R0	Hydrologic pumping test	11 Jan 82
	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
	HP-111,R0	Operating GMC Logging Truck #81890 to obtain temperature, tracejector, and natural gamma logs	TBD
	TBD	Method for measuring discharge of pumping well with an in-line flow meter	TBD
	TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	TBD
	TBD	Preparation of a tracer solution from 3-trifluoromethylbenzoate	TBD
	TBD	Method for injecting a tracer solution in selected intervals of deep wells	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Two-well convergent tests (continued)	TBD	Analysis of water samples (saturated zone) in wells equipped with a multiple-packer system	TBD
	TBD	Analysis of water samples by HPLC	TBD
	TBD	Long-term storage of water samples	TBD
	TBD	Method for conducting a convergent tracer test	TBD
Analysis of conservative-tracer tests	TBD	No technical procedures identified	TBD

[a]TBD = 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 8.3.1.2-31). 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-televiewer, 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

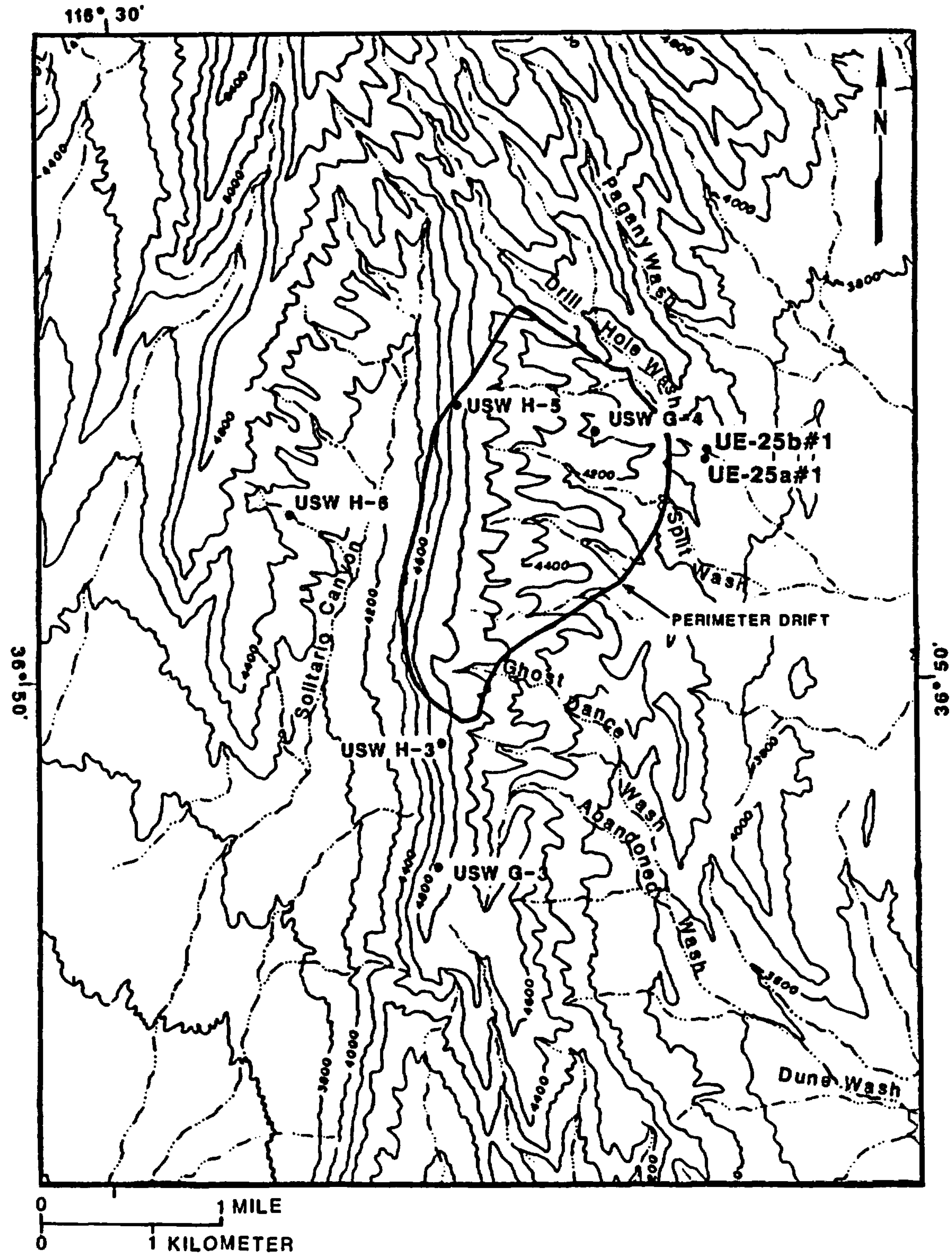

Figure 8.3.1.2-31. Location of the saturated-zone wells that might be used for additional tracer testing.

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 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.

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		
	Number	Title	Date
	(NWM-USGS-)		
Single-well tests	HP-01,R0	Methods for determining water level	11 Jan 82
	HP-03,R0	Hydrologic tracejector test	11 Jan 82
	HP-06,R0	Hydrologic pumping test	11 Jan 82
	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-34,R0	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	15 May 85

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Single-well tests (continued)	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
	HP-60,R0	Method for monitoring water-level changes using pressure transducers	4 May 88
	HP-61,R0	Calibration and use of hand-held steel tapes	TBD[a]
	HP-71,R0	Method for monitoring water-level changes using a Campbell Scientific 21X Micrologger	1 Sept 87
	HP-111,R0	Operating GMC Logging Truck #81890 to obtain temperature, tracejector, and natural gamma logs	TBD
	HP-121,R0	Installing and retrieving information from a Septa pressure transducer	TBD
	TBD	Method for measuring discharge of a pumping well with an in-line flow meter	TBD
	TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	TBD
	TBD	Calibration and use of a pressure transducer in a well with a multiple-packer system	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Single-well test (continued)	TBD	Calibration and use of pressure transducer in a well with a multiple-packer system	TBD
	TBD	Calibration and use of a thermister to monitor water temperature	TBD
	TBD	Method for conducting a large-scale pumping test	TBD
	TBD	Preparation of tracer solution from 3-trifluoromethylbenzoate	TBD
	TBD	Method for injecting a tracer solution in selected intervals of deep wells	TBD
	TBD	Method for conducting drift-pumpback tests	TBD
	TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	TBD
	TBD	Long-term storage of water samples	TBD
	HP-85,R0	Method of monitoring water-level changes using a pressure transducer and the Fluke 2280 B Data Logger	TBD
Multiple-well tests	HP-01,R0	Methods for determining water level	11 Jan 82
	HP-03,R0	Hydrologic tracejector tests	11 Jan 82

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Multiple-well tests (continued)	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-34,R0	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	15 May 85
	HP-39,R0	Method for determining water levels using the trailer-mounted hoist (1-134719)	TBD
	HP-53,R0	Method for calibrating digital and analog watches	15 Nov 84
	HP-60,R0	Method for monitoring water-level changes using pressure transducers	4 May 88
	HP-61,R0	Calibration and use of hand-held steel tapes	TBD
	TBD	Method for measuring discharge of a pumping well with an in-line flow meter	TBD
	TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	TBD
	TBD	Calibration and use of a pressure transducer in a well with a multiple-packer system	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Multiple-well tests (continued)	TBD	Calibration and use of a thermister to monitor water temperature	TBD
	TBD	Method for conducting a cross-hole hydraulic test	TBD
	TBD	Preparation of a tracer solution from 3-tri-fluoromethylbenzoate	TBD
	TBD	Method for injecting a tracer solution in selected intervals of deep wells	TBD
	TBD	Analysis of water samples by HPLC	TBD
	TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	TBD
	TBD	Long-term storage of water samples	TBD
	TBD	Method for conducting a two-well recirculating tracer test	TBD
	TBD	Method for conducting a convergent tracer test	TBD
	HP-85,R0	Method of monitoring water-level changes using a pressure transducer and the Fluke 2280 B Data Logger	TBD

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Analysis of test results	TBD	No technical procedures identified	TBD

[a]TBD = 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 geologic media in the saturated zone in the vicinity of the C-holes that will affect radionuclides retardation during ground-water flow within the saturated zoned.

Parameters

The parameters for this activity are

1. Adsorption rate constants.
2. Sorption equilibrium constants.

Description

Tracer identification and characterization

A group of tracers will be selected that will aid in evaluating various controlling mechanisms of radionuclide sorption by the geologic media within the saturated zone in the vicinity of the C-wells. The tracers will be used in field tests that are part of site characterization investigations.

First, a screening of potential tracers to define controlling sorption mechanisms in various minerals will be conducted from literature reviews and consultations with experts. Second, laboratory tests will be conducted to select those procedures and analyses (for geologic material and water) that can facilitate the distinction among prevailing sorption mechanisms. Third, modeling of sorption experiments will be conducted using both kinetics and equilibrium expressions. Geochemical modeling will assist in defining the prevailing sorption mechanisms in laboratory studies.

The approach used to select these tracers is based upon the possible occurrence of various sorption mechanisms between solutes and geologic media. These mechanisms can be generally classified into two categories, physisorption and chemisorption. Physical adsorption exhibits low-energy changes in physical and chemical properties of the solute. On the other hand, chemical bonding results in energy changes that are strong enough to make the adsorbate (solute) exhibit physical and chemical properties different from those in solution. For example, physisorption shows heats of adsorption of 30 to 50 kJ $mole^{-1}$ compared with 200 to 500 kJ $mole^{-1}$ in chemisorption. Physical adsorption is characterized by small changes in vibrational frequency (~0.1%), while chemical adsorption is characterized by large changes (>0.1%). Chemical bonds, in contrast to physical bonds, are not readily broken at low temperatures. There is a third category, less understood, where sorption may have characteristics of both chemical and physical adsorption.

Within the two general categories of adsorption, two major mechanisms, and possibly a third, are of concern in these investigations: electrostatic adsorption, chemisorption, and possibly, molecular sieve. Electrostatic adsorption represents for this study a physical adsorption where ions in solution migrate to a diffuse layer because of electrostatic attraction of ions to a surface of opposite charge and because of the dispersive influence of diffusion forces. Ion exchange behavior is included in this definition. Chemisorption refers to those cases where forces with the order or magnitude of chemical bonds hold the adsorbate (solute) to a site surface. Molecular sieve falls in the category of physical sorption with energies of adsorption representing diffusional activation energies that are present when molecules are caught in cages as in zeolites.

This task will also evaluate manufactured polystyrene spheres as colloid tracers. These colloid tracers will be evaluated as to their interaction with the other tracers. These spheres have been shown to be conservative, and their size (1 micron) is larger than the dissolved chemical species so the spheres travel through the paths with the largest fractures or pores. It is anticipated that in fractured media, the polystyrene spheres will provide some information on fracture aperture.

The rationale for using sorption mechanisms as a basis for selecting the tracers is the assumption that either of the three general mechanisms can prevail in the sorption of radionuclides at Yucca Mountain. The link between the radionuclides and the sorption mechanisms must be made in the laboratory because of constraints for environmental regulations and the complex chemistry exhibited by many of the actinides. Another advantage of using the sorption mechanism criterion for the reactive tracer study is the acquisition of fundamental information describing the interactions of general tracers with the rock media. This information increases the ability to interpret field experiments because marked differences in relative behavior of the mechanisms can provide a better insight into tracer response. An example is electrostatic sorption, which is a relatively reversible process as compared with chemisorption.

In this study, a combined approach is proposed that is a compromise between a more rigorous analysis based on surface coordination theory, for example, triple-layer concepts, and the more "empirical" approach associated with development of simple isotherms. Rates and isotherms will be derived to describe mathematically the generalized reaction of the tracers with the solid tuff material. At the same time, experiments will be conducted with individual minerals present in the tuff to develop a fundamental data base for mineral-tracer interactions. The number of minerals will be limited to those that are expected to be more reactive, for example, iron oxides. In this manner, some elements of a more rigorous approach are used. This work complements the empirical and mechanistic sorption work in Activity 8.3.1.3.4.1. The data obtained in the C-well reactive tracer work is specific to the C-well site (i.e., mineralogy, stratigraphic unit) and specific only to evaluation of proper tracers for this field test. The mechanistic work of Activity 8.3.1.3.4.1 is applied to the understanding of actinide sorption and will extrapolate or determine a spatial distribution of sorption for all important radionuclides across the site.

Initially, batch experiments will be performed with the primary emphasis on kinetics and equilibrium experiments. Column experiments will follow the batch experiments to evaluate simultaneous migration and interactions among selected tracers, including colloids, under various flow conditions. Geologic material, or their surrogates, and water from the Yucca Mountain vicinity will be used in experiments for isotherm development. Minerals, extracted from Yucca Mountain samples or purchased, and electrolyte solutions will be used in experiments to collect fundamental data on mineral-tracer interactions.

Initial batch experiments will attempt to identify tracers retarded by the primary controlling mechanism using thermodynamic indicators, adsorption-desorption differences, or response to desorption with electrolyte solutions. Supporting experiments will determine changes in electrostatic behavior, for example, zero point of charge. Also, batch experiments will be used to develop kinetics and equilibrium models. Laboratory column experiments will provide breakthroughs to simultaneously evaluate the selected tracers for their interactions with each other and their behavior in a transport environment. These breakthrough curves will also serve to validate the applicability of the models developed from batch data to continuous flow conditions.

Appropriate sorption expressions, both kinetics and equilibrium, will be used to model experimental sorption data. The parameters from these models will be used in defining sorption processes and in predicting and interpreting field-observed breakthrough curves for the well experiments. Geochemical models will assist in designing laboratory experiments and in defining prevailing sorption mechanisms.

Modeling of tests

Concurrently with the tracer identification and characterization task, an extensive program of numerical modeling of the reactive-tracer field tests will be conducted. The purpose of this modeling is to define concentration ranges of tracers for the field tests and to indicate an expected duration and sampling frequency. Modeling of both single-well and multiple-well experiments will be conducted. Currently, it is unknown if the hydraulic response at the scale of the C-wells can be treated as a porous media equivalent. Therefore, both fracture network and porous media continuum models will be used. 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.

Single-well tests

The type of tests, either injection-backflow or drift-pumpback, procedures, pumping rates, tracers, initial tracer concentrations, and durations of single-well tests will be specified by the results of the modeling studies. The goals of the single-well tests are (1) to demonstrate the use of reactive tracers in field tests and (2) to evaluate retardation characteristics of the saturated zone in the region near each of the wells tested.

Multiple-well tests

Two types of multiple-well tests are proposed: two-well recirculating and convergent tests. As for the single-well tests, modeling will be used in conjunction with information on the tracers to design these experiments.

Analysis of test results

In each field test a conservative (nonreactive) tracer will be added with the reactive tracer to permit calculation of flow velocity and dispersion of the tracer. These values will then be used with laboratory values of the sorption parameters for the reactive tracers to predict the response of the reactive tracer. In this way the laboratory parameter values for sorption are evaluated against field data. By making the laboratory connection with radionuclides, the retardation characteristics of the tested regions can be calculated.

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
Software QA	TBD[a]	Procedure to implement NNWSI-SOP-03-02, Software Quality Assurance	TBD
Solid sample handling	TBD	Solid sample handling and transfer	TBD
Solution sample handling	TBD	Solution sample handling and transfer	TBD

Method	Technical procedure Number	Title	Date
Drift-pumpback experiment with tracer	TBD	Drift-pumpback experiment electrostatic tracer	TBD
	TBD	Drift-pumpback experiment with chemisorbing tracer	TBD
	TBD	Drift-pumpback experiment with molecular sieve tracer	TBD
Multiple-well experiment with tracer	TBD	Multiple-well experiment with electrostatic tracer	TBD
	TBD	Multiple-well experiment with molecular sieve tracer	TBD
Injection-backflow tests	TBD	Injection-backflow tests	TBD
Two and three well tests	TBD	Two and three well tests	TBD
Analysis of test results	TBD	Analysis of test results	TBD
Identification and characterization of reactive tracers	TBD	Identification and characterization of reactive tracers to be use in tracer tests	TBD
Modeling of tests	TBD	Modeling of tests	TBD
	(TWS-HSE-)		
Cation and anion exchange capacity	DP-302	Cation and anion exchange capacity	TBD
Zero point of charge	DP-303	Zero point of charge (potentiometric method)	TBD
	DP-304	Zero point of charge (electrophoresis method)	TBD
Batch sorption	DP-305	Equilibrium batch sorption	TBD
	DP-306	Kinetic batch sorption	TBD
Sample identification and control	DP-307	Sample identification and control	TBD

Method	Technical procedure Number	Title	Date
	(TWS-HSE-)		
Determination of material abrasion	DP-309	Determination of material abrasion	TBD
Calibration and use of the phototachometer	DP-310	Calibration and use of the phototachometer	TBD
Sample preparation	DP-311	Sample preparation	TBD
Particle size reduction geologic media	DP-312	Particle size reduction of geologic media	TBD
Calibration and use of centrifuge	DP-313	Calibration and use of centrifuge	TBD
Electrical conductivity measurement	DP-314	Electrical conductivity measurement	TBD
Calibration and use of temperature measurement control devices	DP-315	Calibration and use of temperature measurement control devices	TBD
Preparation of aqueous stock solutions and dilutions	DP-316	Preparation of aqueous stock solutions and dilutions	TBD
Calibration and use of balances	DP-317	Calibration and use of analytical and top-loading balances	TBD
F measurements and acid-base solution standardization	DP-318	pH measurements and acid-base solution standardization	TBD
Particle size analysis	DP-319	Particle size analysis	TBD
Measurement of dissolved oxygen	DP-320	Measurement of dissolved oxygen	TBD
Surface area analysis	DP-321	Surface area analysis	TBD
Magnetic separation of impurities	DP-322	Magnetic separation of impurities	TBD

Method	Technical procedure Number	Title	Date
	(TWS-MSTQA-)		
Research and development	QP-14,R1	Research and development (experimental) procedure	TBD

[a]TBD = 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 geologic 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

Tracer identification and characterization

The same reactive tracers as were used in the C-hole experiments (Activity 8.3.1.2.3.1.7) will be used unless there is an unexpected change in geologic characteristics or ground-water chemistry. Some laboratory experiments will be required to estimate sorption parameters for the reactive tracers.

Modeling of tests

The wells used for this activity will be the same as those used for conservative (nonreactive) tracer tests throughout the site (Activity 8.3.1.2.3.1.6). The modeling will follow the same procedure as was used for the C-hole reactive tracer tests (i.e., laboratory values for sorption parameters will be used to design the tests). Modeling of both single-well and multiple-well tests will be conducted. Again, the type of model, fracture network versus porous media equivalent, cannot be determined until hydraulic studies have been completed. The media properties used in modeling will be obtained on a continuing basis, so the modeling will be as accurate as possible. The experience gained from the C-hole tests and modeling is expected to reduce significantly the amount of modeling required for this activity.

Single-well tests

If single-well tests in the C-holes indicate 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 modeling studies.

Multiple-well tests

If single-well tests do not provide sufficient information, a multiple-well location will be proposed and, if accepted, additional tests will be conducted. If this occurs and the C-hole tests indicate 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 reaction tracer tests.

Analysis of test results

Analyses will proceed in the same fashion as was used in the C-hole study (Activity 8.3.1.2.3.1.7). A conservative tracer will be injected with the reactive tracer, and the conservative tracer will be used to estimate velocity and dispersion parameters. Then using laboratory-derived sorption parameters, the response of the reactive tracer will be predicted and compared with the field test. By making a connection in the laboratory between radionuclides and these tracers, inferences about radionuclide retardation can be made.

Methods and technical procedures

This task is in the early stages of development; therefore, no technical procedures are available.

8.3.1.2.3.2 Study: Characterization of the saturated zone hydrochemistry

The objectives of this study are to (1) describe the chemical composition of, and spatial compositional variations in, saturated-zone ground waters using new and extant data; (2) identify the chemical and physical processes that influence ground-water chemistry; and (3) aid in the identification and quantification of fluxes to, from, and within the saturated zone.

Four activities are planned to meet these objectives. The activities are (1) assessment of saturated-zone hydrochemical data availability and needs, (2) hydrochemical characterization of water in the upper part of the saturated zone, (3) regional hydrochemical characterization, and (4) synthesis of saturated-zone hydrochemistry.

8.3.1.2.3.2.1 Activity: Assessment of saturated-zone hydrochemical data availability and needs

Objectives

The objectives of this activity are to

1. Compile and evaluate extant hydrochemical data for the saturated zone.

2. Identify data deficiencies and potential sampling sites and assemble requisite material for sample and field data collection.

3. Augment extant information by collecting and analyzing new hydrochemical samples and data.

Parameters

The parameters for this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Extant hydrochemical data for the saturated zone at Yucca Mountain, the Nevada Test Site, and the surrounding region will be compiled. The ionic balance of each analysis will be calculated as a means of initially assessing the quality of the data. Preliminary maps and cross sections of the spatial distributions of selected dissolved species and/or physical parameters will be prepared to depict the extant level of information. Published water-level maps will provide information about ground-water flow directions and gradients. This information will be reexamined as additional data become available. Published geologic descriptions of the site and the surrounding region will provide the locations of major structural features and information regarding formation geometries and lithologies. All the previously noted information will be integrated to delineate areas where additional data are needed.

Water samples will be collected to satisfy identified data needs when sampling opportunities arise in the course of other investigative activities, or when other satisfactory sampling sites are identified. All samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of selected radioisotopes, including tritium (hydrogen-3), carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium, and sulfur.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.2.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Water sample and field data collection	HP-10,R1	Packer-injection and shut-in tests	9 Jul 84
	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-48,R0	Method for calibrating hand-held glass thermometers	14 Aug 84
	HP-49,R0	Method for using hand-held glass thermometers	14 Aug 84
	HP-59,R0	Method for calibrating digital thermometers	TBD[a]
Chemical analysis	HP-160,R0	Method for collection and analysis of samples for gas composition by gas chromatography	16 Jun 88
	TBD	Methods for chromatographic determination of dissolved inorganic substances	TBD

[a]TBD = to be determined.

8.3.1.2.3.2.2 Activity: Hydrochemical characterization of water in the upper part of the saturated zone

Objectives

The objectives of this activity are

1. To describe the hydrochemistry of the upper part of the saturated zone by collecting representative water samples from intervals within the upper 100 m of the saturated zone, within and adjacent to

the site area, and studying their chemical and isotopic compositions.

2. To estimate flux to or from the saturated zone by collecting interstitial water and gas samples from immediately above the water table and studying their chemical and isotopic compositions.

Parameters

The parameters for this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Fourteen wells that penetrate from 43 to 99 m into the saturated zone have been constructed within the site area (Table 8.3.1.2-10). These water-table (WT) wells are presently part of the water-level monitoring program. Each has been equipped with 2-in. inner-diameter access tubing for water-level measurement; some are instrumented for continuous water-level data collection. The Desert Research Institute collected water samples from five of these wells in early 1988. The samples were collected from within the access tubing with a small-capacity submersible piston pump. These are the only samples that have been collected from these wells. At least eight additional WT wells will be drilled in the course of other investigations of the saturated-zone geohydrologic system (Table 8.3.1.2-10).

Water samples will be collected from each of the extant and planned WT wells using a submersible electric pump. If determined to be feasible, a packer will be installed at appropriate locations in selected boreholes to enable collection of samples from both the upper and lower parts of the saturated interval penetrated by the wells. After samples have been collected, a removable packer/plug and two access tubes will be set about 10 m below the water surface in each well. An additional sample or samples will be collected from this isolated upper interval at a later date, using a small-capacity submersible piston pump.

All samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of selected radioisotopes, including tritium, carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium, and sulfur. These data will significantly augment the hydrochemical data base for the saturated zone within and adjacent to the site area, as existing information include data from intervals much deeper than those penetrated by the WT wells.

Selected planned WT wells will be cored for about 25 m immediately above and into the saturated zone. Interstitial gases and water will be extracted from several sections of unsaturated core from each well. Several sections of drained saturated core will also be squeezed to extract water from the rock matrix, if feasible. The cored wells and, if feasible, several of the

Table 8.3.1.2-10. Existing (November 1986) and planned water-table wells to be sampled and logged

Well number	Well depth (m/ft)	Approximate depth to water (m/ft)	Thickness of saturated interval penetrated (m/ft)
USW WT-1	515/1,689	471/1,545	44/144
USW WT-2	628/2,060	571/1,873	57/187
UE-25 WT#3	348/1,142	301/986	48/156
UE-25 WT#4	482/1,580	439/1,440	43/140
UE-25 WT#6	383/1,256	284/932	99/324
USW WT-7	491/1,610	421/1,382	69/228
USW WT-8[a]	640/2,100[b]	ND[c]	ND
USW WT-9[a]	670/2,198[b]	ND	ND
USW WT-10	431/1,413	343/1,142	83/271
USW WT-11	441/1,446	364/1,194	77/252
UE-25 WT#12	399/1,310	345/1,132	54/178
UE-25 WT#13	352/1,155	303/994	49/161
UE-25 WT#14	399/1,310	346/1,136	53/174
UE-25 WT#15	415/1,360	354/1,162	60/198
UE-25 WT#16	521/1,710	473/1,552	48/158
UE-25 WT#17	443/1,453	395/1,296	48/157
USW WT-19[a]	335/1,099[b]	ND	ND
USW WT-20[a]	305/1,000[b]	ND	ND
USW WP-21[a]	550/1,805[b]	ND	ND
USW WT-22[a]	395/1,296[b]	ND	ND
USW WT-23[a]	670/2,198[b]	ND	ND
USW WT-24[a]	670/2,198[b]	ND	ND

[a]Planned well.
[b]Estimated depth.
[c]ND = no data.

extant WT wells will be sampled for interstitial gases from a discrete unsaturated interval adjacent to the water table following water-sample collection. Analytical data from these samples will also be used in Study 8.3.1.2.2.7 (hydrochemical characterization of the unsaturated zone).

Data from the WT wells will enable hydrochemical characterization of the upper part of the saturated zone, and comparison with the hydrochemistries of deeper intervals. The comparisons will aid in the development and refinement of a conceptual model of fluid movement in the saturated zone, with respect to fluid flow paths, velocities, and residence times. The data will also enable hydrochemical characterization of that part of the unsaturated zone adjacent to the water table. These data will augment the conceptualization and refinement of flux at the saturated-unsaturated zone interface.

Caliper, epithermal-neutron porosity, magnetometer, magnetic, susceptibility, and possibly other experimental and supporting logs will be run from total well depth to land surface in each of the extent WT wells. These data will (1) aid in the evaluation of physical formation properties, (2) aid in stratigraphic correlations, and (3) determine vertical profiles of water content in the unsaturated zone. This data-collection activity will be carried out under Activity 8.3.1.4.2.1.3 (borehole geophysical surveys), and will precede sampling if it is logistically more efficient.

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 Number	Title	Date
	(NWM-USGS-)		
Water sample, gas sample and field data collection	HP-01,R1	Packer-injection and shut-in tests	9 Jul 84
	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-48,R0	Method for calibrating hand-held glass thermometers	14 Aug 84
	HP-49,R0	Method for using hand-held glass thermometers	14 Aug 84
	HP-56,R1	Gas and vapor sampling from unsaturated-zone test holes	15 Apr 88
	HP-59,R0	Method for calibrating digital thermometers	TBD[a]

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Water sample, gas sample, and field data collection (continued)	HP-86,R0	Method for degassing CO_2 and H_2O vapor samples from unsaturated-zone test holes	16 May 88
	HP-110,R0	Extraction of pore waters by centrifuge methods	8 Jun 88
	HP-125,R0	Method of extraction of pore water from tuff cores by triaxial compression	20 May 88
	HP-126,R0	Extraction of residual waters from tuff samples by vacuum distillation	15 Jun 88
Drill core handling	MDP-01,R0	Identification, handling, storage, and disposition of drill-hole core and samples (REECo)	15 Oct 81
	HP-131,R0	Method for handling and transporting unsaturated core and rubble samples for hydrochemical analysis	13 Jun 88
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

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Chemical analysis	HP-160,R0	Methods for collection and analysis of samples for gas composition by gas chromatography	16 Jun 88
	TBD	Methods for chromatographic determination of dissolved inorganic substances	TBD

[a]TBD = to be determined.

8.3.1.2.3.2.3 Activity: Regional hydrochemical characterization

Objectives

The objective of this activity is to describe regional spatial variations in ground-water chemistry in the saturated zone by collecting representative water samples from wells and springs within the region and by studying their chemical and isotopic compositions.

Parameters

The parameters of this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Water samples will be collected from selected springs and extent wells within the Nevada Test Site and the surrounding region. As appropriate, newly drilled wells will be sampled, but no drilling is proposed for this activity. Sites selected will include some of those where alternative conceptual models of the regional geohydrologic system will be tested by Study 8.3.1.2.1.3 (characterization of the regional ground-water flow system), particularly with regard to ground-water flow rates and directions, and to support the designation of flow-system boundaries. Hydrochemical data from these sites will also provide insight as to the origin of anomalous features in the regional potentiometric surface.

Water samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of elected radioisotopes, including tritium, carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium and sulfur. Water-level drawdown and recovery data will be collected from wells during and after sampling, and used by Study 8.3.1.2.1.3 (characterization of the regional ground-water flow system) to estimate saturated hydraulic conductivities.

Hydrochemical data will be combined with existing data (Walker and Eakin, 1963; Schoff and Moore, 1964; Robinson and Beetem, 1965; Naff, 1973; Winograd and Thordarson, 1975; Benson et al., 1983; Classen, 1985) to describe the spatial compositional variations in regional ground-water chemistry. Radioisotope data will enable estimates of ground-water ages and flow rates. Stable isotope and inorganic concentration data will provide insight as to the origins, evolution, and mixing of ground waters, and will aid in comparison of site-specific data in order to delineate possible flow paths. These data will also be used by Activity 8.3.1.2.3.2.4 (synthesis of saturated-zone hydrochemistry) to identify the chemical and physical processes that influence ground-water chemistry; to aid in the identification and/or quantification of ground-water travel times, flow paths, and fluxes to, from, and within the saturated zone; and to estimate climatic conditions during periods of recharge. The data will also be part of the information base used by Study 8.3.1.3.1.1 (ground-water chemistry model).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.2.3 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Water sample and field data collection	HP-23,R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-48,R0	Method for calibrating hand-held glass thermometers	14 Aug 84
	HP-49,R0	Method for using hand-hand glass thermometer	14 Aug 84

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Water sample and field data collection (continued)	HP-59,R0	Method for calibrating digital thermometers	TBD[a]
Chemical analysis	HP-160,R0	Methods for collection and analysis of samples for gas composition by gas chromatography	16 Jun 88
	TBD	Methods for chromatographic determination of dissolved inorganic substances	TBD

[a]TBD = to be determined.

8.3.1.2.3.2.4 Activity: Synthesis of saturated-zone hydrochemistry

Objectives

The objectives of this activity are to

1. Describe the saturated-zone hydrochemistry.

2. Identify the chemical and physical processes that influence ground-water chemistry.

3. Aid in the identification and/or quantification of ground-water travel times; climatic conditions during periods or recharge; flow paths; and fluxes to, from, and within the saturated zone.

Parameters

The parameter for this activity is geochemical reaction modeling.

Description

Graphical methods will be used to describe spatial distributions of selected chemical and isotopic data. Variations will be integrated with extant information describing ground-water flow directions, spatial distributions of secondary minerals, spatial petrologic variations, and whole-rock and mineralogic compositions, in order to identify sources and sinks of dissolved materials, to infer sources and areas of recharge, and to estimate ground-water flow paths, flow rates, and residence times.

The geochemical modeling code EQ3NR/EQ6 (Wolery, 1979; 1983) will be used with the bases of hydrochemical and mineralogic data to (1) calculate the specifications of dissolved materials, (2) determine the saturation states of relevant solid phases, and (3) test plausible water-rock reaction models. The results of these efforts will aid in the identification of the geochemical process that have combined with ground-water flow to determine the present ground-water chemistry. Process identification will also contribute to an understanding of the paleohydrology of the region, and to general resolution of ground-water flow paths, residence times, and recharge conditions. The analytical and process data will also comprise part of the geochemical base needed by performance and design issues 1.1 through 1.12, as addressed by Section 8.3.1.3.

The information generated by this activity will constitute "nonhydraulic" tests of alternative conceptual models of the ground-water flow system.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.2.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Geochemical reaction modeling		No technical procedures identified	

8.3.1.2.3.3 Study: 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 data objectives of this activity are to synthesize the available hydrogeologic data to develop a conceptual model and make a qualitative analysis of how the site saturated-zone hydrogeologic 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.
7. Potentiometric surface configuration.

Description

All reliable data and reasonable interpretations of these data will be assimilated into a description of the saturated-zone 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 flow-system operation within this framework. The data will contain information accumulated from the published literature and the Yucca Mountain 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
Preliminary hypothesis testing	No technical procedures identified		
Conceptual model development and validation	No technical procedures identified		

Method	Technical procedure Number	Title	Date
Sensitivity analysis	TBD[a]	Reference software documentation	TBD

[a]TBD = to be determined.

8.3.1.2.3.3.2 Activity: Development of fracture network model

Objectives

The objectives of this activity are to

1. Develop and evaluate methods for simulating ground-water flow and conservative solute transport in saturated fractured rock beneath Yucca Mountain.

2. Relate results of hydraulic and conservative-tracer tests in wells to fracture-network characteristics at Yucca Mountain.

3. Develop methods for identifying transmissive fracture zones in rocks penetrated by boreholes.

4. Identify geohydrologic conditions at Yucca Mountain where ground-water flow and conservative solute transport can be properly evaluated using the porous-medium assumption.

Parameters

The parameters for this activity are various flow and transport characteristics needed to predict rates and directions of ground-water flow and radionuclide migration, including

1. Hydraulic conductivity.
2. Storage coefficient.
3. Effective porosity.
4. Hydrodymanic dispersion.
5. Hydraulic gradients.

Description

Major technical components of the hydrologic analysis of fracture networks are broadly placed into three tasks. The first task (preliminary model development) emphasizes model development and evaluation using existing data or data that can be readily obtained. The second task (analysis of well tests) emphasizes model refinement and validation at multiple-well locations in the saturated zone beneath Yucca Mountain. The third task (analysis at the scale of Yucca Mountain) emphasizes model development at the scale of Yucca Mountain and characterization of spatial variations in aquifer properties in the vicinity of Yucca Mountain.

Preliminary model development will include development and documentation of computer programs to describe fracture-network geometry and to simulate flow and transport in fractured rock. A model will be developed that is capable of simulating ground-water flow and conservative-solute transport in a saturated 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 simple 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.

Initially, 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. As data and results developed as part of Activity 8.3.1.4.2.2.2 (surface-fracture) network studies become available, these results may be included in the fracture-mesh generator.

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 simple to evaluate techniques for modeling dispersion. Alternative 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 test whether 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), verification and validation simulations, and program listings.

Parametric studies, using fracture-characteristic data obtained from drillholes UE-25c#1, UE-25c#2, and UE-25c#3 (Figure 8.3.1.2-29), 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, to establish whether fracture statistics from 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 televiewer 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.

Results of Activity 8.3.1.4.2.2.5 (seismic tomography) will be related to characteristics of fracture networks. Major components of the hydrologic investigation that use these results are (1) identification of relations between seismic-wave properties, fractures, and lithology, by prototype vertical seismic profiling at USW G-4; (2) identification of fracture characteristics between boreholes at the scale of well tests by cross-hole seismic profiling at the UE-25c wells and possibly a second multiple-well location; (3) validation of seismic techniques by profiling the exploratory shaft and comparing results to fractures mapped in the shaft; and (4) determination of spatial variations in fracture characteristics in the vicinity of Yucca Mountain by seismic profiling over distances of 0.5 to 1 km.

Fracture networks generated on the basis of preceding geologic and geophysical investigations 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 and Witherspoon (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 that 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.

The analysis of well tests will be done in two phases. The first, involves testing at the UE-25c wells and will emphasize model refinement, in particular, understanding relations between geophysical and hydrologic models. The previous task, preliminary model development, emphasized the use of existing data or data that could be readily obtained. Some aspects of the conceptual models developed on the basis of these data probably will prove incorrect or will not be sufficiently detailed when applied in deeply buried rocks of the saturated zone beneath Yucca Mountain. Furthermore, no data exist that can be used to investigate possible relations between seismic and hydrologic models. Therefore, significant model refinement is expected as a result of interpreting well tests at the UE-25c wells. (These well tests are described in Activities 8.3.1.2.3.1.4 and 8.3.1.2.3.1.5). The second phase of this activity will emphasize model validation at a second multiple-well location. The second phase will be curtailed if a second multiple-well location is not drilled. Drilling and subsequent hydrologic testing of a second multiple-well location is described in Activity 8.3.1.2.3.1.6.

The hydrologic model of fracture networks will be used to interpret results of hydraulic and conservative-tracer tests at the UE-25c wells. On the basis of results from parametric studies and seismic modeling, a set of fracture networks will be generated that brackets the range of uncertainty in fracture characteristics. These networks will be conditioned so that fractures observed in the boreholes are realized. Components of the geologic model of fracture networks that are uncertain also will be considered in selecting fracture networks. Fracture networks initially generated on the basis of geologic and geophysical evidence will be used to simulate hydraulic-test results. Those networks that best match measured results of hydraulic-stress and tracer tests will be considered representative of the fractured rock in the vicinity of the tested wells. Because fracture-network characteristics probably cannot be determined uniquely by simulation of well-test results, statistical algorithms for determining likely fracture networks will be used.

Assuming a second multiple-well location is drilled and tested, model validation probably will be a four-step process. Because conceptual models have not been formulated in detail, it is not appropriate to speculate on detailed interpretive approaches until gaining experience in testing and analysis at the UE-25c wells. The first step in validation will be to drill the wells and collect adequate seismic-profile data to use in geophysical and hydrologic modeling. The second step is to design appropriate hydraulic and tracer tests and predict test results. Geophysical and intraborehole flow data will be used to select appropriate test designs. Geologic and geophysical models will be used to estimate fracture-network geometry. Hydrologic models, using the estimated fracture-network geometry as a basis, will predict test results. Uncertainty in model analysis will need to be evaluated when predicting test results. Therefore, predictions probably will be expressed statistically, either as a range of probable results, or as a best estimate of results and associated confidence regions. The third step will be to conduct the tests. The fourth step in validation will be to compare predicted test results with actual test results.

Hydrologic models that are developed during this investigation probably will be most accurate when applied at the scale of well tests. However, the ultimate use of the model will be at the scale of Yucca Mountain, where details measurable at the scale of well tests will not be measured. Therefore, numerical methods corresponding to the scale of Yucca Mountain will be evaluated and a numerical model will be developed. Computer programs will be written, verified, and documented.

If available, well-documented cases of solute migration in fractured rock will be used to validate models at scales similar to those of Yucca Mountain (1 to 100 km^2). To form an appropriate model-validation exercise, the history of contamination and subsequent migration would need to be known, and the geologic framework would need to be similar to the geologic framework of Yucca Mountain.

Methods for estimating aquifer properties in areas between boreholes will depend on the availability of cross-hole seismic-profiling data and the success in relating seismic-wave propagation to hydrologic properties. If data are available and relations between seismic and hydrologic properties are demonstrated during investigation of multiple-well locations, the geophysical models described previously will be used to estimate spatial variations in fracture networks. Results of geophysical models would then be used in the hydrologic models described previously to predict the spatial distribution of aquifer properties. Aquifer-property estimates obtained from hydrologic well tests, and fracture data obtained from boreholes would be used to condition the predicted spatial distribution of aquifer properties.

If geophysical data are not collected or cannot be used to estimate aquifer properties with confidence, appropriate geostatistical methods might be used to estimate the spatial distribution of aquifer properties. Geostatistical techniques such as kriging and conditional simulation may be appropriate if distances between point estimates of aquifer properties are less than the ranges of the corresponding semivariograms.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.2.3.3.2 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Preliminary model development	TBD[a]	Reference software documentation	TBD
Analysis of well tests	TBD	Reference software documentation	TBD

[a]TBD = 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 to

1. Estimate ground-water flow direction and magnitude for input into travel-time calculations.

2. 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.

Although 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 unpreturbed 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. Models 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-)		
Develop conceptual and numerical models of ground-water flow and conservative-solute transport to be applied at scale of Yucca Mountain	TBD[a]	Reference software documentation	TBD
Characterize spatial variations in aquifer properties	No technical procedures identified		

[a]TBD = 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:

Information need or investigation	Title
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	Pre-waste-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)
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 characteristics)

8.3.1.2.4 Schedule for the geohydrology program

The geohydrology program includes three investigations, which contain 16 studies. The schedule information for each study is summarized in Figure 8.3.1.2-32. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the geohydrology program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.2-11.

The study-level schedules, in combination with information provided in the logic diagrams for this program (Figures 8.3.1.2-1, -2, -3, and -4), are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. the information provided in Table 8.3.1.2-11 and Figure 8.3.1.2-32, however, should be viewed as a snapshot in time.

The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports. Additional schedule information for activities within site program studies are to be provided in SCP support documents. Summary schedule information for the geohydrology program can be found in Sections 8.5.1.1 and 8.5.6.

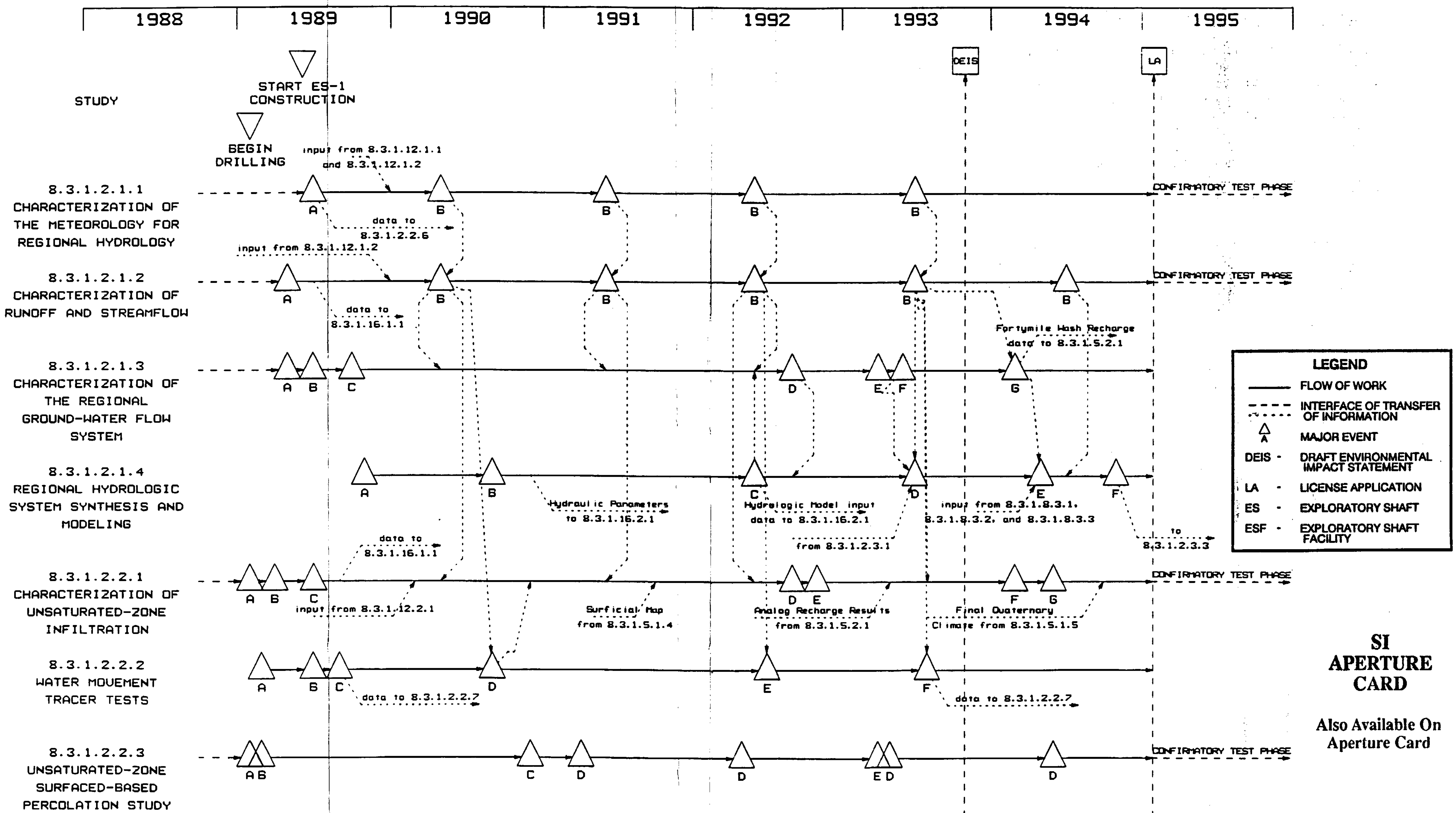

Figure 8.3.1.2-32. Schedule information for studies in Site Program 8.3.1.2 (geohydrology). See Table 8.3.1.2-11 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 1 of 3)

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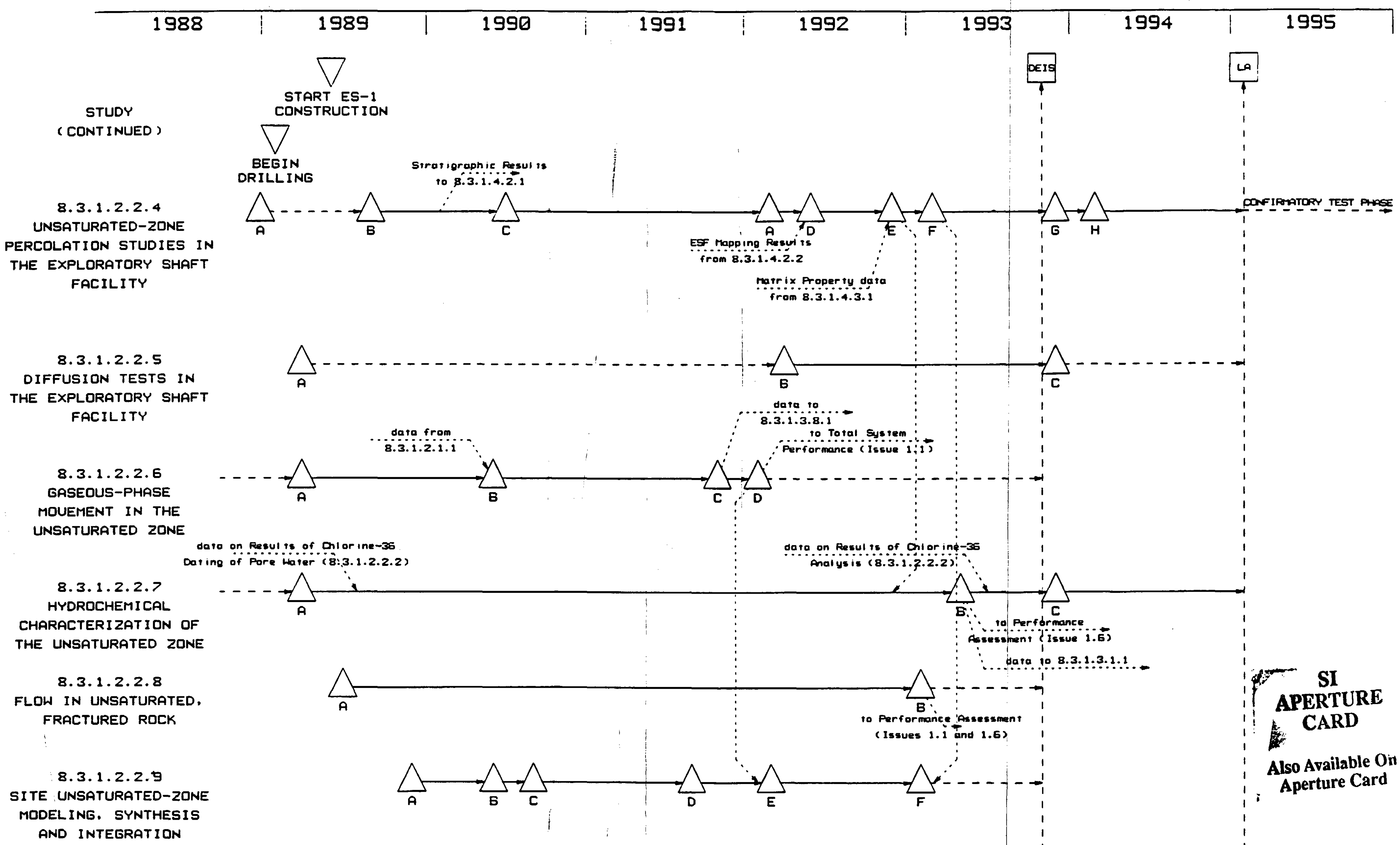

Figure 8.3.1.2-32. Schedule information for studies in Site Program 8.3.1.2 (geohydrology). See Table 8.3.1.2-11 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 2 of 3)

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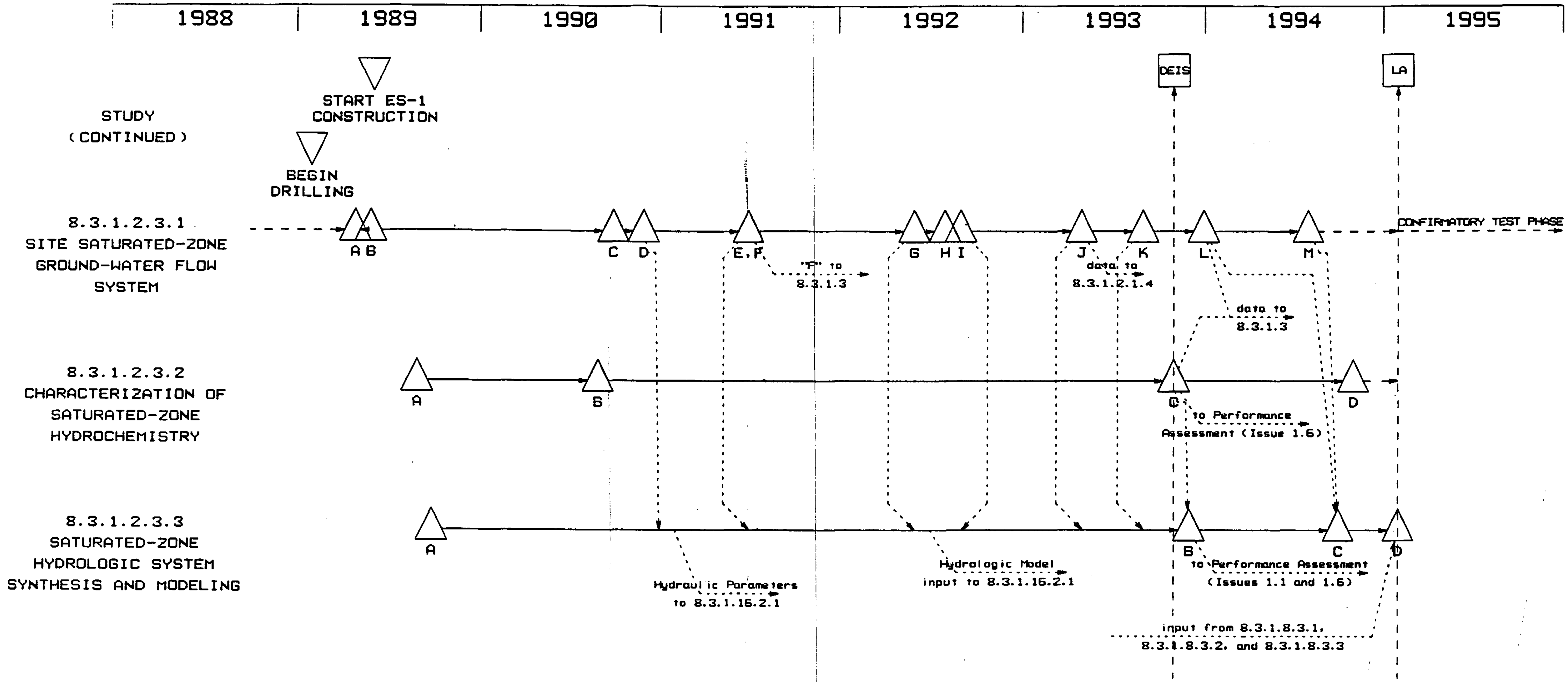

Figure 8.3.1.2-32. Schedule information for studies in Site Program 8.3.1.2 (geohydrology). See Table 8.3.1.2-11 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 3 of 3)

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Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 1 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.1.1 (ongoing)	Meteorology for regional hydrology	A	Study plan approved	6/89
		B	Yearly precipitation data available; precipitation and meteorological monitoring will continue as performance confirmation	4/90 5/91 5/92 6/93
8.3.1.2.1.2 (ongoing)	Runoff and streamflow	A	Study plan approved	4/89
		B	Annual status reports on streamflow, debris flow, and precipitation data available to the U.S. Department of Energy (DOE); surface water runoff monitoring will continue as performance confirmation	4/90 5/91 5/92 6/93 6/94
8.3.1.2.1.3 (ongoing)	Regional ground-water flow system	A	Study plan approved	4/89
		B	Select sites for evapotranspiration studies	6/89
		C	Initiate Fortymile Wash borehole studies	9/89
		D	Draft report available to DOE on the evaluation of steep hydraulic gradients near Yucca Mountain	8/92

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 2 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.1.3	Regional ground-water flow system (continued)	E	Draft report available to DOE on regional potentiometric level	3/93
		F	Draft report and map of results of evapotranspiration available to DOE	5/93
		G	Report available to DOE on the estimate of ground-water recharge at Fortymile Wash	2/94
8.3.1.2.1.4	Regional hydrologic system synthesis and modeling	A	Study plan approved	10/89
		B	Draft report available to DOE on the conceptual model of the saturated zone at Yucca Mountain	8/90
		C	Draft report available to DOE on the two-dimensional cross-sectional ground-water flow model	5/92
		D	Draft report available to DOE on ground-water discharge in the Amargosa Desert	6/93
		E	Report available to DOE on regional three-dimensional ground-water flow model	4/94

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 3 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.1.4	Regional hydrologic system synthesis and modeling (continued)	F	Complete 3-D porous media equivalent flow model of the saturated zone at Yucca Mountain	10/94
8.3.1.2.2.1 (ongoing)	Unsaturated-zone infiltration	A	Study plan approved	2/89
		B	Initiate artificial infiltration activities	3/89
		C	Complete natural infiltration drilling and begin monitoring; natural infiltration monitoring will continue as performance confirmation	6/89
		D	Draft of preliminary report on infiltration based on neutron hole monitoring available to DOE	8/92
		E	Complete characterization of hydrologic properties of surficial materials	10/92
		F	Final report on infiltration based on neutron hole monitoring available to DOE	2/94
		G	Report available to DOE on rainfall simulation studies at Yucca Mountain	5/94

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 4 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.2.2	Water movement tracer tests	A	Study plan approved	6/88
		B	Begin chlorine-36 dating pore water test	6/89
		C	Draft report available to DOE on the results of chlorine-36 dating of pore water	8/89
		D	Draft report available to DOE on results of chlorine-36 infiltration	8/90
		E	Complete chlorine-36 sample analysis	6/92
		F	Draft of final report on results of chlorine-36 analysis available to DOE	7/93
8.3.1.2.2.3 (ongoing)	Unsaturated-zone surface-based percolation	A	Study plan approved	1/89
		B	Begin unsaturated zone drilling	2/89
		C	Instrument drillholes & initiate monitoring	11/90

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 5 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.2.3 (ongoing)	Unsaturated-zone surface-based percolation (continued)	D	Yearly summary of unsaturated-zone monitoring available to DOE; unsaturated-zone monitoring will continue as part of performance confirmation	3/91 4/92 4/93 5/94
		E	Draft of preliminary report on the hydrological properties of tuff matrix available to DOE	3/93
8.3.1.2.2.4	Unsaturated-zone percolation studies in the exploratory shaft facility	A	Study plan, Revision 0, approved	12/88
		B	Start radial borehole, perched water, and unsaturated zone hydrochemistry tests	8/89
		C	Begin excavations effects tests	6/90
		A	Study plan, Revision 1, approved	2/92
		D	Begin intact fracture, infiltration and bulk permeability tests; intact fracture tests, infiltration and bulk permeability tests and near-field thermally perturbed properties determination will continue as performance confirmation	5/92

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 6 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.2.4	Unsaturated-zone percolation studies in the exploratory shaft facility (continued)	E	Draft of final report on the results of hydrochemistry tests in the unsaturated zone available to DOE	11/92
		F	Draft of final report on the results of perched water tests available to DOE	2/93
		G	Complete excavation effects tests	11/93
		H	Final report on the results of radial borehole tests available to DOE	2/94
8.3.1.2.2.5	Diffusion tests in the exploratory shaft facility	A	Study plan approved	3/89
		B	Begin diffusion test	3/92
		C	Draft report available to DOE on the results of the diffusion test	11/93
8.3.1.2.2.6 (ongoing)	Gaseous-phase movement in the unsaturated zone	A	Study plan approved	3/89
		B	Draft report available to DOE on interpretation of results of air flow interference tests	5/90

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 7 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.2.6 (ongoing)	Gaseous-phase movement in the unsaturated zone (continued)	C	Draft of preliminary report on gaseous-phase flow through the unsaturated zone at Yucca Mountain available to DOE	10/91
		D	Draft of final report on the topographic effects on gas-phase circulation available to DOE	1/92
8.3.1.2.2.7 (ongoing)	Hydrochemical characterization of the unsaturated zone	A	Study plan approved	3/89
		B	Draft report available to DOE on the preliminary evaluation of unsaturated-zone hydrochemistry	4/93
		C	Preliminary gas sampling in unsaturated zone complete	11/93
8.3.1.2.2.8	Flow in unsaturated, fractured rock	A	Study plan approved	6/89
		B	Draft of preliminary report on the evaluation of methods for simulating fluid flow and solute transport through fractured rock available to DOE; Begin preparation of final report	1/93
8.3.1.2.2.9	Site unsaturated-zone modeling, synthesis, and integration	A	Study plan approved	11/89

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 8 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.2.9	Site unsaturated-zone modeling, synthesis, and integration (continued)	B	Draft report available to DOE on the preliminary evaluation of unsaturated-zone modeling	5/90
		C	Begin simulation of hydrogeologic system	8/90
		D	Draft report available to DOE on the stochastic model of subsurface flow in the unsaturated zone	8/91
		E	Draft report available to DOE on the summary of unsaturated-zone hydrologic modeling	2/92
		F	Draft report available to DOE on the preliminary evaluation of unsaturated-zone hydrology	1/93
8.3.1.2.3.1 (ongoing)	Site saturated-zone ground-water flow system	A	Study plan approved	3/89
		B	Begin C-hole testing	5/89
		C	Decision to proceed with additional saturated-zone tracer tests at new sites	9/90
		D	Draft report available to DOE on the analysis of water-level fluctuations at Yucca Mountain	11/90

Table 8.3.1.2-11. Major events and planned completion dates for studies in the geohydrology program (page 9 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.3.1 (ongoing)	Site saturated-zone ground-water flow system (continued)	E	Complete hydrologic testing of the saturated zone in USW H-7 and H-6	6/91
		F	Draft of final report on C-well reactive tracers available to DOE	6/91
		G	Draft report available to DOE on cross-hole studies at UE-25c wells	5/92
		H	Draft report available to DOE on experiment design for reactive tracers	7/92
		I	Draft report available to DOE on the geohydrology of USW H-7 and H-6 (Solitario Canyon)	8/92
		J	Draft report available to DOE on the potentiometric surface at Yucca Mountain; site potentiometric-level monitoring will continue as performance confirmation	4/93
		K	Draft report available to DOE on the results of multiple well tracer tests in the saturated zone at UE-25c wells	8/93

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 10 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.3.1 (ongoing)	Site saturated-zone ground-water flow system (continued)	L	Draft of final report on reactive tracers for new wells available to DOE	12/93
		M	Final report on the results of conservative tracer tests in the saturated zone at the second multiple well site available to DOE	7/94
8.3.1.2.3.2	Characterization of saturated-zone hydrochemistry	A	Study plan approved	8/89
		B	Assessment of site saturated-zone hydrochemical data availability and needs complete	8/90
		C	Draft report available to DOE on the hydrochemical characterization of the upper part of the saturated zone within the site area	10/93
		D	Report available to DOE updating the hydrochemical characterization of the upper part of the saturated zone at the Yucca Mountain site	10/94
8.3.1.2.3.3	Saturated-zone hydrologic system synthesis and modeling	A	Study plan approved	9/89
		B	Draft report available to DOE on the preliminary description of the saturated zone	11/93

Table 8.3.1.2-11. Major events and planned conpletion dates for studies in the geohydrology program (page 11 of 11)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.2.3.3	Saturated-zone hydrologic system synthesis and modeling (continued)	C	Report available to DOE on application of fracture network models for saturated zone to UE-25c tests	9/94
		D	Complete conceptual model of the saturated zone	1/95

[a]The letter in this column key major events shown in Figure 8.3.1.16-32.

DOE/RW-0199

DOE/RW-0199

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume IV, Part B

Chapter 8, Section 8.3.1.3, Geochemistry

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

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. 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 yr. 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 yr. 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 yr.

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.

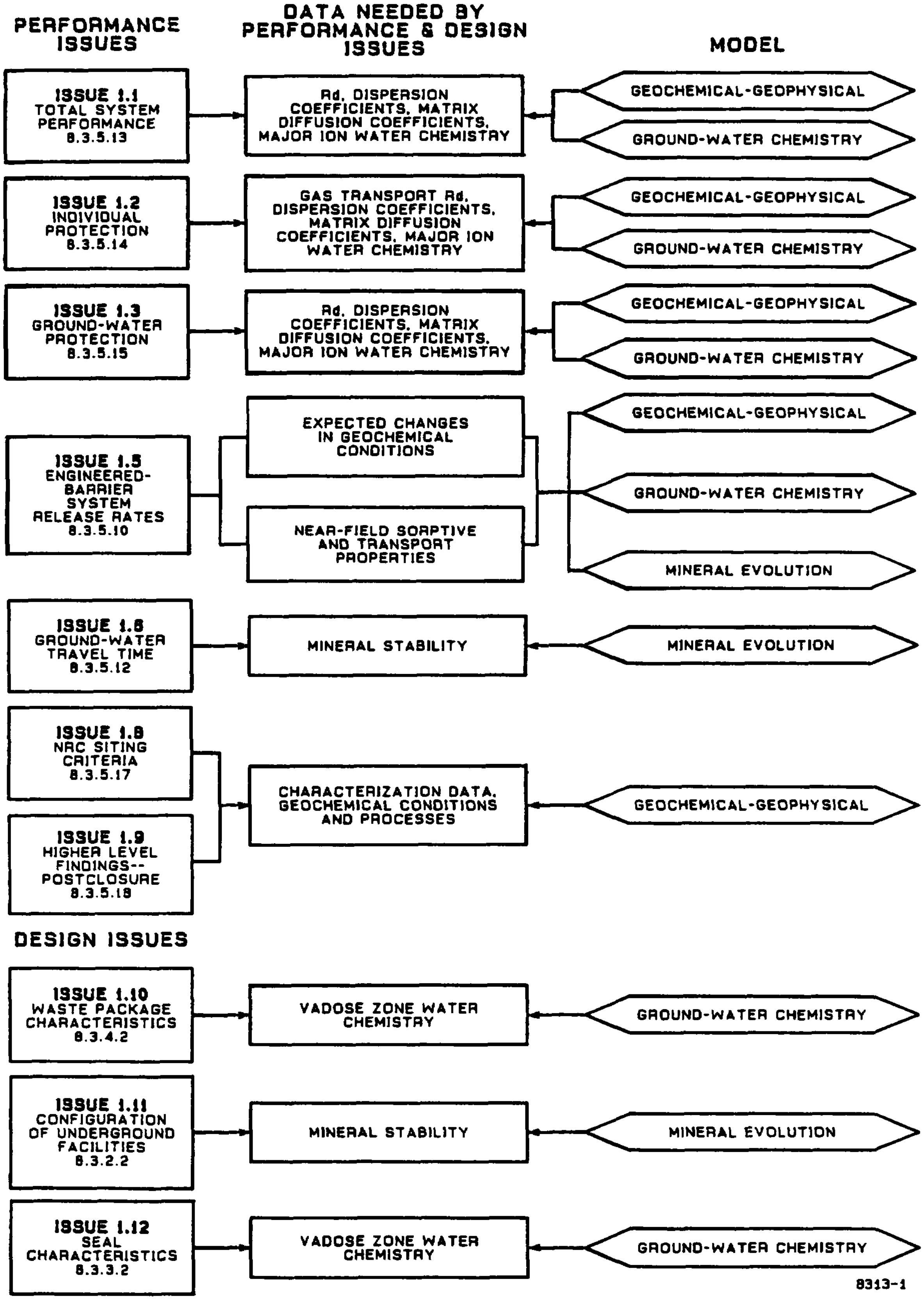

Figure 8.3.1.3-1. Parameter calls and corresponding model from geochemistry test program.

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_fs) 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.

<u>Approach used to satisfy performance and design requirements</u>

In a broad sense, the geochemistry program must characterize and evaluate the effectiveness of the geochemical "barrier." The program of geochemical testing described in this section concerns characterizing the far-field geochemistry at the site. The geochemical studies concerned with characterizing the waste package environment and engineered barrier system performance are discussed in Section 8.3.4.2 and 8.3.5.9, respectively. Section 8.3.5.13, through the use of performance allocation, presents an evaluation that describes the far-field geochemical "barrier" as a reserve barrier in a total systems performance assessment. The geochemical barrier

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 1 of 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	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	8.3.1.3.5.1.1 through 8.3.1.3.5.1.3 8.3.1.3.5.2.1 8.3.1.3.5.2.2
		Saturated zone geochemical properties (sorptive)	Sorption mechanics for radionuclides	8.3.1.3.4.1.1
			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 6)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geochemistry characterization program: 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	8.3.1.3.5.1.1 through 8.3.1.3.5.1.3 8.3.1.3.5.2.1 8.3.1.3.5.2.2
		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 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	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
		Saturated zone hydrologic properties and conditions (groundwater chemistry)	Major ion chemistry	8.3.1.2.1.3.5
		Saturated zone hydrologic properties and conditions (dispersive)	Dispersion characteristics for crushed tuff	8.3.1.3.6.1.1
			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 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	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	8.3.1.2.2.4.8
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	
1.5, Engineered barrier system release rates	8.3.5.10	Changes in geochemical radionuclide conditions, sorptive and transport properties of the near-field host rock	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

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 5 of 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.5, Engineered barrier system release rates (continued)	8.3.5.10		Solubilities of compounds bearing radionuclides having significant representation in the inventory and half-lives > 20 yr	8.3.1.3.5.1.1 through 8.3.1.3.5.1.3 8.3.1.3.5.2.1 8.3.1.3.5.2.2
			Major ion chemistry	8.3.1.2.2.4.8
1.6, Groundwater 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	
1.10, Waste package characteristics (postclosure)	8.3.4.2	Unsaturated zone hydrologic properties (fluid chemistry)	Major ion chemistry	8.3.1.2.2.4.8
		Rock unit characteristics (mineralogy-petrology)	Mineral stability	8.3.1.3.2.2.2

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 6 of 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.11, Configuration of underground facilities (postclosure)	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	8.3.1.2.2.4.8

is an important factor. Thus, the geochemistry test program must test the assumptions and provide confidence in and give support to the release rates determined by the solute transport calculations of Section 8.3.5.13, as well as evaluate alternative conceptual models of the site geochemistry. The goal for the retardation parameter in the solute transport calculations is a value of one, implying that "no credit" is taken for geochemical retardation processes. However, these processes are included in the strategy for demonstrating system compliance by virtue of the inclusion of a retardation factor in the equations. The geochemistry program is directed at quantifying the retardation factor, which is expected to exceed a value of one. Any value greater than one will supply added confidence to the calculations of transport to the accessible environment based on advective/dispersive transport calculations.

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_fs and the one-dimensional system model described in 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, for the far-field

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 yr.

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.

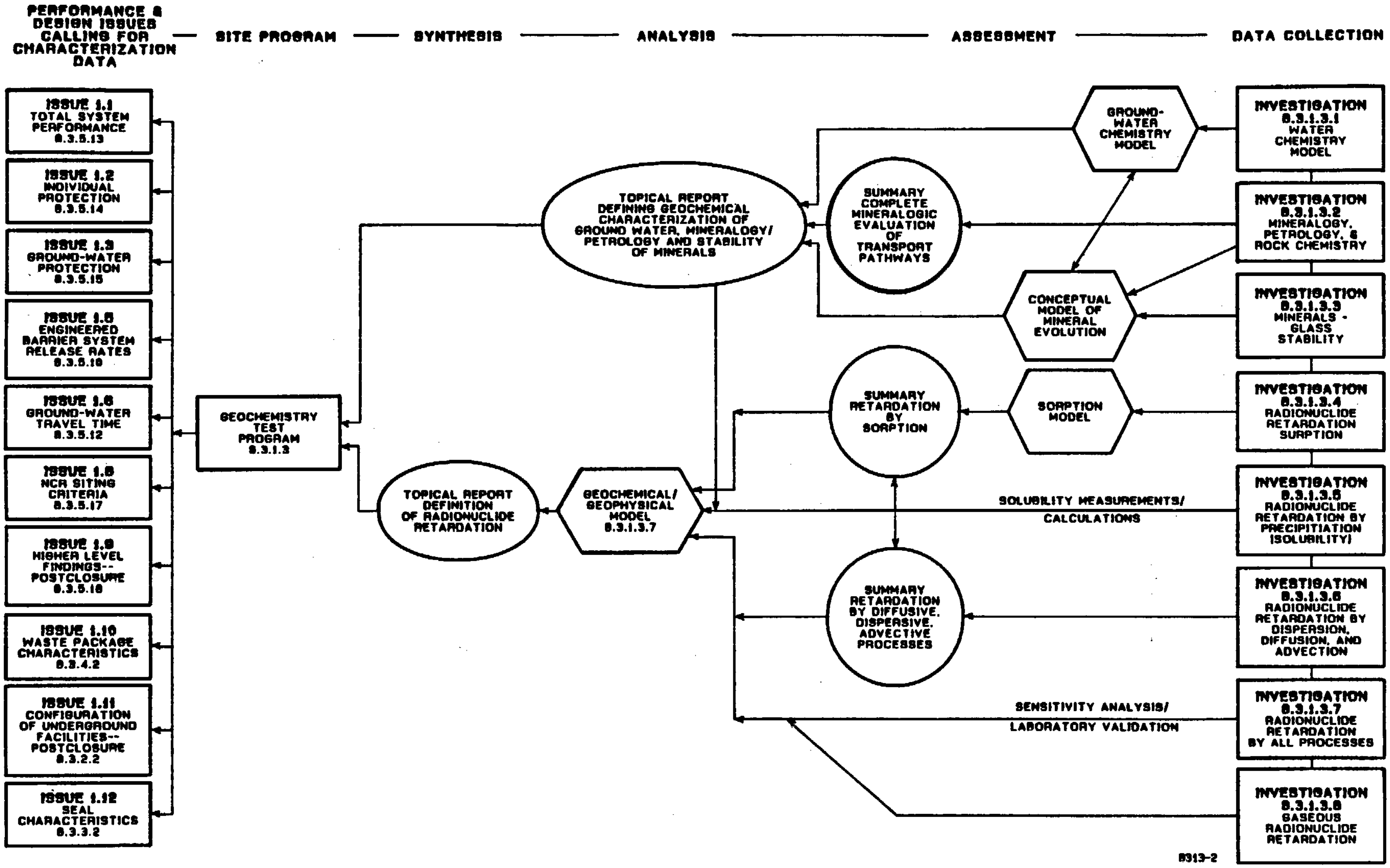

Figure 8.3.1.3-2. Logic diagram for geochemistry program 8.3.1.3.

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 are 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 mineralogy relevant to the definition of the disturbed zone. This information is important to 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.

Alternative Conceptual Models

The intent of Table 8.3.1.3-2 is (1) to present the current conceptual understanding of the geochemical conditions and processes active at the site and how they are expected to function as the geochemical barrier to radionuclide migration during the repository performance period and (2) to present alternative hypotheses that could be supported based on the uncertainty in existing information and understanding. These two aspects are further developed in the table by identifying the performance parameters, or design needs, that may be affected by the results of site characterization work to determine if the current conceptual understanding, or an alternate hypothesis, is correct. The needed confidence in these performance parameters is given (based on system or subsystem performance allocation tables in the SCP), along with an estimated sensitivity of the performance assessments to the alternative hypotheses and the uncertainty involved. The specific studies are aimed at quantifying the geochemical processes, limiting uncertainty, or distinguishing between alternate representations of expected behavior of the site.

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 1 of 8)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
RETARDATION MODEL	Radionuclide mobility is substantially retarded by (1) sorption, (2) solubility, and (3) dispersion/ diffusion/ filtration	High--mechanisms of transport and and retardation are only generally known	Retardation is largely bypassed by flow field characteristics (i.e., rapid along fractures) One retardation process dominates Retardation processes in the natural situation are too complex to model reliably	NA[a]	NA	NA	NA	8.3.1.3.7--retardation, all processes
Gaseous pathway	Gaseous radionuclide release from the near field is upward through the unsaturated zone, rate and amount of transport can be bounded by engineered barrier system performance assessments and data on vapor phase transport collected in the pre-emplacement time frame	High--site data very limited, calculational models not tested with field data	Vapor transport cannot be modeled adequately	NA	NA	NA	NA	8.3.1.3.7--retardation, all processes

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 2 of 8)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Dispersion/ diffusion	Dispersion/ diffusion provide some retardation	High--site data very limited	Vapor phase movement too rapid along preferred flow paths to model adequately Dispersion ineffective as a retardation mechanism	Gaseous radionuclide release to accessible environment	High	High	High	8.3.1.3.8--gaseous transport 8.3.1.2.2.6--gaseous phase movement in unsaturated zone 8.3.1.2.2.7.1--gaseous phase chemistry
Isotopic exchange	Isotopic exchange with the liquid phase in the unsaturated zone provides some retardation for carbon-14	High--site data very limited	Isotopic exchange not effective due to rapid vapor phase transport	Gaseous radionuclide release to accessible environment	High	High	High	8.3.1.3.8--gaseous transport 8.3.1.2.2.6--gaseous phase movement in unsaturated zone 8.3.1.2.2.7.1--gaseous phase chemistry
Liquid pathway	Predominant release pathway is in the liquid phase, movement is downward and laterally from the repository. Retardation provided by chemical and physical processses	Low to medium--current hydrologic data support downward movement. Current data base is not extensive enough	Rapid groundwater movement bypasses chemical and physical retardation processes	NA	NA	NA	NA	NA

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 3 of 8)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
Sorption	Sorption is an element-specific function of water composition, solids, redox condition, pH, temperature, rock texture, hydrologic properties	Medium to high--some uncertainty over site-specific conditions for individual element behavior	Site specific behavior for specific radionuclides is too complex to predict with confidence Sorption "barrier" bypassed by physical conditions, rapid fracture flow, colloidal transport	Geochemical retardation	High	High	High	8.3.1.3.4.3--sorption models 8.3.1.2.3.1.7--C-hole reactive tracer test
Sorption as a function of substrate, water chemistry, and sorbate concentration	Sorption controlled by these parameters	Medium to high--some uncertainty in site conditions	Sorption cannot be modeled as a function of these parameters	Subset of sorption model element; overall ranking given with sorption element above				8.3.1.3.2.1--3-D mineral distribution 8.3.1.3.4.1.1--sorption as a function of solid phase composition 8.3.1.3.4.1.2--sorption as a function of sorbing element concentration 8.3.1.3.4.1.3--sorption as a function of ground-water composition 8.3.1.3.4.1.5--statistical analysis

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 4 of 8)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
- Sorption as a function of substrate, water chemistry, and sorbate concentration (continued)								8.3.1.3.6.1.1--crushed tuff column experiments 8.3.1.3.6.1.2--mass transfer kinetics 8.3.1.3.6.1.3--unsaturated tuff column experiments
- Sorption on particulates and colloids	Sorption on particulates/colloids expected to be minor and filtration would further reduce effects	Low--mobile particulates not expected in the far field	Particulate transport may be possible in a flow field dominated by rapid fracture flow	Subset of sorption model element; overall ranking given with sorption element above				8.3.1.3.4.1.4--sorption on colloids and particulates
- Microbial activity	Not thought to be a significant transport mechanism	Low--microbial activity expected to be low. Consistent with existing field data	No credible alternative	Subset of sorption model element; overall ranking given with sorption element above				8.3.1.3.4.2--biological sorption and transport
Solubility	Solubility limits levels of radionuclides through far field and solubility limited by equilibrium thermodynamic relations and/or precipitation rates	Medium to high--in element thermodynamic data and in site chemical environment	Radionuclide concentrations not limited by thermodynamic relations due to colloid formation; thermodynamic data unavailable; nucleation unfavorable Sorption processes dominate; saturation is not approached	Geochemical retardation	Medium (saturated zone) High (unsaturated zone)	Low to medium--sorption expected to control radionuclide concentrations	Medium	8.3.1.3.5--retardation by precipitation

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 5 of 8)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
- Precipitation (aqueous speciation and solubility modeling)	Radionuclide concentrations in the far field are limited by solubility/precipitation constraints	Medium to high--limited data on actinides under site conditions	Solubility/precipitation relationships cannot be modeled reliably	Subset of solubility model element; overall ranking given with solubility element above				8.3.1.3.5.1--dissolved species concentration limits
- Colloid formation and stability	Colloid formation is limited under far field site conditions for most radionuclides and filtration would limit transportation	Medium--some uncertainty exists about behavior under site conditions	Colloids form for some radionuclides and transport is possible for rapid groundwater movement along fractures	Subset of solubility model element; overall ranking given with solubility element above				8.3.1.3.5.2--colloid behavior 8.3.1.3.7.2--applicability of laboratory data to repository transport
Dispersion/diffusion/filtrations	Retardation of radionuclide transport by physical processes along pathways for matrix-dominated flow field and for some conditions of fracture flow	High--flow mechanism is not well established at the site, data on physical retardation mechanisms very sparse	Flow is dominated by rapid fracture-flow pathways and retardation mechanisms bypassed Data on physical retardation mechanism cannot be obtained for reliable quantification	Geochemical retardation	Medium (saturated zone) High (unsaturated zone)	Low to medium--sorption expected to control radionuclide concentrations	Moderate	8.3.1.3.6.1.4--fractured tuff column studies 8.3.1.3.6.1.5--filtration 8.3.1.3.6.2--diffusion

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 6 of 8)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
WATER CHEMISTRY MODEL	Ground-water chemistry is a controlling factor in retardation by sorption and solubility. Ground-water composition controlled by water-rock interactions trending toward equilibrium	Low to medium--some uncertainty in ground-water composition and thermodynamic modeling of rock/water interactions	Kinetics of rock-water interactions are too slow to alter composition of recharge water and flow is dominated by rapid fracture flow--thermodynamic modeling therefore cannot model ground-water composition and evolution predictably	Ground-water chemistry contribution to retardation factors	High	High	High	8.3.1.3.7--retardation, all processes
Saturated zone	Saturated zone ground-water composition is controlled by rock-water interactions along flow paths. No unexpected changes in ground-water chemistry along pathway to accessible environment	Low--current data are adequate to explain saturated zone ground-water composition	No credible alternative	Saturated zone residence times and retardation processes (If fluid flow is controlled by rapid fracture flow through the unsaturated zone, retardation in the saturated zone must be included in performance assessment of releases to the accessible environment)	High--direct evidence of residence times in saturated zone and origins of water	Medium--some compensation for chemical conditions is possible	Low--saturated zone barrier is backup. Also produces additional lines of evidence for flow path/velocity	8.3.1.3.1.1--ground-water chemistry model 8.3.1.2.3.2--saturated zone hydrochemical characterization

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 7 of 8)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Unsaturated zone	Unsaturated zone ground-water composition is surface recharged, modified by rock water interaction	High--very few data available	Unsaturated zone water composition reflects deep sources in the saturated zone (i.e., former stands of ground-water table, upwelling leading to perched water	Unsaturated zone water residence times and fluid chemistry as it affects dissolution of waste and retardation processes	High	High	High	8.3.1.3.1.1--ground-water chemistry model 8.3.1.2.2.7--hydrochemical characterization of unsaturated zone
MINERAL EVOLUTION MODEL	Tuff secondary mineralogy reflects alteration of tuffs immediately after deposition followed by slower alteration and formation of secondary minerals with surface recharge waters. Alteration predictable from thermodynamic relationships	Low to medium--data base somewhat limited, current data in agreement with theoretical relationships	Mineralogy is metastable kinetics are too slow and rock-water reactions are too complex to predict temporal changes over the performance period	Solid phase contribution to retardation factor	High	High	High	8.3.1.3.2--retardation, all processes 8.3.1.3.3.3--conceptual model of mineral evolution
Mineral alteration history	3-D distribution of mineral zonation from early alteration is predictable (i.e., alteration processes can be understood) at the site and a vertical and lateral stratigraphy can be developed	Medium--current data are not areally extensive enough to develop the stratigraphy	Alteration processes are too complex on the repository scale for a mineralogic stratigraphy to be developed	Retardation factor	High	Medium--sorptive phases are secondary minerals formed by alteration processes	Low--alternative hypothesis not supported by existing data	8.3.1.3.2.1--mineralogy and petrology along transport pathways 8.3.1.3.2.2--mineral alteration history

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 8 of 8)

Current representation		Uncertainty in current understanding	Alternative hypothesis and significance					Tests to distinguish hypothesis and reduce uncertainty
Model element	Current representation	Uncertainty and rationale	Alternative hypothesis	Performance measure design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
Mineral stability	Secondary mineralogy along flow paths (particularly sorptive minerals) will remain stable under postemplacement conditions or, at least, their alteration is predictable based on thermodynamic considerations	Medium--thermodynamic data are not extensive and low temperature alteration processes are difficult to quantify experimentally	Alteration rates are controlled by local conditions (interfaced processes) and are too complex to model reliably	Retardation factor	High	High	Low--alternate hypothesis not supported by existing data	8.3.1.3.3--stability of minerals and glasses

[a]NA = not applicable.

The geochemical understanding of site behavior is intimately connected to the characterization of the hydrologic regime at the site. These two aspects cannot be handled separately; the flow regime at the site (flow dominated by matrix or fracture flow or a combination of both) will determine the effectiveness of the geochemical "retardation barrier." The relative role of retardation processes will vary as a reflection of the ground-water flow regime at the site.

For example, under a matrix dominated flow system at low velocities the role of dispersion/diffusion and filtration would be more important in retarding radionuclide movement than in a flow system dominated by relatively faster ground-water movement in a fracture flow dominated system. In terms of the performance assessment strategy for total systems performance (Issue 1.1), the role of the geochemical "retardation barrier" may become more important in a hydrologic system dominated by relatively faster fracture flow than a slower matrix flow dominated flow regime because ground-water travel times would decrease and geochemical retardation then may be relied on more heavily to retard radionuclide migration.

The geochemistry program described in this section is focused on the far-field portion of the waste isolation system. As such, it is aimed at supplying data needed to predict radionuclide retardation and releases to the accessible environment (Issue 1.1). The program of geochemical work needed to address near-field performance is described in the waste package program (Section 8.3.4.2.4). Some of the geochemical site data collected in the far-field program contribute to the characterization of the waste package environment by establishing the pre-emplacement geochemical conditions.

As mentioned earlier, the hydrologic setting of the site is intimately bound to the geochemistry program. Hydrologic investigations are intended to define the nature of the flow mechanisms (matrix versus fracture flow in both the saturated and unsaturated zones). The geochemistry program will collect data relevant to both flow mechanisms so that the role of geochemical retardation can be assessed for the present hydrologic setting of the site and for possible changes in the hydrologic setting during the repository performance period. Although the geochemistry and geohydrology programs are intimately connected, the geochemistry program is in this sense independent of the geohydrology program. To determine the relative weighting given to various geochemical retardation processes in a total system analysis, the two efforts are brought together.

The organization of the information presented in Table 8.3.1.3-2 is hierarchal in nature. Three conceptual model headings are given, the retardation model, the ground-water chemistry model, and the mineral evolution model. Under each of these models all subordinated elements are listed that describe components of the conceptual models. For example, the ground-water chemistry model considers both the saturated and unsaturated zones. For the larger retardation model, a further subdivision is made based on processes involved in the model components. The retardation model considers pathways for gaseous and liquid movement as the two major elements. Retardation processes expected to be involved are subordinated under these headings. A further subdivision is given for aspects of these processes that can be conveniently separated.

All three models are closely related. The retardation model is the most important from the perspective of predicting site performance and integrates information from all the models. It is recognized that radionuclide retardation is a partial function of the chemistry of the far field rock/ground-water system. The ground-water chemistry is controlled, at least in part, by the rock-water interactions. The mineral evolution model must be integrated with the water chemistry model to understand the present geochemical conditions and the anticipated conditions during the repository performance period, at the site. The results of this understanding is then integrated into the retardation model to predict the behavior of any radionuclides carried into this rock/ground-water system during the repository performance period.

The retardation model considers the gaseous pathway and the liquid pathway (ground-water transport). For the gaseous pathway, dispersion and diffusion processes may supply some retardation, and isotopic exchange with the aqueous phase may contribute additional geochemical retardation, depending on the velocity of vapor-phase movement. For releases to the ground water, three broad categories of retardation are given as mentioned earlier. The relative importance of these retardation processes will vary dependent on the hydrologic regime. In addition to this interface with other site characterization activities, the experimental approach taken to investigate retardation processes determines, at least in part, the confidence that can be associated with the results. As a specific example, sorption testing can be done from a purely empirical approach, involving large numbers of tests determined simply by parameter variation, or an approach tailored exclusively on understanding the controlling sorption mechanisms. These "end-member" approaches generate significantly different testing programs. The approach taken in the geochemistry program is a blend of both, the exact mix determined by the current understanding of element-specific behavior and the overall need to predict the behavior a given radionuclide within the context of the total system (near and far field) performance. The test describing the testing matrices, methods, and approaches supplies further detail on these questions. In addition, testing is included to determine the behavior of radionuclides for mechanisms that, if active at the site, could effectively bypass the sorption barrier, such as sorption on colloid or particulate material. The current understanding of the site indicates that these processes are not expected to be significant but the alternative hypotheses must be tested.

As mentioned previously, the ground-water chemistry and mineral evolution models are supportive to the retardation model. These two models address the questions of determining the stability of the sorptive mineralogy during the repository performance period and the potential evolution of ground-water composition. These two models also have some application to design needs described in more detail elsewhere. More specifically, a mineral stratigraphy for the host rock will be developed from studies of the alteration history of the rocks. This "alteration stratigraphy" based on mineral zonations can be used in designing the layout of repository drifts.

A major effort in the geochemistry program is the integration of all the retardation, alteration, and transport processes into a unified picture of predicted site behavior. The integration effort is described in Section 8.3.1.3.7. This modeling activity is an overview attempt to integrate modeling studies to understand sorption processes (Section 8.3.1.3.4.3), solubility processes (Section 8.3.1.3.5.1.3), etc., within the geochemistry program. The modeling activity is the vehicle that integrates the results of all the testing, determines the relative importance of individual retardation and transport mechanisms for various flow regimes (determining the effects of alternate hypothesis), and ultimately supports the assumptions and data uses in the overall total system performance assessments. This system level modeling is shown at the highest level for each of the three models described in Table 8.3.1.3-2. Modeling work to understand individual processes such as sorption and precipitation are included in the lower level activities cited in column nine of the table.

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 8.3.1.2.3.2.2 and 8.3.1.2.3.2.3 (saturated zone) and data from the ground-water chemistry activities in Activity 8.3.1.2.2.7.2 (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 understanding the sorption and solubility processes in supporting Issues 1.1 to 1.3.

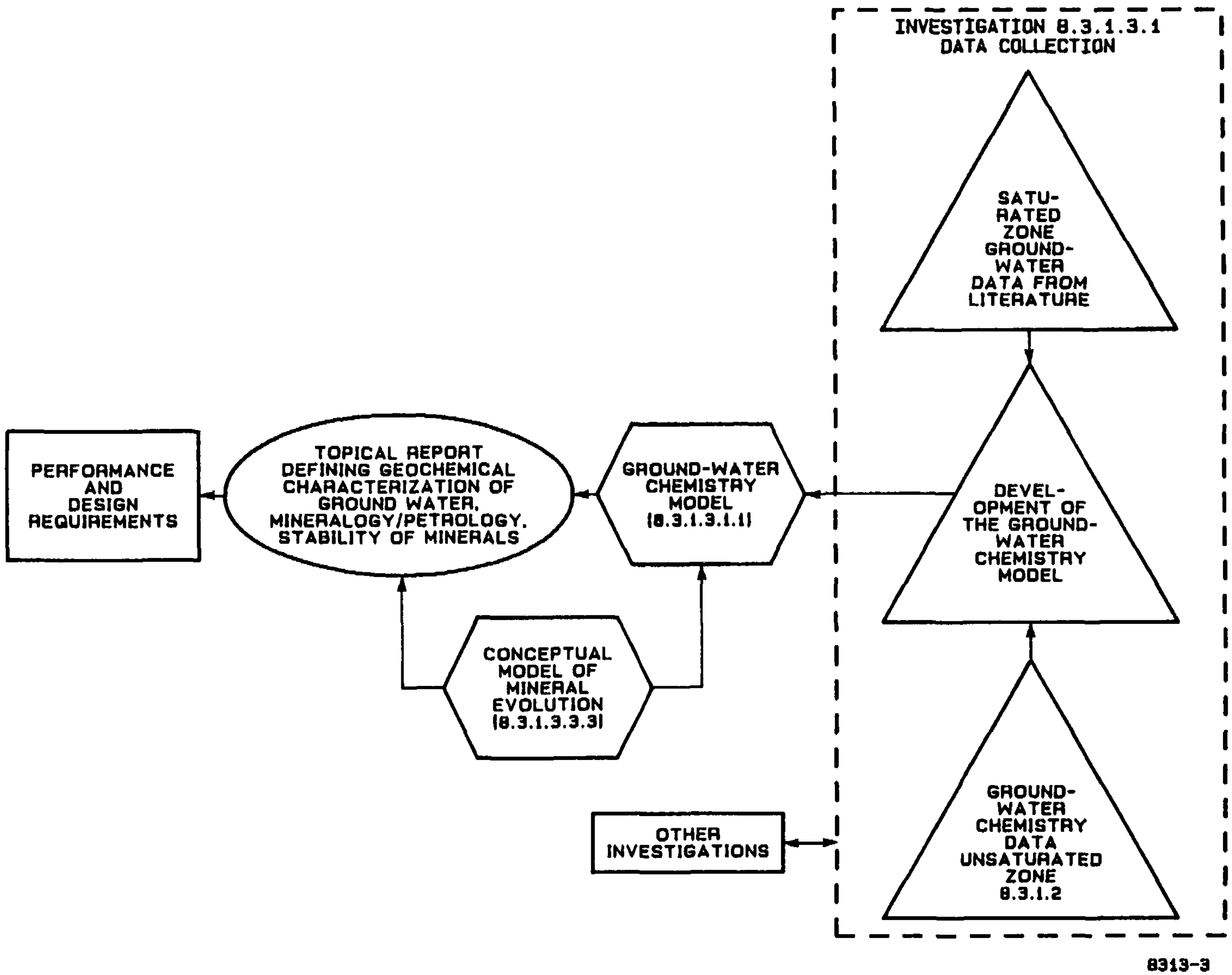

Figure 8.3.1.3-3. Logic diagram for Investigation 8.3.1.3.1 (ground-water chemistry along flow paths to the accessible environment).

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 and will aid in developing a sorption model and also 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 the natural alteration rate over time and alteration due to the thermal pulse from waste emplacement. 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, change in hydrologic parameters due to mineral alteration).

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 understand better 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 data will also be obtained. These studies are the experimental basis for determining the overall mineral stability at Yucca Mountain.

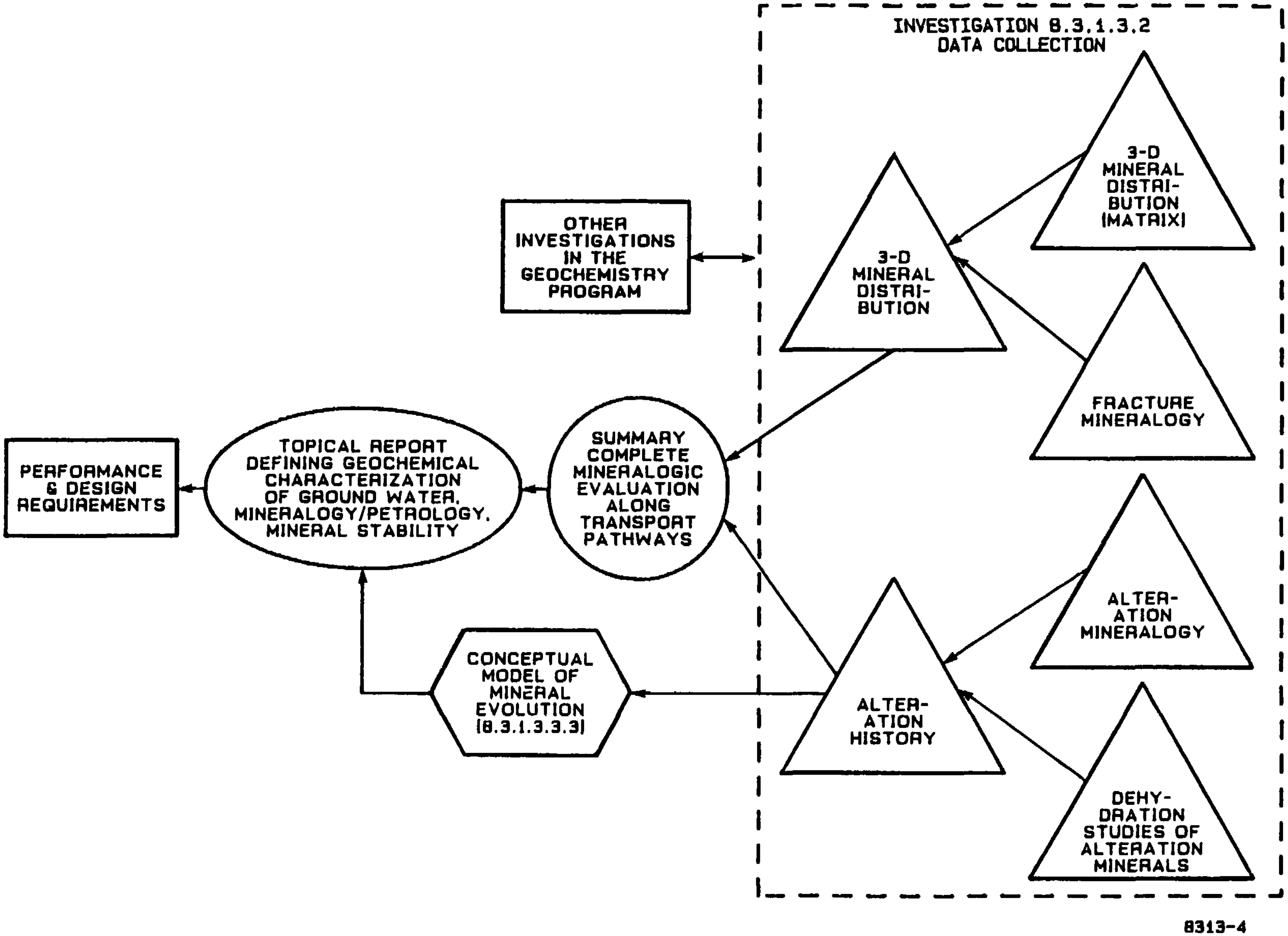

Figure 8.3.1.3-4. Logic diagram for Investigation 8.3.1.3.2 (mineralogy, petrology, and rock chemistry along flow paths to the accessible environment).

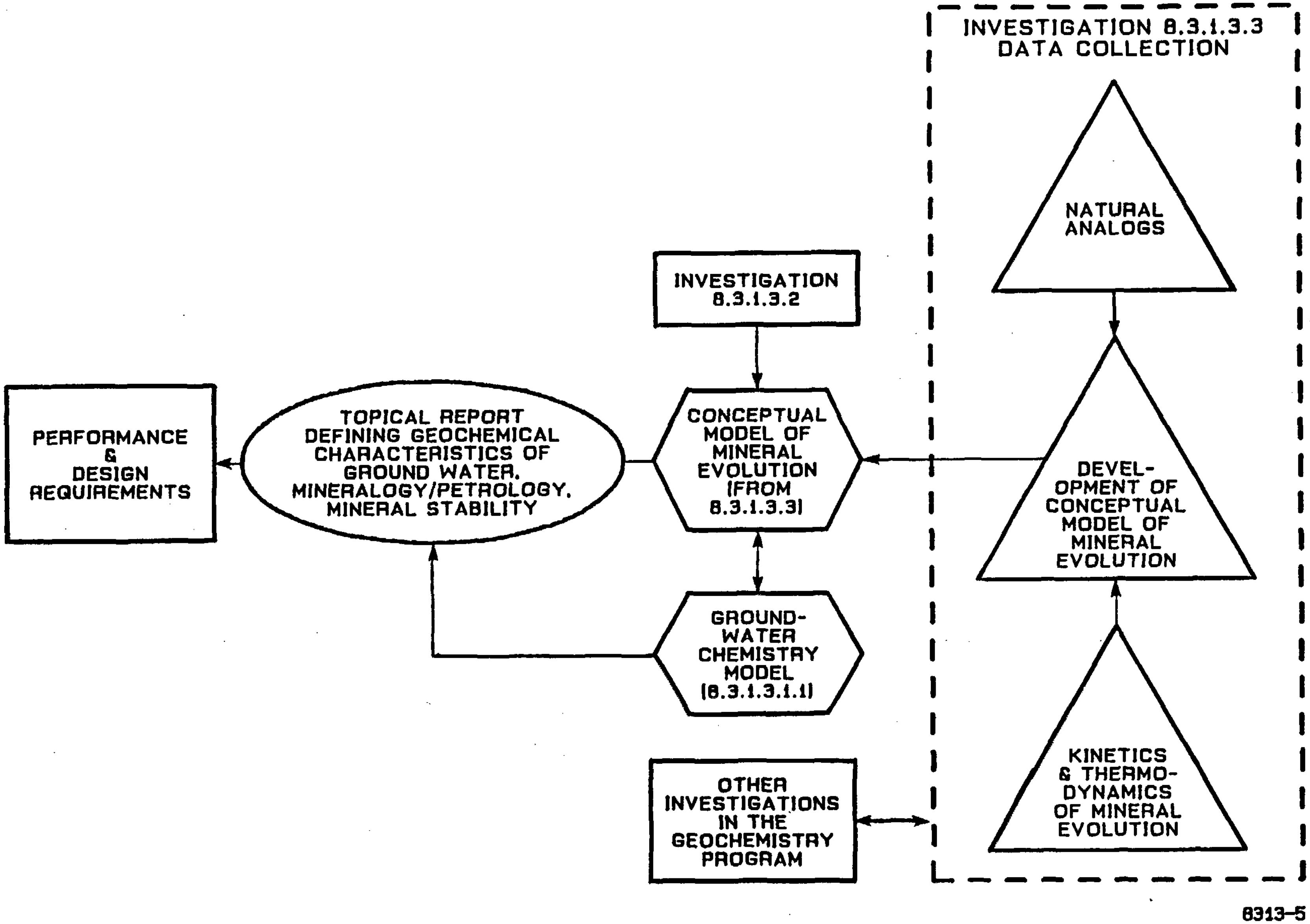

Figure 8.3.1.3-5. Logic diagram for Investigation 8.3.1.3.3 (stability of minerals and glasses).

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 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. Mechanistic and empirical data will be collected on sorptive behavior, and a sorption model will contribute to the understanding of the expected behavior of key radionuclides in the site system.

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 and as a function of the sorbing element concentrations (isotherms). Sorption mechanisms and adsorption kinetics also will be studied. 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.

This study is organized to define and implement experiments to measure the solubility and speciation of important waste elements. Geochemical modeling codes, EQ 3/6, will be used to assess the sensitivity of several parameters that might control solubility. Colloid formation as well as

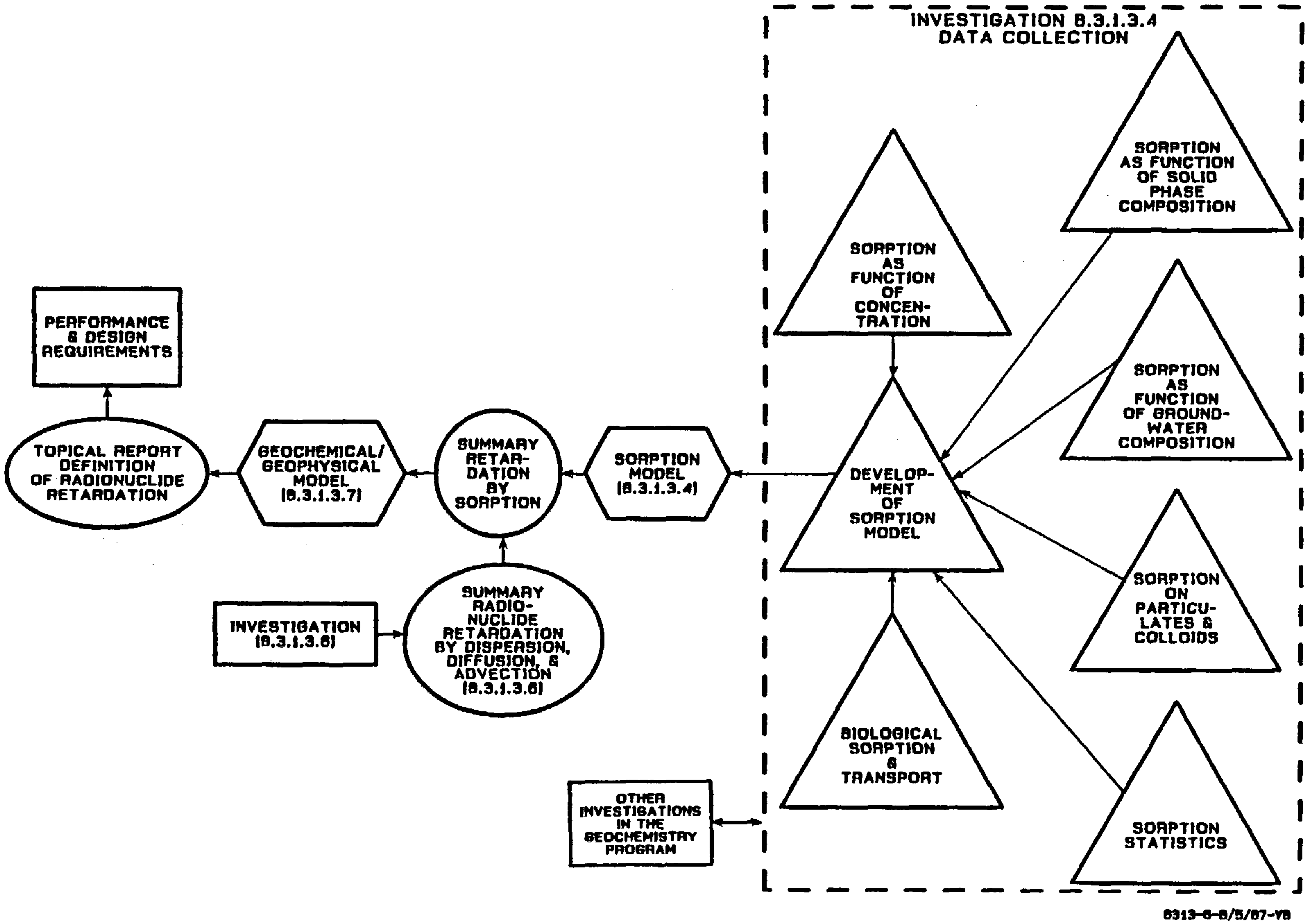

Figure 8.3.1.3-6. Logic diagram for Investigation 8.3.1.3.4 (radionuclide retardation by sorption processes along flow paths to the accessible environment).

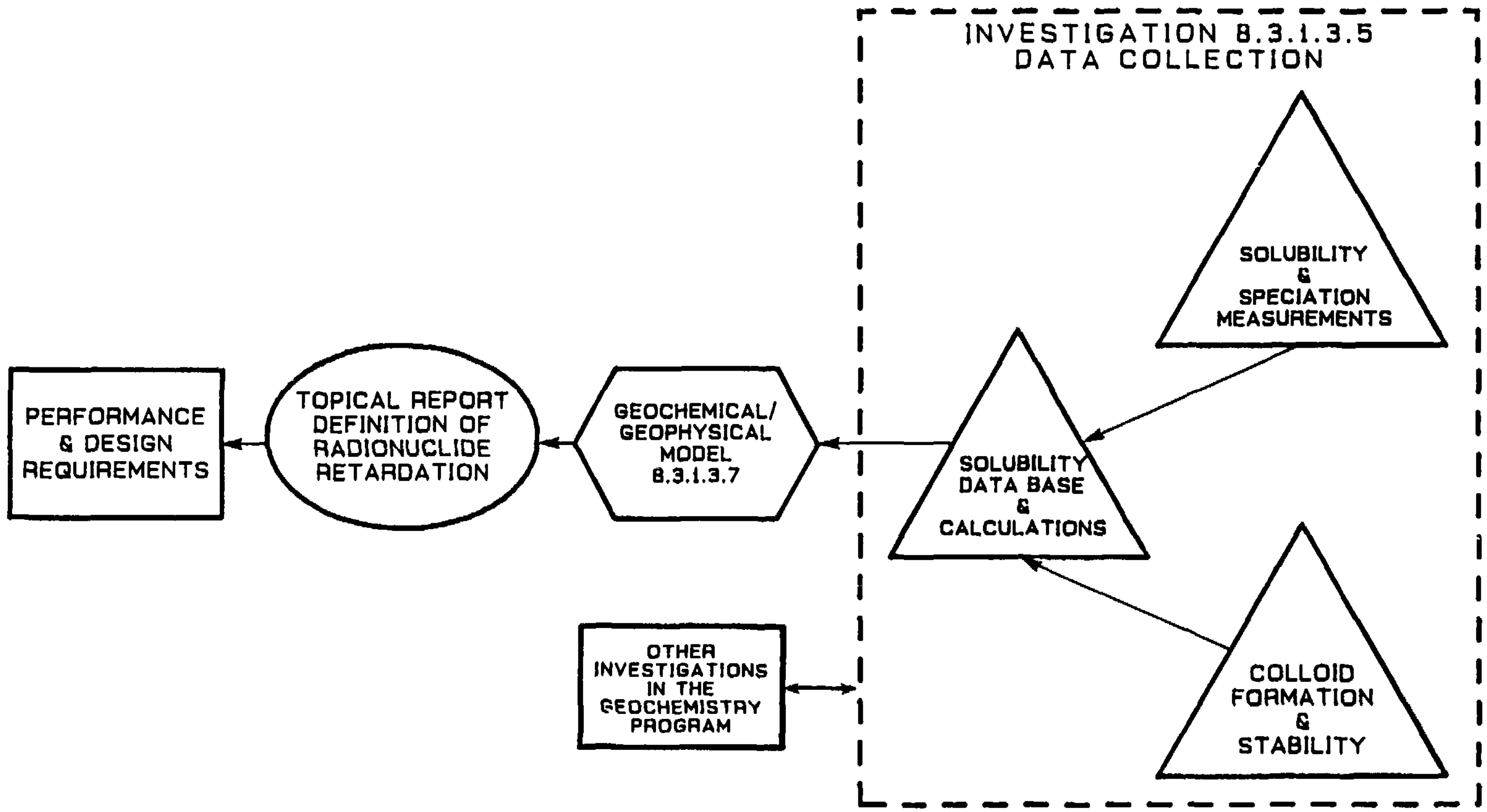

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Figure 8.3.1.3-7. Logic diagram for Investigation 8.3.1.3.5 (radionuclide retardation by precipitation processes along flow paths to the accessible environment) characterization and stability are other aspects of this investigation that will be studied as additional data necessary to understand the potential for transport of a precipitate through tuff. Colloid formation and stability are important because colloid transport 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 (1) provide information on the transport of colloids and adsorption kinetics, (2) evaluate and support the use of the batch distribution coefficients by total system performance in an advective system, and (3) support 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 decouple these 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.

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

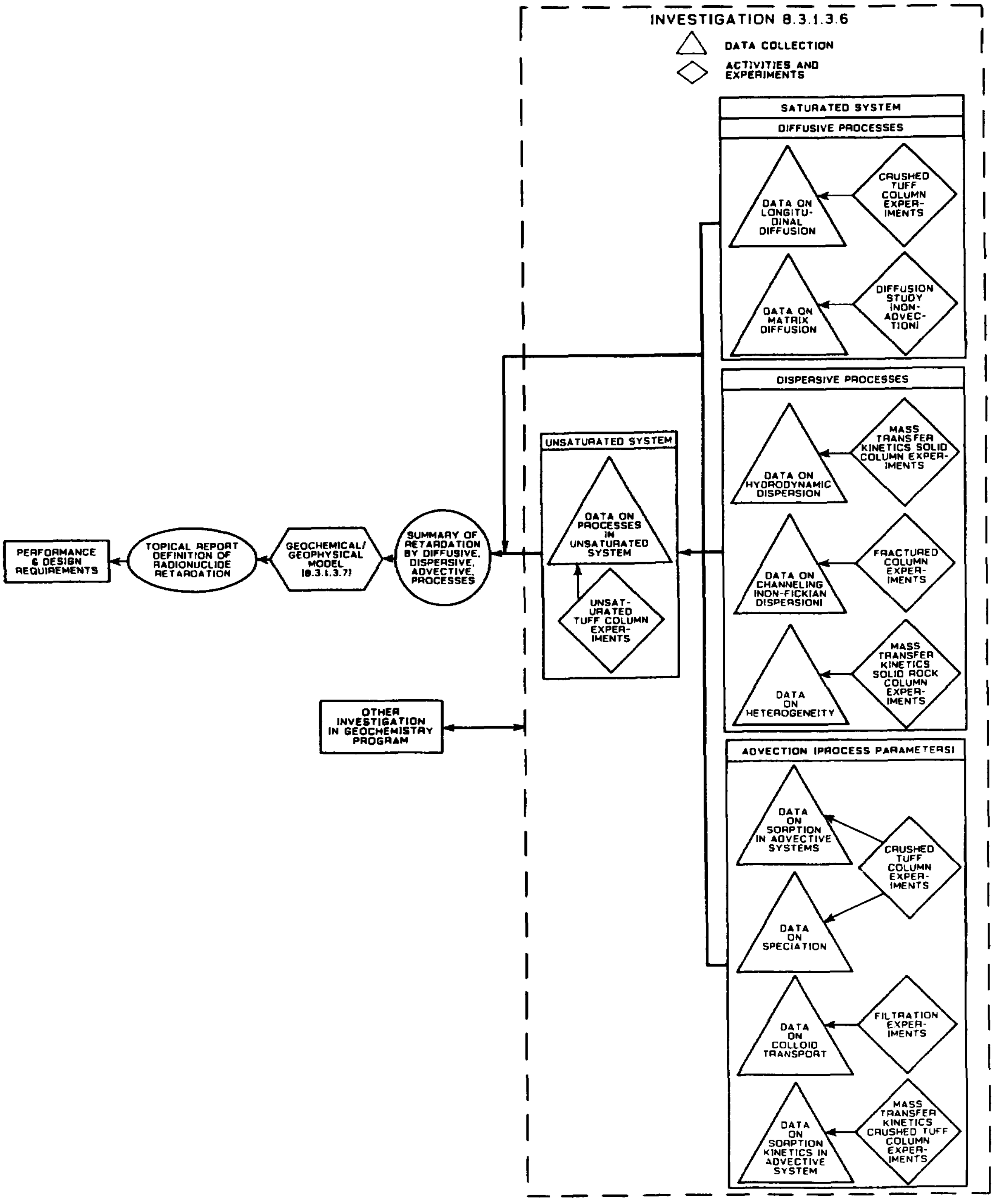

Figure 8.3.1.3-8. Logic diagram for Investigation 8.3.1.3.6 (radionuclide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment).

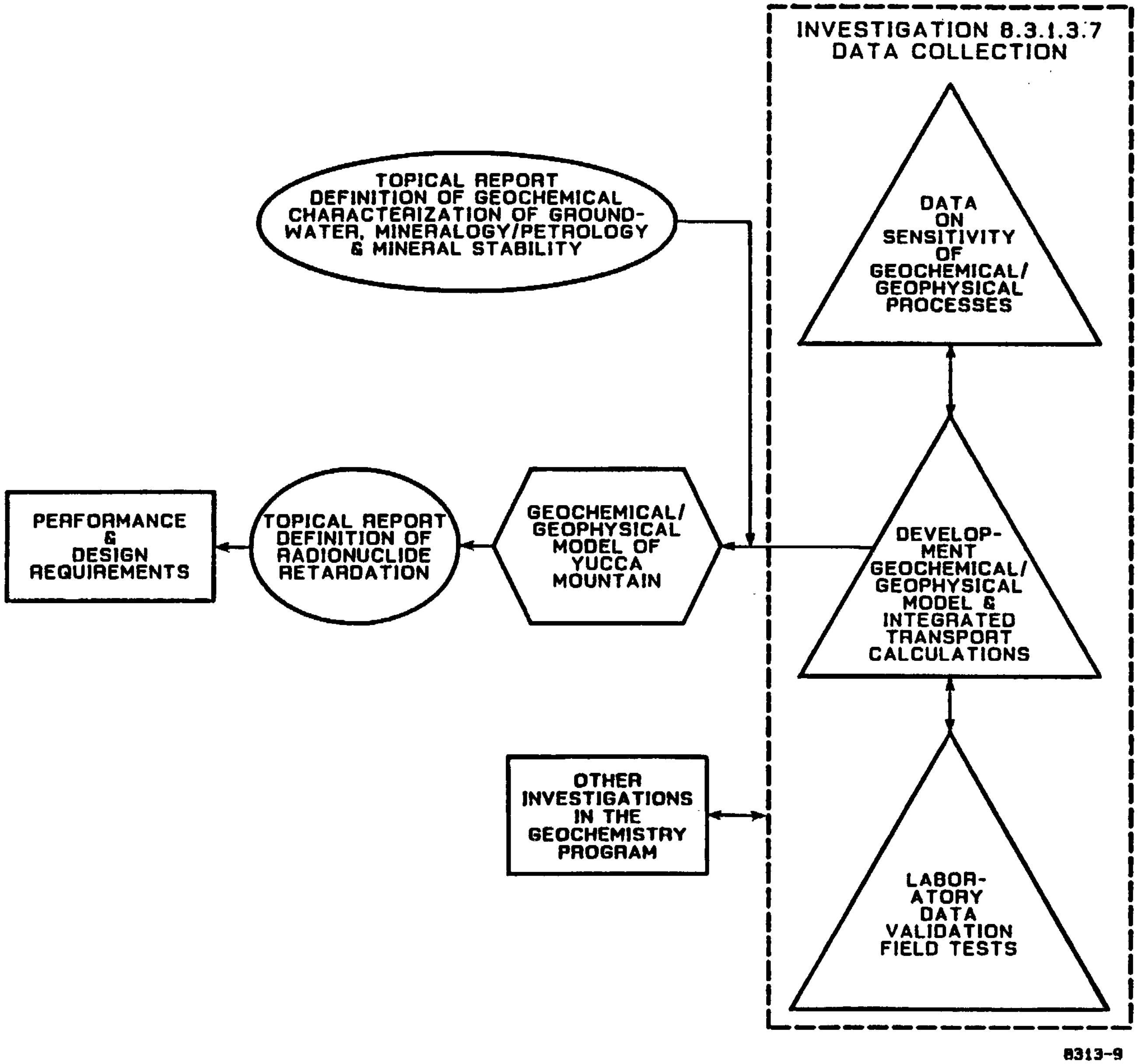

Figure 8.3.1.3-9. Logic for diagram for Investigation 8.3.1.3.7 (radionuclide retardation by all processes along flow paths to the accessible environment).

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, thus providing an evaluation of the effectiveness of the geochemical barrier. 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 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 and geochemical field tests. Study 8.3.1.3.7.2 outlines the field test strategy, large block tests, large scale experiments, geochemical field tests, nuclide migration studies at the NTS, and natural analog studies that will be used to demonstrate that the results of this program are applicable to the release calculations of system performance assessment.

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 for Site Program 8.3.1.3 (geochemistry) is presented in Section 8.3.1.3.9.

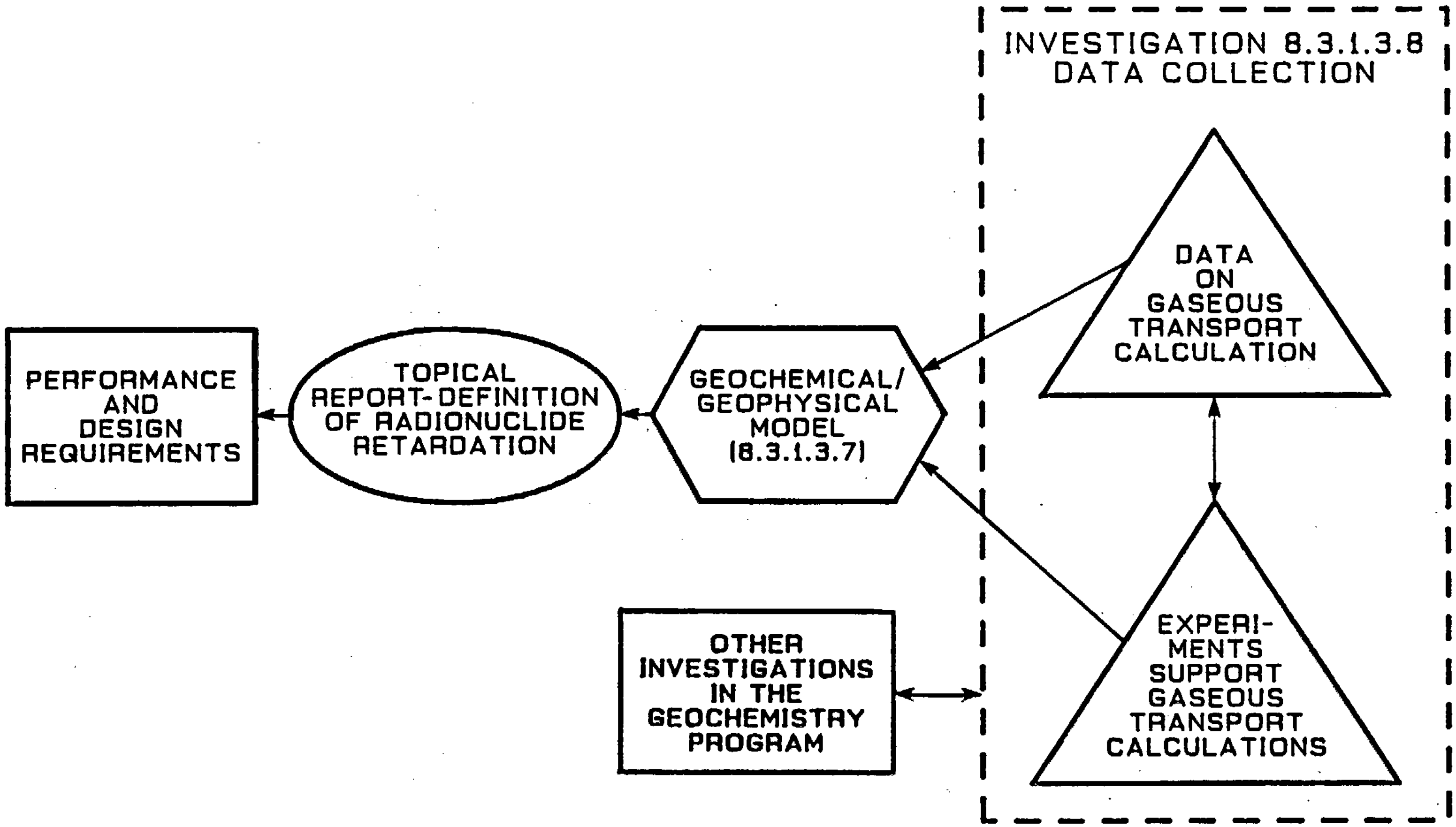

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Figure 8.3.1.3-10. Logic diagram for Investigation 8.3.1.3.8 (radionuclide retardation by gaseous transport processes along flow paths to the accessible environment).

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:

SCP section	Subject
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 ground-water chemistry model that would (1) explain the present ground-water composition as a result of interactions of the ground water with minerals, (2) 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, and (3) support and be integrated with other modeling efforts within the geochemistry program (Section 8.3.1.3).

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), 8.3.1.3.4 (sorption), and 8.3.1.3.5 (solubility), 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 (Section 8.3.1.2) will continue but, more importantly, the unsaturated zone ground-water compositions must be obtained. The unsaturated zone ground-water compositions are necessary data to evaluate 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 assess the overall retardation of waste elements (Investigations 8.3.1.3.4 (sorption), 8.3.1.3.5 (solubility) and Section 8.3.1.3.7 (retardation sensitivity analysis)) 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 ground-water chemistry model that will initially describe pre-emplacement conditions. The model will integrate the unsaturated and saturated zone data with the processes of water infiltration, water flow, and mineralogic changes in order to develop a mechanistic description of the current ground-water chemistry. Future changes in these properties and processes will then be considered, including changes in infiltration as influenced by climatic conditions; long-term mineralogic changes, particularly those influenced by the thermal pulse from emplaced waste; and changes in the material properties due to the emplaced waste, or possible igneous activity. This model of post-emplacement ground-water chemistry will be used to evaluate the chemistry of water interacting with the emplaced waste in the post-emplacement period. This model will be integrated with several investigations in the geochemistry program. In particular, the conceptual model of mineral evolution (Section 8.3.1.3.3) will be supported by and integrated with the ground-water chemistry model. Furthermore, solubility modeling efforts (Section 8.3.1.3.5) as well as sorption modeling efforts (Section 8.3.1.3.4) will also rely on and be integrated with the ground-water chemistry model. Finally, the ground-water chemistry model will provide needed information to retardation sensitivity analyses and associated integrated transport calculations (Section 8.3.1.3.7).

The ground-water chemistry 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.

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, Activity 8.3.1.3.2.2.2)

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 (Section 8.3.1.2).

5. Unsaturated zone ground-water composition (Section 8.3.1.2).

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. Evaluations of present water chemistry. Predictions of future variations in ground-water compositions between the repository and the accessible environment.

2. Models. Ground-water chemistry model.

Description

The ground-water chemistry model is considered to be conceptual with numerical support. The computational support will be provided by the code EQ3/6. Other codes may be used to verify results of EQ3/6. 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 redox state, 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. Further work on the characterization of the saturated zone water chemistry is planned in Study 8.3.1.2.3.2

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 8.3.1.2.2.7.2 (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, Study 8.3.4.2.4.1.3 will characterize the unsaturated zone ground water in order to predict the compositional changes in the water near the waste package. 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.

Details of the model development and the consideration and/or development of alternative models will be described thoroughly in the study plan for the ground-water chemistry model, as well the computational support provided for this work.

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:

Issue, investigation, or information need	Subject
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

Issue, investigation, or information need	Subject
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 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)

8.3.1.3.2 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:

SCP section	Subject
4.1.1.2	Analytical techniques
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

SCP section	Subject
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. This information will also be used to evaluate the potential correlation between mineral distributions and former water-table elevations.

The purposes of the 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 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).

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. Descriptions of the Topopah Spring Member from core samples, from outcrop, and from the exploratory shaft.

The data gathered are as follows:

1. Model 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-latite 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. 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.

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	Technical procedure Number	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

[a]TBD = 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. Chemical analyses of strata between the host rock and the accessible environment.

4. 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, neutron activation analysis (NAA), and electron microprobe analysis, which are summarized in the following table.

Method	Technical procedure		
	Number	Title	Date
X-ray diffraction	TWS-ESS-DP-16,R2	Siemens x-ray diffraction procedure	19 May 86

Method	Technical procedure Number	Title	Date
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	TWS-ESS-DP-111,R0	X-ray fluorescence procedure	TBD
Electron microprobe analysis	TWS-ESS-DP-	Microprobe operating procedure	5 Sep 86
Neutron activation analysis	TBD[a]	Neutron activation operating procedures	TBD

[a]TBD = 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. In particular, this task requires core exhibiting fractures from depths to 3,000 ft. 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) and neutron activation analysis when knowledge of trace chemistry is necessary. 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.

	Technical procedure		
Method	Number	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 07,R2	TWS-ESS-DP-	Microprobe operating procedure	5 Sep 86
Scanning electron microscope (SEM)	TWS-ESS-DP-112 (in preparation)	SEM operating procedure	TBD[a]

Method	Technical procedure Number	Title	Date
Neutron activation analysis	TBD	Neutron activation operating procedure	TBD

[a]TBD = to be determined.

8.3.1.3.2.2 Study: History of mineralogic and geochemical alteration of Yucca Mountain

The goal of this study is (1) to determine the timing, temperatures, and hydrologic conditions of past alteration at Yucca Mountain and (2) to study experimentally 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. Uncertainties in the proposed methods and alternate experimental approaches will be discussed in the study plan. 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. If found, samples of natural gel will be collected from the exploratory shaft.

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.

Method	Technical procedure Number	Technical procedure Title	Technical procedure 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

[a]TBD = 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 (several tens of meters to a few hundred 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.

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_{H2O} 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	Technical procedure Number	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

Method	Technical procedure Number	Title	Date
Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis	TBD	TGA and DSC procedure	TBD

[a]TBD = 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
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)

8.3.1.3.3 Investigation: Studies to provide information required on stability of minerals and glasses

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 investigation:

SCP section	Subject
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.

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 8.3.1.3.3.3).

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. Petrographic description of core.
2. Microprobe analyses of alteration products.
3. Mineral solid solutions.
4. Reaction path calculations.
5. Document discrepancies between predicted and observed mineral assemblages.
6. 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 (see Sections 8.3.5.10.3.2.1 and 8.3.5.10.3.2.2 for discussions of development of 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

This study will rely on published information to select, and then to evaluate, an active hydrothermal system. Selection criteria will include the geologic and hydrologic similarity to Yucca Mountain; similarity of the temperature regime to that expected during the post-emplacement period; availability of published data on hydrothermal characteristics, mineral assemblages, and water chemistry; and availability of core for subsequent analysis. The literature data from the selected site, together with the EQ3/6 computer code, will be used to perform preliminary geochemical modeling of hydrothermal mineral deposition and alteration at the selected site. Samples of the core will be obtained for further determination of mineral assemblages and paragenesis, using the standard methods listed below. These data will be used to further refine the conceptual and computational models. These models, together with observed mineral assemblages from Yucca Mountain, will provide a basis for evaluating possible mineralogic changes due to the hydrothermal pulse resulting from emplaced waste and assessing the possible significance of past hydrothermal activity at Yucca Mountain.

Technical procedures associated with methods used in this study are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Petrographic analysis	TWS-ESS-DP-03,R2	Nevada Test Site core petrography	24 Nov 82
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	EQ3/6 Computer Code User Manual	TBD

[a]TBD = to be determined.

8.3.1.3.3.2 Study: Kinetics and thermodynamics of mineral evolution

The goals of this study are (1) to investigate the kinetics of glass and silica polymorph transitions and their relationship to aqueous silica activity and (2) to 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.

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 with 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 Yucca Mountain 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. Alternate methods of solubility determination are discussed in the study plan. 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 thermodynamics, uses subroutine from CLAMS
SNLS1E	Nonlinear least squares
SCOV	Generates covariance matrix from output of SNLS1E
RPQR79	Finds roots of polynomial with real coefficients from CLAMS
DISSPLA	Graphics

The methods and technical procedures for Activity 8.3.1.3.3.2.2 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure 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
	TWS-MSTQA, QP-14,R1	Research and Development (experimental procedure)	TBD
	TBD	Mineral Solubility Procedure	TBD

Method	Technical procedure Number	Title	Date
	TBD	Procedure to implement Project-SOP-03-02	TBD
	TBD	Hydrothermal reactions with polymorphs for examination of reacting silica polymorphs and coexisting fluids	TBD

[a]TBD = 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.

This model will be a significant contribution to Issue 1.1 (Section 8.3.5.13) in its transport calculation 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 just described 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)

8.3.1.3.4 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:

SCP section	Subject
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

SCP section	Subject
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
4.1.3.4.4	Solubilities of waste elements on Yucca Mountain water
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 and surface structure.
    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. Modeling of whole-rock sorption isotherms.
2. Modeling of sorption mechanisms.

Data supplied from other investigations are as follows:

Investigation	Subject
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)

Investigation	Subject
8.3.1.3.2	Mineralogy, petrology, and rock chemistry
8.3.1.3.3	Stability of minerals and glasses
8.3.1.3.5	Solubility
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 purpose of this investigation is to obtain data on the sorption behavior of key radionuclides as required by Issue 1.1 (Section 8.3.5.13). Specifically, Issue 1.1 requires 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 key radionuclides identified by Issue 1.1 are isotopes of americium, carbon, cesium, curium, iodine, neptunium, plutonium, strontium, technetium, uranium, and zirconium.

The objectives of this investigation are to carry out three separate but related studies. These are (1) to obtain laboratory batch sorption coefficients for the key radionuclides as a function of the parameters listed above, to statistically evaluate these coefficients, and to develop an understanding of sorption mechanisms for each of the key radionuclides; (2) to evaluate the significance of biological sorption and transport; and (3) to develop a capability for the prediction of the sorption behavior of key radionuclides under conditions not assessed in the experimental program.

Technical rationale for the investigation

The degree to which a given radionuclide in solution is sorbed by a solid substrate is controlled by many variables, the most important of which are the composition and structure of the substrate, the composition and temperature of the solvent (e.g., ground water), the concentration of the radionuclide in solution, and the degree to which sorption equilibrium is achieved. To evaluate the potential influence of each of these variables, many individual experiments must be conducted. By carrying out sets of experiments in which all but one of the variables are held constant, the influence of each of the variables can be evaluated separately. For instance, the composition of the solvent (i.e., ground water) and the composition and structure of the substrate could be held constant while the concentration of the radionuclide in solution is varied in separate experiments over a range anticipated in the proposed repository environment. Other sets of experiments could involve variations in solvent (i.e., ground water) or substrate compositions, or in substrate structure (e.g., amorphous versus crystalline iron oxyhydroxides). For the laboratory data to be defensible, they must be shown to be statistically significant; therefore, statistical methods and isotherm equations are needed for the evaluation of variance in the experimental results.

Although varying the concentration of a given radionuclide in solution is generally as simple as adding more of a ready made stock solution to the experimental charge, varying the composition of the solvent and/or the substrate can be more involved. For instance, to maintain a certain pH (acidity) or Eh (oxidation/reduction potential) condition in the solvent, the composition of the atmosphere in contact with the experimental charge may need to be controlled.

If the entire range of conditions and concentrations anticipated in the proposed repository environment is to be included in the experimental program, it is clear that a large number of experiments must be conducted. If sorption kinetics are to be investigated as well, an even larger number of experiments will be required. In order to restrict the number of experiments to a realistic value, the emphasis in the experimental program should be on gaining an understanding of the basic mechanisms involved in the sorption reactions. Once the mechanisms have been identified, independently derived models and data can be used to calculate the influence of variables such as the solvent composition over ranges outside of those included in the experimental program.

8.3.1.3.4.1 Study: Batch sorption studies

The goal of the batch sorption experiments will be to obtain sorption coefficients for key radionuclides as a function of the parameters listed above and discussed in the individual studies below. These studies will use statistical analysis to evaluate the experimental results (Activity 8.3.1.3.4.1.5) and will provide the data base for the development of models to allow prediction of sorption coefficients under conditions not directly addressed by the experimental program. The experimental emphasis will be on the elements americium, neptunium, plutonium, technetium, and uranium. Results for the alkali and alkaline earth elements are discussed in Chapter 4 and are assumed to be adequate for performance assessment calculations. The values for sorption coefficients obtained in this study will be used to interpret the results obtained in crushed-tuff column experiments (Activity 8.3.1.3.6.1.1).

The activities included in this study are

SCP section	Description
8.3.1.3.4.1.1	Batch sorption measurements on rocks and minerals
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 composition

SCP section	Description
8.3.1.3.4.1.4	Sorption on particulates and colloids
8.3.1.3.4.1.5	Statistical analysis of sorption data

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 tuffs, and on pure minerals representative of the minerals present in the rock and fractures of the repository block. Data will be obtained on sorption coefficients ($K_d(i)$) for each of the key radionuclides on whole-rock samples and pure mineral separates under the range of rock-water conditions anticipated in the repository block. The results on pure minerals will be used to interpret the whole-rock data and to derive insight into sorption mechanisms (surface complexation and ion exchange mechanisms). Further insight into sorption mechanisms and sorption kinetics will be provided by comparison of these results with the results of crushed-rock column experiments (Activity 8.3.1.3.6.1.1).

Parameters

The data needed are as follows:

1. Mineral abundance and composition of samples from the tuffaceous beds of Calico Hills and other tuffs of similar composition used in the tests, and of fracture fillings in the repository block (Section 8.3.1.3.2.1).

2. Chemical composition of the pure minerals used (Section 8.3.1.3.2.1).

3. Physical properties and cation exchange capacity of the solids used.

4. Ground-water composition.

5. Radioactive tracers (same tracers used as in Investigation 8.3.1.3.6).

6. Speciation data for key radionuclides in chosen ground-water compositions.

The data gathered are as follows:

1. Surface properties of pure mineral separates.

2. Structure and distribution of surface complexes of the key radionuclides on pure minerals representative of the proposed repository block.

3. Isotherms describing the detailed sorption behavior of selected radionuclides in pure minerals of interest.

4. Sorption coefficients as a function of solid substrate composition.

5. Correlations of sorption coefficients with mineralogy.

6. 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 and Fe and Mn oxyhydroxides such as, goethite, hematite, and pyrolusite. Both sorption and desorption ratios will be measured, using standardized techniques.

The sorption studies on pure minerals will consist of two areas of investigation: (1) sorption by surface complexation and (2) ion exchange. A mechanistic understanding of the sorptive process is sought through these two efforts.

The mechanism for actinide sorption is unknown. It is known that iron and manganese oxyhydroxides, such as goethite, hematite, and pyrolusite, strongly sorb actinides; therefore, sorption on these minerals must be considered. Initially the surface properties of these minerals will be determined by acid titration. Sorption experiments with these oxyhydroxides and the actinides and technetium will be conducted and the structure and distribution of surface complexes of the nuclides on the oxyhydroxide surfaces will be determined by extended x-ray adsorption fine structure (EXAFS). This technique is developed and has been applied to similar systems as described in Hayes et al. (1987) and Brown et al. (1987). The EXAFS technique also will characterize (identify) the oxyhydroxide minerals present in the tuff as will further characterization work in Section 8.3.1.3.2. Further details regarding this technique can be found in the study plan.

The ion exchange mechanism will be studied by developing isotherms describing the sorption of selected radionuclides in pure minerals. These isotherms will be analyzed using an inversion technique of regularization. Selectively coefficients for the studied radionuclides will be obtained for each of the different sorptive sites in the mineral. This site-specific information will be correlated with structural data for the reactive sites in the mineral and will be used to obtain information on the relationship between sorption and structural properties of the sorbing solid. The results obtained in this manner will be used to attempt prediction of the spatial variation of sorption in Yucca Mountain using mineralogic composition.

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 8.3.1.3-3 summarizing the elements and solid phases addressed by this activity. The effects of variations in surface area on sorption will be examined by a limited number of bounding experiments. If significant effects are observed, more detailed testing will be considered.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.3.4.1.1 are given in the following table.

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

Method	Technical procedure Number	Title	Date
Batch sorption method (continued)	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 samples	Bulk Nevada Test Site (NTS) well water	30 Jan 87
	TWS-INC-DP-63,R0	Preparation of NTS core samples for crushed rock experiments	20 Mar 87
Method for determining structure and distribution of the radionuclides on pure minerals	TBD[a]	Extended x-ray adsorption fine structure (EXAFS)	TBD

[a]TBD = to be determined.

Table 8.3.1.3-3. 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	- vitric
Tc	- devitrified
U	
Zr	
Ni	Topopah Spring tuff[c]
Cs	
Sr	Tuff from saturated zone[c]
Ba	

Table 8.3.1.3-3. Testing matrix for batch sorption measurements as a function of solid phase composition (continued)

Elements[a,b]	Solid phase
Pure mineral phases:	- clinoptilolite - mordenite - smectite - calcite - Fe and Mn oxyhydroxides (such as goethite, hematite, and pyrolusite)

[a]Sorption measurements are planned for elements in the first column on the solid phases in the second column.

[b]Tests will be run at only one concentration.

[c]Two samples from different locations.

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. It is important to be able to measure the distribution of redox species for studied elements in the experimental solutions, but the stability of the oxidation states, while desirable, is not critical. 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 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} molar, if possible (Table 8.3.1.3-4). 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), to 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 in Table 8.3.1.3-4. 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. The effects of variations in surface area on sorption will be examined by a limited number of bounding experiments. If significant effects are observed, more detailed testing will be considered.

Table 8.3.1.3-4. Sorbing element concentrations of primary waste elements[a],[b]

Elements	Solid phase[c,d]	Approximate concentration range[e,f] (M)
U	$T1_z$ $T2_v$ $T3_{dv}$	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

[a]Experiments run under ambient laboratory conditions. The liquid phase for all experiments was well J-13 water.

[b]Later studies not presently included in this investigation may run combinations of the actinides to measure the effects of competition among these radionuclides.

[c]$T1_z$ = zeolitic tuff; $T2_v$ = vitric tuff; $T3_{dv}$ = devitrified tuff.

[d]Oxyhydroxides, clays, and zeolites listed in Table 8.3.1.3-3 are also part of this matrix. The isotherm development (ion exchange in Section 8.3.1.3.4.1.1) is based on measurements at different sorbing element concentrations.

[e]E-12 is exponential notation (10^{-12}).

[f]Number of concentrations within given range was approximately eight.

Methods and technical procedures

The methods and technical procedures are to be developed for isotherm determination.

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. The extent of sorption and heterogeneity of sorption are represented respectively by the factors K_d and beta obtained from the Freundlich or modified Freundlich isotherm. 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 could be used to develop maps with isobetas (curves of equal sorption heterogeneity) and iso-K_ds (curves of equal average sorption behavior). ISO-K_d and iso-beta maps could be developed in two or three dimensions by contouring K_d and beta values. The interpretation of these contours could support the selection and development of strategies to model radionuclide transport by providing basic information on the distribution and variability of sorptive characteristics of each radionuclide throughout and within stratigraphic units. 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).

8.3.1.3.4.1.3 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 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 8.3.1.3-5. 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

Table 8.3.1.3-5. General test matrix to be used in measuring batch sorption coefficients in ground waters of varying compositions[a]

Element	Solid phase[b,c]	Sources of ground water[d,e]		
U	$T1_z$ $T2_v$ $T3_{dv}$	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

[a]All 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).

[b]$T1_z$ = zeolitic tuff; $T2_v$ = vitric tuff; $T3_{dv}$ = devitrified tuff.

[c]Zeolites, clays, and oxyhydroxides listed in Table 8.3.1.3-3 may be included in this testing matrix, if needed.

[d]USW 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.

[e]To evaluation potential effects of waste package degradation products, future tests may involve well-13 water spiked with probable contaminants (e.g., iron and zirconium) from the near field.

of the initial testing results. The effects of variations in surface area on sorption will be examined by a limited number of bounding experiments. If significant effects are observed, more detailed testing will be considered.

Although not part of the present investigation, additional testing may be necessary in future studies to evaluate the effects of waste package degradation products in altering sorption characteristics in the ground-water chemistry of the far field. Other studies may be initiated at a later time to measure the effects of competition and interaction among radionuclides, such as possible increases in iron and zirconium concentrations.

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.

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.

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 microorganisms on the movement of actinides, such as colloidal agglomeration and chelation; 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).

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 implemented 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: colloid formation and colloid agglomeration.

Other technical procedures are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Crushed rock column method	TWS-CNC-DP-15,R1	Crushed rock column studies	30 Aug 82
Batch sorption 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

Objectives

The purpose of this study is to model the sorption experiments on rocks and minerals representing the proposed repository block and to derive a capability to predict sorption coefficients for key radionuclides under water-rock conditions not included within the experimental program. This information 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. Sorption isotherm data for the key radionuclides on representative whole-rock samples and pure mineral separates (Sections 8.3.1.3.4.1.1 and 8.3.1.3.4.1.3).

2. Surface properties of pure mineral separates (Section 8.3.1.3.4.1.1).

3. Ground-water compositions in the proposed repository block (Section 8.3.1.3.1.1).

4. Speciation data for key radionuclides in representative ground-water compositions (Section 8.3.1.3.5.1.2).

5. Chemical compositions of the pure minerals (Section 8.3.1.3.2.1).

6. Mineral abundance and composition in rock samples and fracture fillings found in the proposed repository block (Section 8.3.1.3.2.1).

7. Structure and distribution of surface complexes of the key radionuclides on pure minerals representative of the proposed repository block (Section 8.3.1.3.4.1.1).

The data gathered are as follows:

1. Models describing the sorption of key radionuclides in the proposed repository block as a function of the mineralogic composition of the host rocks or fracture fillings, ground-water composition, radionuclide concentration, and temperature.

Description

This study will develop the best possible capability for the prediction of sorption coefficients for key radionuclides in the proposed repository block based on the available data. The predictive capability will be based on ion exchange and surface complexation models and data obtained in Studies 8.3.1.3.4.1, 8.3.1.3.4.2, and 8.3.1.3.4.3.

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.

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)
1.1.3	Calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release scenario classes (Section 8.3.5.13.1)
1.1.4	Determination of the radionuclide releases to the accessible environment associated with realization 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.

The sorption program as described in the previous sections will produce sorption mechanism data. The data base will be augmented by the sorption mechanism work being done in Section 8.3.1.2.3.1.7, reactive tracer testing in the C-holes. The sorption work in support of the C-hole tests is very specific to the mineralogy of the saturated unit in which the pump tests will be conducted. Furthermore, the C-hole sorption work of Section 8.3.1.2.3.1.7 is being conducted to select the proper reactive tracers to be used in these field tests. Certainly the C-hole work will enchance the sorption data base but it is not considered to be the primary source of sorption mechanistic data as are the data to be produced from this investigation. More importantly, however, the C-hole tests will provide data on geochemical processes and extrapolation capabilities (laboratory data to field), thereby providing needed assurance that the geochemistry test program (8.3.1.3) retardation data base may be applicable to the field. This concept will be tested in Section 8.3.1.3.7.2, geochemical field testing activities focusing on unsaturated flow and transport. The study plan for the sorption work (8.3.1.3.4.1; 8.3.1.3.4.3) and the reactive tracer tests (8.3.1.2.3.1.7) will provide more detail regarding the study integration.

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
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, 1984a).
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, redox state).
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, 1984a) 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:

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 redox (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, 1984a). 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

<u>Objectives</u>

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 concentration limits of important waste elements under these conditions.

<u>Parameters</u>

The data needed are as follows:

1. Water chemistry (composition, pH, redox state, 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 8.3.1.3-6 shows the test conditions for water used in measuring the solubility of waste elements.

Table 8.3.1.3-6. Test conditions for water used in solubility measurements[a]

Water	pH	Temperature (°C)
J-13	6, 7, 8.5	25, 60, 90
UE-25p#1	6, 7, 8.5, 9.5	25, 60
Neutral electrolyte	6, 7, 8.5	25, 60

[a]Waters will be oxygen saturated.

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; drillhole 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. 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 in the present investigation to include other solids such as tuff from Yucca Mountain in the solubility experiments. The presence of tuffs may compromise the ability to obtain meaningful data on the solubility of radionuclides. Including tuffs in the tests greatly increases the complexity of the solubility work because it may not be possible to deconvolute the effects of two operative processes, sorption and precipitation. When sufficient data have been gathered to generate a fundamental understanding of solution chemistry, then the Project will consider expanding the scope and complexity of the testing to include solubility experiments with tuff. 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.

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 Yucca Mountain 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.

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, an analytical technology (Schrepp et al., 1983; Stumpe et al., 1984; Eiswirth et al., 1985; Buckau et al., 1986; Kim, 1986) is being refined to apply to this activity. Although the capabilities of the photoacoustic spectroscopy render 17 measurements uniquely applicable to the speciation, other techniques may be considered if this method proves unsuitable.

Technical procedures are under development and will be provided in the study plans.

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 (see Sections 8.3.5.10.3.2.1 and 8.3.5.10.3.2.2 for discussions on development of 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). Although only plutonium and americium will be investigated during the initial phase of the study of waste element colloids, work will be extended to other radionuclides if performance assessments of engineered barrier system performance and other field and laboratory data show other radionuclides are potentially important in colloid formation. 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).

The conditions to be studied for colloid formation, stability, and break up will include pH, redox state, 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).

8.3.1.3.6 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:

SCP section	Subject
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:

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 8.3.1.3-7. 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_ds 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

Table 8.3.1.3-7. 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.

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)).

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 radio-elements. The empirical diffusivities can only be useful in Issue 1.1 if the 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 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, permits the measurement of a single process because the parametric dependencies 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

<u>Objective</u>

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.

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.

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.

Method	Technical procedure Number	Title	Date
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 radionuclides	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 implement SOP-03-02	TBD

[a]TBD = 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_ds) 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. 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. It is unclear whether or not the rock-water ratio affects radionuclide sorption. The nonlinear behavior exhibited by some adsorption isotherms may be explained by irreversible adsorption on small numbers of sites, such that increasing the rock-water ratio effectively increases the K_d. Conversely, zeolites generally show a decrease in K_d as the rock-water ratio increases. This may be an experimental artifact related to the difficulty of separating phases. At any rate, the effects of varying rock-water ratio will be investigated and details will be in the study plans. The summary report (Daniels et al., 1982) discussed the effect of rock-water ratio on sorption isotherms. 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.

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. Specifically, the coupling of flow in fractures and diffusion into the matrix must be described and, more importantly, dispersion due to heterogeneity and channeling must be evaluated.

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. Elution curve (tracer concentration as a function of time).
5. Elemental analysis of cations.

The data derived are as follows:

1. Fracture aperture.

2. Retardation factors for tracers and retention volumes.

3. Dispersion, diffusion into the matrix, and sorption ratios.

4. Evaluate retardation in a fracture flow system for retardation sensitivity analysis (8.3.1.3.7.1) to determine 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. Some nonsorbing tracers and 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. Dispersion will also be derived. 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.

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:

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)

8.3.1.3.7 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:

SCP section	Subject
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

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 three-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 principal 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 laboratory 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 Yucca Mountain 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 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 (1) to interpret sorption, solubility, water chemistry, and precipitation data; (2) to design future experiments; (3) to examine and define the limits of the applicability of laboratory-measured sorption values to the field situation at Yucca Mountain; and (4) to 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 (1) to interpret results obtained under Investigation 8.3.1.3.6, (2) to examine and define the limits of the applicability of laboratory-measured diffusion and constrictivity values to the field situation at Yucca Mountain, (3) to examine the impact that fracture versus matrix flow has on transport, and (4) to 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 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 the following investigations and activities:

Investigation	Subject
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
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
   a. Geochemical processes.
   b. Physical processes.
   c. Particulate transport.
2. Extents of
   a. Microbial activity.
   b. 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 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 Yucca Mountain Project milestones associated with them. They are listed here.

Code	Citation
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," Milestone C717, Los Alamos National Laboratory (October, 1985).
FEHMS	Zyvoloski, G., and S. Kelkar, "FEHMS: A Finite Element Heat-Mass-Stress Code for Coupled Geological Processes," Milestone R346, Los Alamos National Laboratory, Los Alamos, NM (March 31, 1987).
COLLOID	Nuttall, H. E., "Population Balance Model for Colloid Transport," 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 Number	Title	Date
	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

[a]TBD = to be determined.

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 Yucca Mountain 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 Yucca Mountain 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 Yucca Mountain 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 objective of this activity is to verify the computer codes and to validate the models used in this study and to identify important contributors to the uncertainties in retardation calculations (sensitivity analyses). Because of the special quality assurance requirements placed on the codes and models used to estimate the performance of a repository, it is expected that they will require some degree of verification and validation (Section 8.3.5.20.2). Sensitivity analyses 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. The results of 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.

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. 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. While this activity is closely linked to Activities 8.3.1.3.7.2.1 and 8.3.1.3.7.2.2, the results of this activity are critical, and therefore, this activity is recognized as being distinct.

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 conceptual models. As appropriate, alternative conceptual models will be considered in order to identify the significant processes in the transport calculation. Alternative numerical methods that increase computational efficiency and numerical stability will also be examined.

Parameters

The data needed are as follows:

1. Computer model results from all models used in the Yucca Mountain Project (hydrologic and transport).

2. Results from Activity 8.3.1.3.7.1.1 and Study 8.3.1.3.1.2.

Description

To comply with the Quality Assurance procedure SOP-03-02 (Software Quality Assurance) the codes being used and generated under this study must be verified and the models 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 (SOP-03-02). Validation of a model is defined as the assurance that a model correctly represents the physical processes embodied in it and the software is applicable to the problem. Plans for verification and validation are discussed in Section 8.3.5.20.2.

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.

Methods and technical procedures

Method	Technical procedure		
	Number	Title	Date
Benchmarking	TWS-MSTQA-QP-14,R1 Procedure	Research and Development (Experimental)	TBD[a]
	TBD	Procedure to implement SOP-03-02 for Software Quality Assurance	TBD

[a]TBD = to be determined.

The following codes will be used

Code	Citation
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," Milestone C717, Los Alamos National Laboratory (October, 1985).
FEHMS	Zyvoloski, G., and S. Kelkar, "FEHMS: A Finite Element Heat-Mass-Stress Code for Coupled Geological Processes," Milestone R346, Los Alamos National Laboratory (March 31, 1987).
COLLOID	Nuttall, H. E., "Population Balance Model for Colloid Transport," 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 the validity of the laboratory generated geochemical data and the validity of transport calculations using that data. In particular, the data to be validated is from the Geochemistry Program (8.3.1.3) and the transport model is the code TRACR3D (8.3.1.3.7.1). This study will also support the total system performance calculations described in Section 8.3.5.13.

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 field tests described below. The tests themselves may then serve to partially validate the transport models.

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 being conducted in 8.3.1.3.6.1 (dynamic transport column experiments) are necessary to investigate scaling phenomenon. Intact tuff blocks may also be removed from areas where other surface based testing may occur, for example, that described in the third activity in this section (field-scale tests). A tuff block (1 m by 1 m) would be removed from the Calico Hills unit. Blocks with discrete fractures would be preferred in order to resolve the question whether the Calico Hills unit would have open or closed fractures. Furthermore, zeolites are abundant in this unit and the unit is considered to be the primary natural barrier to nuclide migration.

The intact tuff blocks would be sent to the geochemical laboratory in Canada supported by the Canadian waste repository program where an existing facility is available to do these larger scale flow and transport experiments on rock blocks. Information would be gained regarding flow paths, scale and effective retardation. This effort to scale up the experiments is an important step to doing field-scale transport experiments.

Field testing

Field testing may be the only way to establish the applicability of laboratory data in system performance transport calculations. Furthermore, validation of unsaturated zone flow and transport models is necessary. There are three activities that make up the overall field test strategy. The first activity is planned intermediate scale flow and transport experiments in caissons at the Los Alamos National Laboratory. The second activity is geochemical field tests to be conducted in a surface facility outside the Yucca Mountain exploratory block. The third activity is aimed at utilization of nuclide migration and transport data from the Nevada Test Site.

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.

A. Intermediate scale tests (caisson tests)

The goal of the caisson test is to provide data that will exercise the physics embodied in three-dimensional models of flow and transport in unsaturated porous media. Modeling of the data by Yucca Mountain Project participants will answer questions concerning validity of unsaturated zone flow and transport models.

A caisson is basically a galvanized highway culvert 3 m in diameter and 6 m deep put on its end on a concrete floor. The caissons are clustered around a central access caisson with six experimental caissons composing a single cluster. These intermediate-scale experiments offer many of the advantages of laboratory scale experiments over field experiments, while allowing for a much larger experimental scale. These advantages are as follows:

1. Known porous materials are used so that heterogeneities can be controlled and material characteristics are more well defined.

2. Instrumentation can be placed in desirable positions at the time of construction.

3. Input and boundary conditions can be more easily controlled.

These factors all help to minimize characterization problems in data analysis. Disadvantages of intermediate-scale experiments include

1. The effects of natural heterogeneities cannot be investigated.

2. The scale of the facility may not be sufficient for scale-dependent processes to be exhibited.

Therefore, while intermediate-scale experiments cannot replace field experiments for model validation because the effects of system heterogeneities and scale-dependent processes must be identified, they serve as a mechanism to move from laboratory-scale to field-scale experiments because scale-up effects can be studied independent of system heterogeneities.

The proposed experiment will be conducted at the intermediate-scale caisson facility located at the Engineering Experimental Test facility as Los Alamos National Laboratory. Six experimental caissons are clustered around a central access caisson at the facility. Access ports are located between the experimental and access caissons that allow instruments such as solution sampling devices, neutron probe access tubes, and tensiometers to be inserted with depth. When filled with a porous medium, the caissons can be used to conduct well-controlled, well-monitored experiments of flow and transport in either saturated or unsaturated porous media.

For the proposed experiment, the caissons will be filled with crushed Bandelier tuff, which has been used as the porous medium in several previous caisson studies and has been extensively characterized mineralogically, chemically, and hydraulically. A flux will be applied over a small area at the top boundary of the caisson so that a three-dimensional flow and transport region will develop. The flux will be applied at a rate that is low enough to avoid saturated conditions but high enough to maintain tensions above a 500-cm level, which is necessary to avoid operational difficulties with tensiometers and solution samplers. Pre-experimental modeling exercises will be used to determine the design flux, the inflow area, and the placement of the monitoring instruments for the experiments.

The study plan to be developed for the caisson tests will include information on previous caisson experiments, the characterization of the Bandelier tuff, experimental constraints (limitations of the experimental apparatus and facilities), and the experimental design and test implementation.

B. Field-scale tests

The purpose of field-scale tests is to study tracer migration in the Calico Hills unit, to determine if fracture flow is possible in the unit, to validate the laboratory generated geochemical data, and to validate transport codes being used to model nuclide migration in the unsaturated tuffs at Yucca Mountain. A field scale test outside the exploratory block at a surface facility, an audit in the Calico Hills unit, is recommended. It is very important to be able to characterize and test this primary barrier at the field scale. The adequacy of unsaturated tuff in Yucca Mountain as a barrier must be sufficiently proven, and as yet, there are relatively few data on this system.

The adit would be designed such that several different field tests could be conducted, such as diffusion tests, in situ single fracture tests, and flow tests in complex fractures (by injection or infiltration). These tests would answer some key questions:

1. In the absence of moving water, what are the rates of diffusion of specific elements into the pore system of the Calico Hills tuff?

2. In fractures containing flowing water, what mechanisms control the movement of specific elements?

3. What is the fracture network in the Calico Hills, and what is the fracture/matrix coupling?

The field test proposal is only in a conceptual phase. The study plan for proposed tests will include the design of the surface facility (adit), the details of each proposed geochemical test, and details of preliminary modeling work.

C. Field studies at the Nevada Test Site

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 geologic setting 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 yr old. Interaction with the hydrology/radionuclide migration program already established by the Nevada Operations Office of the DOE has been initiated (Blanchard and Elle, 1988). The possibility for utilizing this information source will be investigated, consistent with the limitations imposed by the need to maintain appropriate national security measures.

Natural analogs

A complimentary approach to laboratory testing, field testing and geochemical modeling is the study of natural analogs. Natural analogs provide a tool for evaluating the operation of potentially important geochemical processes over geologic time. These studies have not received major attention in the geochemical site characterization program for Yucca Mountain. The geochemical studies, which are described in Chapter 4, have been concerned largely with developing an understanding of the basic geochemistry of radionuclide transport. However, as these studies progress and the site characterization activities for geochemistry become better understood, detailed models will be developed for the geochemical environment of Yucca Mountain. These models will be based on laboratory and field data, and the extrapolation of these data to the Yucca Mountain site will be through computer modeling as part of the retardation sensitivity task. As these models are refined, it will be possible to identify key elements of the geochemical system that affect strongly site performance and must be understood with a high degree of confidence. Furthermore, it is possible that inferences relative to the sorption behavior of selected radionuclides in the rock-water system at Yucca Mountain can be obtained from analyses of some U-Th decay chain daughters in ground water. This additional natural analog approach will be considered during site characterization and used, if appropriate. The information that will be needed to validate the application of performance modeling can be provided in part through studies of carefully chosen natural analogs.

A primary benefit of natural analog studies that is unique is the time perspective. Field studies of processes of radionuclide migration are time limited and are restricted to small volumes of rock compared with the site. These limitations may restrict the use of highly sorptive tracers; may not adequately represent scaling problems; may not allow complete evaluations of fracture networks and the relative importance of down-gradient, geometric variations in fracture systems; and may not allow adequate extrapolation of results for the required 10,000 yr containment period. Studies of natural analogs provide one means to evaluate the impact of these limitations. Natural analogs can be chosen that provide data concerning the operation of geochemical and geochemical rock systems for periods of tens to hundreds of thousands of years.

There are, however, some limitations to natural analog studies. The most important is past work involving natural analogs was concerned with systems that are no longer active. Complete information may not be available concerning the geochemical environment of the system or the hydrologic system that controlled radionuclide migration. Natural analog systems must be as similar as possible to the hydrological and geochemical environment of the Yucca Mountain site to provide useful information for site characterization and model validation. Studied natural analog systems must be carefully chosen so that useful information can be provided for the Yucca Mountain site or attempts must be made to extract analog information from the Yucca Mountain site. Two possible study directions for natural analogs are proposed. First, analog studies can be restricted to currently active systems where information can be obtained for geochemical and hydrological processes. Second, considerable technical progress is being made in the development of radiometric methods for estimating processes of radionuclide migration. In addition to the more conventional isotope systems (U-Th decay series, T, D, oxygen-18, carbon-14), new progress has been made with other systems such as chlorine-36, iodine-129, and the noble gases. These isotopic systems may allow inferences or bounds to be developed concerning the operation of geochemical and hydrologic processes in the analog environment. Innovative applications of studies of natural isotope systems can be applied to analog environments and to Yucca Mountain itself.

The role of natural analog studies for the characterization of the Yucca Mountain site at this time cannot be described with certainty. However, studies using information from natural analogs will probably be required for several geochemical topics. These include (1) validation of sorption models for individual waste radionuclides, (2) evaluation of the retardation models for elements showing complex and variable geochemical behavior in the natural environment (actinides), (3) validation of transport models involving flow through fracture networks, and (4) validation of SiO_2-kinetics models concerning the stability of secondary alteration minerals in Yucca Mountain (Study 8.3.1.3.3.1).

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. Focus will be placed on the proposed INTRAVAL field tests, particularly those being conducted by the University of Arizona. Investigative overlap with Yucca Mountain Project studies will be identified. A study plan will be developed based on the evaluation and literature review.

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:

Investigation	Study
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:

SCP section	Description
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)

8.3.1.3.8 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:

SCP section	Subject
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.

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 8.3.1.2.2.7.1 (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 (1) to 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) to 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).
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.

8.3.1.3.9 Schedule for the geochemistry program

The geochemistry program includes 8 investigations, which contain 16 studies. The schedule information for each study is summarized in Figure 8.3.1.3-11. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the geochemistry program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.3-8.

The study-level schedules, in combination with information provided in the logic diagrams for this program (Figures 8.3.1.3-2 through 8.3.1.3-10), are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.3-8 and Figure 8.3.1.3-11, however, should be viewed as a snapshot in time. Summary schedule information for the geochemistry program can be found in Sections 8.5.1.8 and 8.5.6.

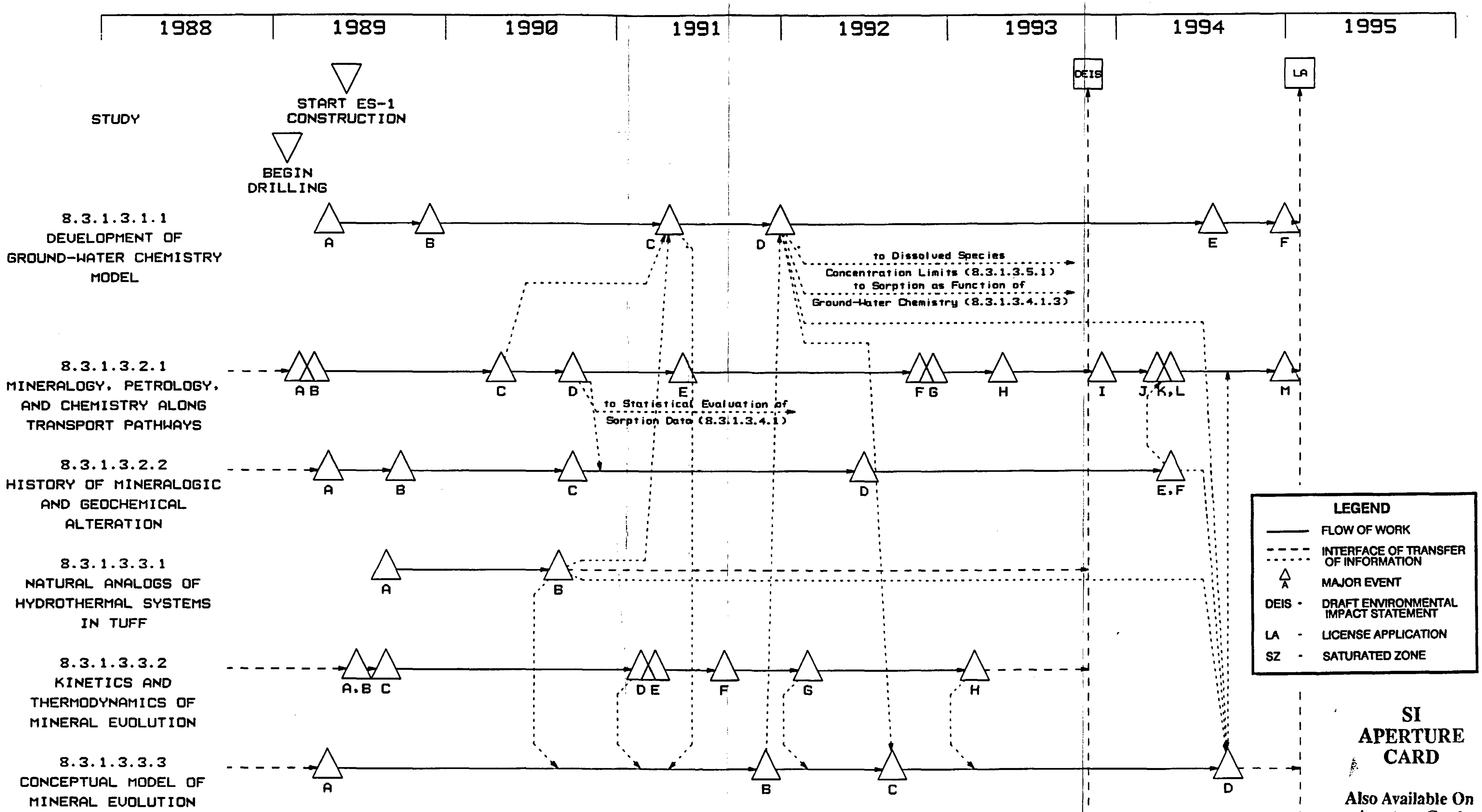

Figure 8.3.1.3-11. Schedule information for studies in Site Program 8.3.1.3 (geochemistry). See Table 8.3.1.3-8 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 1 of 3)

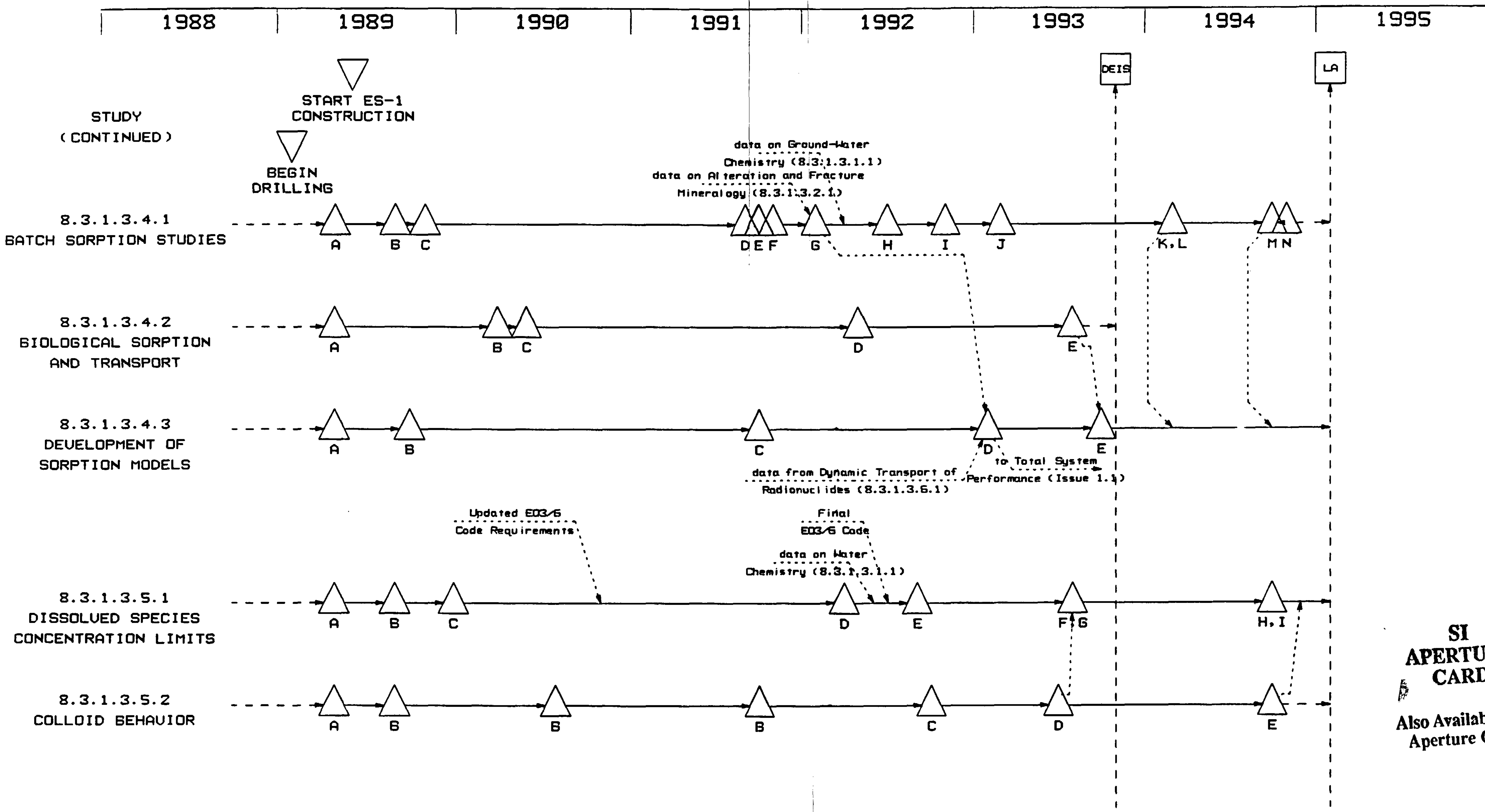

Figure 8.3.1.3-11. Schedule information for studies in Site Program 8.3.1.3 (geochemistry). See Table 8.3.1.3-8 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 2 of 3)

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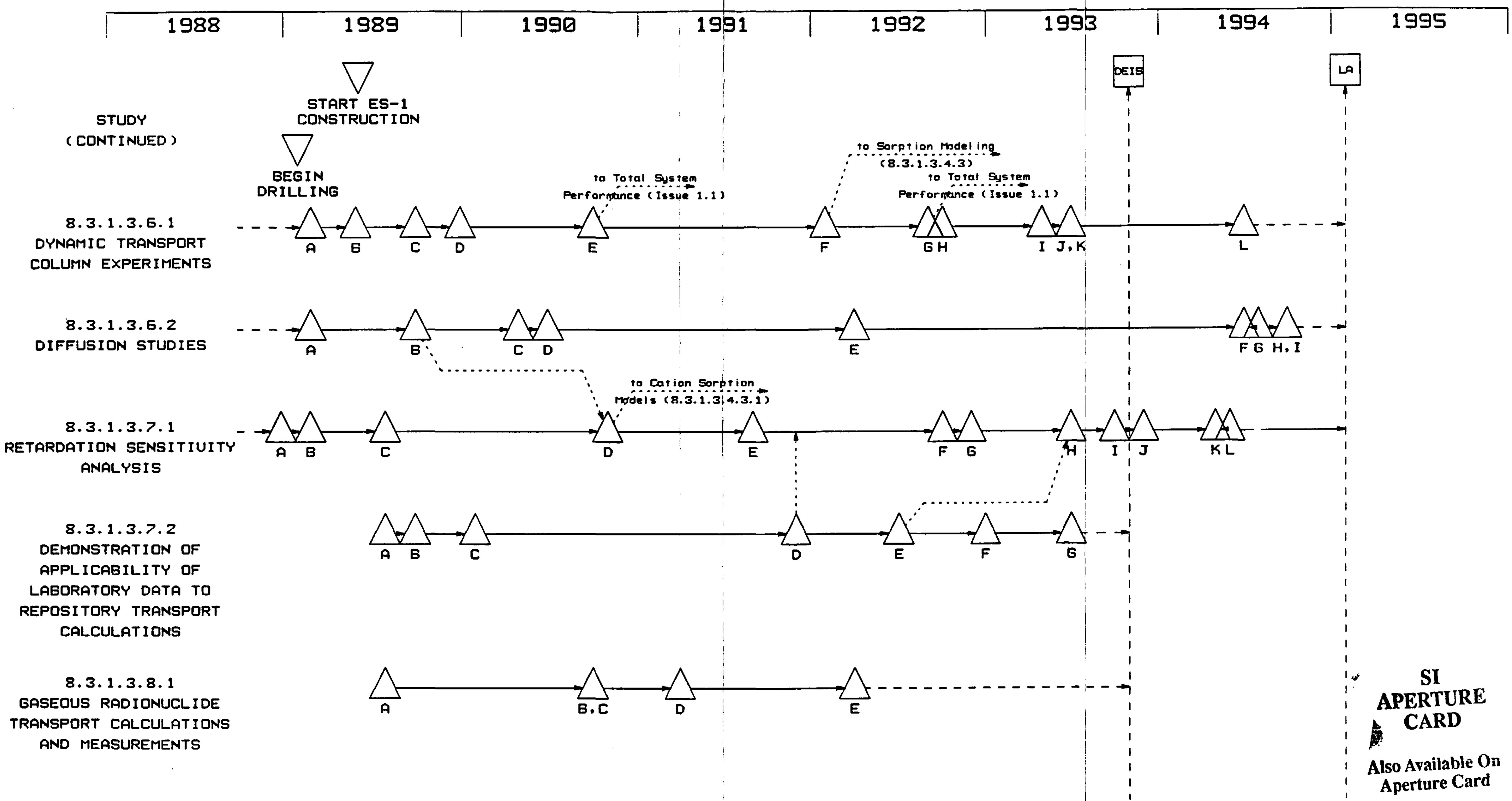


Figure 8.3.1.3-11. Schedule information for studies in Site Program 8.3.1.3 (geochemistry). See Table 8.3.1.3-8 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 3 of 3)

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 1 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.1.1	Development of ground-water chemistry model	A	Study plan approved	4/89
		B	Interim report on water chemistry available to the U.S. Department of Energy (DOE)	11/89
		C	Modeling results of variations in pore and ground-water chemistry available to DOE	4/91
		D	Interim report on modeling of water chemistry of the saturated-zone available to DOE	12/91
		E	Report available to DOE on modeling of unsaturated-zone water chemistry	7/94
		F	Report on modeling of ground-water geochemistry available to DOE; report feeds final ground-water chemistry model	12/94
8.3.1.3.2.1 (ongoing)	Mineralogy, petrology, and chemistry along transport pathways	A	Study plan approved	2/89
		B	Draft report available to DOE on fracture-lining manganese minerals from drill core USWG-4	3/89
		C	Interim three-dimensional mineralogic model available to DOE	4/90

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 4 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.2.2 (ongoing)	History of mineralogic and geochemical alteration (continued)	F	Final report on the history of chemical alteration at Yucca Mountain available to DOE	4/94
8.3.1.3.3.1	Natural analogs of hydrothermal systems in tuff	A	Study plan approved	8/89
		B	Draft report available to DOE on natural analogs	8/90
8.3.1.3.3.2 (ongoing)	Kinetics and thermodynamics of mineral evolution	A	Study plan approved	6/89
		B	Draft report available to DOE on aqueous silica activity coexisting with mixtures of cristobalite and quartz	6/89
		C	Complete model for analcime thermodynamics	8/89
		D	Draft report available to DOE on the kinetics of cristobalite/quartz transition at neutral pH	2/91
		E	Complete solid solution description	3/91
		F	Draft report available to DOE on the kinetics of opal-ct ordering as a function of pH	8/91

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 5 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.3.2 (ongoing)	Kinetics and thermodynamics of mineral evolution (continued)	G	Draft report available to DOE on the kinetics of cristobalite/quartz transition as a function of pH	2/92
		H	Draft report available to DOE on the thermodynamic model for clinoptilolite and heulandite	2/93
8.3.1.3.3.3 (ongoing)	Conceptual model of mineral evolution	A	Study plan approved	4/89
		B	Begin final compilation of mineral evolution data	11/91
		C	Complete revision of model of mineral evolution	8/92
		D	Report available to DOE on the conceptual model of mineral evolution	8/94
8.3.1.3.4.1 (ongoing)	Batch sorption studies	A	Study plan approved	4/89
		B	Draft report available to DOE on sorption measurements with known oxidation states of plutonium	8/89
		C	Draft report available to DOE on deconvolution of isotherms of known mineralogy	10/89

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 6 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.4.1 (ongoing)	Batch sorption studies (continued)	D	Draft report available to DOE on the sorption on particulates	8/91
		E	Draft report available to DOE on actinide sorption isotherms (deconvolution)	9/91
		F	Complete assessment of unsaturated ground-water chemistry of the Topopah Spring Member and integration of sorption data	10/91
		G	Draft report available to DOE on the statistical evaluation of sorption data	1/92
		H	Draft of final report on actinide batch sorption available to DOE	6/92
		I	Draft report available to DOE on ground-water composition effects on actinide sorption	10/92
		J	Draft of final report on the statistical evaluation of sorption data available to DOE; report feeds final sorption report	2/93

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 7 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.4.1 (ongoing)	Batch sorption studies (continued)	K	Final report on batch sorption available to DOE; report feeds final sorption report	2/94
		L	Final report on the effects of ground-water composition on sorption available to DOE; report feeds final sorption report	2/94
		M	Final report on the sorption on particulates available to DOE; report feeds final sorption report	9/94
		N	Final report on sorption isotherms (deconvolution) available to DOE; report feeds final sorption report	10/94
8.3.1.3.4.2 (ongoing)	Biological sorption and transport	A	Study plan approved	4/89
		B	Draft of final report on colloids available to DOE	3/90
		C	Draft of final report on chelation available to DOE	5/90
		D	Draft of final report on microbiological activity and its influence on sorption available to DOE; report feeds final sorption report	4/92

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 8 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.4.2 (ongoing)	Biological sorption and transport (continued)	E	Draft of final report on microbial colloid and geochemical transport models available to DOE	7/93
8.3.1.3.4.3 (ongoing)	Development of sorption models	A	Study plan approved	4/89
		B	Interim report on sorption modeling available to DOE	9/89
		C	Complete cation sorption models	9/91
		D	Draft of final report on sorption modeling available to DOE; report feeds final sorption report	1/93
		E	Begin preparation of final report on sorption	9/93
8.3.1.3.5.1	Dissolved species concentration limits	A	Study plan approved	4/89
		B	Draft of final report on measured solubilities of Pu, Am, and Np in typical ground water at Yucca Mountain available to DOE	8/89
		C	Data report on the measured solubilities of uranium and thorium available to DOE	12/89

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 9 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.5.1	Dissolved species concentration limits (continued)	D	Letter report available to DOE on solubility calculations for elements on the U.S. Environmental Protection Agency (EPA) critical list	3/92
		E	Interim report available to DOE on speciation measurements of selected elements	8/92
		F	Draft report on EQ3/6 database of solubility measurements available to DOE	7/93
		G	Draft report on solubility measurements available to DOE; begin final report on solubility	7/93
		H	Report on the results of speciation measurements available to DOE; report feeds final report on solubility	9/94
		I	Complete solubility calculations for elements on the EPA critical list; data feeds final report on solubility	9/94

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 10 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.5.2 (ongoing)	Colloid behavior	A	Study plan approved	4/89
		B	Interim reports on colloid stability and characterization available to DOE	8/89 7/90 9/91
		C	Final report on Pu(IV) colloid available to DOE	9/92
		D	Interim report on colloid formation of other nuclides available to DOE	6/93
		E	Final report on colloid formation and stability of Np, Pu, and Am available to DOE; input to final report on solubility	9/94
8.3.1.3.6.1 (ongoing)	Dynamic transport column experiments	A	Study plan approved	2/89
		B	Progress reports on unsaturated flow column experiments available to DOE	5/89 6/90 6/91 6/92
		C	Letter report on crushed tuff column experiment available to DOE	9/89
		D	Letter report on the kinetics of sorption available to DOE	12/89

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 11 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.6.1 (ongoing)	Dynamic transport column experiments (continued)	E	Draft report on the transport of radionuclides by fracture flow under saturated conditions available to DOE	9/90
		F	Draft of preliminary report on filtration of radionuclides available to DOE	1/92
		G	Draft report available to DOE on transportation and retardation in fractured flow	8/92
		H	Completion of crushed tuff column experiments	9/92
		I	Draft of summary report on the kinetics of sorption available to DOE; report feeds summary report on retardation by diffusion, dispersion, and advective processes	4/93
		J	Draft of summary report on unsaturated flow column experiments available to DOE; report feeds summary report on retardation by diffusion, dispersion, and advective processes	6/93

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 12 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.6.1 (ongoing)	Dynamic transport column experiments (continued)	K	Draft report available to DOE on the results of fractured tuff column experiments; report feeds summary report on retardation by diffusion, dispersion, and advective processes	6/93
		L	Summary report on filtration of radionuclides available to DOE; report feeds summary report on retardation by diffusion, dispersion, and advective processes	6/94
8.3.1.3.6.2 (ongoing)	Diffusion studies	A	Study plan approved	2/89
		B	Preliminary report on retardation by diffusion in saturated tuff slab available to DOE	9/89
		C	Final report available to DOE on diffusion of bromide cell experiment in saturated rock beakers	4/90
		D	Letter report available to DOE on retardation by diffusion based on the results of testing with unsaturated tuff block	6/90

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 13 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.6.2 (ongoing)	Diffusion studies (continued)	E	Draft of preliminary report on retardation by diffusion in unsaturated tuff slab available to DOE	3/92
		F	Complete saturated rock beaker diffusion experiments for Am, Pu, and Np	6/94
		G	Complete saturated tuff slab kinetic studies for Am, Pu, and Np	7/94
		H	Final report on retardation by diffusion available to DOE; report feeds summary report on retardation by diffusion, dispersion, and advective processes	9/94
		I	Complete unsaturated tuff slab diffusion studies for Am, Pu, and Np	9/94
8.3.1.3.7.1 (ongoing)	Retardation sensitivity analysis	A	Updates of the geochemical/ geophysical model available to DOE	12/88 1/91
		B	Study plan approved	2/89
		C	Update on benchmarking calculations available to DOE	7/89

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 14 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.7.1	Retardation sensitivity analysis (continued)	D	Draft report available to DOE on the results of the retardation sensitivity analysis	10/90
		E	Draft of final report on particulate transport available to DOE	8/91
		F	Draft of final report on coupled phenomena available to DOE	9/92
		G	Draft of final report on the geochemical transport code available to DOE	11/92
		H	Complete revised integrated transport calculations; begin final validation of transport models	6/93
		I	Draft of final report on the significance of physical processes affecting transport available to DOE	9/93
		J	Draft of final report on the significance of geochemical processes affecting transport available to DOE; report feeds final geochemical/geophysical model	11/93

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 15 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.7.1	Retardation sensitivity analysis (continued)	K	Final report on the results of retardation sensitivity analysis available to DOE; report feeds final geochemical/geophysical model and report on effectiveness of geochemical barrier	4/94
		L	Final report on the sensitivity code available to DOE; report feeds final geochemical/geophysical model	5/94
8.3.1.3.7.2	Demonstration of applicability of laboratory data to repository transport calculations	A	Study plan approved	7/89
		B	Draft report available to DOE on the evaluation and recommendation for field tests, laboratory block tests, Caisson tests, natural analog work, and Nevada Test Site (NTS) nuclide migration work	9/89
		C	Initiate field tests (Caisson, unsaturated zone geochemistry field tests, and large tuff block tests)	1/90
		D	Preliminary test results available to DOE	11/91
		E	Final test results available to DOE	6/92

Table 8.3.1.3-8. Major events and completion dates for studies in the geochemistry program (page 16 of 16)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.3.7.2	Demonstration of applicability of laboratory data to repository transport calculations (continued)	F	Draft report available to DOE on natural analog studies	12/92
		G	Draft report on nuclide migration work at NTS	6/93
8.3.1.3.8.1	Gaseous radionuclide transport calculations and measurements	A	Study plan approved	7/89
		B	Draft report on results of the calculated gas transport rate assessment available to DOE	9/90
		C	Begin planning experiments to measure radionuclide transport rates and retardation rates to verify calculational models	9/90
		D	Complete assessment of whether calculated gas transport rates are adequate to assess gaseous radionuclide releases for performance assessment	3/91
		E	Draft report available to DOE on the results of experimental measurements of gaseous transport rates and retardation rates	3/92

[a]The letters in this column key major events shown in Figure 8.3.1.3-11.

The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports.

DOE/RW-0199

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume IV, Part B

Chapter 8, Section 8.3.1.4, Rock Characteristics

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.4 Overview of the rock characteristics program: Description of the present and expected rock characteristics required by performance and design issues

Summary of performance and design requirements for rock characteristics information

Compliance with performance and design criteria for a geologic repository will require information about the rock characteristics of the Yucca Mountain site. This information will be used in the design of underground repository facilities and to support assessments of site performance related to ground-water travel time, waste-package lifetime, radionuclide releases from the engineered-barrier system (EBS), and radionuclide releases to the accessible environment. The various regulatory requirements are concerned with rock characteristics, conditions, and processes in different subsurface regions within and around Yucca Mountain. The rock characteristics are also an important component of model validation, particularly for establishing the boundary and initial conditions and the geometry of the model.

The siting criteria discussed in 10 CFR 60.122 must also be evaluated, including the favorable condition for waste emplacement at a minimum depth of 300 m and characterization of structural, stratigraphic, and geomechanical conditions to determine if potentially adverse conditions are present. Design criteria for the underground facility, seals of shafts and boreholes, and waste packages are also evaluated in the context of the natural rock properties of the site. Assessments of whether the performance objectives, siting criteria, and design criteria can be met will rely on information about the stratigraphy and structure of the Yucca Mountain site, the properties of the rock units occurring at the site, and the temperature and stress conditions before excavation of underground openings.

Approach to satisfy performance and design requirements

The geologic and geophysical site characterization activities described in this section provide an important category of information needed to develop a three-dimensional physical property model, i.e., the geometry associated with the material properties of the rock at the Yucca Mountain site. The objective of the three-dimensional model is to provide a computer-based representation of the physical properties of the rocks at the site. The data base for the model will contain the distribution of parameters (physical properties) within property-dependent units. An important function of the computer-based model will be to provide input for numerical computer analyses that involve hydrologic, thermal, thermomechanical, and geochemical processes.

The three-dimensional physical properties model is a representation of the Yucca Mountain repository site containing various kinds of data on its geologic, geohydrologic, thermal, mechanical, and geochemical properties. The model will allow predictions of how a physical property changes spatially within and across the boundaries of the model. 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. The physical properties model could be developed based entirely on the samples from site characterization. However, the geologic complexity of the Yucca Mountain site may cause large amounts of uncertainty associated with the variability of the properties between sample locations. Therefore, the physical property data will be correlated with the geologic and geophysical data to reduce the uncertainty between sample locations. The nature and number of site characterization studies to be conducted will be determined by the current understanding of the site and by the level of confidence required for the physical properties and the numerical models in which they are being input.

Figure 8.3.1.4-1 provides the overall logic for developing the three-dimensional physical property model. The geologic, hydrologic, geochemical, and thermal/mechanical properties are the fundamental information to be contained in the model. The geologic framework serves as the geometric framework for the physical property model. The hydrologic, geochemical, and thermal mechanical properties will be developed in Sections 8.3.1.2, 8.3.1.3 and 8.3.1.15 respectively. These separate categories of properties are called on in this section in order to integrate them into the physical properties model. Table 8.3.1.4-1 serves as the first step in the correlation of parameter requests from design or performance issues (e.g., performance or design parameters in sections 8.3.5.12, 8.3.5.13, 8.3.2.2, and 8.3.3) and results from data gathering activities (activity parameters and associated characterization parameters). The parameter categories listed in Table 8.3.1.4-1 are topical categories that are used to translate data requests for types of design and performance information into similar types of site data to be collected. Because of the diversity and volume of data needs called for in the design and performance issues and data provided by characterization activities, it is inappropriate to expect a one-to-one correspondence between a requested performance parameter and an activity parameter. Rather, a given characterization parameter in almost every case will require data reduction and analysis to transform them into the information directly used in design or performance analysis. In order to improve the confidence in the results from a characterization activity, data from related activities will be analyzed for corroboration.

Characterization parameters commonly will take the form of maps and other two- or three-dimensional illustrations, such as isopach maps, isopleth maps and structure contour maps, or diagrams displaying statistical distributions of activity parameters throughout the site. Many parameters will also include a spatial or unit-specific component such as an isopach map of a specific stratigraphic unit within a specified area. The eventual formulation of an appropriate testing basis for each characterization parameter will include the identification of (1) tentative parameter goals, (2) current estimate of parameter values, (3) current confidence level, and (4) needed confidence level. For example, if an isopach map of the thermomechanical unit TSw2 within the boundary of the repository perimeter drift is identified as a characterization parameter, then the tentative parameter goal may be that contours are accurate to within ±30 m. Current estimates of the parameter will be obtained from information or references in Chapter 1 of the Site Characterization Plan (SCP). Needed confidence levels will indicate how important this information is to design and performance issues. Current levels of confidence will, in most cases, be low.

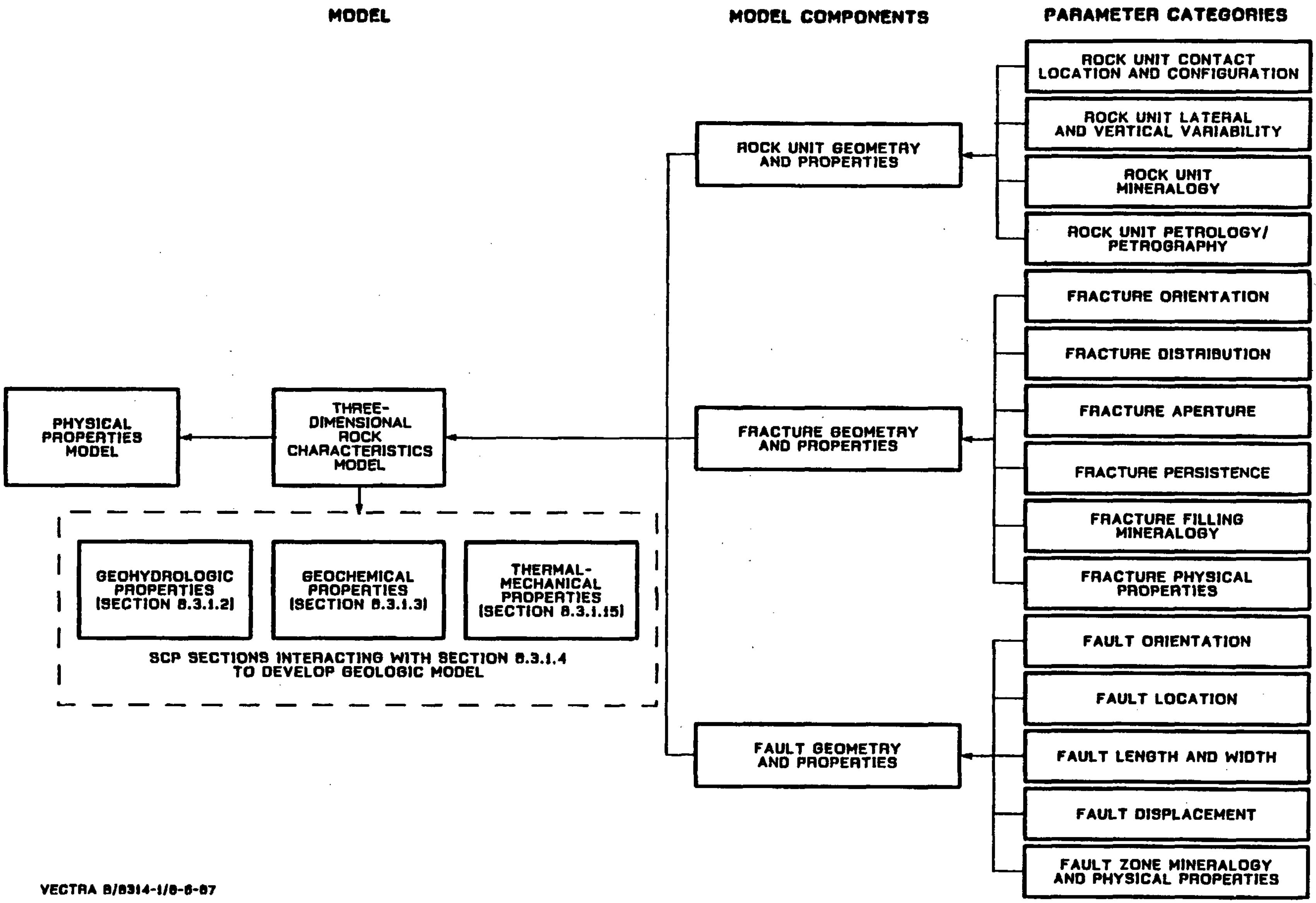


Figure 8.3.1.4-1. Logic diagram for the three-dimensional physical properties model.

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 1 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Rock-unit contact location and configuration	Attitude, ash-flow zones	8.3.1.4.2.2.1
1.6	8.3.5.12		Attitude, bedded-tuff zones	8.3.1.4.2.2.1
1.11	8.3.2.2		Attitude, lithostratigraphic units	8.3.1.4.2.1.1
1.12	8.3.3.2		Borehole diameter	8.3.1.4.2.1.3
4.4	8.3.2.5		Color, lithostratigraphic units	8.3.1.4.2.1.1
			Contacts, flow units	8.3.1.4.2.1.5
			Contacts, lithostratigraphic units, nature	8.3.1.4.2.1.1
			Correlatable sequences	8.3.1.4.2.1.1
			Depth, lithostratigraphic units	8.3.1.4.2.1.1
			Geophysical signature, litho-stratigraphic markers	8.3.1.4.2.1.3
			Key marker beds	8.3.1.4.2.1.1
			Lateral continuity of horizons	8.3.1.4.2.1.2
			Lithology, stratigraphic sequence	8.3.1.4.2.2.4
			Locations, bedded tuff units	8.3.1.4.2.1.1
			Magnetic property changes, core samples	8.3.1.4.2.1.5
			Petrographic changes, core samples	8.3.1.4.2.1.4
			Seismic velocities	8.3.1.4.2.1.3
			Spontaneous potential	8.3.1.4.2.1.3
			Stratigraphic sequence, Topopah Spring welded unit	8.3.1.4.2.2.4
			Stratigraphic sequence, litho-stratigraphic units	8.3.1.4.2.1.1
			Thickness, flow units	8.3.1.4.2.1.5
			Thickness, lithostratigraphic units	8.3.1.4.2.1.1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 2 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
			ROCK UNIT GEOMETRY AND PROPERTIES (continued)	
			Vertical distribution, lithostratigraphic units	8.3.1.4.2.1.2
1.1	8.3.5.13	Rock-unit lateral and vertical variability	Acoustic velocity, core samples	8.3.1.4.2.1.4
1.6	8.3.5.12		Age, potassium-argon, lithostratigraphic units	8.3.1.4.2.1.1
1.11	8.3.2.2		Areal extent, exposed bedrock	8.3.1.4.2.2.1
1.12	8.3.3.2		Density, bulk, in situ	8.3.1.4.2.1.3
4.4	8.3.2.5		Density, grain and bulk, core samples	8.3.1.4.2.1.4
			Density, variations	8.3.1.4.2.1.2
			Depositional characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Depositional units, Topopah Spring Member	8.3.1.4.2.1.5
			Electrical conductivity	8.3.1.4.2.1.3
			Electrical resistivity, core samples	8.3.1.4.2.1.4
			Electromagnetic properties, variations	8.3.1.4.2.1.2
			Emplacement history, ash-flow tuffs	8.3.1.4.2.1.1
			Extent, lithostratigraphic units	8.3.1.4.2.1.1
			Gravitational field, variations	8.3.1.4.2.1.2
			Hydraulic conductivity, core samples	8.3.1.4.2.1.4
			Induced polarization, core samples	8.3.1.4.2.1.4
			Laboratory/in situ rock property correlation, surface and subsurface geophysics	8.3.1.4.2.1.4
			Lateral continuity, horizons	8.3.1.4.2.1.2

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 3 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Lateral continuity, repository host horizon	8.3.1.4.2.2.4
			Lateral extent, ash-flow zones	8.3.1.4.2.2.1
			Lateral extent, bedded-tuff zones	8.3.1.4.2.2.1
			Lateral variability, lithostratigraphic units, exploratory shaft facility drifts	8.3.1.4.2.2.4
			Lithic fragments, concentration variations, subunit contacts	8.3.1.4.2.1.5
			Lithic fragments, type and abundance, lithostratigraphic units	8.3.1.4.2.1.1
			Lithic-rich subzones, locations, flow units	8.3.1.4.2.1.5
			Lithologic uniformity, relations to density, seismic velocity, porosity, and resistivity	8.3.1.4.2.1.4
			Lithophysal zone characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Lithophysal zones, geophysical signatures	8.3.1.4.2.1.3
			Magnetic field intensity, total	8.3.1.4.2.1.2
			Magnetic field, variations	8.3.1.4.2.1.2
			Magnetic susceptibility	8.3.1.4.2.1.3, 8.3.1.4.2.1.5
			Porosity, core samples	8.3.1.4.2.1.4
			Porosity, variations	8.3.1.4.2.1.3

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 4 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Pumice characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Pumice clasts, concentration variations, subunit contacts	8.3.1.4.2.1.5
			Pumice clasts, concentrations, flow units	8.3.1.4.2.1.5
			Rock characteristics, changes, Topopah Spring Member	8.3.1.4.2.1.5
			Seismic velocity, contrasts	8.3.1.4.2.1.2
			Statistical analysis crossplots, geophysical measurements	8.3.1.4.2.1.3
			Thickness, ash-flow zones	8.3.1.4.2.2.1
			Thickness, bedded-tuff zones	8.3.1.4.2.2.1
			Thickness, volcanic section, from electromagnetic surveys	8.3.1.4.2.1.2
			Transport history, ash-flow tuffs	8.3.1.4.2.2.1
			Variability, lateral, lithostratigraphic units	8.3.1.4.2.1.1
1.1	8.3.5.13	Rock-unit mineralogy and petrology	Alteration history, ash-flow tuffs	8.3.1.4.2.2.1
4.4	8.3.2.5		Alteration, degree and type, lithostratigraphic units	8.3.1.4.2.1.1
			Clay concentrations, from induced polarization data	8.3.1.4.2.1.4
			Compositional changes, anomalous, subunit contacts	8.3.1.4.2.1.5
			Cooling history, ash-flow tuffs	8.3.1.4.2.2.1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 5 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Curie temperature	8.3.1.4.2.1.5
			Demagnetization, alternating field	8.3.1.4.2.1.5
			Demagnetization, thermal	8.3.1.4.2.1.5
			Depositional breaks, locations, flow units	8.3.1.4.2.1.5
			Essential minerals, abundance	8.3.1.4.2.1.1
			Gamma-radiation intensity temperature, relative	8.3.1.4.2.1.3
			Glassy intervals, lithostratigraphic units	8.3.1.4.2.1.1
			Grain size, bedded-tuff intervals, lithostratigraphic units	8.3.1.4.2.1.1
			Grain size, variations, flow units	8.3.1.4.2.1.5
			Induced polarization	8.3.1.4.2.1.3
			Isotopes, gamma-ray spectrometry	8.3.1.4.2.1.1
			Magnetic minerals, composition	8.3.1.4.2.1.5
			Magnetic minerals, grain size	8.3.1.4.2.1.5
			Magnetic minerals, grain size variation	8.3.1.4.2.1.5
			Magnetic minerals, relative abundance	8.3.1.4.2.1.5
			Magnetization, anhysteritic remanent	8.3.1.4.2.1.5
			Magnetization, isothermal remanent	8.3.1.4.2.1.5
			Magnetization, remanent, orientation and magnitude	8.3.1.4.2.1.5
			Magnetization, saturation	8.3.1.4.2.1.5
			Mineral phases, diagenetic, bedded tuffs	8.3.1.4.2.1.1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 6 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Mineral phases, diagenetic, bedded tuffs	8.3.1.4.2.1.1
			Mineral phases, distinctive morphologies	8.3.1.4.2.1.1
			Mineralogy, bedded-tuff units	8.3.1.4.2.1.1
			Mineralogy, lithostratigraphic units	8.3.1.4.2.1.1
			Paleomagnetic directions, lithostratigraphic units	8.3.1.4.2.1.5
			Petrography, lithostratigraphic units	8.3.1.4.2.1.1
			Potassium, uranium, thorium content	8.3.1.4.2.1.3
			Primary crystallization, lithostratigraphic units	8.3.1.4.2.1.1
			Smectite-rich intervals, geophysical signatures	8.3.1.4.2.1.3
			Sorting, bedded-tuff units	8.3.1.4.2.1.1
			Sorting, lithostratigraphic units	8.3.1.4.2.1.1
			Spherulitic zones, lithostratigraphic units	8.3.1.4.2.1.1
			Textural variation, across flow-unit boundaries	8.3.1.4.2.1.5
			Texture, lithostratigraphic units	8.3.1.4.2.1.1
			Welding characteristics, anomalous, subunit contacts	8.3.1.4.2.1.5
			Welding, lithostratigraphic units	8.3.1.4.2.1.1
			Zeolite-rich intervals, geophysical signatures	8.3.1.4.2.1.3
			Zeolites, concentrations, from induced polarization	8.3.1.4.2.1.4

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 7 of 12)

Calls by performance and design issues		Parameter	Response by rock characteristics program	
Issue	SCP section	category	Activity parameter	SCP activity
		FRACTURE GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Fracture distribution	Fractal analysis	8.3.1.4.2.2.2
1.6	8.3.5.12		Fracture characteristics, spatial variation	8.3.1.4.2.2.5
1.11	8.3.2.2			
1.12	8.3.3.2		Fracture distribution, spatial	8.3.1.4.2.2.2
4.4	8.3.2.5		Fracture frequency, apparent, lateral variability	8.3.1.4.2.2.3
			Fracture frequency, variation with depth	8.3.1.4.2.2,3
			Fracture frequency, variation with lithostratigraphic unit	8.3.1.4.2.2.3
			Fracture location	8.3.1.4.2.2.3
			Fracture network geometry	8.3.1.4.2.2.2
			Fracture network, three-dimensional distribution, exploratory shaft facility	8.3.1.4.2.2.4
			Fracture networks	8.3.1.4.2.2.2
			Fracture patterns, local, variations	8.3.1.4.2.2.2
			Fracture, spatial distribution	8.3.1.4.2.2.4
			Fractures, subsurface, near fault zones, lateral variability	8.3.1.4.2.2.3
			Seismic properties, relation to fracture properties	8.3.1.4.2.2.5
			Seismic shear-wave amplitudes	8.3.1.4.2.2.5
			Seismic shear-wave polarizations	8.3.1.4.2.2.5
			Seismic shear-wave travel times	8.3.1.4.2.2.5
			Seismic-wave propagation characteristics	8.3.1.4.2.2.5

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 8 of 12)

Calls by performance and design issues		Parameter category	Response by rock characteristics program	
Issue	SCP section		Activity parameter	SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
1.6 1.11 4.4	8.3.5.12 8.3.2.2 8.3.2.5	Fracture orientation	Fracture attitude, statistical distribution	8.3.1.4.2.2.3
			Fracture attitude, variation with depth	8.3.1.4.2.2.3
			Fracture attitude, variation with lithostratigraphic unit	8.3.1.4.2.2.3
			Fracture orientation	8.3.1.4.2.2.2
			Fracture orientation, statistical distribution	8.3.1.4.2.2.2
			Fracture strike direction, lateral variability	8.3.1.4.2.2.3
1.6 1.11 4.4	8.3.5.12 8.3.2.2 8.3.2.5	Fracture aperture	Fracture aperture	8.3.1.4.2.2.2, 8.3.1.4.2.2.3, 8.3.1.4.2.2.4
1.6 1.11 4.4	8.3.5.12 8.3.2.2 8.3.2.5	Fracture persistence	Fracture connectivity	8.3.1.4.2.2.2
			Fracture dimension	8.3.1.4.2.2.3
			Fracture intersections, distribution	8.3.1.4.2.2.2
			Fracture persistence	8.3.1.4.2.2.2
			Fracture persistence, statistical distribution	8.3.1.4.2.2.4
1.11 4.4	8.3.2.2 8.3.2.5	Fracture-filling mineralogy and physical properties	Fracture mineralization, degree	8.3.1.4.2.2.3
			Fracture roughness	8.3.1.4.2.2.2, 8.3.1.4.2.2.3
			Fracture surface profile	8.3.1.4.2.2.4

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 9 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
			Fracture surface profile	8.3.1.4.2.2.3
			Fracture types	8.3.1.4.2.2.3
			Fracture-filling mineralogy	8.3.1.4.2.2.2, 8.3.1.4.2.2.3, 8.3.1.4.2.2.4
		FAULT GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Fault location	Fault location	8.3.1.4.2.2.3
1.6	8.3.5.12		Fault trends, from electromagnetic surveys	8.3.1.4.2.1.2
1.11	8.3.2.2		Structural domains	8.3.1.4.2.2.4
4.4	8.3.2.5		Structural rotations, magnitude from paleomagnetic directions	8.3.1.4.2.1.5
			Tectonic style, faults	8.3.1.4.2.2.4
			Tectonic style, faults, Ghost Dance fault	8.3.1.4.2.2.4
1.1	8.3.5.13	Fault orientation	Fault and fault-zone attitude	8.3.1.4.2.2.1
1.6	8.3.5.12		Fault orientation	8.3.1.4.2.2.4
1.11	8.3.2.2		Structural rotations, magnitude from paleomagnetic directions	8.3.1.4.2.1.5
4.4	8.3.2.5			
1.1	8.3.5.13	Fault length and width	Fault and fault-zone length	8.3.1.4.2.2.1
1.6	8.3.5.12		Fault-zone width	8.3.1.4.2.2.1, 8.3.1.4.2.2.3
1.11	8.3.2.2			
4.4	8.3.2.5			

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 10 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		FAULT GEOMETRY AND PROPERTIES (continued)		
1.11 2.3 4.4	8.3.2.2 8.3.5.5 8.3.2.5	Fault displacement	Fault displacement, deep-seated faults, indication from lateral discontinuities	8.3.1.4.2.1.2
			Fault displacement, faults and fault zones	8.3.1.4.2.2.1
			Strike-slip faults, indications from lateral discontinuities	8.3.1.4.2.1.2
			Structural domains	8.3.1.4.2.2.4
			Tectonic styles, faults	8.3.1.4.2.2.4
			Tectonic styles, faults, Ghost Dance fault	8.3.1.4.2.2.4
4.4	8.3.2.5	Fault-zone mineralogy and physical properties	Alteration characteristics, fault zones	8.3.1.4.2.1.2
			Fault and fault-zone characteristics, near-surface faults and zones	8.3.1.4.2.2.1
			Fault physical characteristics	8.3.1.4.2.2.4
		GEOLOGIC FRAMEWORK		
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	Geologic framework	Correlation diagrams, lithostratigraphic units	8.3.1.4.2.3.1
			Correlation of laboratory values and in situ values for rock properties	8.3.1.4.2.3.1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 11 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			GEOLOGIC FRAMEWORK (continued)	
			Cross sections, lithostratigraphic units	8.3.1.4.2.3.1
			Fractures, spatial distribution	8.3.1.4.2.3.1
			Geologic model, three-dimensional	8.3.1.4.2.3.1
			Interpretation of depositional and and diagenetic history of rock units	8.3.1.4.2.3.1
			Interpretation of distribution of lithology, petrology, petrography, and mineralogy of rock units	8.3.1.4.2.3.1
			Isopach maps, lithostratigraphic units	8.3.1.4.2.3.1
			Isopleth maps, rock property values	8.3.1.4.2.3.1
			Relations between geologic and geophysical characteristics of rock units	8.3.1.4.2.3.1
			Rock properties, three-dimensional distribution	8.3.1.4.2.3.1
			Structure contour maps, lithostratigraphic units	8.3.1.4.2.3.1
			Surface geologic maps	8.3.1.4.2.3.1
			GEOLOGIC MODEL	
1.1	8.3.5.13	Geologic model synthesis	Age, fracturing	8.3.1.4.2.2.4
1.6	8.3.5.12		Chronology, faulting	8.3.1.4.2.2.1
1.11	8.3.2.2		Chronology, faulting, relative	8.3.1.4.2.2.3

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 12 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
		GEOLOGIC MODEL (continued)		
1.12	8.3.3.2		Faulting chronology	8.3.1.4.2.2.1
4.4	8.3.2.5		Fracture chronology, fracture development	8.3.1.4.2.2.2
			Fracture chronology, relative changes due to tectonism--see tectonism studies	8.3.1.4.2.2.3 8.3.1.8.2
			Fracture chronology, relative changes due to erosion--see erosion studies	8.3.1.6.4.1
			Saturation	8.3.1.4.2.1.3
			Water content	8.3.1.4.2.1.3
			Relationships among hydrologic test results, VSP fracture data and lithologic data	8.3.1.4.2.2.5
			Relationships among geochemical test results, VSP fracture data, and lithologic data	8.3.1.4.2.2.5
			Poisson's ratio	8.3.1.4.2.1.3
			Young's modulus	8.3.1.4.2.1.3
			Relationships among geomechanical test results, VSP fracture data, and lithologic data	8.3.1.4.2.2.5

The grouping of performance parameters into categories is a necessary first step because individual parameter requests commonly differ with respect to such things as specific spatial locations, stratigraphic units, and associated goals, in some cases for the same parameter type within a given category. Thus, the parameter categories are defined to properly correlate sets of related design or performance parameters with corresponding sets of characterization parameters.

Table 8.3.1.4-1 lists activity parameters associated with each parameter category that incorporates information provided by the rock characteristics program. The following explanation is provided to summarize the types of design and performance parameters encompassed by each category.

The table entries labeled "rock unit geometry and properties," "fracture geometry and properties," "fault geometry and properties," and "geologic framework" each represents a broad group of geologic and geophysical information (Figure 8.3.1.4-1). "Rock unit geometry and properties" is divided into three parameter categories: rock unit contact location and configuration; rock unit lateral and vertical variability; and rock unit mineralogy and petrology. The performance and design parameters associated with "rock unit contact location and configuration" include such items as unit contact attitudes for geohydrologic, geochemical, thermomechanical, and lithologic units; thickness of the Topopah Spring and other rock units; lateral extent of thermomechanical units; attitudes of various units; and depths to various unit contacts. Rock unit lateral and vertical variability includes such performance and design parameters as spatial correlation scales for hydrologic and geochemical properties, and extent and abundance of lithophysal cavities in the Topopah Spring Member. The category "rock unit mineralogy and petrology" combines requests for site information on such parameters as calcite cementation above the repository, radionuclide concentrations, and mineralogy around the waste packages.

The second group of parameter categories, "fracture geometry and properties," addresses information about the fracture network of Yucca Mountain. It includes five parameter categories. The first, "fracture distribution," includes design and performance requests primarily for fracture frequency, spacing, and abundance, as well as for spatial distribution to aid classification of fracture and joint sets. The second category, "fracture orientation," is self explanatory and provides a rare one-to-one match with performance and design requests. The next category in this group, "fracture aperture," includes requests for fracture widths and their local spatial distribution. The category for "fracture persistence" includes requests for persistence, as well as fracture length. The last category in this group, "fracture filling mineralogy and physical properties," includes parameter requests for such items as roughness of fracture walls, distribution and concentrations of fracture fillings in the repository, and fracture weathering information in the Topopah Spring Member.

The next broad group of parameters categories, "fault geometry and properties," deals with the characteristics of faults and fault zones. The first four of these categories are self-explanatory and summarize design and performance requests for information on fault locations, orientations, length and width, and displacement. The fifth and last entry, "fault zone mineralogy and physical properties," has no specific corresponding requests from design and performance issues that are directly addressed by the characterization program for rock characteristics. The hydrological, thermomechanical, and geochemical properties of rock materials within fault zones are requested, but are listed under parameter categories for the type of property (e.g., permeability or retardation coefficient) in the appropriate characterization program (Sections 8.3.1.2, geohydrology program; 8.3.1.3, geochemistry program; and 8.3.1.15, thermal and mechanical properties program). Also, several requests for information relating to faulting potential and to location of faults with such potential are not listed here but are addressed in the sections on postclosure tectonics (Section 8.3.1.8) and in preclosure tectonics (Section 8.3.1.17).

The last general category of parameters, "geologic framework," represents a set of synthesized parameters that will eventually constitute "characterization parameters." The form and content of these parameters are under development but will provide a vehicle for reducing the data represented by "activity parameters" to a proper form for transfer to uses in design and performance analysis.

As previously mentioned, a three-dimensional model could be developed based only on physical property data from core samples. Various interpolation methods can be used to estimate the variation in the value of a property of the rock between the locations of the samples. The use of the rock property data determines the degree to which it is important to know precisely how a particular property varies with the distance from the sample location. For example, if a hydrologic numerical model for calculating ground-water travel time requires a value for the effective permeability, several considerations will determine how well effective permeability must be known. First, the question of what level of uncertainty on travel time is acceptable should be addressed. Second, the sensitivity of the travel-time calculation to the effective permeability must be determined. If the travel time is very sensitive to permeability and the uncertainty associated with the calculation must be small, activities to obtain additional information to better describe the spatial variability of the parameter are justified. The planned geologic and geophysical studies are intended to identify correlations between the properties of interest that can be directly measured and other properties 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.

Alternative conceptual models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses that are also consistent with available data and that may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) the activities or studies designed to discriminate between alternative hypotheses or to reduce uncertainty. Integration of information from different disciplines increases confidence in the data and is often necessary to comprehensively evaluate alternative hypotheses. The inductive reasoning process based on the results of hypothesis tests will be used to validate models for assessing the long-term performance of the site (Section 8.3.5.20). Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate. Table 8.3.1.4-2 is the hypothesis-testing table for the site rock characteristics program.

To help ensure comprehensiveness of the hypotheses considered in Table 8.3.1.4-2, hypotheses for modeling site rock characteristics have been divided into elements or components that describe the geological domain covered by the model, the stratigraphic geometry that affects the behavior of the model, and the structure elements that affect the model. These elements are listed in column one.

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

The third column in Table 8.3.1.4-2 provides a judged level of uncertainty designated high, medium, or low associated with the current representation for each element. A brief rationale for the judgment is also given.

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

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

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

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

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

The final column identifies the characterization studies or activities that will discriminate among alternative hypotheses or that will reduce

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 1 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Geologic domain	Area encompassing controlled area and defined by major structural boundaries to west, north, and east, and arbitrarily by a few km outside controlled area to south	Low--properties and processess outside model domain unlikely to affect rock properties within controlled area	None	Ground-water travel time (GWTT); radionuclide release to accessible environment, repository design	High	Low--geologic domain encompasses likely extent of controlled area	Low--existing data indicate that geologic domain is not likely to change	Investigation 8.3.1.4.2--geologic framework
	Vertical extent includes entire Tertiary section	Low-medium--properties of rock below Tertiary unlikely to be significant influence on design	Vertical extent includes Tertiary section plus upper part of underlying Paleozoic	GWTT; radionuclde release to accessible environment	High	Low--repository, all facilities and primary barrier (unsaturated zone) are entirely within upper part of Tertiary section	Low--performance or design not likely to be affected by properties below Tertiary section	8.3.1.4.2.1, 8.3.1.4.3.1
Stratigraphic geometry	First-order vertical variability imparted by east-dipping layered volcanic and volcaniclastic sequences	Medium--distinct changes in lithology, including welding of ash flows, correspond to well-defined stratigraphic units, however vertical variation within units are less well defined and may be as important	Laterally anisotropy due to variation in primary crystallization and secondary alteration of individual layers	GWTT; ground quality, thermal/mechanical response, radionuclide releases to accessible environment, depth to lower boundary of primary barrier, geochemical retardation properties of host rock and underlying units	High	High--vertical variability defines GWTT and radionuclide migration	Low-medium--more adequate characterization of unit contacts and and vertical variability within units needed	8.3.1.4.2.1, 8.3.1.4.3.1
	Second-order vertical variability in rock properties imparted by	Medium--geometry of mineralogical alteration zones not well known	Mineralogical alteration does not affect rock properties of interest	Same as above	High	High--GWTT and radionuclide migration	High--more adequate characteristics of the upper boundary of	8.3.1.3.2.1, 8.3.1.3.2.2, 8.3.1.3.4.1, 8.3.1.4.2.1, 8.3.1.4.3.1

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 2 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Strati-graphic geometry (continued)	mineralogical alteration in distinct quasi-horizontal zones transecting primary unit contacts		Mineralogical alteration is geometrically random and cannot be mapped				mineralogical alteration is very important	
	First-order lateral variability within layered rock units imparted by volcanic and volcaniclastic depositional processes related to distance to source, i.e., properties within units are non-stationary	Medium--site data and numerous analyses strongly indicate lateral change in rock properties and magnitude of changes is related to coefficient of variation and is unknown	No systematic lateral change in rock properties occur in layered volcanic and volcanistic sequences	Same as above	High	Medium--lateral variability has less effect on GWTT and radionuclide migration	High-medium--magnitude of lateral changes need to be better characterized before effect on performance and design can be evaluated	8.3.1.4.1.3, 8.3.1.4.2.1, 8.3.1.4.3.1
	Lateral and vertical variability of rock properties is heterogeneous and geostatistical analysis techniques (variogram, autocorrelation) are adequate for characterizing heterogenity	Medium-high--local small-scale variability may be so great that units may be considered homogeneous, i.e., nugget effect is large relative to variance at sill	Variability of parameters within the units is purely homogeneous Other Markovian processes can be used to characterize heterogeneity such as fractal analysis, Fourier analysis, and others	Same as above	High to medium	Medium--model used significantly affect resulting GWTT and radionuclide migration calculations and design	Low--for performance assessment because modeling scale will be set conservatively equal to or larger than the variogram range Medium--for design since local failures may depend on small-scale variogram structure	8.3.1.4.2.1, 8.3.1.4.3.1, 8.3.1.4.3.2

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 3 of 5)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Structure	First-order lateral anisotropy imparted to rock mass by tectonic faults and fractures that increase in abundance to south	Low--available data indicate faults and fractures are zonally distributed	Faults and fractures are uniformly distributed in geologic domain	GWTT (depth to water table, gradient fracture permeability), usable area	High	Medium--GWTT in saturated zone may be dependent on fracture distribution	Medium--effects of structural anisotropy on performance needs better understanding	8.3.1.4.1.3, 8.3.1.4.2.1, 8.3.1.4.2.3, 8.3.1.4.3.1, 8.3.1.4.3.2
	Intact blocks are inclined and rectangular in cross-section and are bounded by imbricate normal faults that continue at depth as parallel faults	High--faults are curvlinear in plan; they may curve and flatten with depth	Intact blocks are lensoid in all dimensions due to imbricate normal faults that anasiomose and flatten with depth	Usable area, ground quality, potential for significant displacement, drifts and accesses usable for 100 yr, rockfall	High	High--alternative interpretation of geometry of fault blocks could affect usable area of repository	High--effects of fault geometry on usable area of repository needs evaluation	Same as above
	Fractures along some interconnected pathways are open	Low--drillhole data indicate many fractures are open in upper km	Fractures are essentially closed Fractures apertures correlated with orientation and magnitude of principal stresses	GWTT; radionuclide release to accessible environment Same as above	High	High--open fractures would significantly effect GWTT, especially in the saturated zone	Medium--saturated-zone GWTT depends on fracture aperture, but is backup barrier, unsaturated-zone GWTT depends on matric potential more than aperture	Same as above
	Vertical and lateral variation in degree of alteration	Medium--preliminary data support current representation	Converse	Same as above	High	High--openess of fractures would significantly affect GWTT and radionuclide migration	Medium--saturated-zone GWTT depends on fracture aperture, but is backup	Same as above

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 4 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
							barrier, unsaturated-zone GWTT depends on matric potential more than aperture	
	Open fractures are coated with secondary minerals	Medium--preliminary data support current representation	Converse	Same as above	Medium	Medium--secondary coating of open fractures not expected to significantly affect GWTT or radionuclide migration	Medium--additional data needed on nature of secondary minerals coating open fractures	8.3.1.3.2.1.3, 8.3.1.4.2.2, 8.3.1.4.2.3, 8.3.1.4.3.1, 8.3.1.4.3.2
	Fracture aperture is very sensitive to small changes in stress and to applied hydraulic loading	Low-medium--variation in tectonic stress not likely in 10,000 years	Fracture aperture is not sensitive to stress changes	Same as above	High	Low--probability of changes in stress and significant hydraulic loading is low	Medium--effect on GWTT not significant for pre-waste emplacement in controlled area, but radionuclide migration of 10,000 yr may be significant	8.3.1.17.4.8

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 5 of 5)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Structure (continued)			Lateral variation in fracture aperture correlated with lateral variation in in situ stress	Same as above	High	Medium--heterogeniety in distribution of aperture could affect GWTT	Medium--additional data needed on possible correlation between aperture and stress	8.3.1.17.4.8
Rock characteristics	The repository block does not contain a large number of faults that will result in localized failures throughout the repository when subjected to expected conditions (i.e., temperature, excavation and thermally induced stress)	Medium--current estimates of the in situ stress state and assumed distribution, orientation, and properties of faults precludes inducing movement along a majority of the faults when excavation and thermally induced stresses are introduced	Converse	Emplacement borehole stability (retrieval, container lifetime), room stability (worker safety), permeability (GWTT, radionuclide migration), seal performance	High	High--GWTT; radionuclide migration	High--alternative hypothesis questions suitability of site	8.3.1.4.2.2, 8.3.1.8.2.1, 8.3.1.8.3.3, 8.3.1.15.2.1, 8.3.1.17.2.1, 8.3.1.17.4.8
	Localized failure along numerous fracture zones when subjected to expected conditions (i.e., temperature, excavation and thermally induced stress	Medium--stable openings indicated by empirical and numerical analysis	Converse	Same as above	High	Same as above	Same as above	8.3.1.4.2.2, 8.3.1.4.2.3, 8.3.1.8.2.1, 8.3.1.8.3.1, 8.3.1.8.3.2, 8.3.1.8.3.3, 8.3.1.17.2.1, 8.3.1.17.4.8

uncertainties associated with the current representation for each model element.

Interrelationships of rock characteristics investigations

This characterization program has been divided into three investigations: (1) development of an integrated drilling program and integration of geophysical activities, Investigation 8.3.1.4.1; (2) geologic framework of the Yucca Mountain site, Investigation 8.3.1.4.2; and (3) development of three dimensional models of rock characteristics at the repository site, Investigation 8.3.1.4.3. Feeding into Investigation 8.3.1.4.3 will be the results of investigations in Section 8.3.1.2 (geohydrology), Section 8.3.1.15 (thermal and mechanical rock properties) and Section 8.3.1.3 (geochemistry).

The schedule information for Site Program 8.3.1.4 (rock characteristics) is presented in Section 8.3.1.4.4.

8.3.1.4.1 Investigation: Development of an integrated drilling program and integration of geophysical activities

This investigation is composed of two planning and evaluation activities. The first activity is designed to provide a mechanism for overall integration of the surface-based activities to be conducted during site characterization. Integration is important to ensure that the data needed to improve site models for use in performance assessment and repository design are obtained in an efficient and cost-effective manner. The second activity is designed to provide a focal point for integration of all geophysical site characterization activities. Because geophysical activities provide data to a number of site programs, as well as to both performance and design issues, it is important that the planned activities are periodically reviewed to determine if the data base being developed is adequate for the range of planned uses.

8.3.1.4.1.1 Activity: Development of an integrated drilling program

Objectives

The objectives of this activity are to

1. Ensure representativeness of data acquired during surface-based site characterization activities and that data represent the range of phenomena and structural characteristics needed for performance assessment.

2. Integrate and prioritize surface-based activities to produce a schedule that best addresses representativeness and efficacy concerns, given budgetary constraints. Monitor conformance with plans, especially with respect to site performance impact (particularly the nature and extent of surface disturbance, fluid use, and penetrations of the unsaturated zone and the repository

horizon). Review planned activities with respect to methodology, monitor activities in progress, and provide a means to effect changes if necessary. Address sample and data requirements through linkage and integration with other activities.

3. Maintain a system of technical element baseline approval and control. Such a system is needed to ensure conformance with planning and integration, and to control changes to plans that have the potential to adversely impact site performance; testing interference; or data and samples exchanged between activities.

Parameters

There are no parameters for this activity.

Description

Drilling is an integral part of many of the surface-based investigations planned to obtain information needed for repository design and performance assessment. The specific activities and proposed boreholes are summarized in Section 8.4 and each program investigation. More specific and updated technical data on these activities are provided in the Surface Based Investigation Plan (in draft). Boreholes have been sited to satisfy two different strategies: (1) characterize anomalies and gather data on subsurface conditions to sample known or inferred features of interest and (2) characterize the statistical distribution of needed parameters to obtain samples representative of an entire volume of interest. Consistent with the requirements of 10 CFR 60(d)(4), the location and drilling of the exploratory boreholes are being coordinated with the repository design. More details of this coordination, particularly with regard to the potential impact of site characterization activities on repository performance, are provided in Section 8.4.

To this end, the integration of surface-based borehole siting, sampling, and testing will be optimized by (1) coordinating sampling and testing programs to reduce redundant sampling and testing; (2) minimizing both the potential alteration of ambient surface and subsurface conditions within the repository environment and the creation of possible preferential pathways caused by drilling boreholes that need to be sealed as required by 10 CFR 60.134; (3) ensuring that drilling and sampling methods are well matched to applicable technical, regulatory, and scientific requirements; (4) maximizing cost-effectiveness of drilling program; and (5) maximizing information obtained by increasing both the sampling of the subsurface rock mass and the data obtained from in situ monitoring activities. Each drillhole proposed in various site characterization programs (see Section 8.4 and specific program investigations) represents a source of data intended to answer a particular requirement of design or performance assessment. Where feasible, objectives for separate, currently planned holes may be combined, if appropriate data can be obtained from a single hole. The process of integrating the drilling program as site characterization proceeds may include the addition of new drillholes or deletion of previously scheduled holes as a result of preliminary results of early studies and activities.

Planned surface-based field activities have been integrated to a significant degree. Examples of such integration are (1) all planned penetrations of the repository horizon in the immediate vicinity of the site will meet the criteria of the systematic drilling program to reduce the total number of penetrations; (2) the prototype unsaturated-zone drilling activity will support selection of drilling methods for the multipurpose boreholes (MPBH), the unsaturated-zone boreholes, the systematic drilling program, and the site vertical borehole study; (3) a series of tracer tests in the C-hole complex will determine if existing drillholes across the site will suffice for saturated-zone characterization instead of additional multi-well complexes; and (4) the drilling schedule is based on prioritization of surfaced-based testing activities, which is linked to generally recognized performance assessment requirements.

An initial program of surface-based activities will be evaluated and baselined. Additional detail on the drilling and borehole testing proposed in the SCP is provided in the Surface Based Investigation Plan (SBIP). The effect of this integration activity will be two-fold: (1) the program of activities will be evaluated and modified, as necessary, to ensure that interference between activities and potential effects on site performance will either be eliminated or mitigated to the extent practical and (2) the program will be subject to a technical change-control procedure pertaining to surface-based testing that will ensure that changes to activities will not have an adverse impact on site performance or adjacent activities. Activities in the SCP will be evaluated to identify proposed sampling and to identify any changes needed to the existing drilling program to satisfy sampling requirements that are not attached to specific boreholes.

Revisions resulting from evaluations of representativeness of data, potential test interference, site performance, advanced conceptual design, and license application design impacts will be described in the semiannual progress reports. Likewise, new data, analyses, or topical information will be made available in order to continue the process of integration. This process will develop, using the above information, new priorities and schedules to be used for near-term and long-term field activities planning. The SBIP will be updated at regular intervals to maintain current information on the updated activity plans for drilling and borehole testing.

8.3.1.4.1.2 Activity: Integration of geophysical activities

Objectives

This activity will provide a mechanism for information exchange, an analysis of data and other technical information, and an overview of planned geophysical site characterization activities. The objectives for geophysics integration are to increase (1) the effectiveness of planned geophysical surveys through consideration of past efforts both within and outside the Yucca Mountain Project and (2) the overall effectiveness of geophysical exploration by analysis of how each planned survey addresses specific information requirements for site licensing.

Parameters

No activity or characterization parameters are produced by this activity.

Description

Planned geophysical surveys will collect different types of data that will be used to support geologic, hydrologic, and tectonic models of the site. These models serve as the basis for certain performance assessment and design analyses. The models are identified in Sections 8.3.1.2 through 8.3.1.17. Much of the geophysical information obtained will not directly provide parameters for use in probabilistic assessments. Rather, performance assessment and design are supported by the use of such geophysical information to ensure that the range of variability of site characteristics considered in calculations is representative of actual site conditions. Similarly, geophysical applications such as fault detection are a form of nonprobabilistic support for the representativeness of site data.

This integration activity will review and evaluate planned geophysical surveys for (1) consistency with the results from past surveys, (2) direct or supportive uses of the data for licensing, (3) the likelihood that useful data will be generated, (4) the need for the planned effort with respect to alternate methods for obtaining the data, and (5) scheduling with respect to other studies and the overall priorities for site characterization. An ongoing component of this activity involves planning, study plan review, monitoring performance of field activities, review of applicability of various geophysical activities, and development of an overall strategy for application of geophysical methods.

An additional component of this activity will involve detailed review and evaluation of particular applications for geophysical methods, including feasibility studies when appropriate. Methodological information, including results from past geophysical activities at Yucca Mountain, will be reviewed to ensure the effectiveness of planned activities. Existing geologic and hydrologic information, and interpretations from past geophysical activities, will be evaluated to identify specific needs to be addressed. Information needs identified through the performance allocation process for technical areas, such as tectonics, mineral resources, rock characteristics, and hydrology, will be further defined and assessed for common objectives. The following applications of geophysical methods will be reviewed: (1) intermediate depth structural characterization of Yucca Mountain and vicinity (Study 8.3.1.17.4.7), (2) detection and characterization of fractures and the extent of fault zones within the conceptual perimeter drift boundary and immediate vicinity (Study 8.3.1.4.2.2), (3) depth to the water table in the vicinity of the site (Study 8.3.1.2.3.1.2), and (4) detection of potentially economic mineral deposits (Study 8.3.1.9.2.1). As the reviews and evaluations progress, changes in planned activities will be reported in semiannual progress reports.

8.3.1.4.2 Investigation: Geologic framework of the Yucca Mountain site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of Chapter 1 of this document summarize available data relevant to the Yucca Mountain stratigraphy and structure, and identify areas of insufficient or inconclusive information:

SCP section	Subject
1.2.2.2	Cenozoic rocks (stratigraphy and lithology at Yucca Mountain)
1.3.2.2.2	Structures and structural history of Yucca Mountain
1.8.1.2	Stratigraphy and lithology
1.8.1.3	Structural geology and tectonics
1.8.2.1	Relation of geology to repository design

Parameters

Table 8.3.1.4-1 summarizes the geologic characteristics that will be measured or calculated as a result of the studies planned for this investigation. The geologic characteristics provided through this program will be used in developing the hydrogeologic stratigraphy in Section 8.3.1.2, and the geochemical stratigraphy in Section 8.3.1.3. The geologic characteristics will also be combined with the data developed in Investigations 8.3.1.15.1 and 8.3.1.15.2 and in Site Programs 8.3.1.2 and 8.3.1.3 to develop three-dimensional models of thermal, mechanical, hydrologic, and geochemical properties in Study 8.3.1.4.3.2.

Purpose and objectives of the investigation

The objectives of this investigation are three-fold and, in general, cover those studies and activities that will allow an understanding of the large-scale variation in stratigraphy and structure in support of design and performance assessment calculations. First, this investigation will provide primary data on the lateral and vertical variations in site stratigraphy through acquisition of borehole cores and cuttings and surface geologic mapping. Second, it will provide information that will allow three-dimensional modeling (through the use of borehole and surface geophysical surveys) of the variation in properties of interest between points of primary data. Lastly, it will provide information on the lateral and vertical variation of structural elements that may affect in situ properties of interest (e.g., fracture-related flow) in conjunction with site characterization investigations on geohydrology, geochemistry, postclosure tectonics, and seismicity (i.e., preclosure tectonics) (Sections 8.3.1.2, 8.3.1.3, 8.3.1.8, and 8.3.1.17).

Technical rationale for the investigation

Development of a comprehensive, three-dimensional description of geologic and geophysical characteristics of the site requires integration of information from subsurface investigations, geologic mapping, surface-based and subsurface geophysical surveys, and geologic studies in the exploratory shaft and underground drifts. This model provides the geologic constraints for developing quantitative three-dimensional models of rock properties in Investigation 8.3.1.4.3. Such a model must be compatible with the stratigraphic, structural, and tectonic setting of the region, and must incorporate genetic models that address depositional, thermal, and alteration histories of local volcanic rock units, part of which are developed under Site Program 8.3.1.8.

On the basis of structural considerations, the areal extent of geologic investigations at Yucca Mountain can be divided into two areas, repository perimeter drift and site, as defined below (Figure 8.3.1.4-2). The perimeter drift defines an area where a significantly lower concentration of faults has been mapped relative to surrounding areas. This area is bounded on the north and northeast by Drill Hole Wash. The Solitario Canyon fault zone marks its western border, and a belt of small-scale structural features north of Abandoned Wash limits its eastern and southeastern extents. The site area boundary is located outward approximately 4 to 12 km from the boundaries of the perimeter drift. The northern, eastern, and southern limits of the region of investigation around the site are selected primarily on the basis of differences in structural styles inferred from existing geologic maps (Scott and Bonk, 1984; Maldonado, 1985). They include Prow Pass (Claim Canyon Caldron), Fortymile Wash, and a northeast-trending lateral fault south of Busted Butte. The western boundary of the study region has been selected at the Windy Wash fault zone on the basis of maintaining a similar amount of lateral distance from the perimeter drift.

The site geologic investigations can be divided into three principal investigations: (1) development of an integrated drilling program (8.3.1.4.1), (2) geologic framework of the Yucca Mountain site (this investigation), and (3) development of three-dimensional models of rock characteristics at the repository site (8.3.1.4.3). The area of investigation will include a larger area than the site as the understanding of the characteristics of each lithostratigraphic unit on a regional scale will allow a higher level of confidence when using deterministic information to interpolate between drillholes, shafts, and surface exposures within the site area. Integration of these investigations requires continual correlation at all levels from data collection to analysis and interpretation. These investigations will provide geologic, geomechanical, geothermal, geohydrologic, and geochemical information for the data base needed by the performance and design issues (Table 8.3.1.4-1).

Geophysical surveys may play a major role in providing information on the gross spatial distribution of bulk properties. They also will be used at particular drillholes to interpolate between depth intervals from which cores or other samples were acquired. Geophysical surveys will be evaluated, and if proven effective, will be used to detect possible rock property contrasts between drillholes. Surveys not proven to be effective will be eliminated from the investigations program. The results of direct in situ measurements

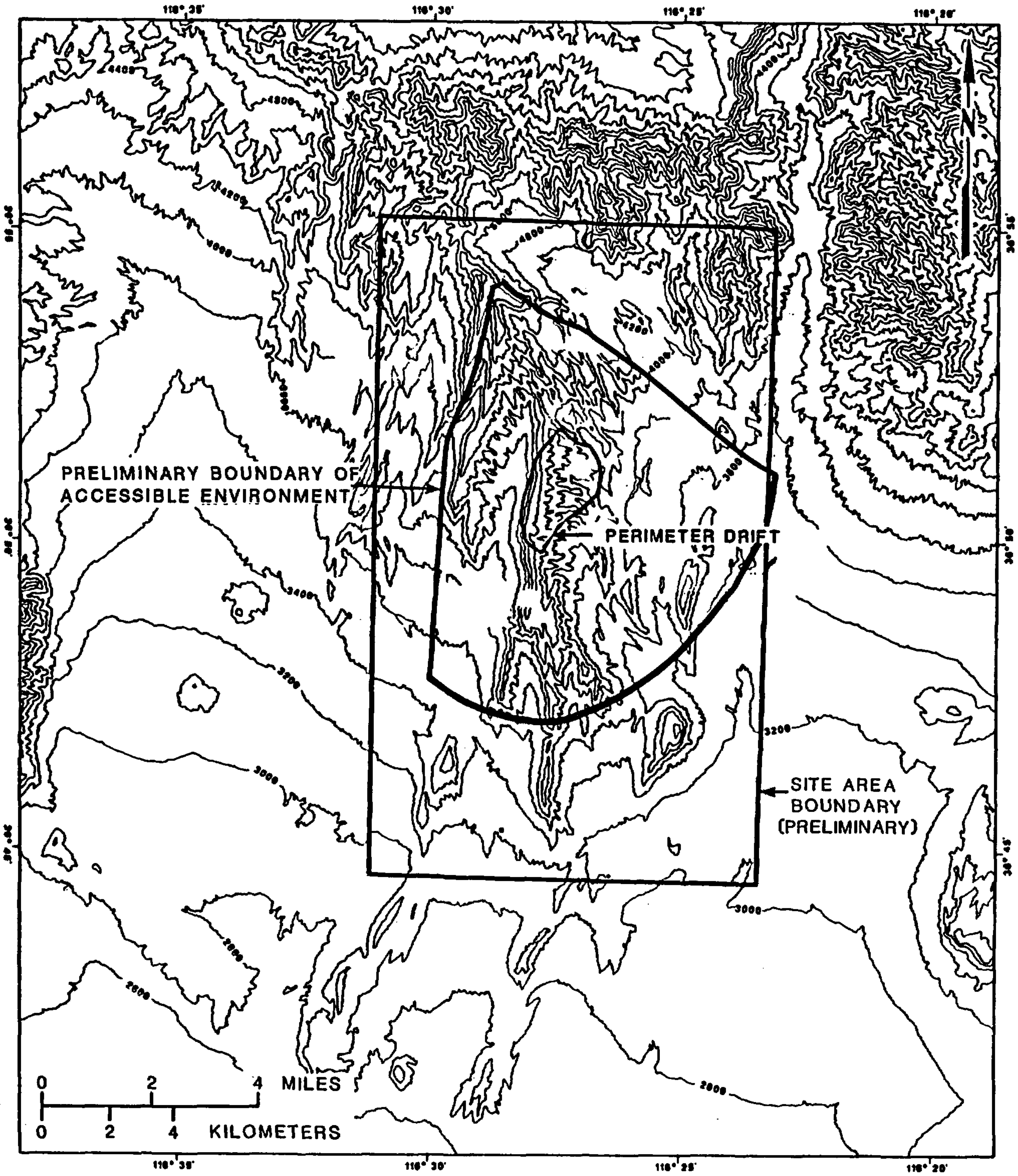


Figure 8.3.1.4-2. Areas of geologic investigation at Yucca Mountain.

made from drillholes and from the exploratory shaft facility, will be used to analyze data from methods such as seismic or electrical tomography to develop quantitative and empirical relationships needed to characterize subsurface variability between shafts and drillholes. A fundamental element of stratigraphic studies is the development of a data base of rock sample analyses collected from holes drilled for geologic and hydrologic purposes. Continuously cored geologic drillholes will continue to be used to establish the reference stratigraphic framework to currently planned depths of 1,828 m from which comparative studies between geophysical and geologic characteristics can be made. Geophysical relationships that are established in core studies can then be applied to the stratigraphic study of rotary drillholes (where rock samples are limited to drill bit cuttings and sidewall samples) and to the geologic interpretation of data derived from surface-based and subsurface geophysical surveys. With the incorporation of additional stratigraphic data collected from surface field studies, a more complete stratigraphic data base will be used to map the distribution of intrinsic lithologic characteristics within Yucca Mountain. Primary geologic parameters that influence the distribution of rock properties include chemical composition, degree of welding, primary crystallization, and type and degree of alteration. Surface and subsurface mapping of lithologic characteristics within stratigraphic units aids in interpreting the transportation, emplacement, cooling, and alteration histories of major ash-flow tuff sheets. In turn, these interpretations will aid in the prediction of physical properties in parts of the repository block where relatively few subsurface samples will be collected. Stratigraphic investigations are grouped under Study 8.3.1.4.2.1.

Characterization of the structural setting of the site requires detailed study of local fault and fracture systems and their relation to the local and regional stratigraphic, tectonic, and geophysical framework. Recognition of small-scale structures within and near the site area is achieved through detailed mapping of zonal features of exposed ash-flow stuffs and interpretation of detailed surface and subsurface geophysical surveys. An understanding of the fracture network at the site requires the application of innovative approaches because the fracture system (1) is poorly exposed at the surface, (2) is predominantly composed of steeply dipping (high-angle) fractures, (3) includes fractures induced by both tectonic and cooling processes, and (4) includes strata-bound subsystems. Lateral components of the system are studied principally by mapping and analyzing surface exposures. Characterization of the vertical component of the fracture system will largely be achieved through detailed study of the exploratory shaft and drifts, and to a lesser degree, by examination of drillhole walls and core samples. In addition, borehole geophysics, particularly surface-to-borehole seismic profiling, cross-hole seismic surveys, and borehole-to-surface electrical resistivity methods may provide information regarding bulk distribution of fractures. Structural investigations are grouped under Study 8.3.1.4.2.2.

Stratigraphic and structural information will be used in Investigation 8.3.1.4.3, to constrain the interpretation of thermal and mechanical properties (Investigation 8.3.1.15.1), the in situ thermal and stress conditions (Investigation 8.3.1.15.2), geohydrologic properties (Investigations 8.3.1.2.1 and 8.3.1.2.2), and geochemical properties (Investigation 8.3.1.3.2). The final product (Study 8.3.1.4.3.2) is a three-dimensional model of rock characteristics of Yucca Mountain, which will be used in verifying the design of the underground facility and assessing performance.

8.3.1.4.2.1 Study: Characterization of the vertical and lateral distribution of stratigraphic units within the site area

The objective of this study is to determine the vertical and lateral variability and emplacement history of stratigraphic units and lithostratigraphic subunits within the Yucca Mountain site area.

Geologic mapping, geophysical surveys, borehole evaluations, and geologic sampling, testing, and analysis will be used to gather pertinent geologic data, develop lithologic correlations, and describe the geologic stratigraphy of the site area. Surface-based mapping and borehole activities will be complemented by geologic mapping and testing in the exploratory shaft and drifts (Activity 8.3.1.4.2.2.4).

Activities planned for this study include (1) surface and subsurface stratigraphic studies of the host rock and surrounding units, (2) surface-based geophysical surveys, (3) borehole geophysical surveys, (4) petrophysical properties testing, and (5) correlation of stratigraphy and rock magnetic properties.

8.3.1.4.2.1.1 Activity: Surface and subsurface stratigraphic studies of the host rock and surrounding units

Objectives

The objective of this activity is to determine the spatial distribution, history, and characteristics of stratigraphic units within the Paintbrush Tuff, tuffaceous beds of Calico Hills, Crater Flat Tuff, and possibly older volcanic rocks within the site area.

Parameters

The characterization parameters for this activity are

1. Welding and primary crystallization characteristics of lavas and ash-flow tuffs.

2. Petrographic characteristics.

3. Pumice characteristics.

4. Type and abundance of lithic fragments.

5. Characteristics of lithophysal zones.

6. Degree and type of alteration.

7. Depth, thickness, attitude, and extent of lithostratigraphic units.

8. Location and general characteristics of bedded tuff intervals, including grain size and sorting characteristics, diagenetic mineral phases, and depositional characteristics.

Description

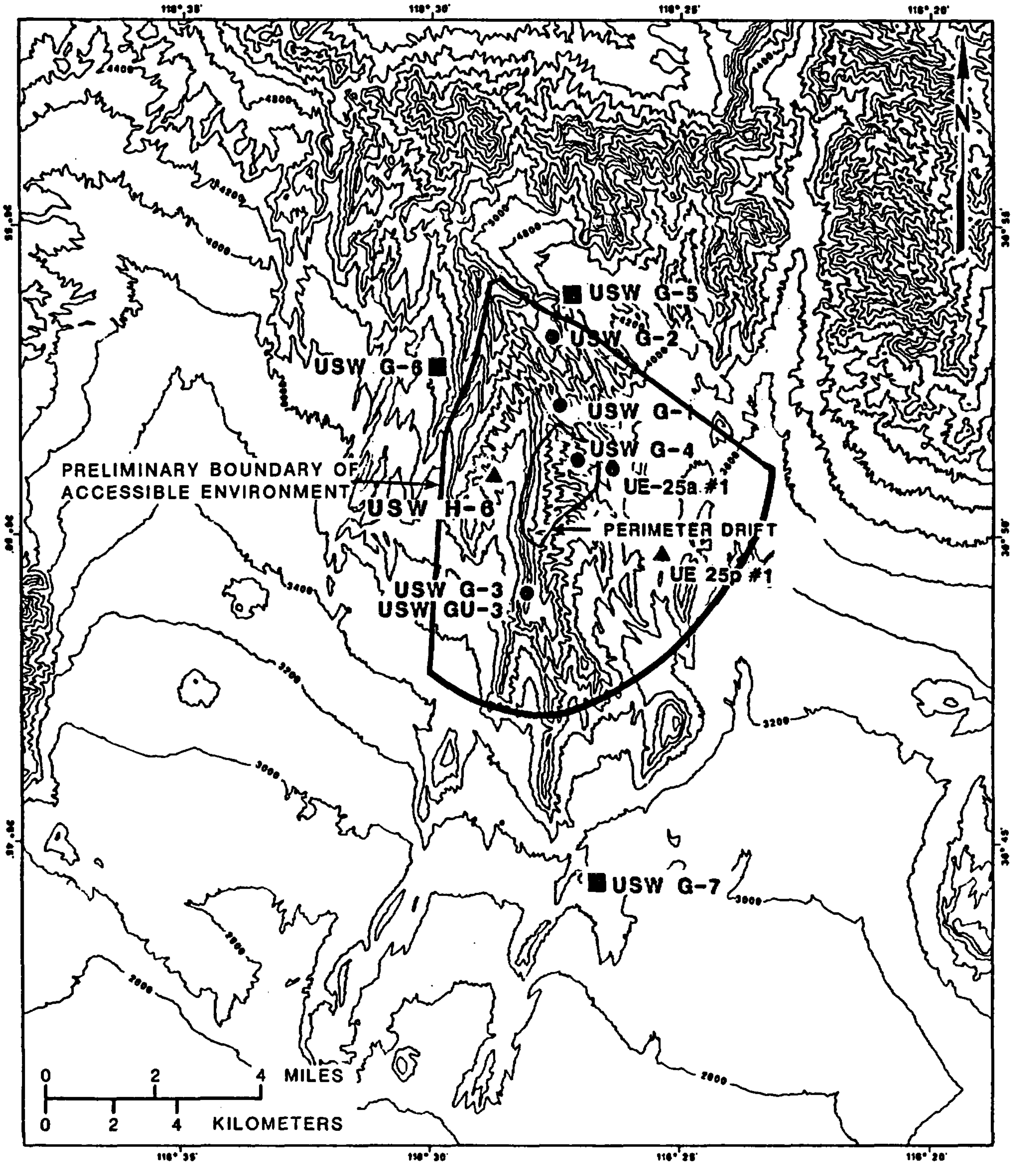
Characterization of the stratigraphic sequence within the site area will use (1) borehole drilling and coring, (2)sampling, lithologic examination, and analysis of drill-bit cuttings and core, (3)borehole video surveys and logging, (4) surface-outcrop mapping; (5) petrographic and geochemical analysis of drillcore, cuttings, and outcrop samples, and (6) surface and borehole geophysical surveys.

Geologic and geophysical data derived from existing holes and additional holes will provide information to aid in the development of three-dimensional rock characteristics models of the proposed repository area.

Pending the integration of the drilling program, three additional continuously cored holes may be drilled (Figure 8.3.1.4-3) in the vicinity of the site to better explain inferred geologic and geophysical anomalies and to help determine the lithologic variability in the Paintbrush Tuff, tuffaceous beds of Calico Hills, and Crater Flat Tuff. One hole (USW G-5) would be located along the northeast flank of Yucca Mountain, to determine if abrupt changes in lithologies of underlying units or changes in structural style within Yucca Wash are factors that influence the steeper gradient in the potentiometric surface north of drillhole USW G-1. Another hole (USW G-6) is planned along the northwest flank of Yucca Mountain in the vicinity of Windy Wash. This hole is expected to provide representative stratigraphic data for this area and allow correlation of thicknesses of key stratigraphic units across the site area. A third hole (USW G-7) may be located about 5 km southwest of Busted Butte in the southern part of Yucca Mountain. Within this area the Paintbrush Tuff is extremely thin and appears to on lap an inferred high point in the preexisting topography. This hole will be used to determine the nature of this feature and its effect on ground-water travel times and potential flow paths in southern Yucca Mountain for saturated zone flow modeling (Section 8.3.1.2.3.3). These holes will allow interpolation of lithologic characteristics between the repository area where more densely spaced holes may be drilled (Investigations 8.3.1.4.1 and 8.3.1.4.3) and the preliminary boundary of the accessible environment.

Studies of the hydrology of the unsaturated and saturated zones include plans for borehole drilling and coring (Section 8.3.1.2). The total suite of holes drilled by the DOE will provide an opportunity to study the lateral variability of the Topopah Spring Member, other members of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, Crater Flat Tuff, and other units, and will provide samples for geologic evaluation.

Excavation of the exploratory shaft and drifts, and vertical and lateral boreholes drilled from the underground openings will provide additional opportunity to sample and perform geophysical measurements for characterizing the lithostratigraphic subunits between the ground surface and the upper part of the tuffaceous beds of the Calico Hills. The distribution of lithophysal



EXPLANATION

● EXISTING CONTINOUSLY CORED HOLE

■ PROPOSED CONTINOUSLY CORED HOLE

▲ INTERMITTENTLY CORED HOLE

Figure 8.3.1.4-3. Locations of existing and proposed continuously cored holes at Yucca Mountain.

zones within the Topopah Spring Member will be mapped in the exploratory shaft facility.

Bedded tuffs that divide major ash-flow tuffs commonly range in thickness from less than 1 m to about 61 m (Table 8.3.1.4-3) and include a variety of lithologies that range from fine-grained tuffaceous sandstone to very coarse ash-fall tuff. Core recovery is typically poor in the unsaturated zone; consequently nearby outcrops will be sampled in the northern part of Yucca Mountain to fill gaps in the data. This study will aid in identifying stratigraphic lateral continuity and inhomogeneities that may act as potential lateral flow paths.

Video camera surveys will be performed in all holes drilled in the vicinity of Yucca Mountain. The textural and tonal contrasts that are seen on camera logs will provide valuable information about key stratigraphic features such as the vertical distribution of lithophysal cavities, thin-reworked and ash-fall tuff intervals, non- to partially welded zones, lithic-rich zones, spherulitic zones, glassy intervals, relative degree of sorting, relative sizes of pumice clasts, and nature of contacts between units. Video-camera observations will be correlated with core, drill bit-cuttings, and geophysical logs to interpret the subsurface characteristics of rock units.

The ability to predict lateral variability of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff beyond the perimeter drift can be enhanced by conducting a study of outcrops in highlands surrounding the site area. Stratigraphic sections of sufficient thickness will be described and measured principally within the southwest quadrant of the NTS and in Crater Flat. Areas of particular interest will include northern Crater Flat, Calico Hills, Fortymile Canyon, Little Skull Mountain, Skull Mountain, and the northernmost part of Yucca Mountain. Efforts will focus on identifying and correlating lateral variations of subunits of the Topopah Spring Member (Figure 8.3.1.4-4). Additional thickness data also will be collected for the Yucca Mountain and Pah Canyon members, tuffaceous beds of Calico Hills, and Prow Pass and Bullfrog members (Figure 8.3.1.4-5).

Rock samples will be examined megascopically as well as with hand lens and binocular microscope. Samples of particular interest will be selected for further petrographic, mineralogical, and isotopic analyses. Samples also will be selected for detailed petrographic and geochemical analyses (see activities described in the geochemistry program (Section 8.3.1.3)). Megascopic descriptions, coupled with analyses of selected thin sections and grain mounts, will focus on identifying distinctive lithologies, key marker beds, and correlatable sequences. Scanning electron microscopy (SEM) will be used to characterize distinctive morphologies and interpret modes and environments of deposition. X-ray powder diffraction and microprobe analyses on selected samples will be used to identify relative abundance of mineral phases.

On the basis of the mineralogical studies by Los Alamos National Laboratory (Section 8.3.1.3, geochemistry) of core from Yucca Mountain, about 100 intervals (samples) of mordenite-bearing or suspected mordenite-bearing core from drillholes USW G-1, USW G-2, USW G-4, and UE-25b#1h will be selected for additional studies. All samples will be from the Crater Flat Tuff,

Table 8.3.1.4-3. Volcanic stratigraphy at Yucca Mountain

Potassium-argon dating method age (million years)	Magnetic polarity[b]	Rock unit[a]	Range in thickness (m)
10.2	ND[c]	Basalt dikes	ND
		* Timber Mountain Tuff	ND
11.3		* Rainier Mesa Member	0-46
		Bedded tuff	0-61
		* Paintbrush Tuff	ND
12.5	R	* Tiva Canyon Member	69-148
		Bedded tuff	1-15
	R	* Yucca Mountain Member	0-29
		Bedded tuff	0-47
	R	* Pah Canyon Member	0-71
		Bedded tuff	0-9
13.1	N	* Topopah Spring Member	287-359
		Bedded tuff	1-17
13.4[d]		Tuffaceous beds of Calico Hills	27-289
		Bedded tuff	0-21
		* Crater Flat Tuff	ND
	N	* Prow Pass Member	80-193
		Bedded tuff	2-10
13.5	N	* Bullfrog Member	68-187
		Bedded tuff	6-22
	R	* Tram Member	190-369
		Bedded tuff	3-50
	N	Dacite lava and flow breccia	0-249
		Bedded tuff	0-14
	I	* Lithic Ridge Tuff	ND
		Bedded tuff	3-7
13.9		Older volcanic rocks and volcanogenic sedimentary rocks	345+

[a]Names and rankings of some units do not conform to U.S. Geological Survey usage. Formally recognized names are preceded by asterisks.

[b]Polarity symbols: R = reversed, N = normal polarity, I = intermediate between reversed and normal.

[c]ND = not determined.

[d]Age determined from associated lava flow.

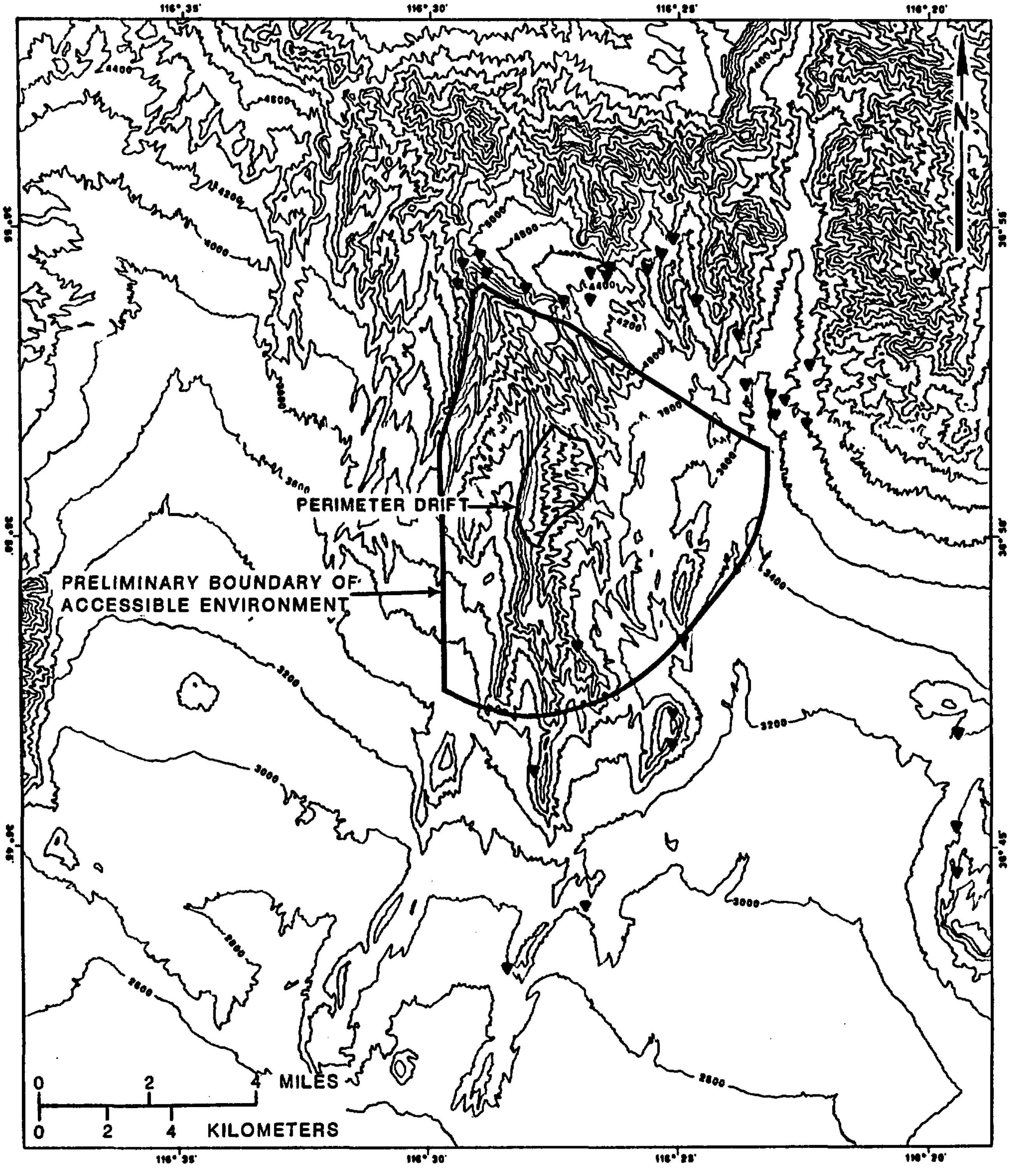


Figure 8.3.1.4-4. Approximate locations of additional surface stratigraphic studies of the Topopah Spring Member of the Paintbrush Tuff.

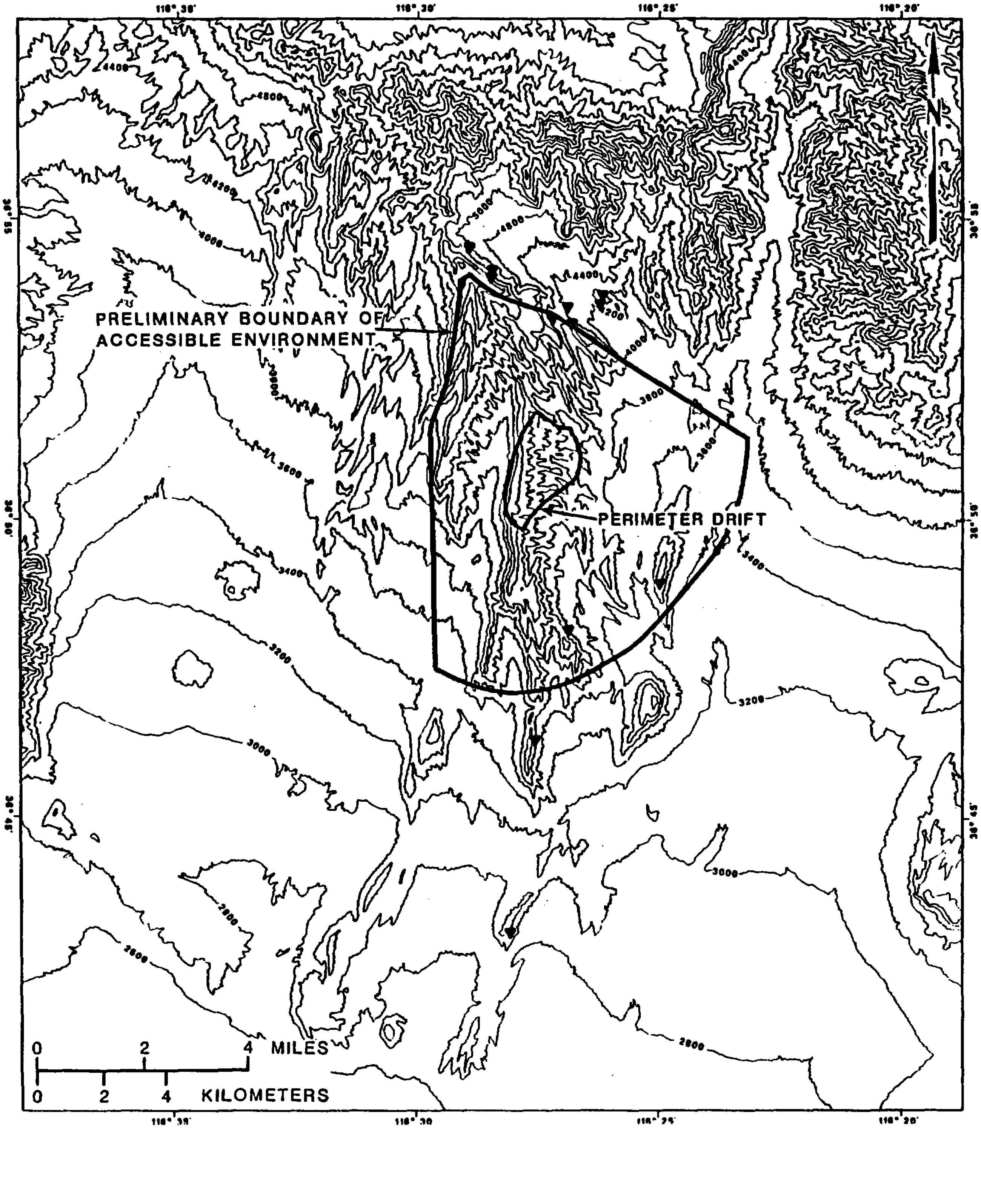


Figure 8.3.1.4-5. Approximate locations of additional surface stratigraphic studies of the Yucca Mountain and Pah Canyons Members of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Prow Pass and Bullfrog Members of Crater Flat Tuff.

tuffaceous beds of Calico Hills, and the lower part of the Paintbrush Tuff. The mineralogy of each sample will be determined by X-ray powder diffraction. Results of these determinations will provide the abundance of mordenite (a zeolite) in each sample and will be the basis for further selecting of certain samples for additional investigation by optical microscopy of these sections and grain mounts, SEM, and electron microprobe analysis. Studies by optical microscopy and SEM will provide information on the morphology and zonation of the various zeolite minerals that may act as sorbing agents for radionuclides during the postclosure time frame.

Data obtained from geologic mapping, borehole drilling, coring, video surveys, sampling and petrographic analysis and geophysical studies will be compiled into stratigraphic and lithologic models. This information will be used with geophysical data (Activities 8.3.1.4.2.1.2 and 8.3.1.4.2.1.3) petrophysical data (Activity 8.3.1.4.2.1.4), rock magnetic properties (Activity 8.3.1.4.2.1.5), and data from investigation of tectonics and igneous processes (Site Programs 8.3.1.8 and 8.3.1.17) to formulate the site geologic model in Study 8.3.1.4.2.3. These models will provide the geologic framework for use in the development of models of the vertical and lateral variability of subsurface rock properties.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole drilling and coring	GP-19,R0	Procedure for the identification, handling, and disposition of drillhole core and cutting samples from the drill site to the core library	6 Mar 87
	TBD[a]	Borehole drilling and coring procedures	TBD
Sampling, lithologic examination, and analysis of drill-bit cuttings and core	GP-16,R0	Procedure for the handling and storage of drill core at the core library	20 Mar 87

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Sampling, lithologic examination, and analysis of drill-bit cuttings and core (continued)	GP-18,R0	Volcanic stratigraphic studies	24 Sept 86
	GP-19,R0	Procedure for the identification, handling, and disposition of drill-hole core and cutting samples from the drill site to the core library	6 Mar 87
	GP-20,R0	Volumetric estimation of lithophysae	10 Sept 87
Borehole video surveys and logging	GP-10,R0	Borehole-video fracture logging	12 Apr 85
Surface-outcrop mapping of exposures of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff units	GP-01,R0	Geologic mapping	1 May 83
	GP-05,R0	Geologic support activities	1 May 83
	GP-18,R0	Volcanic stratigraphic studies	24 Sept 86
	GP-20,R0	Volumetric estimation of lithophysae	10 Sept 87
Isotopic and geochemical studies	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-05,R1	Radium-equivalent uranium, thorium, and potassium analysis by gamma-ray spectrometry	9 May 88
	GP-08,R0	Correlation of tephra by means of chemical analyses	19 Feb 86

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Isotopic and geochemical studies (continued)	GP-16,R0	Procedure for the handling and storage of drill core at the core library	20 May 87
	GP-18,R0	Volcanic stratigraphic studies	24 Aug 86
	GCP-07,R0	Mineral separation for geochemistry and isotopic analysis	27 May 88

*TBD = to be determined.

8.3.1.4.2.1.2 Activity: Surface-based geophysical surveys

Objectives

The objective of this activity is to improve confidence in stratigraphic models of Yucca Mountain by incorporating geophysical constraints.

Parameters

The parameters of this activity are

1. Seismic velocity contrasts, seismic attenuation, seismically reflective horizons, density variation, local variations in magnetic field orientation and strength, and variations in electrical properties which are associated with vertical or lateral changes in lithology.

2. Lateral continuity of horizons defined by geophysical surveys.

Description

Surface-based geophysical surveys will be used to help define the lateral and vertical distribution of the stratigraphic units and lithostratigraphic subunits of the Yucca Mountain tuffs. These tests will be integrated under Activity 8.3.1.4.2.1.6 with surface-based geophysical surveys being performed in other site characterization programs. Table 8.3.1.4-4 summarizes the geophysical techniques that will be used to

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 1 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
			ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2		
Seismology					
Vertical seismic profiling	8.3.1.4.2.2.5	Repository block and vicinity	15 to 25 geotomographic profiles, 0.2 to 2 km in length, cross-hole and surface-down-hole surveys. Directional shear and compression energy sources	Decision to proceed (DTP) after feasibility test DTP after calibration in shaft and drifts	Used to map 3-dimensional network of rock mass fractures. 20-m per pixel geometry.
Intermediate depth seismic refraction	8.3.1.4.2.1.2	E-W line across Yucca Mountain, N of block	Explosive sources; shotholes	None	See Sutton (1985)
Paleomagnetism					
Site	8.3.1.4.2.1.5	Yucca Mountain	Orient drill core as it becomes available. Establish reference orientation through study of outcrop samples. Determine magnetic character of outcrop samples to aid in interpretation of aeromagnetic data	None	See Rosenbaum (1983), Rosenbaum and Rivers (1984), Rosenbaum and Snyder (1985), Rosenbaum (1985)
Borehole geophysical methods					
Geophysical logging					
Borehole gravimetry	8.3.1.4.2.1.3	Yucca Mountain	15 water-table (WT) drillholes, existing deep holes that can be made available, and all new holes that reach the base	None	Already have data in H-1, P 1, C 1, G-3, and G-4. Data will be used to model structure in the immediate vicinity of each borehole, to study

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 2 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2 (continued)					
Borehole gravimetry (continued)			of the Topopah Spring Member (Tpt)		lithophysal zones, and to model the Paleozoic surface beneath Yucca Mountain. See Robbins et al. (1982), Healy et al. (1984), and Healey et al. (1986)
Borehole magnetic logs	8.3.1.4.2.1.3	Yucca Mountain	15 WT drillholes, and new drillholes before casing operations	None	Used to determine mappable magnetic events for studying structural integrity of Yucca Mountain, and to supplement paleomagnetic and lithophysal studies. See Hagstrum et al. (1980).
Induced potential logs	8.3.1.4.2.1.3	Yucca Mountain	Test in one or two drillholes	Evaluate for effectiveness after 1 or 2 drillholes	Feasibility study to determine if the method can be used to map zeolitized rock
Commercially available logs	8.3.1.4.2.1.3	Yucca Mountain	All existing unlogged drillholes, all new holes, and relog selected holes	None	To obtain parameters for hydrologic, geologic, and geophysical models, and to determine uniformity and lateral distribution of rock properties within the stratigraphic units. See Spengler et al. (1979), Maldonado et al. (1979), Daniels and Scott (1981), Hagstrum et al. (1980), Daniels et al. (1981), Muller

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 3 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
		ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2 (continued)			
Commercially available logs (continued)					(1982), Muller and Kibler (1983 and 1984), Spengler and Chornack (1984), Muller (1985), and Muller and Kibler (1985)
Borehole radar logs	8.3.1.4.2.2.3	Yucca Mountain	Drillholes that penetrate the base of the Topopah Spring Member	Evaluate for effectiveness after 1 or 2 drillholes	Primarily used for fracture detection or to demonstrate the absence of fractures in the unsaturated zone
Acoustic televiewer logs and TV camera logs	8.3.1.4.2.2.3	Yucca Mountain	All Yucca Mountain drillholes	None	For fracture and fault zone detection, and stratigraphic and lithologic correlation. See Healy et al. (1984), Stock et al. (1984), Stock and Healy (1984), Stock et al. (1985)
Large spacing electromagmetic (EM) and resistivity logs	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	To determine accurate large-volume in situ values for studying fracture and lithophysal zones, and for interpreting anomalies detected with surface and borehole data
Borehole to surface methods					
Resistivity and EM methods	8.3.1.4.2.1.3, 8.3.1.4.2.2.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	For fracture studies in the unsaturated zone, to obtain detailed structure in areas of anomalous surface

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 4 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2 (continued)					
Resistivity and EM methods (continued)					geophysical data and in critical locations such as the shaft site and surface facilities locations, and to verify projected faults at critical locations. See Daniels and Scott (1981)
High resolution P and S wave seismic	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as previous, and to obtain parameters for designing effective, deeper-penetrating seismic surveys
Surface to hole seismic refraction	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as two previous, and for critical fault location and bed tracing
Borehole to borehole methods	8.3.1.4.2.2.5	Yucca Mountain close-spaced holes for hydrologic testing and for surface facilities studies	Selected drillholes	None	Geotomography to map fractures and demonstrate mappability of features that intersect the drillholes using resistivity, EM, radar, and high resolution P and S seismic (Yo Yo) methods
Petrophysics	8.3.1.4.2.1.4	Yucca Mountain	Selected core from cored drillholes	None	To verify geophysical log accuracy, calibrate computed logs, determine properties that are not or cannot be measured in situ, and to model and interpret surface geophysical studies

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 5 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2					
Seismology					
Deep refraction	8.3.1.17.4.3.1	E-W transect, Indian Spring-Stovepipe Wells (Figure 8.3.1.-17-12)	Reversed profiles and cross-profiles, shot-points 8- to 20-km spacing	None	Existing surveys shown in Figure 8.3.1.17-13. See Pankratz (1982), Mooney et al. (1982), Hoffman and Mooney (1983), Hoover et al. (1982), Monfort and Evans (1982), and Sutton (1984)
Shallow (Bison) refraction and shear wave refraction and reflection	8.3.1.17.4.4.1 and others	Quaternary faults, Yucca Mountain and vicinity	250-500 m traverses, portable instruments, sledgehammer energy source. Shear wave method uses 12 (or more) geophones, 3-m spacing	Number and location to be decided on the basis of geologic mapping	Maximum depth of penetration 100 m. Used to detect offset in surficial deposits. Shear wave method capable of detecting 30 cm offset
Evaluation of proposed deep reflection survey	8.3.1.17.4.3.1	Proposed survey 15km test located to the south of Amargosa Valley or southwest of Beatty	To be determined	DTP after evaluation of preliminary tests (15 km recon. line) and peer review	COCORP survey extending northward into southern Death Valley produced marginal quality data, although data in the upper one second are locally good. Five- and ten-second reflections were imaged with fair continuity. See de Voogd et al. (1986).

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 6 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
		SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)			
Intermediate reflection and intermediate refraction	8.3.1.17.4.7.1	Controlled area, Yucca Mountain	Evaluate previous results, assess potential for application of this method to Yucca Mountain, plan new application if appropriate	None	This is a planning activity only. Previous reflection survey using Vibroseis at Yucca Mountain failed (McGovern, 1983). More recent surveys using air gun at Mid Valley produced useful results (McArthur and Burkhard, 1986). See also Hoover et al. (1982).
Shallow (Mini-sosie) reflection	8.3.1.17.4.7.8 and others	Crater Flat, Jackass Flats (Figure 8.3.1.17-8)	7 to 15 profiles, 1 to 5 km in length, hand carried instruments. Energy from battery of hand-operated tampers	DTP after evaluation of two preliminary profiles selected from profiles indicated in Figure 8.3.1.4-8	Maximum depth of penetration 1 km. Used to map shallow structural and stratigraphic features. Additional Mini-sosie surveys at Yucca Mountain are planned in Activity 8.3.1.4.2.1.1
<u>Gravity investigations</u>					
Regional maps	8.3.1.17.4.12.1	Yucca Mountain and vicinity	Beatty 1:100,000 quad, Pahute Mesa 1:100,000 quad, NTS 1:100,000 map area, Yucca Mountain, 1:48,000 map area	None	Field work complete, compilation complete, final results not yet available. See Snyder and Oliver (1981), Ponce (1981), Ponce and Oliver (1981), Hoover et al. (1982), Ponce and Hanna (1982), Jasma et al. (1982), Ponce (1984), and Snyder and Carr (1984).

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 7 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
			SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)		
Site area map	8.3.1.17.4.7.2	Yucca Mountain	1:24,000 map of site and vicinity, 200 ft spacing of stations along E-W lines spaced 500 ft apart (where topography permits)	None	Will require as many as 7,500 additional stations. Useful for establishing strati-graphic variability of repository host rock and fault location and offset. See Snyder (1981), Snyder and Carr (1982), Jansma et al. (1982), Kane et al. (1981), Ponce et al. (1985)
Detailed surveys, deep reflection profiles and shallow reflec-tion profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Moun-tain, Indian Springs. Pre-cise location to be deter-mined.	Gravity determinations along profiles at 500 ft (150 m) spacing	DTP only if seis-mic surveys run	Assists interpretation of seismic results
<u>Magnetic methods</u>					
Regional aero-magnetic maps	8.3.1.17.4.12.1	Yucca Mountain and vicinity	Beatty, Pahute Mesa, Indian Springs, and Pahranagat 1:100,000 quadrangles to be compiled from exis-ting surveys	None	Field investigations com-plete; compilation 80% (?) complete. See Kane et al. (1981), Hoover et al. (1982), Kane and Bracken (1983), U.S. Geological Survey (1984), Ponce (1984)
Site aeromag-netic maps	8.3.1.17.4.7.3	Yucca Mountain	1:12,000 scale map of site and vicinity, continuous aeromag-netic survey along	None	1:62,500 scale map com-plete (U.S. Geological Survey, 1984). See also Jansma et al. (1982),

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 8 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
			SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)		
Site aeromagnetic maps (continued)			E-W flight lines spaced 1/16 mile (0.1 km)		Bath et al. (1982), Kane et al. (1982), Kane and Bracken (1983), and Bath and Jahren (1984)
Ground magnetic survey, deep reflection profiles and shallow reflection profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Mountain, Indian Springs. Precise location to be determined.	Magnetic determinations along profiles at 10 to 20 ft (3 to 6 m) spacing where accessible by truck, 50 to 100 ft (15 to 30 m) spacing elsewhere	DTP only if seismic surveys run	Assists interpretation of seismic results
Site ground magnetic surveys	8.3.1.17.4.7.4	Yucca Mountain (Figure 8.3.1.4-9)	Ground magnetic surveys at (1) known and inferred structures, (2) vicinity of drillholes, (3) vicinity of shaft and surface facilities, (4) anomalies detected. Surveys to be semicontinuous: 10 to 20 ft (3 to 6 m) spacing	Number and location to be determined through evaluation of geologic and geophysical mapping	Primary purpose is to locate concealed extensions of faults. See Bath and Jahren (1984), Scott et al. (1984), and Bath and Jahren (1985)
Curie isotherm	8.3.1.8.5.2.1	Yucca Mountain region	Analysis of existing regional aeromagnetic data	None	Purpose is to map configuration of Curie isothermal surface, and to compare areas of shallow isotherms with areas of high heat flow and recent volcanism. See Connard et al. (1983).

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 9 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)					
Electrical methods					
Regional magnetotelluric (MT)	8.3.1.17.4.3.1	Yucca Mountain, Crater Flat, Jackass Flats, Amargosa Desert, Death Valley (Figure 8.3.1.17-12)	Detailed survey with stations at 3 to 5 km spacing of Yucca Mountain, Crater Flat, and northern Amargosa Desert. Reconnaissance survey with stations at 10 km spacing in remainder of area	None	Previous survey by Furgerson (1982) shows mappable conductivity contrasts in 1 to 15 km depth range. See also Kauahikaua (1981), and Hoover et al. (1982)
Surface geoelectric investigations (airborne EM, slingram, VLF, dc resistivity, EM soundings, tensor audio magnetotelluric and telluric profiling filing)	8.3.1.17.4.7.5	Yucca Mountain	Assess potential for application of these methods, evaluate previous results, plan new applications if appropriate, conduct prototype tests	DTP with full-scale application of selected methods only if warranted by results of prototype testing	Applied to structural and stratigraphic problems at the site by Flanigan (1981), Smith and Ross (1982), Fitterman (1982), Hoover et al. (1982), Senterfit et al. (1982), Scott et al. (1984), Frischkenecht and Raab (1984). Other studies in region include Zablocki (1979), Anderson (1982), Smith et al. (1981), Greenhaus and Zablocki (1982).
Radiometric and remote sensing methods					
Surface and airborne gamma ray investigations	8.3.1.17.4.7.6	Yucca Mountain	Assess potential for application of these methods with preliminary survey over known faults using static ground measurements	DTP with full-scale application of airborne methods only if warranted by results of preliminary survey	Could detect percolation of radon through fault zones (gamma emitting daughter bismuth-214)

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 10 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)					
Thermal infrared investigations	8.3.1.17.4.7.7	Yucca Mountain	Assess potential for application of aircraft and satellite thermal infrared imagery in mapping of fracture network	DTP based on evaluation of cost and expected results	Method depends on detection of surface temperature variation, which are largely dependent on soil moisture content, which in turn is in part related to infiltration along fractures.
Thematic Mapper Satellite Imagery	8.3.1.17.4.3.5	Yucca Mountain and vicinity	Tapes of the four Thematic Mapper V scenes encompassing the Yucca Mountain Region (Beatty, Indian Springs, Pahute Mesa, and Pahranagat 1:100,000 quads) to be used to produce spectral and spectral ratio maps, from which areas containing distinctive patterns of lineations will be delineated.	None	Used to define structural domains, areas of well-developed desert varnish, and areas of hydrothermal alteration.
<u>Paleomagnetism</u>					
Region	8.3.1.17.4.3.2	Little Skull Mountain, Crater Flat, Skull Mountain, southern Yucca Mountain, eastern Yucca Flat.	10 to 20 sites at Little Skull Mountain will be sampled. If useful results are obtained, other sites as listed may be sampled.	DTP only if useful results obtained at Little Skull Mountain, and if suitable strata are present.	Preliminary results at Yucca Mountain indicate 30 degrees rotation (Scott and Rosenbaum, 1986)

study the vertical and lateral continuity of rock units. The table provides information on the location and scope of the survey and is divided into two parts. The first part describes geophysical surveys to be used by Characterization Program 8.3.1.4, and the second part identifies geophysical surveys that are used primarily for Characterization Program 8.3.1.17 (preclosure tectonics) and Characterization Program 8.3.1.8 (postclosure tectonics) but will be used to develop the geologic model. Geophysical surveys will also aid in determining favorable sites for drillholes. These detailed geophysical surveys will include (1) seismic refraction, (2) seismic reflection, (3) gravity and magnetics, and (4) electromagnetic soundings.

A seismic refraction profile will be acquired in the Yucca Wash area (Figure 8.3.1.4-6). This profile will be used to investigate significant velocity contrasts in the volcanic section that are associated with abrupt lateral changes in lithology, and that may be the result of structural displacement or alteration associated with a steep gradient in the potentiometric surface north of drillhole USW G-1 and in the vicinity of proposed corehole USW G-5.

After proof-of-technique trials, as many as 15 seismic reflection profiles may be performed using a shallow penetrating, high-resolution method called Mini-sosie (Barbier, 1983). This technique will be used to study the position of marker-horizons that have a sufficient contrast in seismic velocity and is expected to be useful to a maximum depth of about 1,000 m. Of specific interest are possible marker horizons that may be buried beneath Yucca Wash and Midway Valley (Figure 8.3.1.4-7). Information collected will also be used to trace individual faults by studying the lateral continuity of reflecting horizons. This technique differs from previous reflection studies because it is designed to penetrate only the upper geologic section.

Two detailed ground magnetic and gravity surveys will be performed across Yucca Wash (near USW G-5) and south of Busted Butte (near USW G-7) (Figure 8.3.1.4-8) in association with proposed geologic coreholes USW G-5, USW G-6, and USW G-7. In situ magnetic and density variations will be used to map the local vertical and lateral distribution of lithostratigraphic units.

A number of geophysical surveys that will be performed for tectonics Investigation 8.3.1.17.4 will also provide information for evaluation of stratigraphy and structure. These surveys and methods are indicated in the second part of Table 8.3.1.4-4. Many of these methods have not been tried at the Yucca Mountain site and will be tested before application for data collection purposes.

Shallow seismic refraction and shear wave refraction and reflection, will be used for investigation of faults in the vicinity of Yucca Mountain, using sledgehammer and shear wave sources. The number and location of the traverses will be based on the results of detailed geologic mapping. These surveys are more completely described in Activities 8.3.1.17.4.4.1 and 8.3.1.17.4.4.4. In addition, a program of intermediate seismic reflection in the vicinity of Yucca Mountain is planned in Activity 8.3.1.17.4.7.1, using such sources as vibrators, explosives, and air guns. The locations of these seismic lines will be determined after further acquisition and analysis of

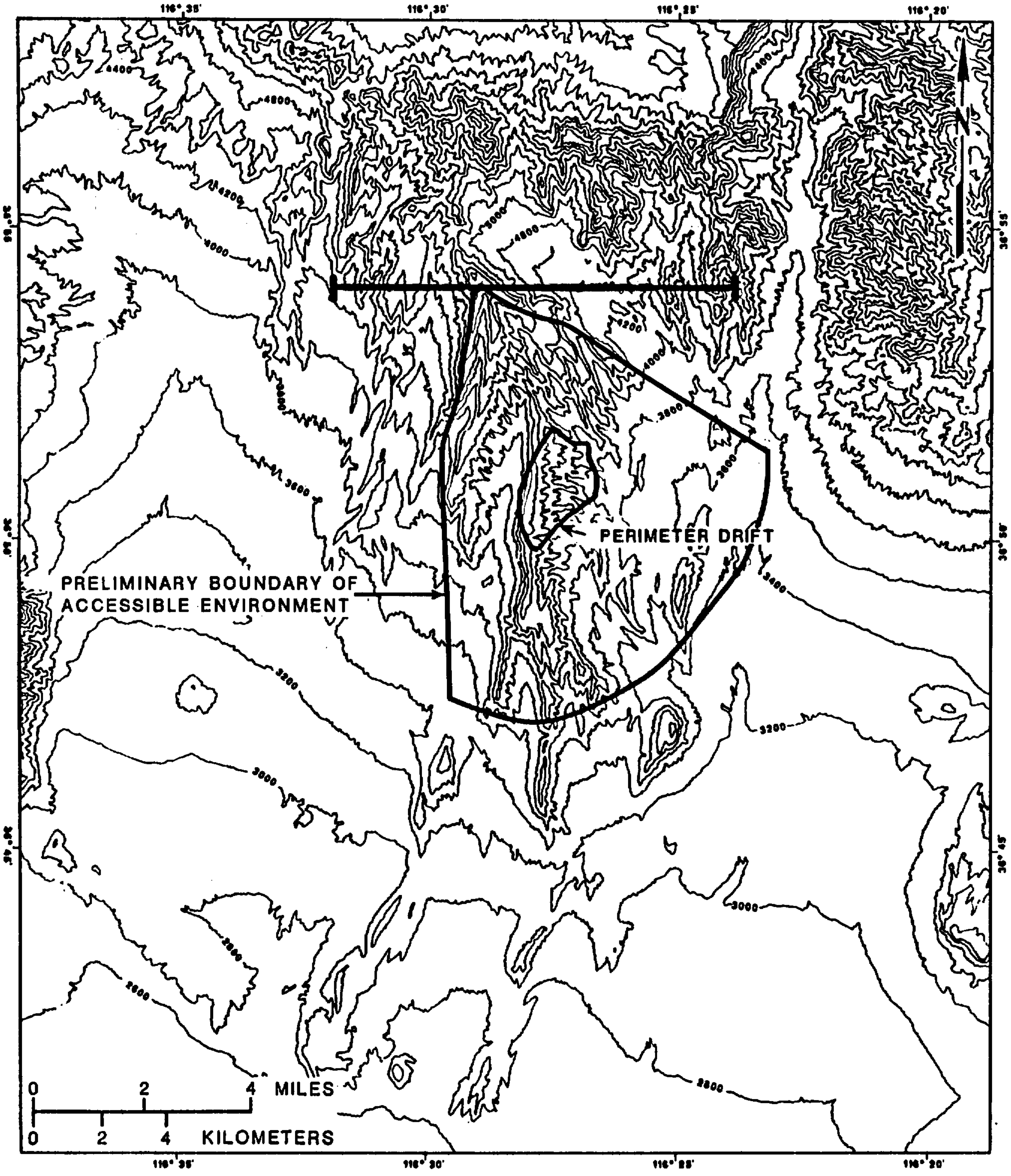


Figure 8.3.1.4-6. Approximate location of proposed seismic refraction survey across Yucca Wash.

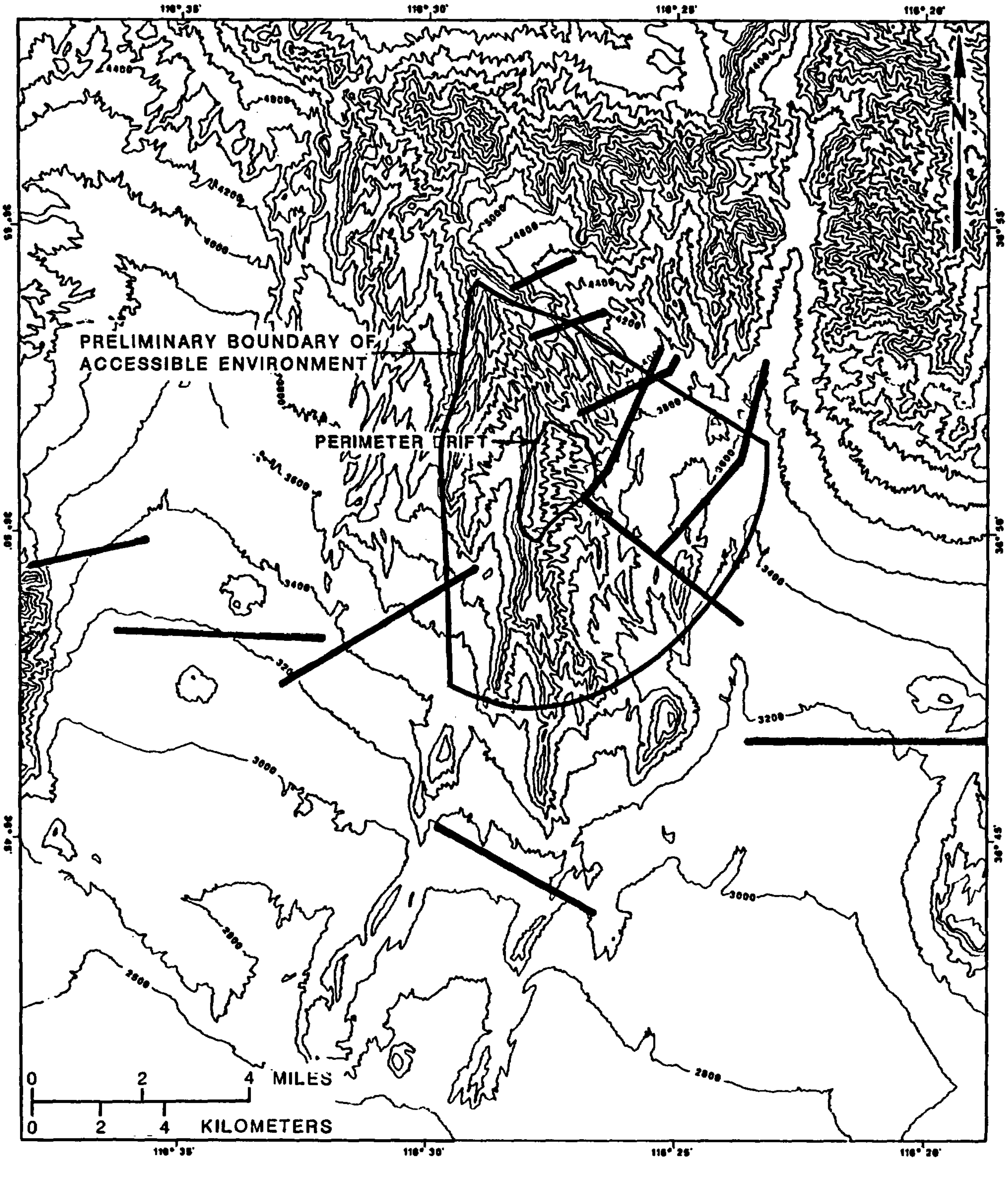


Figure 8.3.1.4-7. Approximate location of proposed seismic reflection surveys at Yucca Mountain.

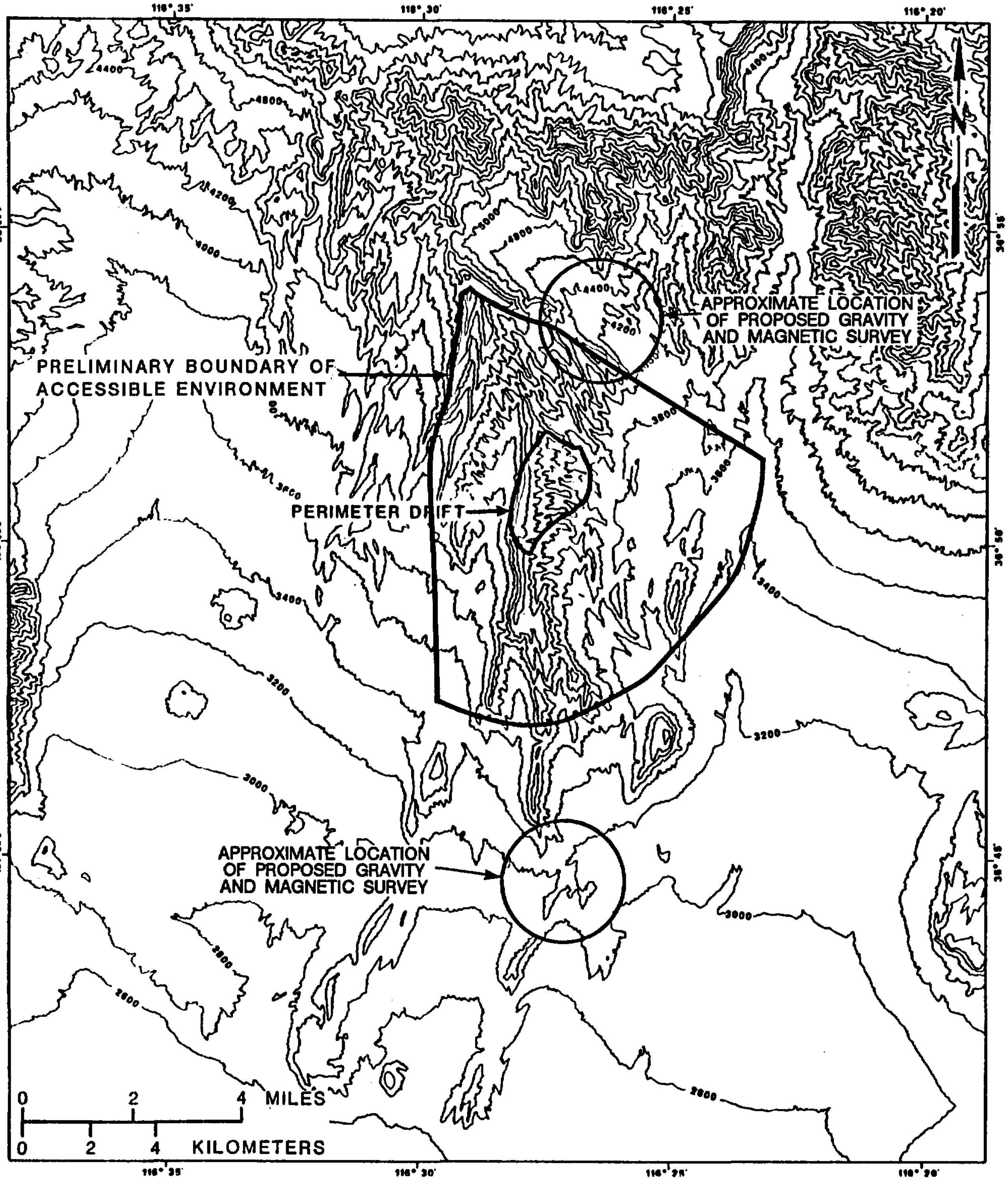


Figure 8.3.1.4-8. Approximate locations of proposed gravity and magnetic surveys near proposed coreholes.

tectonic data using criteria that will include obtaining the requisite stratigraphic information needed to input to the geologic model of the site.

Gravity and magnetic data will be acquired at 500-ft intervals along the same surface profiles as the intermediate seismic data and shallow seismic surveys. In addition, a site gravity map at a scale of 1:24,000 is proposed (Activity 8.3.1.17.4.7.2), for which as many as 7,500 gravity stations would be required. The stations would be located at 200-ft intervals along lines spaced about 500 ft apart. An aeromagnetic survey is proposed which would produce a higher resolution map (1:24,000 scale) than previous surveys (Bath et al., 1982; Jansma et al., 1982; Kane and Bracken, 1983; Bath and Jahren, 1984), but over a smaller region. Additional gravity and ground magnetic surveys may be performed to investigate aeromagnetic anomalies, the location of proposed shafts and repository surface facilities.

Various electrical methods including airborne electromagnetic (EM) surveys, EM soundings, tensor audio magnetotellurics, telluric profiling, and direct current resistivity will be evaluated for application to tectonic, structural, and stratigraphic problems in Activity 8.3.1.17.4.7.5. In addition, radiometric (airborne gamma intensity) and remote sensing methods (thermal infrared scanner and Thematic Mapper V) will be evaluated in Activities 8.3.1.17.4.7.7 and 8.3.1.17.4.3.5 for application to detection of faults and fractures at the surface. Radiometric or surface temperature anomalies may be associated with radon emanation or water infiltration, respectively, along faults or fractures. Application of these electrical and remote sensing methods for site characterization will depend on the outcome of feasibility tests.

Electromagnetic surveys will be performed to investigate the thickness of the volcanic section and fault trends in Yucca Wash (near USW G-5). Alteration zones associated with fault zones will be evaluated and may provide evidence of hydraulic connectivity of the inferred fault system.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.2 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Seismic refraction surveys	SP-08,R0	Seismic study of the tectonic environment	6 June 83
	SP-09,R0	Calibration of seismic refraction equipment	20 Feb 86

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Seismic reflection surveys (continued)	TBD[a]	Seismic-refraction surveys	TBD
	SP-10,R0	Deep seismic reflection study of the tectonic environment	15 Apr 87
	TBD	Intermediate depth seismic reflection	TBD
	TBD	Mini-sosie surveys	TBD
Gravity surveys	GPP-01,R0	Gravity measurement and data reduction	14 Jan 85
Magnetic surveys	GPP-11,R0	Magnetic methods	TBD
	TBD	Acquisition of aeromagnetic data	TBD
Electromagnetic surveys	GPP-18,R0	Magnetotelluric measurements	27 May 86

[a]TBD = to be determined.

8.3.1.4.2.1.3 Activity: Borehole geophysical surveys

Objectives

The objectives for this activity are (1) to aid in the definition and refinement of the location and character of lithostratigraphic units and contacts between units and (2) to determine the distribution of rock properties within lithostratigraphic units.

Parameters

The parameters for this activity are the direct measurements and quantities derived from geophysical logs, statistical analysis, cross plots, and correlation with core data, including the borehole diameter, in situ bulk density, electrical conductivity, resistivity, spontaneous potential, gamma radiation intensity, temperature, induced polarization, porosity, saturation, potassium-uranium-thorium (K-U-Th) content, water content, seismic velocities, deformation moduli, magnetic susceptibility, and total magnetic field intensity.

Description

A suite of commercially available geophysical logs will be obtained in future holes drilled in the vicinity of Yucca Mountain. Additional experimental geophysical logs also will be obtained in selected boreholes. Geophysical log data will be correlated with measurements of properties such as porosity, saturation, water content, seismic velocity (in the unsaturated zone), deformation moduli, magnetic susceptibility, total magnetic field intensity, K-U-Th content, and hydraulic conductivity.

Compensated-density, induction, resistivity, and spectral-gamma logs will be used most frequently for lithologic correlations, although other logs may be used such as caliper, spontaneous potential, temperature, neutron, and induced polarization. Signatures of compensated-density logs will provide information to identify dominant lithophysal zones in boreholes where only drill bit-cutting samples will be available, or where poor resolution exists on borehole video-camera logs. Induction, resistivity, and spectral-gamma logs are expected to serve as indicators of smectite- and zeolite-rich intervals. These logs also will be used to identify key stratigraphic markers at the top and base of major ash-flow tuffs, which commonly show an increase in alteration.

Borehole samples, borehole video-camera logs, and geophysical logs will be correlated to help determine the vertical and lateral continuity of the lithostratigraphic units. Geophysical log data will provide rock property data for the unsaturated and saturated zone hydrology models and mechanical and thermal models of the host rock and surrounding units.

Borehole gravimetry will be used in available boreholes to obtain bulk density and structural information for the region around each hole. In addition, data from this technique will be used to study lithophysal zones, and to model the Tertiary-Paleozoic surface at the site. Gravimeter logs have been obtained for several holes (UE-25p#1, UE-25c#1, and USW H-1) including several which were continuously cored (USW G-3 and USW G-4). Additional logs will be acquired from as many as 15 of the existing and proposed water table holes which are nearest the site, existing deep holes as available, and all of the proposed holes which penetrate the base of the Topopah Spring Member.

Large spacing electromagnetic (EM) and resistivity logging will be tested and evaluated to determine applicability for studying fracture and lithophysal zones, and for interpreting anomalies detected by means of other borehole and surface geophysical methods. The application of these methods to acquisition of site characterization data will depend on the outcome of preliminary testing.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.3 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole geophysical surveys and logging	GP-02,R0	Subsurface investigations	1 Mar 83
	GPP-12,R0	Borehole gravity measurement and data reduction	20 Mar 85
	GPP-14,R0	Induced polarization borehole logging operations	27 May 86
	TBD[a]	Logging procedures	TBD

[a]TBD = to be determined.

8.3.1.4.2.1.4 Activity: Petrophysical properties testing

Objectives

The objective of this activity is to provide geophysical and rock property data to be used in the interpretation of surface-based and borehole geophysical surveys.

Parameters

The parameters for this activity are

1. Electrical resistivity and bulk density of core samples containing in situ pore waters.

2. Electrical resistivity, induced polarization, bulk density, grain density, porosity, seismic velocities, and hydraulic conductivity on resaturated samples.

Description

Rock property testing will provide data for use in the interpretation of surface and borehole geophysical surveys (Activities 8.3.1.4.2.1.2 and 8.3.1.4.2.1.3). Laboratory measurements will be made on core samples obtained from boreholes drilled in the area of interest. Mechanical and thermal properties determined by those testing activities described in Investigation 8.3.1.15.1 and other activities under Investigation 8.3.1.4.2

(this investigation) will also be used in interpretation of geophysical surveys.

This activity will provide data on (1) the degree of water saturation within the rock above the static water level, (2) the moisture flux through the rock matrix, (3) preferential paths for water flow, (4) the potential for contaminant transport by means of diffusion processes, (5) concentrations of clays and zeolites within the measured stratigraphic section, (6) statistical relationships of various rock properties to provide information on the degree of welding, alteration, and compositional uniformity, and (7) rock property variation for integration in a three-dimensional geophysical model of the site.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.4 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Laboratory measurements of rock properties	GPP-10,R1	Rock properties analysis of Yucca Mountain core samples	6 Jul 88

8.3.1.4.2.1.5 Activity: Magnetic properties and stratigraphic correlations

Objectives

The objectives of this activity are to

1. Provide magnetic property data to aid the interpretation of volcanic stratigraphy and structure of rock units within the Yucca Mountain site area.

2. Use paleomagnetic directions to provide orientations for drill core segments.

3. Assess the rotation of rock units in relation to the geologic structures of Yucca Mountain from paleomagnetic indications.

Parameters

Three categories of parameters are required for this activity.

1. Measured magnetic parameters:

   a. Orientation and magnitude of remnant magnetism.
   b. Magnetic susceptibility.
   c. Curie temperature.

2. Measured properties of flow units:

   a. Textural variations across boundaries.
   b. Grain size variations.
   c. Pumice clast concentrations.
   d. Locations of lithic-rich subzones.
   e. Nature of contacts between flow units.

3. Inferred properties of flow units:

   a. Locations of deposition breaks.
   b. Thicknesses of individual flow units.

Description

Natural remanent magnetization (NRM) and magnetic susceptibility exhibit systematic variation that correlates with depositional breaks within several major ash-flow tuffs. Data will be collected to help understand the observed mineralogical variations that produce the observed changes in magnetic susceptibility and remnant magnetization. Empirical relationships will be developed between depositional breaks and variations in these magnetic properties to provide information for the three-dimensional geologic model.

Lithologic relationships will be developed based on observations of the following rock properties: (1) measurement of NRM, (2) measurement of anhysteritic remanent magnetization (ARM), (3) measurement of isothermal remanent magnetization (IRM), (4) measurement of saturation magnetization (M_{sat}), (5) measurement of magnetic susceptibility, (6) alternating field demagnetization, (7) thermal demagnetization, and (8) curie temperature determination.

Oriented samples for rock magnetic properties testing will be collected from surface outcrops in the vicinity of Yucca Mountain. Sampling sites will be selected where geologic evidence indicates that the area is relatively undisturbed and the identity of the unit sampled is well known. These sites are used to establish reference paleomagnetic directions for geologic units. Other sites will be selected where rotations of the geologic structure will be evaluated. Data from these sites will be used to assess the magnitudes of the rotations.

Samples have been collected from drill core segments at 3-m intervals from throughout drillholes USW G-1, USW G-2, USW GU-3, and USW G-3. Samples also have been collected from throughout the sections penetrated by two drillholes located on Crater Flat (VH-1 and VH-2). Further sampling from drill core will be obtained from oriented core segments.

Variations in magnetic properties determined in the laboratory will be used to collect intervals of core from drillholes USW G-1, USW G-2, USW GU-3, and USW G-3 for detailed petrographic studies. Studies will focus on identifying subtle variations across contacts that separate subunits of major ashflow tuffs. These features include textural changes, localized concentrations of pumice clasts and lithic fragments, anomalous welding characteristics, and subtle compositional changes that may correlate with abrupt changes in magnetic properties.

Measurement of NRM and remanent magnetization will be determined with a spinner magnetometer after at least one level of alternating field demagnetization. Progressive alternating field and thermal demagnetization will help assess mineralogical variations within the rock. Additional rock magnetic measurements (ARM, IRM, M_{sat}) will be used to help assess variation in the composition, relative abundance, and magnetic grain size of magnetic minerals. Selected samples are subjected to progressive thermal demagnetization in order to determine blocking temperature spectra and to assess whether samples possess multiple components of remanent magnetization. Curie temperatures will be determined from rock chips of mineral separates to help define the magnetic minerals present in the samples.

Measurements of the relative magnitude of magnetic susceptibility will be obtained using a hand-held magnetic susceptibility meter. This meter will provide relative values, and will help limit the size of intervals of core selected for petrographic studies. If this technique proves to be successful, the instrument will be used in continuously cored holes.

To measure total intensity and magnetic susceptibility variation with depth, borehole magnetic surveys using an experimental flux-gate magnetometer, proton-spinner magnetometer, and susceptometer will be performed as described in Activity 8.3.1.4.2.1.3. These logs will be correlated with available geologic data. Geologic correlations will focus on identifying depositional units and rock characteristics changes in the Topopah Spring Member.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.5 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Sampling, examination and petrographic analysis of selected intervals of core and outcrop	GP-16,R0	Procedure for the handling and storage of drill core at the core library	20 Mar 87
	GP-19,R0	Procedure for the identification, handling, and disposition of drill-hole core and cutting samples from the drill site to the core library	6 Mar 87
Density variation in rock mass	GP-14,R0	Measurement of dry bulk-rock densities from paleomagnetic samples	25 Apr 86
Use of the hand-held magnetic susceptibility meter	GP-16,R0	Procedure for the handling and storage of drill core at the core library	20 Mar 87
	GPP-06,R0	Rock and paleomagnetic investigations	1 Nov 84
Borehole magnetic surveys and logging	GPP-15,R0	Magnetic-susceptibility borehole logging operations	27 May 86
	GPP-17,R0	Magnetometer borehole logging operations	27 May 86
Sampling, and paleomagnetic testing and analysis of selected intervals of core and outcrop	GP-16,R0	Procedure for the handling and storage of drill core at the core library	20 Nov 87
	GPP-06,R0	Rock and paleomagnetic investigations	1 Nov 84

Method	Technical procedure Number	Title	Date
Sampling, and paleomagnetic testing and analysis of selected intervals of core and outcrop	TBD[a]	Logging procedure	TBD

[a]TBD = to be determined.

8.3.1.4.2.1.6 Activity: Integration of geophysical activities

Objectives

This activity will provide a mechanism for information exchange, analysis of data and other technical information, and review of planned geophysical site characterization activities. The operating principles for geophysics integration are that (1) the effectiveness of planned geophysical surveys can be increased through consideration of past efforts both within and outside the Yucca Mountain Project; and (2) the overall effectiveness of geophysical exploration can be increased by analysis of how each planned survey addresses specific information requirements for site licensing. The objectives of the geophysics integration activity are then to optimize the effectiveness of geophysical activities for providing data that support site licensing, from cost and technical perspectives.

Parameters

No activity or characterization parameters are provided by this activity.

Description

Planned geophysical surveys will collect different types of data, which may be used to support geologic, hydrologic, and tectonic models of the site. (In this context, model refers to interpretation of the history of causative processes giving rise to the present state, based on observations and inference.) Such models are identified as steps in the issue resolution strategies of Sections 8.3.1.2 and 8.3.1.4, although the form and content are not described explicitly. Much of the information contained is expected to be nonquantitative and therefore will not directly support probabilistic assessments. However, performance assessment is supported by the use of such information to ensure that the range of variability of the site characteristics included in performance calculations is representative of actual site conditions. Similarly, geophysical applications such as fault detection are a form of nonprobabilistic support for the representativeness of site data.

8.3.1.4.2.2 Study: Characterization of the structural features within the site area

The objective of this study is to determine the frequency, distribution, characteristics, and relative chronology of structural features within the Yucca Mountain site area.

Surface and subsurface structural studies will be performed to identify and characterize fracture-fault systems within the site area. Detailed geologic mapping of zonal features in ash-flow tuffs that crop out at the surface of Yucca Mountain will provide the necessary stratigraphic control for identifying small-scale faults. Lateral variability of fracture networks will be studied by detailed mapping and pavement analysis. Subsurface distribution and geologic characteristics of fracture-fault zones will be studied by analysis of core samples, borehole evaluations, exploratory shaft studies, and application of geophysical techniques. Results of these studies will be integrated with hydrologic study results described in Section 8.3.1.2 to provide information for the development of geologic models of the site (Study 8.3.1.4.2.3).

Geologic mapping of the exploratory shaft and drifts will include detailed fracture mapping and photogeologic recording. Borehole evaluations in the exploratory shaft facility after drilling and coring, will include video, geophysical and vertical seismic profiling surveys. Fracture-filling mineralogy studies in the shaft, drifts, and boreholes will be conducted to evaluate the chronology of fracture development.

Preparation of a three-dimensional geologic model (Study 8.3.1.4.2.3) requires discrimination between natural fractures and those induced by excavation and construction-related activities. The photographic methods discussed in Activity 8.3.1.4.2.2.4 (Geologic mapping of the exploratory shaft and drifts) are useful in documenting the existing fracture network but may have difficulty in discriminating natural from induced fractures. Geologic mapping in the underground can aid in recognizing blast-induced fractures, by, for example, noting the absence of mineralization or by tracing the fracture back to the point of origin at a shot point.

In addition to the characterization of structural features, the geological mapping of the shafts and drifts will include mineralogic, petrologic, and petrographic studies as described in Section 8.3.1.3.2.1.

Activities planned for this study include (1) geologic mapping of zonal features in the Paintbrush Tuff at a scale of 1:12,000, (2) surface-fracture network studies, (3) borehole evaluation of fractures and faults, (4) geologic mapping of the exploratory shaft and drifts, and (5) vertical seismic profiling studies.

8.3.1.4.2.2.1 Activity: Geologic mapping of zonal features in the Paintbrush Tuff

Objectives

The objectives of this activity are (1) to map zonal variations within exposed tuffs that will aid in the identification of structural displacements at a scale of 10 m or less, and (2) to detect subtle changes in structural styles.

Parameters

The parameters for this activity are

1. Thickness, attitudes, and lateral extent of zones within ash-flow and bedded tuff intervals, areal extent of exposed bedrock.

2. Attitudes, lengths, displacements, and near-surface characteristics of faults and fault zones.

Description

Geologic mapping of zonal variations in ash-flow sheets and structural features that are exposed over much of the site area has been completed and published at a scale of 1:12,000. The mapped area forms an irregular pattern, the boundaries of which roughly coincide with prominent topographic features (Figure 8.3.1.4-9, Area A). The northernmost limit of the map is Prow Pass; the northeastern boundary is Yucca Wash; the eastern limit is Fortymile Wash; the southern extent is the southernmost exposure of Fran Ridge; and the western limit is Windy Wash.

Mapping will extend outward from the western and southern boundaries of the mapped area to include areas east of longitude 116° 32′ and areas north of latitude 36° (Figure 8.3.1.4-9, Area B). The mapping will identify thickness, attitude, and lateral extent of zones within ash-flow tuffs and bedded tuff intervals; areal extent of exposed bedrock; and attitudes, lengths, displacements, and near-surface characteristics of faults and fault zones. Northern, northeastern, and eastern limits of the map area will not be extended because rock units of interest are poorly exposed in those areas. The need for larger scale mapping (e.g., 1:2,400) in the immediate vicinity of the repository facilities will be assessed.

Geologic information that is initially documented on aerial photographs during field mapping will be transferred to stable topographic base maps by using high-precision photogrammetric techniques.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.1 are given in the following table.

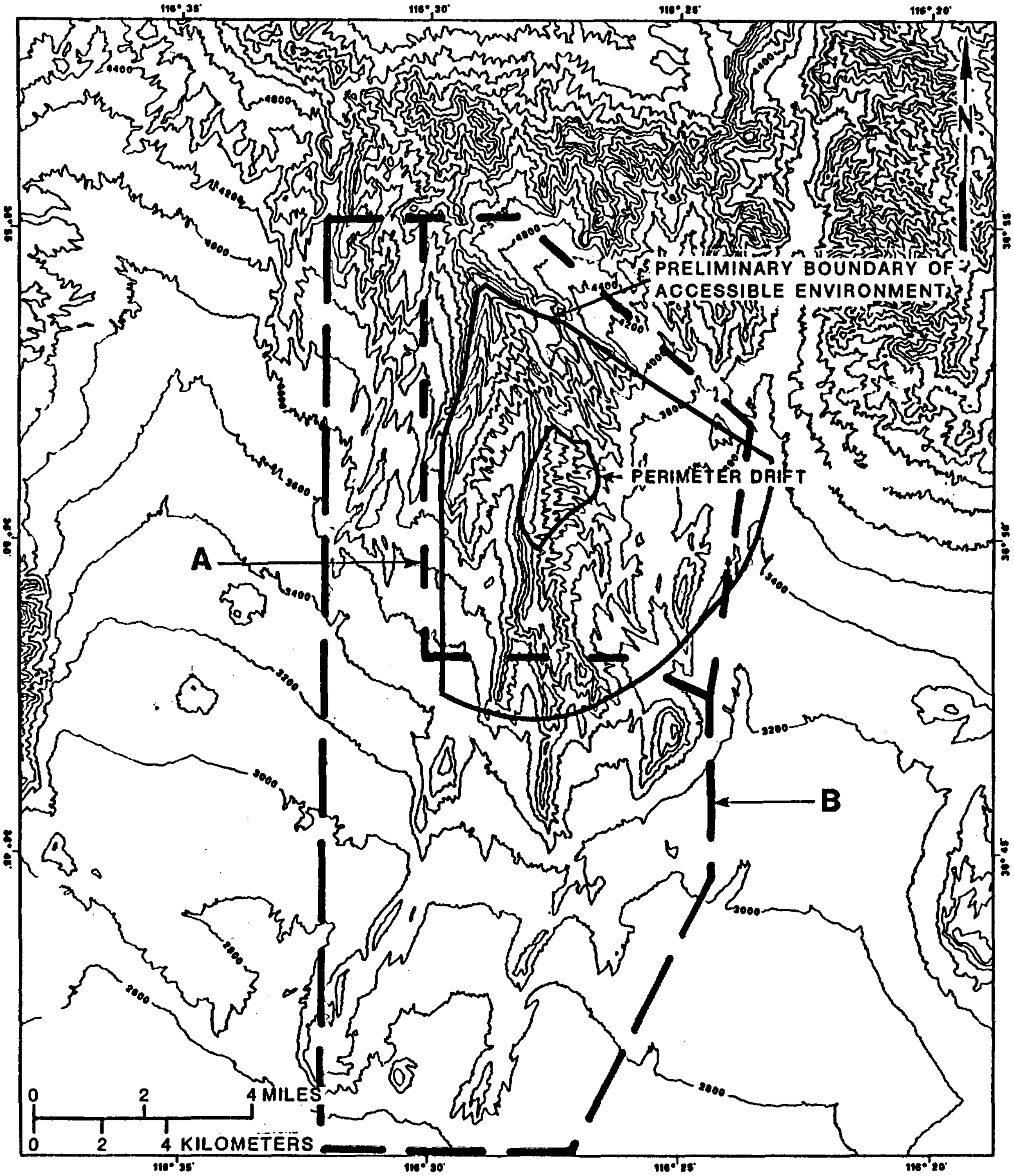


Figure 8.3.1.4-9. Approximate areal limits of mapped area (A) and area of additional mapping (B).

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Field mapping using aerial photographs	GP-01,R0	Geologic mapping	1 Mar 83
Transfer of geologic features to topographic base maps using high-precision photogrammetric techniques	GP-01,R0	Geologic mapping	1 Mar 83

8.3.1.4.2.2.2 Activity: Surface-fracture network studies

Objectives

The objective of this activity is to provide measurements and analyses of fracture networks to support modeling of hydrologic potential flowpaths, particularly in unsaturated zones. Applications are also expected to aid development of tectonic models and determination of the mechanical response of fractured rock to excavation and thermal loading. The analyses will provide quantitative data for determining spatial distribution of fractures, chronology of fracture development, and parametric characteristics of fractures. Applications are expected to aid in the development of tectonic models and possibly to aid in the determination of the bulk response of fractured rock in the context of excavation and loading.

Parameters

The parameters for this activity are fracture orientation, frequency, aperture, roughness, persistence, spatial distribution, fracture-filling mineralogy, relative age, and tectonic style.

Description

The characterization of fracture networks on the surface of Yucca Mountain will be carried out through a phased program of detailed studies of outcrops (either natural or cleared). Because analyses of fractures in drillholes (Activity 8.3.1.4.2.2.3) and fractures exposed in the exploratory shaft (Activity 8.3.1.4.2.2.4) are based on relatively small samples that emphasize the vertical dimension, analyses based on surface exposures of fractures provide a unique opportunity to understand lateral variations and other fracture characteristics in different stratigraphic units. The applicability of data from fracture studies and fracture networks projected to the subsurface will depend largely on the comparison of the data with the result of fracture analyses conducted in the exploratory shaft and associated drifts.

Detailed studies included in this activity will provide site-specific data from outcrops on Yucca Mountain. This activity will focus primarily on the Paintbrush Tuff, and to a lesser extent, the tuffaceous beds of Calico Hills units exposed within the site area boundary (at Prow Pass). Stratigraphically lower units, such as the Crater Flat Tuff, do not crop out in the site area boundary but are exposed within several miles of the site. If preliminary studies in the site area clearly establish that there is a need for additional fracture network data from offsite outcrops, preliminary evaluations of the transferability of data from offsite outcrops will be performed. If these studies demonstrate that these data are convincingly transferable to the site (e.g., apparently good correlation with fractures mapped in exploratory shafts and drifts), additional fracture data may be derived from exposures in such areas as the southern part of Yucca Mountain, Little Skull Mountain, northern Crater Flat, and along U.S. Highway 95.

As no detailed surface-fracture network study of this scope involving comparable rocks has been attempted, extensive innovation in measurement and analytical procedures will be required. Throughout this activity a phased approach will be employed whereby the results from sites already studied in a given unit will be considered in determining the need for additional data.

Preliminary work indicates that most fractures are strata-bound. Therefore, fluid-flow paths through fractures depend to a large degree on the changes of fracture networks within lithostratigraphic units. Outcrop locations will be chosen to provide lateral coverage and vertical sampling through the stratigraphic section exposed at the surface of Yucca Mountain. The outcrops will provide two-dimensional surfaces through three-dimensional fracture networks.

Three methods are planned for surface fracture studies: (1) bedrock-pavement (pavement method), (2) uncleared-outcrop method (outcrop method), and (3) photogeologic method. For the pavement method, cleared bedrock surfaces are mapped, and fracture parameters are recorded. For the outcrop method, fracture parameters are recorded from incompletely exposed natural outcrops. For the photogeologic method, linear features are mapped from aerial photographs by means of a stereoplotter. Differences between the uncleared outcrop methods and the pavement method hinge on the degree of exposure (and, therefore, mappability) and the number of parameters that can be measured by each method.

Aerial photographs of 1:2,400 scale were used to test the photogeologic method (Throckmorton, 1987). Results of this study showed that most fracture traces were not discernible because of poor exposures and inadequate (too small) photographic scale. In addition, trace bearings and trace lengths measured on the photos differed from those measured in the field, indicating that many traces mapped from the photos represented lineations other than fractures. On the basis of these results, the photogeologic method was rejected, but may be tested again with larger-scale photographs.

Data collected on parameters listed previously will be analyzed in various ways. Fracture orientations (strike and dip) of each network will be plotted onto lower hemisphere equal-area projections. Frequency distributions of fracture trace-lengths, aperture, and surface roughness will be plotted and characterized for fracture networks. Other statistical-geometric methods will be applied to the fracture data base where appropriate. In addition to other analytical methods, a fractual analysis of each pavement will quantify the spatial distribution of fracture traces and fracture trace intersections. Fractual geometry will be used as a means of statistically determining scaling characteristics of fracture networks (Barton et al., 1986). Fractal analysis may offer a technique to characterize the complex three-dimensional fracture systems in the repository block (Barton and Larson, 1985; Barton et al., 1985).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Fracture mapping of hydraulically-exposed pavements and natural washout strips (pavement method)	GP-12,R1	Mapping fractures on pavements, outcrops, and along traverses	6 Mar 83
Uncleared outcrop studies (outcrop method)	GP-12,R0	Mapping fractures on pavements, outcrops, and along traverses	6 Mar 83
Photogeologic method	GP-01,R0	Geologic mapping	1 Mar 83

8.3.1.4.2.2.3 Activity: Borehole evaluation of faults and fractures

Objectives

The objectives of this activity are to

1. Assess the reliability and usefulness of available borehole techniques for identifying and characterizing the subsurface fracture distribution.

2. Determine vertical and lateral variability and characteristics of subsurface fractures.

3. Identify subsurface characteristics of fault zones.

Parameters

The parameters for this activity are

1. Fracture location, dimension, type, orientation, relative chronology, aperture, degree of mineralization, mineralogy of fillings, surface profile, roughness, and apparent frequency.

2. Lateral variability in apparent fracture frequencies and strike directions of fractures within lithostratigraphic units, and subsurface fracturing closely associated with fault zones.

Description

Analysis and interpretation of subsurface characteristics of faults and fractures in the site area will, in part, be based upon (1) core sampling and fracture logging, (2) borehole video camera logging, and (3) acoustic televiewer surveys and logging.

Fracture and fault studies in continuous core will help determine the relative spatial relationships of these features. Measurements will include relative chronology, apertures, and fracture surface characteristics (such as surface profile and roughness), degree of mineralization, and mineralogy of fillings. Attitudes of fractures and faults will be obtained by analysis of oriented cores and by orienting segments of core based on reorientation using paleomagnetic techniques (Activity 8.3.1.4.2.1.5).

The term "roughness" is used to represent the condition of joint roughness, which can be parameterized in different ways including the joint roughness coefficient of Barton and Choubey (1977). The term "roughness coefficient" is used exclusively to refer to this parameterization; whereas the usage "roughness" is more general.

Careful reconstruction and analysis of core segments will not eliminate many of the sampling limitations that are inherent to the study of fractures in near-vertical coreholes, particularly at Yucca Mountain where vertical fractures dominate. Characterization of fractures in core provides only one dimension of the total fracture network and will be integrated with surface studies that provide information from other sampling orientations to help understand sample bias in corehole data. The relatively small sample size of core also precludes the study of fracture dimensions. No distinction can be made between large, through-going fractures and fractures that have very short trace lengths. Future coreholes will be used to aid in planning studies in the exploratory shaft and associated drifts (Activity 8.3.1.4.2.2.4) where more accurate observations of three-dimensional fracture networks can be made.

A continuous visual display of borehole walls will be obtained in future holes drilled in the vicinity of Yucca Mountain by using an instrument assembly that includes a borehole television camera, compass, light source, and digital depth readout. Video-camera tapes will be reviewed and the location, orientation, and relative abundance of fractures will be recorded. Fracture data will be compiled to show changes in the apparent frequency of fractures as a function of depth, stratigraphic unit, and lithostratigraphic unit. Directional orientation histograms will be constructed that illustrate distribution of strike and dip directions within appropriate lithostratigraphic and stratigraphic units. These types of compilations will provide a means for estimating the degree of lateral variability in apparent fracture frequencies and strike directions of subhorizontal fractures within lithostratigraphic units, and provide a means for estimating subsurface fracturing closely associated with fault zones. Variability of vertical fractures will be compiled from mapping in the drifts and horizontal boreholes in the exploratory shaft facility.

Acquisition of a continuous record of fractures intersecting a borehole is the primary advantage of using oriented borehole television to map fractures in the subsurface. However, several limitations of the method can be identified that limit the characterization of fracture networks. They include the following:

1. Data are biased because vertical fractures are not adequately sampled as in core studies.

2. Only one dimension of the fracture network is sampled.

3. Inaccuracies in identifying and measuring the toes and heels of fracture planes that cut the borehole limit data acquisition from borehole television to strike and dip directions only; the amount of dip of fracture planes often cannot be confidently measured and, therefore, true fracture spacings cannot be obtained.

4. Important fracture parameters that are useful for characterizing fracture sets, such as persistence, roughness, and mineral coatings, cannot be measured directly from borehole television images.

The significance and validity of subsurface fracture analyses based on core and television camera logging will depend largely on comparison with results of fracture analyses conducted in the exploratory shaft and associated underground workings.

Acoustic televiewer logging is an additional technique that can be used to study the distribution of fractures in the saturated zone by inspection of borehole walls. The televiewer provides an oriented image of the acoustic scattering profile of the borehole, in the form of a continuous log. The borehole is displayed on the log as if it were split vertically along magnetic north and unrolled onto a vertical plane. Nonvertical fractures form distinctive sinusoidal features that can be used to measure strike and dip directions as well as the amount of dip.

Fracture attitudes will be measured from existing televiewer logs as well as from logs of future holes. Data sets will be compiled to show the vertical variations as a function of depth and lithostratigraphic units. As in the analysis of fractures from video-camera observations, data will be displayed on direction orientation histograms. This will allow comparative analyses between drillholes. Unlike the video-camera log, the amount of dip often can be calculated from the televiewer log at depths where accurate determinations of hole diameters can be made from existing caliper logs. Acquisition of these data will allow application of statistical methods such as stereonet contouring to determine the significance of any preferential spatial distributions.

Several other borehole geophysical methods, including borehole-to-borehole techniques, will be evaluated in available drillholes at the site. These methods will include borehole radar, crosshole resistivity, crosshole EM, crosshole radar, and high resolution crosshole seismic surveys (Table 8.3.1.4-4). Evaluations also will involve comparative studies of the various methods used to identify subsurface fractures. Stratigraphic intervals for which fracture data are available for several subsurface techniques will be analyzed to assess the utility of each method.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.3 are given in the following table.

Method	Technical procedure Number	Title	Date
Core sampling and fracture logging, including oriented core	GP-11,R0	Logging fractures in core	15 May 85
	GP-16,R0	Procedure for the handling and storage of drill core at the core library	20 May 87
	GP-19,R0	Procedure for the identification, handling, and disposition of drillhole core and cutting samples from the drill site to the core library	6 Mar 87
	GPP-06,R0	Rock and paleomagnetic investigations	1 Nov 84

Method	Technical procedure Number	Title	Date
Borehole video camera survey and logging	GP-10,R0	Borehole-video fracture logging	12 Apr 85
Acoustic televiewer surveys and logging	GP-13,R0	Fracture logging from acoustic-televiewer images	8 Jan 87
	GPP-04,R0	In situ stress investigations	27 Jun 83
	HP-02,R0	Acoustic televiewer investigations	14 Aug 84

8.3.1.4.2.2.4 Activity: Geologic mapping of the exploratory shaft and drifts

Objectives

The objectives of this activity are to

1. Determine the vertical and horizontal variability of fracture networks in the exploratory shaft facility shaft, drifts, and boreholes.

2. Characterize major fault and fault zones in the subsurface.

3. Map the lithostratigraphic features of the subunits, and the abundance and character of lithophysal zones.

4. Assist in evaluation of test locations in the exploratory shaft test facility.

Parameters

Three categories of parameters are required for this activity.

1. Fault parameters:

   a. Geometry.

   b. Physical characteristics.

   c. Tectonic styles of faults bounding the repository on the northeast and east, and of the Ghost Dance fault.

2. Fracture parameters:

   a. Orientation.
   b. Aperture.
   c. Roughness.
   d. Fracture persistence.
   e. Surface characteristics.
   f. Mineralogy.
   g. Relative ages.
   h. Spatial distribution.

3. Stratigraphic parameters:

   a. Hard-specimen lithology of Yucca Mountain stratigraphic sequence.

   b. Lateral variability of repository host horizon.

Description

Figure 8.3.1.4-10 shows the conceptual layout of the exploratory shaft facility with drift projections to major structural features. Subsurface structures, such as the Drill Hole Wash and imbricate normal fault zones near the northeastern and eastern boundaries respectively, of the repository, will be directly studied at the ends of northeast and southeast drifts. The character of the Ghost Dance fault within the repository will be investigated by a northwest drift. Lateral variability of the lithologic character of the repository host rock will be determined. Data obtained from fracture mapping in the drifts will be combined with fracture data from the shafts (ES-1 and ES-2) and surface studies to describe the three-dimensional fracture network within the exploratory shaft facility.

Geologic mapping of the exploratory shaft will take place after each round of excavation is completed and after the new wall exposures are cleared and surveyed.

Mapping in the shafts and drifts can provide a detailed description of stratigraphic, lithologic, and structural features and will provide data as required by 10 CFR 60.21(c) for inclusion in the safety analysis report. Descriptions of fracture networks and intersections are enhanced by continuous observation because fracture spacing and attitude commonly vary over distances of tens to hundreds of meters. Both objectives can be met in a timely manner by a two-tiered approach to the mapping: (1) analysis of stereoscopic photographs (photogrammetric geologic mapping) and (2) continuous detailed mapping along reference lines (detailed line surveys).

Stereoscopic photographs will be taken of all exposed surfaces in the exploratory shafts, and walls and crown of all drifts in the exploratory shaft facility, as mining progresses; floors and working faces will not be mapped unless anomalous geologic features are exposed. Geologic maps will include discontinuities such as faults, fractures, breccia zones, and other features of interest including lithologic and stratigraphic features. These features will be identified based in part, but not exclusively, on prede-

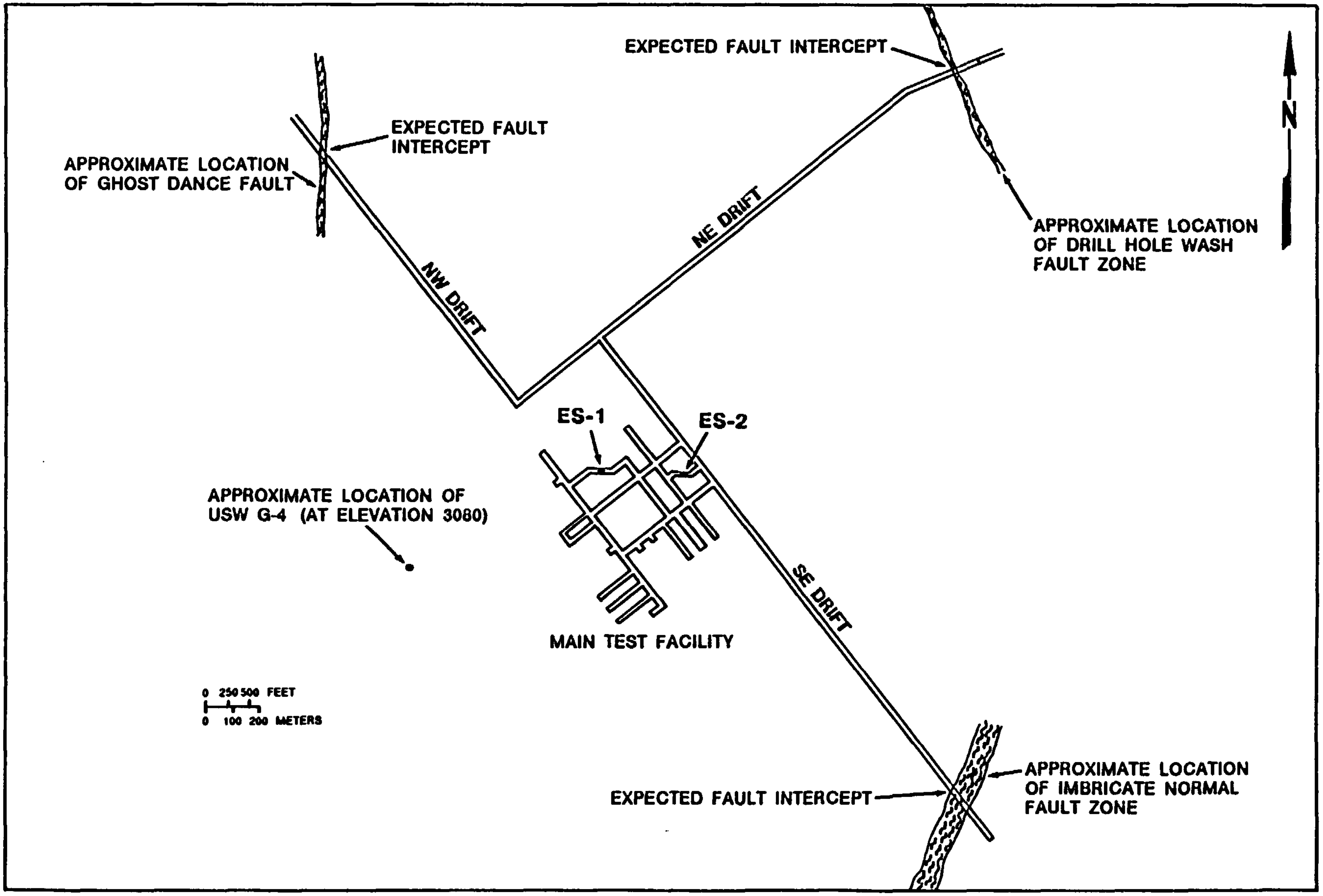


Figure 8.3.1.4-10. Proposed layout of exploratory shaft and drifts. Note: Figure does not exactly represent Title I design layout.

termined criteria. The maps will be prepared from stereoscopic photographs using close-range photogrammetry and direct observation.

Stereophotography and in situ mapping of the shafts and drifts will be done routinely as fresh rock is exposed. Close-range photogrammetry will provide continuous data in the shafts and drifts. In the shafts, detailed in situ measurements will be made of geologic features along horizontal reference lines approximately 2 m apart in ES-1 and along horizontal lines spaced approximately 15 m apart in ES-2. In the drifts, line surveys will be done continuously along one wall, or more as required at significant changes or geologic features.

Detailed mapping will be emphasized in the area adjacent to the exploratory shaft facility tests, areas near major geologic structures within the repository, and across geologic structures near the borders of the repository. In addition, investigators will make detailed maps of test rooms and will log cores from holes drilled for hydrologic, geomechanical, and geochemical tests in the ESF test area.

If unusual zones of alteration or fracture-filling minerals are encountered, representative samples will be acquired in conjunction with geologic mapping, as appropriate for mineralogical and age determinations. The location of origin of such samples, and the observed relationships between fracture mineralization and fracture orientation, will be recorded. Petrographic and x-ray diffraction analysis, and uranium-thorium disequilibrium dating, will be performed on collected samples by scientists working on other activities.

In addition to sample collection performed by geologists working on this activity as described above, two 55-gal (210-L) drums of muck will be obtained from every round for the use of geologists working on other activities and for future use of investigations within the Project. These samples will be stored at the Yucca Mountain Project Core Storage Facility.

Fracture coatings are more commonly preserved underground than near the surface, and are protected to a greater degree from isotopic exchange. Uranium-thorium disequilibrium dating of calcite and uraniferous opal will be performed as a part of other activities (Investigation 8.3.1.3.2). Electron spin resonance (ESR) dating of quartz and potassium-argon dating of clay fracture coatings from subsurface samples will also be performed as a part of Investigation 8.3.1.3.2.

Studies of fracture-filling mineralogy by other activities will be used to determine formation of the filling minerals to help infer the ages of fracturing and to estimate rates of tectonism. This information will be used in assessments of the potential for and likely character of additional fracturing and seismic activity at Yucca Mountain. The results of these analyses will be integrated with the evaluations planned for postclosure and preclosure tectonics and repository design.

Analyses of the ages of fracture mineralogy also provide information to aid in the interpretation of past fracture hydrologic-mineralogic processes in the repository host rock and surrounding units. These studies will be integrated with fracture mineralogy evaluations in unsaturated zone hydrology and mineralogic and geochemical activities.

Products derived from this activity will include (1) a stereophotographic record of the geologic features exposed on the walls of ES-1 and ES-2 and on the walls and crown of all drifts; (2) geologic maps (combination in situ and photogrammetric) of lithologic, stratigraphic, and structural features including fracture networks as exposed on the walls of shafts ES-1 and ES-2 and on the walls and crown of all drifts; (3) fracture orientations and statistical distributions; (4) fracture persistence and statistical distributions; (5) fracture roughness and statistical distributions; (6) fracture apertures and statistical distributions; (7) fracture infilling percentage and statistical distributions; (8) fracture intersection data; (9) two- and three-dimensional expression of fracture density; (10) three-dimensional estimate of fracture network characteristics and variability (fractural analysis); (11) structural domains; (12) tectonic style; (13) paleostresses as suggested by displacements along faults; (14) lithology and stratigraphy; (15) an assessment of the lateral variability of geologic features within the shafts and drifts; and (16) representative lithologic and mineralogic samples.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
In situ measurement and recording of geologic features in the shafts and drifts	TBD[a]	In situ measurement of geologic features	TBD
Stereophotographic recording of geologic features in exploratory shafts and drifts	TBD	Photogeologic recording	TBD
Borehole logging in the exploratory shaft and drifts	TBD	Borehole logging in the exploratory shaft and drifts	TBD
Sampling of fracture filling minerals	TBD	Sampling of fracture filling minerals	TBD

Method	Technical procedure Number	Title	Date
Sampling lithologies in exploratory shafts and drifts	TBD	Sampling lithologies in exploratory shafts and drifts	TBD

[a]TBD = to be determined.

8.3.1.4.2.2.5 Activity: Seismic tomography/vertical seismic profiling

Objectives

The objectives of this activity are to

1. Investigate, and if successful, provide a means for broadly detecting and characterizing the subsurface fracture network in regions between the surface, boreholes, and underground workings.

2. Calibrate and relate the seismic propagation characteristics of the host rock to the fracture patterns observed in boreholes and underground workings, and to extrapolate the observed fracture patterns to the surrounding region.

Parameters

The parameters for this activity are travel time, amplitudes, and polarizations of the direct, reflected, and refracted compressional and shear waves (SH and SV), as well as other wave propagation characteristics identified by investigating the relationship of wave propagation characteristics to fracture properties.

Description

Tomographic vertical seismic profiling (VSP) techniques may be used to study the degree and character of fracturing of the rock mass. Feasibility studies will be performed to establish whether these techniques are applicable to the unsaturated zone at Yucca Mountain. If they are successful, then multi-offset, multisource (P, SV, and SH) VSP surveys would be conducted between the surface and existing drillholes, and between the surface and the underground excavations of the exploratory shaft facility, to detect and map spatial variation of seismic propagation characteristics in the repository area. Seismic characteristics are expected to correlate in a useful manner with observed fracture characteristics. The objective will be to derive a series of maps of the fracture characteristics of the subsurface, to be used in development of a three-dimensional descriptive model of fracturing at Yucca Mountain. From previous VSP studies, it is estimated that significant spatial variation of seismic propagation characteristics may be detected using pixels with dimensions as small as 20 m. The velocities, amplitudes, and polarizations of seismic phases recorded on three-component sensors may be used to broadly characterize fracture orientations, density, and spacing. Tomographic analysis using the travel times, amplitudes, and shear wave polarization may be used to relate seismic characteristics to the fracture characteristics. Three-component sensors will be placed in available boreholes with the compressional and shear wave sources placed at the surface. Interpretation of surveys in boreholes will be augmented by performing similar surveys in the shafts and underground workings where more direct observations of fracture characteristics can be obtained. The hydrologic, geochemical, and geomechanical test results obtained in the exploratory shaft facility will be evaluated in terms of the fracture information from the VSP surveys. If successful, the VSP approach may provide a means for extrapolating important characteristics of the site directly measured at select locations to the greater region encompassed by VSP studies.

The following steps are proposed for the VSP work. First, structural and fracture domains with similar properties will be selected and defined in the exploratory shaft facility soon after each section of shaft has been mapped. Second, appropriate sensors will be installed in drillholes into the shaft wall, providing a vertical array of sensors that can then be used to carry out the VSP work with the P- and S-wave sources at the surface. (A similar array of sensors also will be installed in ES-2 and the drift walls to all additional ray path coverage.) Finally, after the instrumentation has been emplaced, the VSP survey will be conducted.

Laboratory analysis of core samples will be performed to observe and measure seismic propagation effects needed for interpreting the characteristics of the in situ rock mass. Fractured and unfractured specimens will be subjected to seismic excitation at test conditions (frequency, strain amplitude) representative of field test conditions.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.5 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Tomographic/vertical seismic profiling surveys using P- and S-wave data	TBD[a]	Yucca Mountain Project vertical seismic profiling	TBD

[a]TBD = to be determined.

8.3.1.4.2.3 Study: Three-dimensional geologic model

Objectives

The objective of this study is to develop a three-dimensional geologic model of the site area. In doing so, much of the study will involve synthesis of the results of other studies in the investigation to develop a model that will be integrated into the three-dimensional rock characteristics model described in Study 8.3.1.4.3.2 of Investigation 8.3.1.4.3.

8.3.1.4.2.3.1 Activity: Development of a three-dimensional geologic model of the site area

Objectives

The objective of this activity is to develop a three-dimensional geologic model of the Yucca Mountain site that incorporates stratigraphic, structural, geophysical, and rock properties information pertinent to site characterization, and design and performance assessment activities.

Parameters

The parameters of this activity fall into three categories.

1. Stratigraphy-lithology (lateral and vertical variations in lithostratigraphic units):

    a. Depth.
    b. Thickness.
    c. Attitude.
    d. Welding and crystallization.
    e. Alteration.
    f. Petrography.
    g. Lithophysal zones in Topopah Spring Member.
    h. Geophysical characteristics.

2. Faults:

    a. Distribution.
    b. Displacements.
    c. Orientations.
    d. Age relationships.
    e. Physical features.
    f. Geophysical characteristics.
    g. Tectonic styles.

3. Fractures:

    a. Spatial distribution.
    b. Frequencies.
    c. Persistence.
    d. Orientations.

e. Age relationships.
f. Surface characteristics.
g. Interconnectedness.
h. Aperture.
i. Filling mineralogy.
j. Mineral infilling distribution.
k. Geophysical characteristics.

Description

Geologic data that are collected from coreholes, drillholes, outcrops, and geophysical studies will be used to construct isopach maps, structural contour maps, correlation diagrams, and cross sections. These illustrations will show the distribution and lithologic variability of stratigraphic units that underlie the site and surrounding areas such as Crater Flat and Jackass Flats. Principal scales of compilations will be 1:48,000, 1:24,000, and 1:12,000.

As stratigraphic, structural, and geophysical studies progress from data collection and documentation phases into interpretation phases, important sources of information will be reviewed, assessed, and integrated into a model that describes all relevant aspects of the site geology. This descriptive model will also incorporate geologic constraints discovered during development of models of the depositional and diagenetic histories of units.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.3.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Synthesis of geologic and geophysical data	TBD[a]	No technical procedure required based on existing data	TBD

[a]TBD = to be determined.

8.3.1.4.2.4 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:

The areas of performance assessment include the following:

Issue or information need	Subject
1.1.1	Site information needed to calculate the releases of radionuclides to the accessible environment (Section 8.3.5.13.1)
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)
1.8	NRC siting criteria (Section 8.3.5.17)
2.4.1	Site and design information required to support retrieval (Section 8.3.5.2.1)

The areas of design include the following:

Issue or information need	Subject
1.10.4	Description of the postemplacement near-field environment (Section 8.3.4.2.4)
1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility that contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions (Section 8.3.2.2.3)
1.11.6	Predicted thermal and thermomechanical response of the host rock, surrounding strata, and ground-water system (Section 8.3.2.2.6)
1.12.1	Site, waste package, and underground facility information needed for design of seals and their placement methods (Section 8.3.3.2.1)
2.7.1	Radiological protection (Section 8.3.2.3.1)
4.2.1	Site performance information needed for design (Section 8.3.2.4.1)
4.4.1	Site and performance information needed for design (Section 8.3.2.5.1)

The areas of characterization include the following:

Investigation	Subject
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
8.3.1.3.2	Mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths
8.3.1.4.2	Geologic framework
8.3.1.4.3	Three-dimensional rock characteristics model
8.3.1.8.2	Tectonic effects on waste package
8.3.1.15.1	Spatial distribution of thermal and mechanical properties
8.3.1.15.2	Spatial distribution of ambient stress and thermal conditions
8.3.1.17.2	Potential fault movements at the site

8.3.1.4.3 Investigation: Development of three-dimensional models of rock characteristics at the repository site

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections summarize available data relevant to the development of three-dimensional models of rock characteristics for the repository area and the immediate vicinity.

SCP section	Subject
1.2.2.2	Cenozoic rocks (stratigraphy and lithology at Yucca Mountain)
1.3.2.2.2	Structures and structural history of Yucca Mountain
1.8.1.2	Stratigraphy and lithology (summary of significant results)
1.8.1.3	Structural geology and tectonics (summary of significant results)

SCP section	Subject
1.8.2.1	Relation of geology to repository design
2.9.1.1	Geoengineering properties (summary)
2.9.1.2	Relationship of data to performance objectives
2.9.1.3	Preliminary evaluation of data uncertainty
3.6.1	Hydrogeologic units
3.10.1	Summary of significant results (hydrogeology)
4.5	Summary of significant results (geochemistry)

Parameters

The principal result of this investigation will be the development of computer-based representations of the three-dimensional distribution of physical property data. Contour maps or cross sections will show the spatial distribution of such parameters as rock compressive strength, thermal conductivity, or gas permeability. Specific parameters to be modeled include those rock characteristics parameters requested as input to design or performance assessment information needs. As an intermediate step in the three-dimensional modeling process, this investigation will provide data such as porosity, saturated hydraulic conductivity, and saturation to provide a basis for defining the detailed spatial variability of the tuff rock mass upon which all rock characteristic distributions depend. Analysis of the core obtained by this study will also provide data pertaining to the following:

1. Location of geologic contacts.

2. Basic rock descriptions including degree of welding, types of pumice or lithic fragments, abundance of lithophysae, gross mineralogy, and alteration.

3. Subsurface characteristics of faults.

4. Fracture frequencies and orientation.

5. Rock quality designation.

The core will be available for more detailed examination of lithology, fractures, faults or other geologic features by other studies and investigations (particularly Investigation Section 8.3.1.4.2, geologic framework). As additional information from detailed study of core, geophysical logs, and other investigations becomes available, the three-dimensional model will be modified to reflect the new data.

Purpose and objectives of the investigation

The purpose of developing three-dimensional, computer-based models of rock characteristics at the Yucca Mountain site is two-fold: (1) to summarize information gained during the course of Investigations 8.3.1.4.2 (geologic framework), 8.3.1.2.1 through 8.3.1.2.3 (hydrologic material properties), (thermal/mechanical properties) and (2) to provide a mechanism for transfer of this integrated information to the design and performance assessment issues.

Specifically, performance assessment and design issues have called for quantitative information regarding the spatial distribution of various rock characteristics (Table 8.3.1.4-1). Numerous investigations have been designed to acquire the basic quantitative data or to develop the geologic framework that must be considered in the development of a three-dimensional model of rock characteristics.

Technical rationale for the investigation

This investigation consists of activities that integrate information collected by numerous other investigations. These diverse types of field and laboratory data are presented in the form of three-dimensional models of rock characteristics--models that have been requested by, and that will be utilized directly by, design and performance assessment studies.

Construction of a three-dimensional block model of rock properties that represents actual rock characteristics at the Yucca Mountain site is much more than the arbitrary "plugging" of quantitative values for some rock property into the proper "box" in three-dimensional space. Interpolation algorithms are numerous, yet application of different procedures may yield vastly differing interpretations of identical input values. The critical factor for developing a model that is representative of in situ conditions is the extent to which the quantitative determinations of some rock property value are constrained by the geologic framework (Investigation 8.3.1.4.2) of the Yucca Mountain area. A porosity model that does not respect constraints imposed by geologic knowledge of the eruptive and depositional history of the rocks involved, the general vertical and lateral variability of similar rocks elsewhere, and the observed displacement of original rock units by faulting will not be generally accepted and therefore will not be useful to a performance assessment analyst or design engineer.

The essential philosophy of model development will be to use detailed information regarding the spatial structure of selected rock characteristics (e.g., porosity, saturated hydraulic conductivity) obtained by Study 8.3.1.4.3.1 (systematic drilling program) and less abundant, quantitative rock characteristics data obtained by Investigations 8.3.1.2.1. through 8.3.1.2.3, 8.3.1.3.2 and 8.3.1.15.1 in order to determine the spatial correlation structure of the rock characteristic(s) under current consideration. Quantitative descriptions of the identified spatial structure will be compared with descriptions of the geologic framework of Yucca Mountain (Investigation 8.3.1.4.2), and major discrepancies will be resolved. The quantitative descriptive data will then be interpolated and projected using a standard mathematical algorithm to create a model of the desired property(ies) as requested by performance assessment and design issues.

8.3.1.4.3.1 Study: Systematic acquisition of site-specific subsurface information

Only one activity is planned under this study.

8.3.1.4.3.1.1 Activity: Systematic drilling program

Objectives

This activity will acquire physical rock samples, analytical data, and basic descriptions of the subsurface geology of the repository site on a systematic basis. These samples and information are important for characterizing the three-dimensional distribution of rock characteristics, and hydrologic and geochemical variables, for the unsaturated zone at Yucca Mountain. Other information and samples will also be provided because of this access to the shallow saturated zone.

Borehole locations and drilling methods used by this activity are technically and programmatically integrated with other activities, including 8.3.1.2.2.3.2 (site vertical boreholes study), 8.3.1.2.3.1.1 (Solitario Canyon fault study in the saturated zone), and 8.3.1.2.3.1.2 (site potentiometric-level evaluation). Consistent with the requirements of 10 CFR 60(d)(4), the location and drilling of the boreholes in the systematic drilling program are being coordinated with the repository design. More detail on this coordination effort (particularly regarding the potential impact on repository performance of site characterization activities in general and the systematic drilling program in particular) is provided in Section 8.4. The integration and coordination of these activities will be accomplished in Activity 8.3.1.4.1.1, development of an integrated drilling program.

Parameters

Parameters to be provided through the acquisition of samples and data by this activity include the following:

1. Locations of contacts of geologic and thermal-mechanical stratigraphic units (Ortiz et al, 1985).

2. Lithologic and petrologic descriptions of core or cuttings, including welding and primary crystallization characteristics.

3. Locations and characteristics of lithophysal zones and other altered zones.

4. Locations and characteristics of faults.

5. Fracture frequency and orientation.

6. Core recovery data, including rock quality designation (RQD).

7. Matrix porosity.

8. Unsaturated matrix hydraulic conductivity.

9. Matrix saturation and in situ potential.

The sample logging, wireline logging, and laboratory testing needed to investigate these parameters will be conducted under the associated geologic, hydrologic, and geochemical activities. The strategy for locating boreholes is based on the requirements of the three-dimensional rock characteristics model (Study 8.3.1.4.3.2), and on other studies that involve analysis of spatial variability (e.g., Activity 8.3.1.2.2.3.1, matrix hydrologic properties testing). The objectives of this strategy are to provide areal coverage within and immediately adjacent to the perimeter drift and to provide information for the evaluation of the geostatistical approach for characterizing spatial variability and obtaining representative data.

Description

Surface based testing planned for site characterization may be categorized according to two different approaches: the "feature sampling" program or the systematic program. The feature sampling approach tests specific hypotheses about behavior of the site; boreholes are located where anomalous behavior is expected or proximal to important structures controlling variability. The systematic approach uses only certain information for locating boreholes, and thus, is unbiased with respect to what is known about the site. Representative (conditionally unbiased) sampling may yield smaller predictive uncertainty if known anomalies are avoided, or greater uncertainty if extreme behavior is not restricted to known anomalies. The systematic approach relies on the feature sampling approach, and thus on hypothesis testing, for characterizing extremes. The systematic approach involves more closely spaced boreholes in the immediate site area than the feature sampling approach. Both approaches provide the sampling coverage needed for engineering design and performance assessment calculations.

The systematic drilling program consists of twelve boreholes, located in conjunction with the feature sampling program, including (1) seven boreholes to provide areal coverage and (2) five boreholes to provide information for evaluation of the geostatistical approach. The systematic drilling program is intended to provide samples and data for evaluating the variability of hydrologic, geochemical, geomechanical, and other characteristics as discussed in Section 8.4.2.1.5. This information, in conjunction with that from the feature sampling program, will be used to evaluate the current understanding of unsaturated-zone flow and transport and alternative hypotheses for flow processes. The most pervasive data needs are for the immediate site area where such processes as gaseous transport lateral diversion, fracture-matrix interaction, nuclide sorption in the unsaturated zone, and geomechanical rock mass response could significantly affect site performance. The systematic drilling program, therefore, focuses on the immediate site area; additional information from outside the area will be obtained from various existing and planned boreholes of the feature sampling program.

If feature(s) are discovered, characterization plans will be reevaluated and may be modified. It is expected that the feature sampling program would be modified, for example, by adding drillholes to the site vertical boreholes study of the unsaturated zone to investigate newly discovered features.

However, the systematic drilling program could also be modified by changing the location of a planned borehole or adding a new one. Data from the feature sampling program and the systematic program will be reevaluated on an ongoing basis during site characterization, as discussed in Investigation 8.3.1.4.1 (development of an integrated drilling program). All drilling plans are flexible and can be modified as the result of ongoing evaluation.

The unsaturated portion of each borehole will be drilled dry, without the use of water or other conventional drilling circulation liquids, to preserve sample quality and prevent damage to the formation to the extent practicable. Each borehole will be drilled to a depth of approximately 100 m below the water table; the unsaturated zone will be protected by casing or other means from water produced while drilling below the water table. Other drilling criteria are (1) continuous core sampling capability; (2) penetration to at least 2,600 ft; (3) monitoring of circulation air for immediate detection of perched water in the unsaturated zone; (4) modest drill pad requirements (i.e., approximately 200 ft in the largest dimension); and (5) incorporation of borehole standoff from repository drift into the borehole siting. Borehole locations were selected according to the areal coverage and spacing criteria described below, and then modified slightly where necessary to provide better access in rugged terrain, thus reducing surface disturbance. The selection of a drilling method is linked to the results of prototype drilling, which is associated with the site vertical boreholes study (Activity 8.3.1.2.2.3.2).

Areal Coverage

Seven boreholes, USW SD-1 through USW SD-7, are located within or just outside of the conceptual perimeter drift boundary (CPDB) (Figure 8.3.1.4-11). These seven holes, when combined with planned USW boreholes UZ-2, UZ-3, UZ-7, UZ-8, H-7, MP-1, and MP-2 of the feature sampling program, result in approximately uniform areal coverage of the area within the CPDB at an effective borehole spacing of roughly 3,000 ft. (MP-1 and Mp-2 are described in Section 8.3.1.2.2.4.9) Figure 8.3.1.4-11 shows the planned borehole locations with circles of a 1,500-ft radius centered at each borehole; deviations from regular coverage result from a requirement for reasonable access in the rugged terrain. Two quantities were considered in adopting the 3,000-ft spacing: (1) the correlation length for variability of basic physical properties (e.g., matrix porosity; pneumatic conductivity) and (2) the minimum number of boreholes in the feature sampling program with which data from the systematic program will be compared for detection of bias.

The tuffaceous beds of the Calico Hills have been designated as a primary barrier for waste isolation in the performance allocation process described in Section 8.1. Hand samples collected along the arbitrarily selected horizon in outcrop indicated that the maximum range of statistical correlation for physical properties (porosity and air permeability) of this unit was roughly 3,000 ft (Rautman et al., 1988). This 3,000-ft distance is a preliminary estimate of the distance over which these properties can be interpolated using the geostatistical approach. These preliminary results suggest that one or more boreholes should be less than 3,000 ft away from any given location to reduce the uncertainty (relative to taking the mean and standard deviation of all the data). The 3,000-ft spacing also provides that for 87.2 percent of the area within the CPDB, any given point within the CPDB will be less than 1,500 ft away from at least one borehole. The integrated feature sampling and

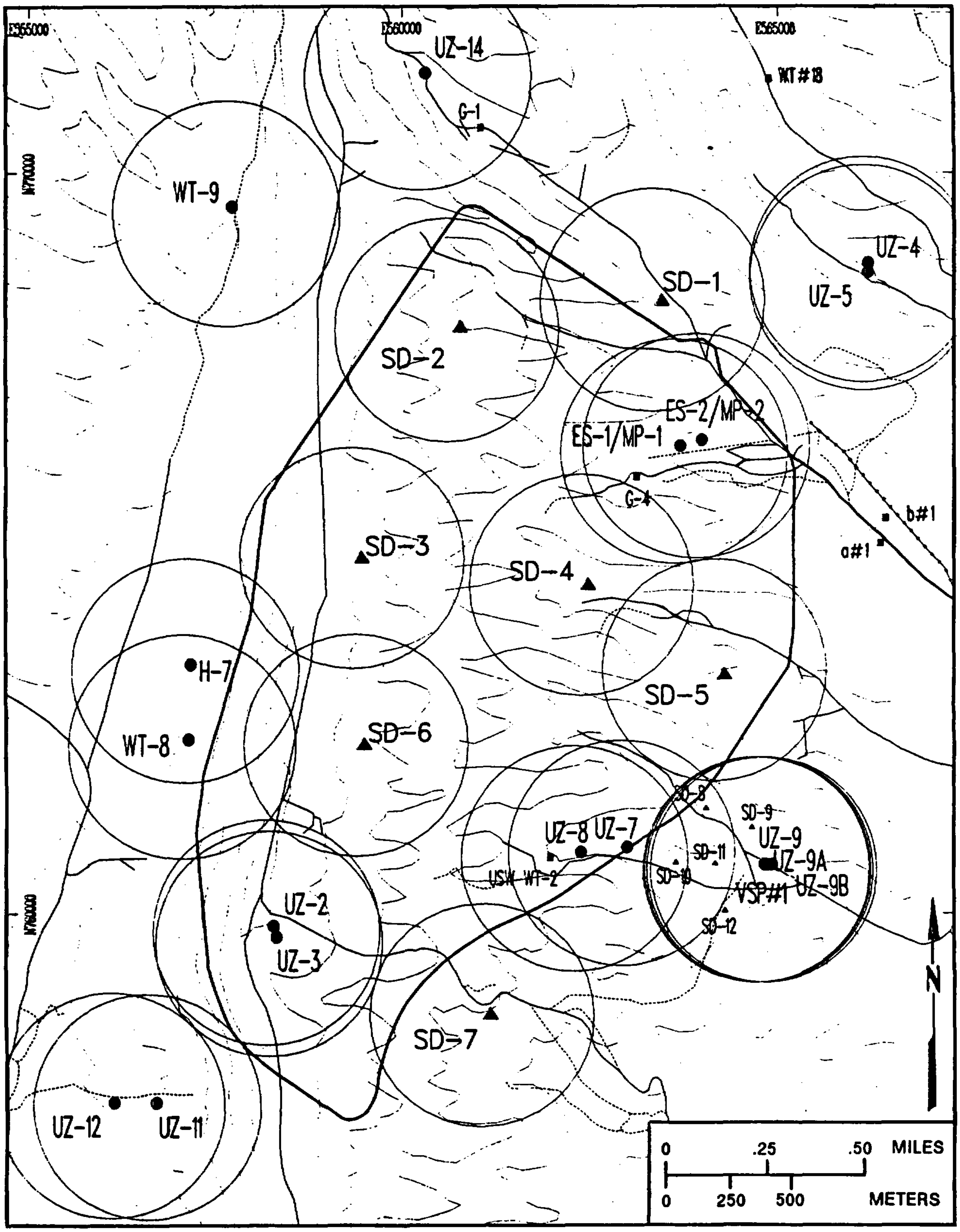


Figure 8.3.1.4-11a. Yucca Mountain systematic drilling program– areal coverage scheme. See Figure 8.3.1.4-11b for legend.

LEGEND

▲ SYSTEMATIC DRILLING PROGRAM

● FEATURE SAMPLING PROGRAM INTEGRATED WITH SYSTEMATIC PROGRAM

■ EXISTING HOLES SUITABLE FOR RESAMPLING

500 FOOT BUFFER

LIGHT DUTY ROADS

UNIMPROVED ROADS

TRAILS

POWERLINES

PERIMETER DRIFT BOUNDARY

SOURCES:

50 M ELEVATION CONTOURS - USGS 1:100,000 BEATTY QUAD

1956 1:24,000 USGS TOPOGRAPHIC MAPS

1976 1:24,000 USGS ORTHOPHOTO MAPS

1983 1:100,000 USGS TOPOGRAPHIC MAPS

7/1986 AND 9/1987 1:24,000 AERIAL PHOTOGRAPHY

GRID TICKS BASED ON NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE

PERIMETER DRIFT BOUNDARY - SNL DRAWING R07003A

MAP COMPILED IN AUGUST 1988

NOTE: THE FOLLOWING DRILL HOLES SHOWN ON FIGURE 8.3.1.4-11a ARE WITHIN THE NEVADA TEST SITE BOUNDARY AND ARE DESIGNATED WITH PREFIX UE25: a#1, b#1, WT#18, UZ-4, UZ-5, UZ-9A, UZ-9B, SD-9, AND VSP#1. ALL THE REST ARE DESIGNATED WITH THE PREFIX USW.

Figure 8.3.1.4-11b. Legend for Figure 8.3.1.4-11a.

systematic drilling programs will thus provide acceptable areal coverage of the area within the CPDB. If a geostatistical model with correlation length of about 3,000 ft or more is used in conjunction with performance assessment, then reduction of statistical uncertainty throughout the site area would result without additional drilling.

An alternative basis for the number of boreholes in the areal coverage scheme is to approximate the minimum number of similar boreholes in the feature sampling program, with which statistical comparison can be used for detection of bias. The number of such boreholes in the feature sampling program has been set by plans for hypothesis testing. Seven such boreholes are planned in the immediate site vicinity including USW holes UZ-2, UZ-3, UZ-7, UZ-8, H-7, MP-1, and MP-2 (Activities 8.3.1.2.2.3.2, 8.3.1.2.3.1.1, and 8.3.1.2.2.4.9). Other such boreholes are also available at slightly greater distances from the site. In general the number of boreholes in the "unbiased" set should be comparable to the number of other boreholes, for statistical comparison. This rationale assumes that the Calico Hills unit will eventually be investigated by borehole penetration or possibly excavation at the exploratory shaft facility location. This outcome may be realized through a decision to proceed with shaft penetration (discussed in Section 8.4.2.1.6.1), or through additional drilling beyond the twelve planned boreholes of the systematic drilling program.

Geostatistical evaluation

The systematic drilling program is intended to provide sufficient data for meaningful evaluation of the geostatistical approach to modeling spatial variability, particularly for basic matrix properties including porosity, saturation, and saturated hydraulic conductivity. Preliminary plans for new drilling, combined with data from existing boreholes, will provide information about the spatial variation of certain rock characteristics at the site.

The information needed to evaluate the geostatistical approach consists of sufficient numbers of pairs of observations (boreholes) separated by various distances ranging from about 1,000 ft up to about 10,000 ft. The lower separation value corresponds roughly to the upper spacing limit of sampling in the ESF and associated boreholes. The upper value approximates the maximum dimension of the CPDB.

Trend analysis is typically required for geostatistical evaluation. Data trends with depth or borehole location may be related to such factors as distance to the eruptive source of a tuff unit, or stratiform lithologic differentiation that occurs during welding and cooling (Section 8.4.2.1.5.4). Methods used for trend fitting usually require data from outside the study area (e.g., outside the CPDB) to constrain the trend model at the edges of the study area. A wide distribution of boreholes, is therefore, needed for detection and modeling of data trends within the site area. For hydrologic state information (e.g., matrix saturation), this control will be provided by a number of planned boreholes outside the perimeter drift (including UE25 holes UZ-4, UZ-5, UZ-9, UZ-9A, and UZ-9B, and USW holes UZ-10, UZ-11, UZ-12, UZ-13, UZ-14, WT-8, and WT-9). The same boreholes may be used for modeling trends in stratigraphy or physical properties, and additional control may be obtained from numerous existing boreholes (including UE25 holes a#1, b#1, c#1, c#2, c#3, and WT#18, and USW holes H-1, H-3, H-6, G-1, G-2, G-3, GU-3, WT-1, WT-7, and UZ-1).

Gridded locations provide the maximum density of borehole pairs at discrete spacings; however, the need to control surface disturbance at Yucca Mountain, and the integration of systematic drilling with the feature sampling program, make a gridded program impractical. Instead, a standard approach is used whereby borehole pairs are grouped in spacing ranges. A rule of thumb for geostatistical analysis holds that the number of pairs in each spacing range should be at least 30. The actual number of pairs that is acceptable for each spacing range will depend heavily on the data values. However, the rule is a valid basis for planning the systematic drilling program, because insufficient information is available (especially at the smaller spacings) to indicate otherwise.

According to statistical principles, the borehole pairs used for statistical modeling should reside within a domain where it is physically reasonable to use a single model for prediction, and where certain statistical properties of variability are uniform. For the systematic drilling program, the domain is taken as the area within the perimeter drift and immediate vicinity. It would be impractical to drill the entire domain at 1,000-ft spacing, and so the small spacings are investigated in a limited area. The assumption that this area is representative of the domain will be evaluated from the results of the twelve planned boreholes, and other boreholes of the feature-sampling program, and possibly investigated further in additional systematic drilling.

Boreholes SD-8 through SD-12 on Figure 8.3.1.4-12 are located just outside the southeastern part of the CPDB. They are clustered in reasonably accessible locations near USW UZ-7, USW UZ-8, and the UE25 UZ-9/9A/9B complex of boreholes, which increases the number of spacings. The distribution of different spacings possible from the systematic drilling program (USW holes SD-1 through SD-8 and SD-10 through SD-12, and UE25 SD-9), plus the other planned penetrations indicated on Figure 8.3.1.4-11, is shown by the histogram of Figure 8.2.1.4-13. The spacings in this figure are sorted in ranges of 1,000 ft, but may be redefined if appropriate for geostatistical modeling. Several existing boreholes within the perimeter drift or immediate vicinity are accessible for relogging and resampling; if these holes (USW holes UZ-6, UZ-6S, H-6, G-1, G-3, GU-3, G-4, and WT-Z; and UE25 holes a#1, b#1, c#1, c#2, and c#3) are included in the spacing compilation, the histogram of Figure 8.3.1.4-14 results. The two figures show that the systematic drilling program, together with existing boreholes and additional planned drilling, results in greater than 30 borehole pairs in spacing ranges up to 10,000 ft. Thus the systematic drilling program meets the requirements for geostatistical evaluation, and will provide significant additional information for a subset of rock characteristics if integrated with existing boreholes.

Some loss of information may be incurred from separate use of boreholes located in clusters, for generating larger spacings. For example, the USW UE25 USW UZ-9 complex of boreholes (spaced about 100 ft apart) will be used in conjunction with USW holes SD-8, SD-10, SD-11, and SD-12; and UE25 SD-9 for generating multiple spacings of 1,000 ft or more. This effect depends on the correlation structure, and on persistence of residual trends in the data set. When the data from the boreholes just listed become available, the effect will

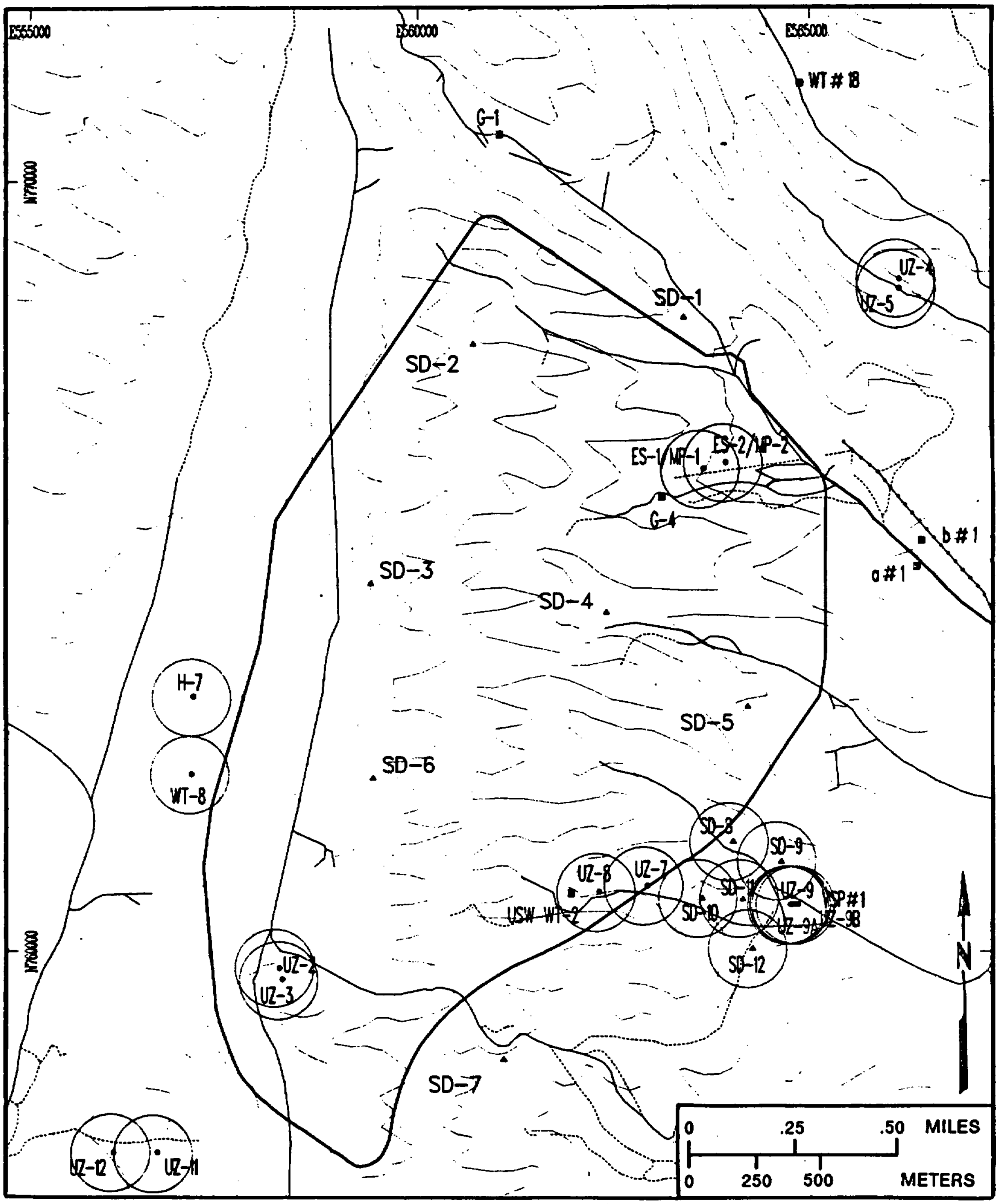


Figure 8.3.1.4-12a. Yucca Mountain systematic drilling program– small scale variability test drill hole location. See Figure 8.3.1.4-12b for legend.

LEGEND

- ▲ SYSTEMATIC DRILLING PROGRAM
- ● FEATURE SAMPLING PROGRAM INTEGRATED WITH SYSTEMATIC PROGRAM
- ■ EXISTING HOLES SUITABLE FOR RESAMPLING
- 500 FOOT BUFFER

- LIGHT DUTY ROADS
- UNIMPROVED ROADS
- TRAILS
- POWERLINES
- PERIMETER DRIFT BOUNDARY

SOURCES:

50 M ELEVATION CONTOURS – USGS 1:100,000 BEATTY QUAD

1956 1:24,000 USGS TOPOGRAPHIC MAPS

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1983 1:100,000 USGS TOPOGRAPHIC MAPS

7/1986 AND 9/1987 1:24,000 AERIAL PHOTOGRAPHY

GRID TICKS BASED ON NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE

PERIMETER DRIFT BOUNDARY – SNL DRAWING R07003A

MAP COMPILED IN AUGUST 1988

NOTE: THE FOLLOWING DRILL HOLES SHOWN ON FIGURE 8.3.1.4-12b ARE WITHIN THE NEVADA TEST SITE AND ARE DESIGNATED WITH THE PREFIX UE25: a#1, b#1, WT#18, UZ-4, UZ-5, UZ-9, UZ-9A, UZ-9B, SD-9, AND VSP#1. THE REMAINING DRILL HOLES (OUTSIDE THE BOUNDARY) ARE DESIGNATED WITH THE USW PREFIX.

Figure 8.3.1.4-12b. Legend for Figure 8.3.1.4-12a.

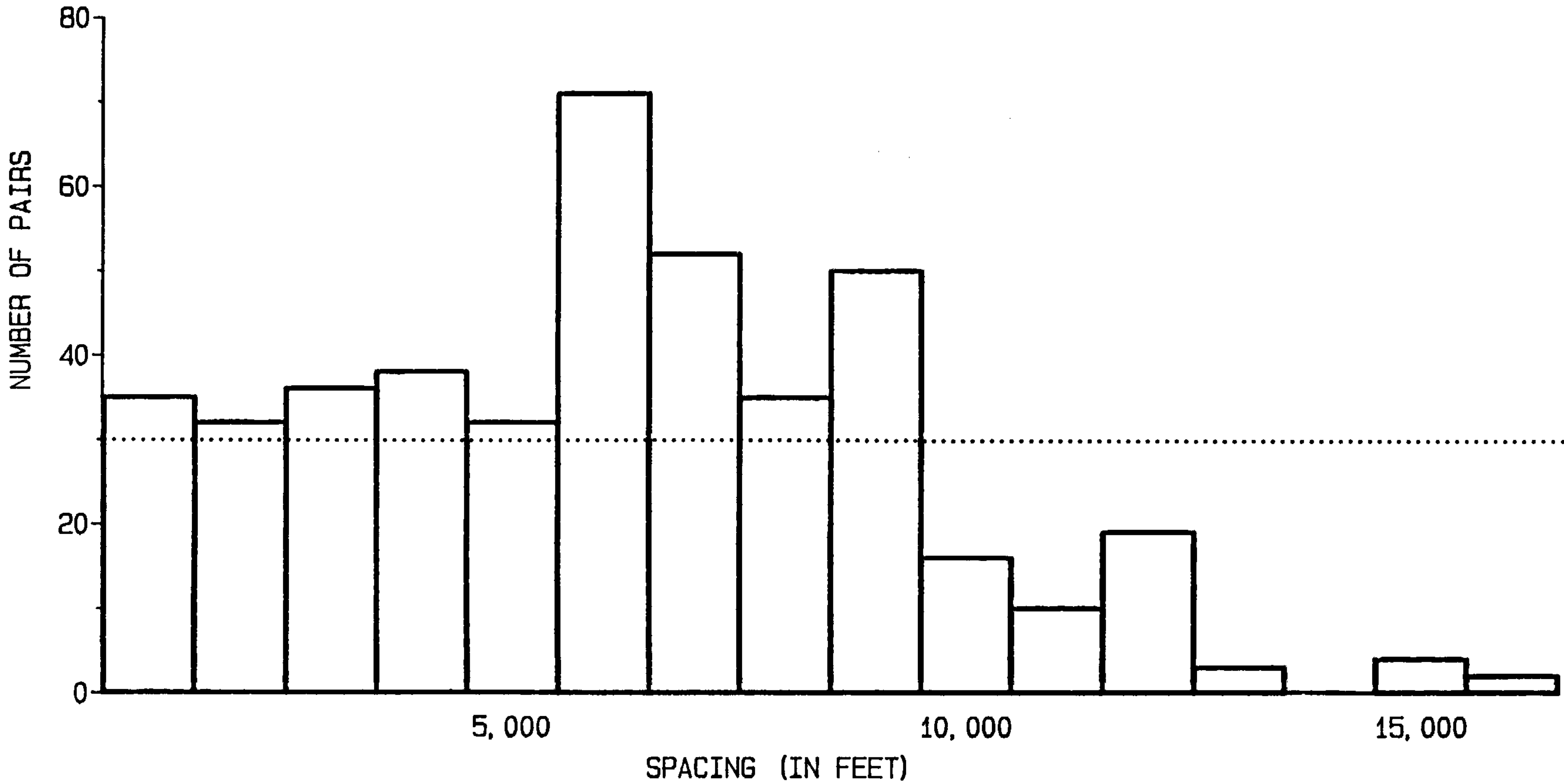

Figure 8.3.1.4-13. Histogram of data pairs for geostatistical analysis. Based on systematic drilling program, plus selected proposed boreholes from the site vertical boreholes study, site potentiometric level monitoring activity, and Solitario Canyon Fault study in the saturated zone.

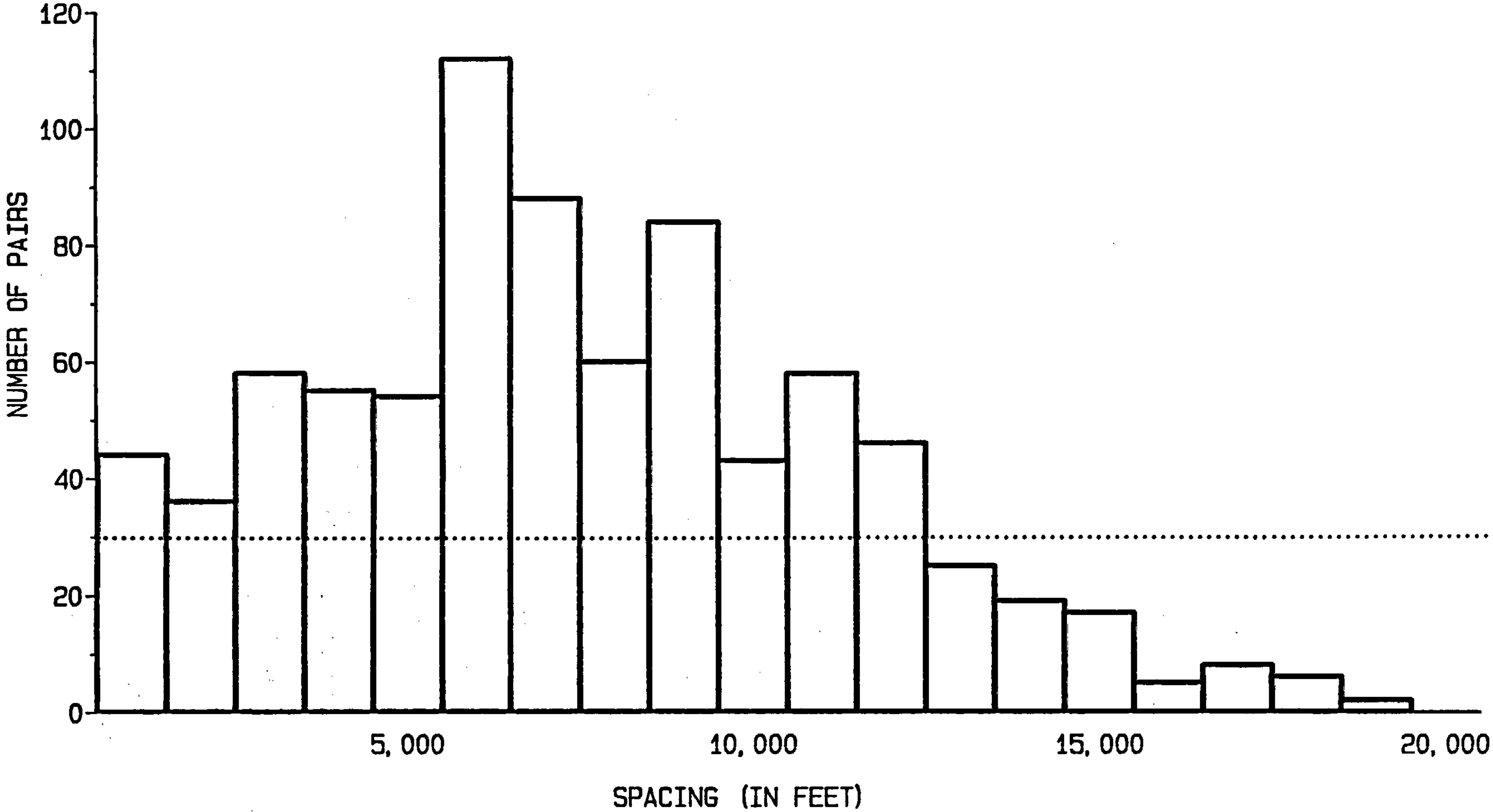

Figure 8.3.1.4-14. Histogram of data pairs for geostatistical analysis. Based on systematic drilling program, plus selected existing and proposed boreholes from the feature sampling program.

be evaluated to determine the extent to which it causes bias in the evaluation of the geostatistical approach.

Analysis and sampling strategy

All available core will be described, photographed, and logged graphically for unit contacts, fracture parameters, and gross engineering indicators such as RQD. A small suite of matrix properties including porosity, saturation, and saturated conductivity will be intensively analyzed for spatial dependence. The underlying logic is that the basic spatial correlation patterns determined in this manner can probably be correlated statistically to the spatial distribution of other rock characteristics. Measurement of these parameters is relatively inexpensive and can be extended to a large number of samples, increasing confidence. Rock characteristics such as unsaturated matrix conductivity are much more costly to measure and cannot be similarly repeated. Once a common correlation structure has been established, the set of more frequent measurements can be used directly for estimating the sparse set.

Subsequent to logging, the recovered material will be sampled systematically according to a predetermined scheme. This scheme is designed to support statistically representative measurements of the following basic properties saturation, porosity, and saturated hydraulic conductivity. After basic measurements are completed, the same samples (along with other samples according to the scheme) will be analyzed by different studies, culminating in measurements that require destructive testing. Determination of multiple properties from the same specimens is important for correlating variability of different parameters with nonuniform measurement support. Figure 8.3.1.4-15 summarizes in a conceptual manner the coordination of multiple sampling efforts for the same specimens. The scheme that is actually used will be determined through further planning and the integration function of the Project Sample Overview Committee.

The sampling program for sample group A (sampled for porosity, saturated hydraulic conductivity, and saturation) will be conducted in the Sample Management Facility according to the predetermined scheme. In this conceptual scheme, porosity and saturation data are measured on samples collected every 1.5 m (5 ft); saturated conductivity would be measured for alternating samples, or every 3 m (10 ft). A secondary sampling program would be undertaken in at least two intervals within each unit to sample close-order variability. This secondary program is represented schematically on the left-hand side of Figure 8.3.1.4-15.

Sample group B (Figure 8.3.1.4-15) may be collected to investigate rock characteristics that do not require the same intensity of sampling as group A. This may be because less confidence in the parameter is required by the performance allocation, or because the cost of a single measurement is many times the cost of a porosity or saturation test. Similarly, sample groups C and D would be collected for investigation of properties with different requirements. All the sample groups are referred back to the basic matrix properties, because all the samples were originally tested in the same way. The statistical model for variability of each group can be enhanced (at least in principle) through the use of the model for basic properties.

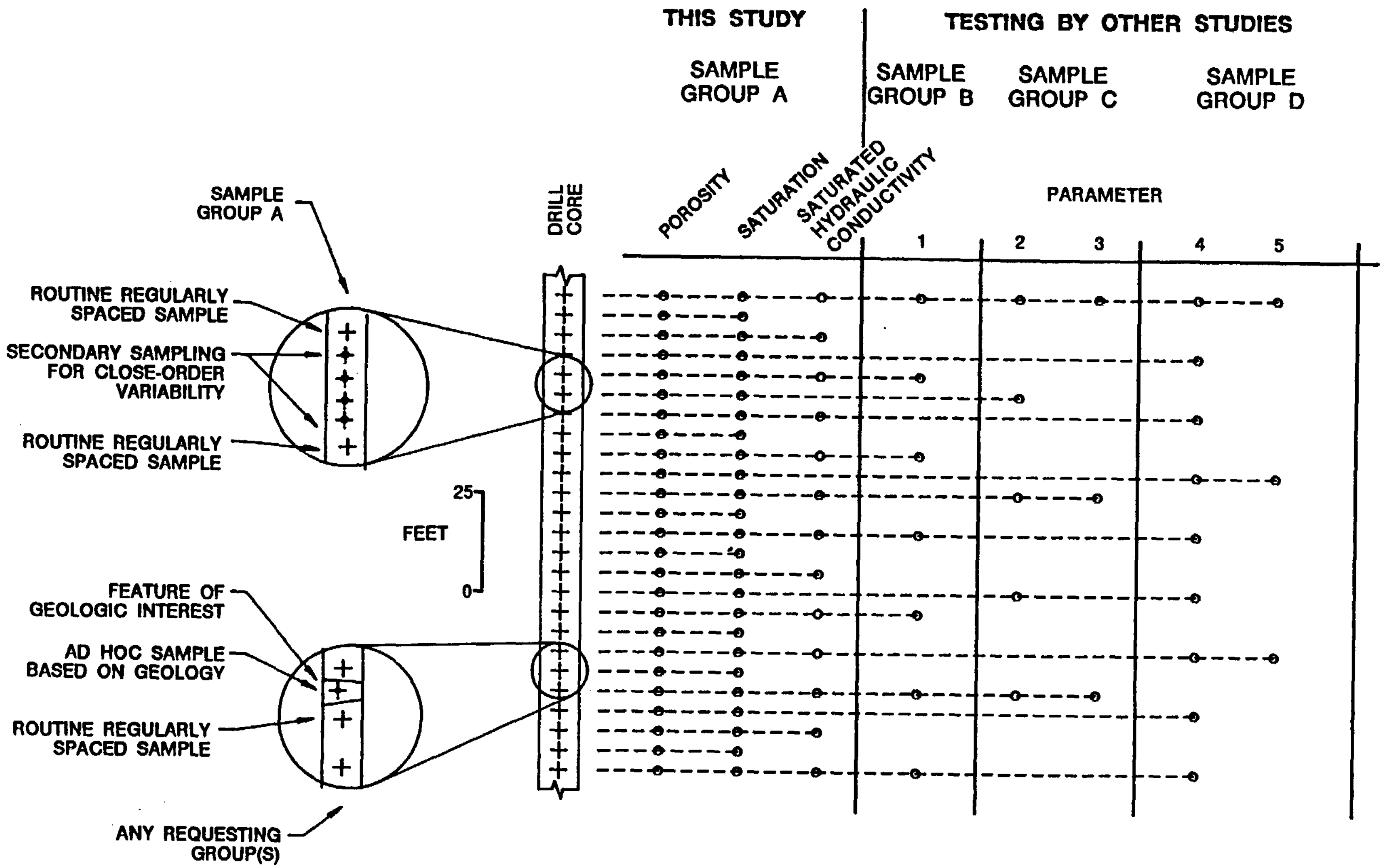

Figure 8.3.1.4-15. Possible systematic sampling program.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.3.1.1 are given in the following table.

Method	Technical procedure Number	Title	Date
Drilling and coring	TBD[a]	Drilling and coring	TBD
Graphic logging	TBD	Graphic logging of drill core	TBD
Drillhole sampling	TBD	Routine sampling of drillholes	TBD
Sample identification, handling, and storage	TBD	Sample tracking	TBD

[a]TBD = to be determined.

8.3.1.4.3.2 Study: Three-dimensional rock characteristics models

8.3.1.4.3.2.1 Activity: Development of three-dimensional models of rock characteristics at the repository site

Objectives

The objective of this activity is to develop computer-based three-dimensional models that integrate quantitative and semiquantitative data on rock characteristics in light of constraining information developed by studies of the geologic framework of the Yucca Mountain site (Investigation 8.3.1.4.2).

Description

This study will serve as the process whereby the majority of location-specific site characterization data describing rock characteristics is summarized and interpreted in light of a constraining geologic framework (Investigation 8.3.1.4.2) for Yucca Mountain. This study also will result in models that will be the means by which these data pass from site characterization investigations to design and performance assessment studies. Because the rock characteristics data and the geologic framework information both will be represented as three-dimensional computer-based models that are closely linked to the Yucca Mountain Project Technical Data Base, representations of the model may take many forms depending upon the use of the information. For example, information from the model may be represented as contour (isopleth) maps, cross sections, level plans, "3-D" perspective illustrations, statistical distributions (histograms, means, variances), and as numerical data files for direct input to computer codes used for performance assessment or design analyses. The primary requirement of input data for the three-dimensional rock property models is systematic and statistically valid (unbiased) sampling at scales adequate to allow quantitative characterization of the spatial variability of the parameters of interest at Yucca Mountain. Characterization of spatial variability will depend heavily upon geostatistical techniques. Determination of sampling intervals and parameters will rely upon geostatistical analysis in conjunction with sensitivity studies conducted by the associated performance assessment or design information needs.

Much of the analysis of the spatial variability will depend upon detailed knowledge of a few selected rock characteristics (e.g., porosity, saturated hydraulic conductivity, saturation) that will be obtained as part of the integrated drilling program described by Investigation 8.3.1.4.1. These parameters will serve as surrogates in determining the spatial variability of several other parameters needed by performance assessment and design issues in preliminary stages of the analyses. Because the basic spatial distribution of properties of the rock mass at Yucca Mountain is that produced by the processes of volcanic eruption, transport, deposition, and post-depositional alteration (including welding and devitrification), the quantitative description of the distribution should correspond to parameters that derive their distribution from some part of those emplacement and alteration processes.

The measured values of parameters from which the final modeling activities will be conducted, will come largely from Site Programs 8.3.1.2 (geohydrology), 8.3.1.3 (geochemistry), and 8.3.1.15 (thermal and mechanical properties).

The models typically will be constructed as follows. First, measured values of the hydrogeologic, geochemical, or thermal/mechanical parameters of interest (from drillholes and the exploratory shaft facilities) will be mapped into their proper three-dimensional location in model space. Second, geologic framework information (the altitude of geologic contacts, fault locations and offsets, etc.), from Investigation 8.3.1.4.2 also will be mapped into three-dimensional model space. The spatial structure of the observed values (actual measurements) will be determined by geostatistical techniques (variogram or covariance analysis). The spatial structure of a group of related parameters may be further refined by study of the cross-covariances among those quantities. Conflicts between the observed spatial structure of quantitative data and the structure implied by the geologic framework will be resolved (e.g., identification of a concealed fault, reinterpretation of volcanic source area or flow path, or identification of some previously unknown alteration phenomenon). Surface-based and borehole geophysical interpretations will also provide a constraint upon subsurface modeling. The geostatistical techniques of covariance analysis and kriging will be used to determine when the spatial structure of a parameter of interest is sufficient.

Hydrologic, thermal/mechanical, and geochemical rock property measurements then will be interpolated into unsampled areas constrained by the observed values at sampling points, by the faulted stratigraphy, and by the identified spatial structure. The most detailed approach to this phase of modeling involves the formulation of a three-dimensional block model, wherein the site is divided into numerous orthogonal blocks and each block is sufficiently small that the parameter of interest may be treated as constant within the block. Once the structure of the data is determined, the values of unsampled blocks are estimated (interpolated) by techniques such as kriging (or cokriging). Geostatistical techniques provide estimates of the uncertainty associated with each parameter within each block. Estimates of the probability that the true value in each block exceeds some predetermined limit or is within some range of values (specified by the corresponding performance assessment or design issue) are also possible.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.3.7.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Rock characteristics model evaluation	TBD[a]	TBD	TBD

[a]TBD = to be determined.

8.3.1.4.3.3 Application of results

The models and associated uncertainty information derived from this investigation will be used in the following areas of performance assessment and design.

The areas of performance assessment include the following:

Issue or information need	Subject
1.1.1	Site information needed to calculate the releases of radionuclides to the accessible environment (Section 8.3.5.13.1)

Issue or information need	Subject
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)
1.8	NRC siting criteria (Section 8.3.5.17)
2.4.1	Site and design data required to support retrieval (Section 8.3.5.2.1)

The areas of design include the following:

Issue or information need	Subject
1.10.4	Near-field environment (Section 8.3.4.2.4)
1.11.1	Site characteristics needed for design (Section 8.3.2.2.1)
1.12.1	Information needed for seal design and placement (Section 8.3.3.2.1)
2.7.1	Radiological protection (Section 8.3.2.3.1)
4.2.1	Site performance information needed for design (Section 8.3.2.4.1)
4.4.1	Site and performance information needed for design (Section 8.3.2.5.1)

8.3.1.4.4 Schedule for the rock characteristics program

The rock characteristics program includes three investigations, which contain five studies. The schedule information for each study is summarized in Figure 8.3.1.4-16. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the rock characteristics program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.4-5.

The study-level schedules, in combination with information provided in the logic diagram for this program (Figure 8.3.1.4-1), are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.4-5 and Figure 8.3.1.4-16, however, should be viewed as a snapshot in time. The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports. Summary schedule information for the rock characteristics program can be found in Sections 8.5.1.1 and 8.5.6.

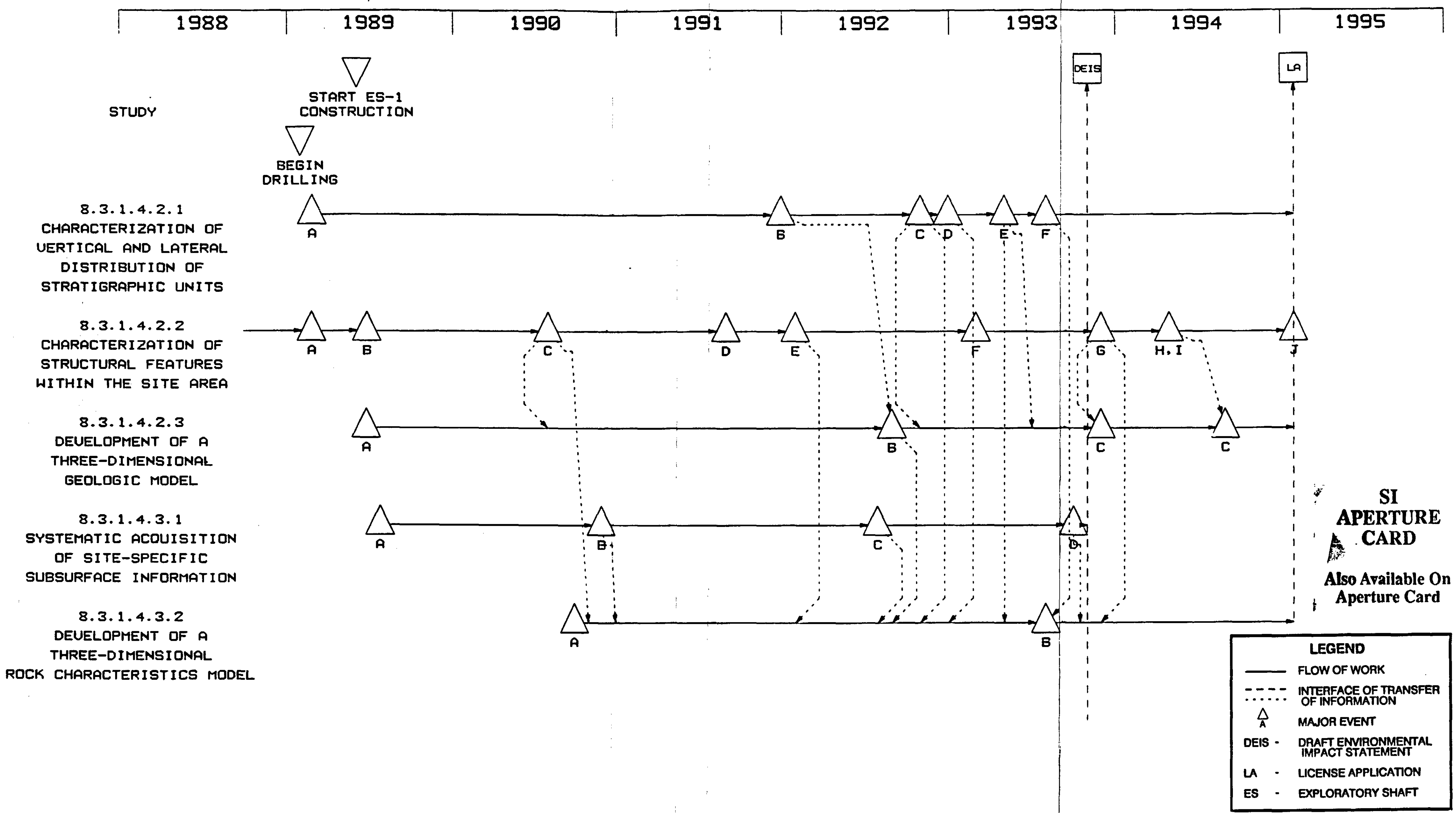

Figure 8.3.1.4-16. Schedule information for studies in Site Program 8.3.1.4 (rock characteristics). See Table 8.3.1.4-5 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

Table 8.3.1.4-5. Major events and completion dates for studies in Site Program 8.3.1.4 (rock characteristics) (page 1 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.4.2.1	Characterization of the vertical and lateral distribution of stratigraphic units	A	Study plan approved	2/89
		B	Draft report available to U.S. Deprtment of Energy (DOE) lateral variation in stratigraphy	12/91
		C	Draft of preliminary report on the results of petrophysical properties testing available to the DOE	10/92
		D	Complete compilation of structural and stratigraphic information from geologic drillholes	12/92
		E	Complete magnetic properties testing	4/93
		F	Draft of report on preliminary borehole geophysics available to DOE; continue surface-based and borehole geophysical surveys and petrophysical properties testing	7/93
8.3.1.4.2.2	Characterization of the structural features within the site area	A	Begin vertical seismic profiling (8.3.1.4.2.2.5)	2/89
		B	Begin shaft wall mapping	6/89
		C	Draft of final report on geologic mapping of the Paintbrush Tuff available to DOE	7/90

Table 8.3.1.4-5. Major events and completion dates for studies in Site Program 8.3.1.4 (rock characteristics) (page 2 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.4.2.2	Characterization of the structural features within the site area (continued)	D	Begin draft wall mapping	8/91
		E	Draft report available to DOE on the results of shaft wall mapping	1/92
		F	Draft report available to DOE on the borehole evaluation of stratigraphy/structure	2/93
		G	Draft report available to DOE on fracture distribution at Yucca Mountain	11/93
		H	Report available to DOE on the results on vertical seismic profiling	4/94
		I	Drift wall mapping complete; begin final report	4/94
		J	Begin preparation of the final report on borehole evaluation of faults and fractures	1/95
8.3.1.4.2.3	Development of a three-dimensional geologic model	A	Study plan approved	6/89
		B	Draft report available to DOE on the preliminary site geologic description	8/92

Table 8.3.1.4-5. Major events and completion dates for studies in Site Program 8.3.1.4 (rock characteristics) (page 3 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.4.2.3	Development of a three-dimensional geologic model (continued)	C	Continue development of three-dimensional geologic model following input from 8.3.1.4.2.1 and 8.3.1.4.2.2	11/93
8.3.1.4.3.1	Systematic acquisition of site-specific subsurface information	A	Study plan approved	7/89
		B	Begin performance assessment-based systematic drilling program	11/90
		C	Complete performance assessment-based systematic drilling program	7/92
		D	Complete compilation of systematic drilling data for license application design (LAD) and draft environmental impact statement (DEIS)	9/93
8.3.1.4.3.2	Development of a three-dimensional rock characteristics model	A	Study plan approved	9/90
		B	Reference model for three-dimensional rock characteristics available to DOE for LAD and DEIS; model feeds final three-dimensional model	7/93

[a]The letters in this column key major events shown in Figure 8.3.1.4-16.

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