Study Plan for
Study 8.3.1.2.2.4

# Characterization of the Yucca Mountain Unsaturated Zone Percolation Exploratory Shaft Facility Study

Revision 0

January 1989

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

Prepared by
U.S. Geological Survey

# YUCCA MOUNTAIN PROJECT

T-AD-088
10/88

CONTROLLED COPY NO. 1

Study Plan Number 8.3.1.2.2.4

Study Plan Title Characterization of the Yucca Mountain Unsaturated-Zone Percolation Exploration-Shaft-Facility Study

Revision Number R0, January 1989

**Prepared by:**

U.S. Geological Survey

**Date:**

January 1989

Maxwell B. Blanchard 1-9-89
Director, Regulatory and Site Evaluation Division Date

[signature] for J Blaylock 1-9-89
Project Quality Manager Date

[signature] 1-9-89
Project Manager Date

*RECORD OF REVISIONS*

| *REVISION NUMBER* | *REVISION* | *DATE* |
|---|---|---|
| R0 | Study rationale and plans for four construction-phase activities<br>Radial-borehole tests (Section 3.4)<br>Excavation-effects tests (Section 3.5)<br>Perched-water tests (Section 3.7)<br>Hydrochemistry tests (Section 3.8) | 3-24-88 |
| | Addition of plans for multipurpose-borehole activity (Section 3.9); revision of radial-borehole activity in response to addition of multipurpose-borehole activity. Revisions in response to SCP statutory draft changes. | 1-03-89 |

# ABSTRACT

This study plan describes the plans for five site-characterization activities to be performed in and adjacent to the Yucca Mountain exploratory shafts during their construction. These activities will contribute to an understanding of the *in situ* hydrologic characteristics of the unsaturated zone, provide an understanding of the impacts of shaft construction on the *in situ* characteristics, and provide hydrologic-parameter input for the resolution design and performance issues. The activities include:

- Radial-borehole tests,
- Excavation-effects test,
- Perched-water test,
- Hydrochemistry tests, and
- Multipurpose-borehole tests.

Plans for five additional activities will be included in a subsequent revision of the study plan. The plans for *in situ* hydrologic testing in the main test level of the exploratory-shaft facility (ESF) include:

- Intact-fracture test,
- Percolation test,
- Bulk-permeability tests,
- Calico Hills test, and
- Hydrologic properties of major faults.

The rationale of the overall unsaturated-zone ESF study is described in Sections 1 (regulatory rationale) and 2 (technical rationale). Section 3 describes the specific activity plans, including the tests and analyses to be performed, the selected and alternate methods considered, and the technical procedures to be used. Section 4 summarizes the application of the study results and Section 5 presents the schedules and associated milestones.

## 3.5 Excavation-effects test

### 3.5.1 Objectives of activity

The objective of this activity is to estimate the magnitude and extent of the modification to the Topopah Spring welded unit (TSw) properties caused by the excavation and lining of the shaft.

### 3.5.2 Rationale for activity selection

The activity is designed to estimate the effects of excavating and lining the shaft on the hydrologic properties of the TSw and to measure any changes. Results of this test are needed to evaluate errors that might be introduced by these effects in the results of other ESF hydrologic tests.

Excavation in fractured rocks can significantly alter the hydrologic properties of the rock near an underground opening (Montazer, 1982). These changes are a concern for the following reasons. Modification of the hydrologic properties, such as permeability, may alter existing pathways or introduce new pathways for gaseous and water flow. The travel time of water and gases along these changed or new pathways may be significantly different from those along natural pathways. If travel time is significantly changed, then the effects of excavation will have to be considered during other hydrologic tests.

The magnitude of changes in permeability, effective porosity, and saturation depends on the *in situ* stress tensors and fracture orientation around the shaft. Permeability may increase or decrease, depending on the orientation of the excavation with respect to fractures and to *in situ* stress. Most fracture sets in the TSw are steeply dipping (70° to 85° to the northwest); therefore, ES-1 will intersect these fractures at very small angles. With gravity loading, excavation may open some fractures and close others, depending on whether fracture planes are tangential or radial to the shaft. This deformation of fractures will alter fracture permeability and porosity. In addition, deformation of fracture apertures may significantly change saturation within the fractures, so that some fractures attain larger water saturation. Increased saturation will correspond to closing the fractures; therefore, although the closing results in decreased saturated permeability, the corresponding increased saturation also increases the fracture's relative permeability to water. This complex relation may be evaluated only by monitoring fracture deformation, saturation, stress changes, and permeability during shaft construction.

The effects of excavation also need to be evaluated to determine how they affect the reliability of the findings of other hydrologic tests. Data from the radial-borehole (Section 3.4), percolation (Section 3.2), and bulk-permeability (Section 3.3) tests are influenced by hydrologic properties of the rock around openings constructed to conduct the tests. Tests are therefore needed to determine the significance of these effects and to develop procedures to correct for errors that might be introduced by modification of the rock hydrologic properties near these openings.

Lining the shaft may partly reverse the changes caused by its excavation. If this proves to be the case, expensive remedial grouting operations may not be necessary during repository closure. Emplacement of the lining may also alter the results obtained from the radial-borehole tests. Although the radial-borehole tests are designed to evaluate this effect, the excavation-effects test will provide data in a direction that the radial boreholes cannot provide because of their orientation.

Combining the results of this test with those from the radial-borehole and bulk-permeability tests will enable evaluation of the variation of the excavation effects on hydrologic properties with orientation of the opening. The radial-borehole tests also are designed to evaluate the effect of excavation on nonwelded tuff, which has smaller fracture frequency and different mechanical constitutive properties.

Evaluation of the state of stress, in addition to other purposes outlined in the geomechanical tests, is needed to interpret the results of this test and to provide predictive and extrapolation capabilities. In addition, this test will provide fracture-deformation values at various distances from the shaft and at several levels. Based on the mechanical properties of the rock, stress deformation, and fracture deformation, data will then be used to model the test and calculate affected hydrologic parameters, thereby providing a method for extrapolating the results to other parts of the repository under different stress conditions.

The excavation-effects test is not intended to be representative of the repository block. The purpose of the test is to quantify the effects of excavation and lining of the shaft in the TSw in the immediate vicinity of the shaft. The results of this test are needed to correct errors that might be introduced by excavating and lining in the data of other ESF hydrologic tests. In other words, the excavation-effects test will insure that other ESF hydrologic tests are representative of the repository area.

Because the ES-1 has not been constructed at Yucca Mountain, geologic and hydrologic prototype testing will be conducted at G-tunnel in Rainier Mesa, which is located at the Nevada Test Site about 60 k (40 mi) from Mercury, Nevada. An instrumentation and monitoring method will be developed in this prototype test to evaluate the changes in fractured rock permeability that could be attributed to measurable changes in *in situ* stresses around an underground opening. The redistribution of the original ground stress field is due mainly to the opening. Based on this prototype test, an instrumentation and monitoring design will be selected for the excavation-effects test in the exploratory shaft. Established procedures will minimize shaft construction delays and provide quality-assured data in the licensing process.

### 3.5.3 General approach and summary of tests and analyses

The effects of excavating and lining ES-1 will be evaluated by a comparison of air permeability, deformation, stress changes, and water content measured before and after the shaft is excavated and lined. These tests will be conducted in 12 vertical and 6 inclined holes drilled in radial arrangement in the floors of each of the 2 breakout rooms, the upper and the lower. Neutron logs will be used to measure the water content. Permeability and stress changes will be measured in the 12 vertical boreholes. The six inclined boreholes will be used to measure axial deformation using borehole extensometers. A coupled hydrologic-mechanical model will be used to analyze the results.

Figure 3.5-1 summarizes the organization of the excavation-effects test. A descriptive heading for each test and analysis appears in the shadowed boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized during testing. Cross-reference to other study plans which provide input to the excavation-effects test also appear in Figure 3.5.1. Figure 3.5.2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed test/analysis boxes, respectively, in Figure 3.5-2.

The two figures summarize the overall structure of the planned activity in terms of methods to be employed and measurements to be made. The descriptions of the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) the site-characterization parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

The conceptual design of this test is based on the assumption that excavation of ES-1 would cause fractures to open or close at various locations near the shaft. This opening or closure would modify the hydrologic properties and conditions of the rock, which would be detectable by measurements made at various times during shaft construction. The orientation of the fractures in relation to the shaft will determine whether they would open or close. Previous research (Montazer, 1982) provides some basis for predicting the expected changes. Saturated fractures that are parallel to the long axis of the opening (but not radial from this axis), therefore, would open due to the stress relaxation in the radial direction. Fractures perpendicular to this axis, however, would close because of redistribution of the stress in the axial direction. The permeability of individual fractures could double, quadruple, or lessen

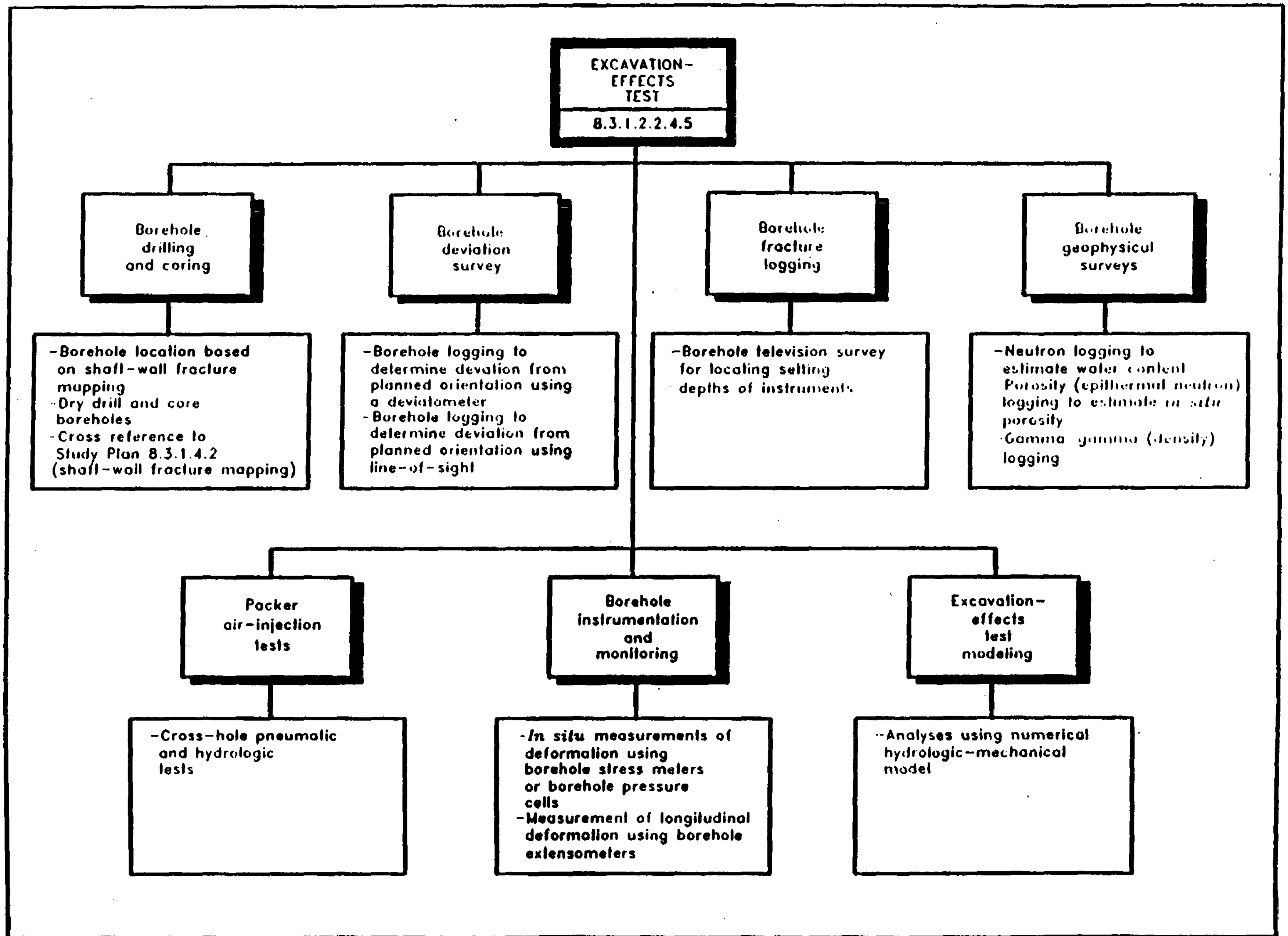



**Figure 3.5-1. Organization of the excavation-effects activity showing tests, analyses, and methods.**

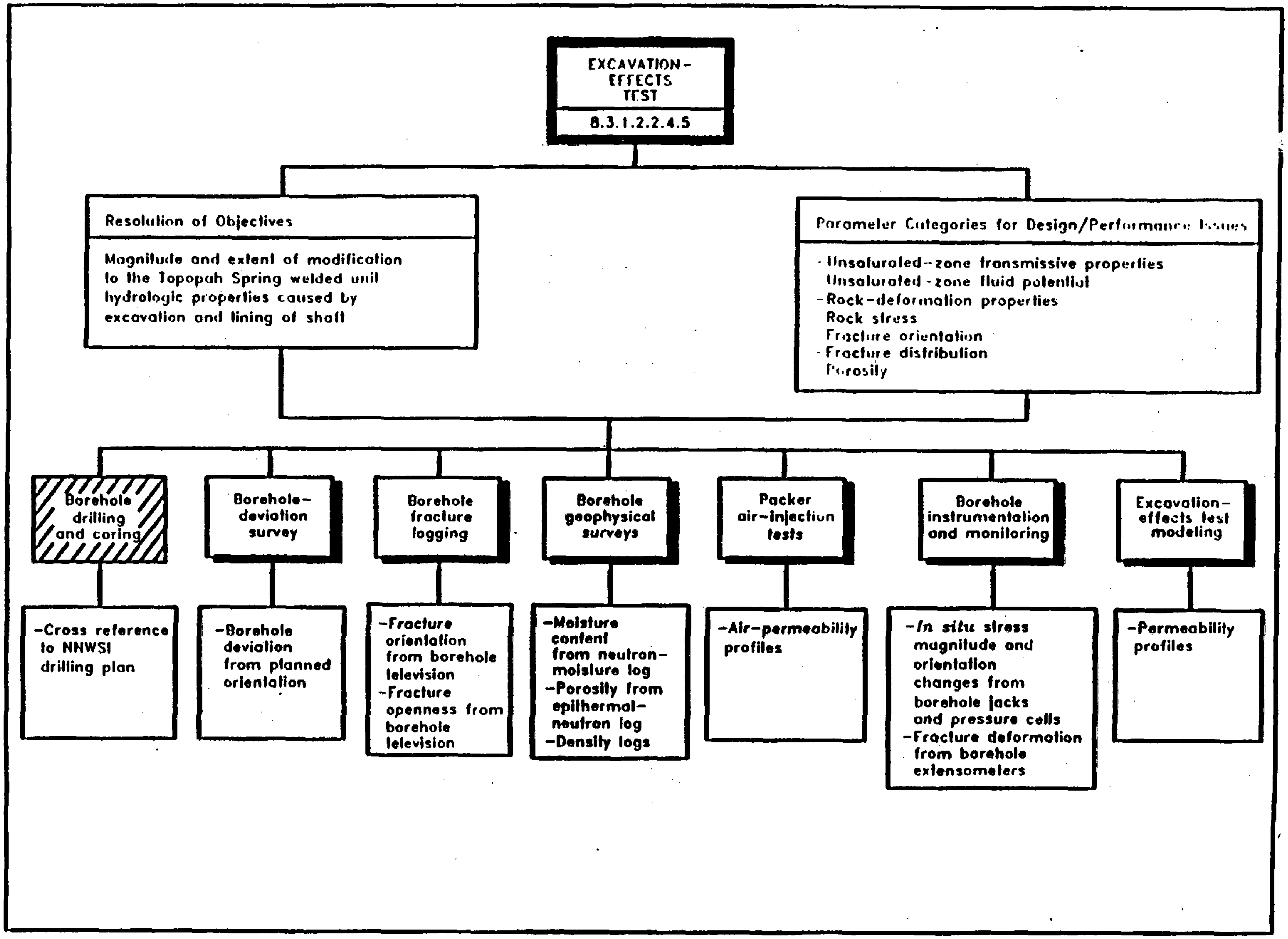



**Figure 3.5-2. Organization of the excavation-effects activity, showing tests, analyses, and site parameters. The cross-hatched box indicates that no site parameter will be generated.**

correspondingly, which may change overall rock permeability by one to two orders of magnitude.

Changes due to excavation are more complicated in unsaturated fractures. Increased permeability to air when a fracture is opened may correspond to a decrease in its permeability to water. The complex relation between fracture deformation and redistribution of saturation of both fluids could increase air permeability and decrease water permeability. Such relations are poorly understood and will be investigated as part of the intact-fracture test (Section 3.1).

The excavation-effects test will be conducted from the two breakouts at 158-m and 311-m (520- and 1,020-ft) depths. The two levels were selected to evaluate the effects at two different stress conditions and rock properties. If the measured changes match those calculated using the model in the two breakout rooms by using measured material properties from the two locations, then the model will be used to predict changes around other openings within the repository.

After each breakout is completed, six vertical boreholes, 76 mm (3 in.) in diameter, will be diamond-bit drilled with air for permeability measurements. These boreholes will be between 15.2 and 30.5 m (50 and 100 ft) deep, depending on the straightness of the boreholes. Maximum deviation of 1 unit per 100 units of length is acceptable. Tentative distances of the boreholes from the shaft wall will be approximately 1.4, 2.8, and 4.3 m (4.7, 9.3, and 14 ft). These distances were chosen because the stress redistribution, and hence permeability changes, around circular openings is mostly effective within two radii. The stress changes beyond two radii are expected to be so small that reliable measurements with existing *in situ* stress-measuring devices will be very difficult. Ambient-permeability estimates beyond the two-radii zone will be evaluated in the radial-borehole tests (Section 3.4). The preliminary location of the vertical boreholes is shown in Figure 3.5-3. If the breakout-room construction allows, the permeability boreholes will be drilled at an angle toward the shaft. Such a scheme will allow these holes to intersect more fractures because the majority of the fractures dip at high angles.

Another set of six vertical holes will be drilled at the same distances (1.4, 2.8, and 4.3 m [4.7, 9.3, and 14 ft]) away from the shaft wall for installation of borehole-stress meters and/or pressure cells to measure the changes in stresses. These stress-relief boreholes will be between 38 and 76 mm (1.5 to 3 in.) in diameter, depending on the type of stress-measuring instruments, and as deep as the permeability boreholes.

The third set of six holes will be diamond-bit drilled with air and will be 76 mm (3 in.) in diameter and inclined toward the shaft at 45 degrees as shown in Figure 3.5-3. The preliminary distances of these boreholes from the shaft wall are 5, 10, and 15 m (16.4, 33, and 49 ft). These boreholes will be instrumented with extensometers to measure the axial deformation.

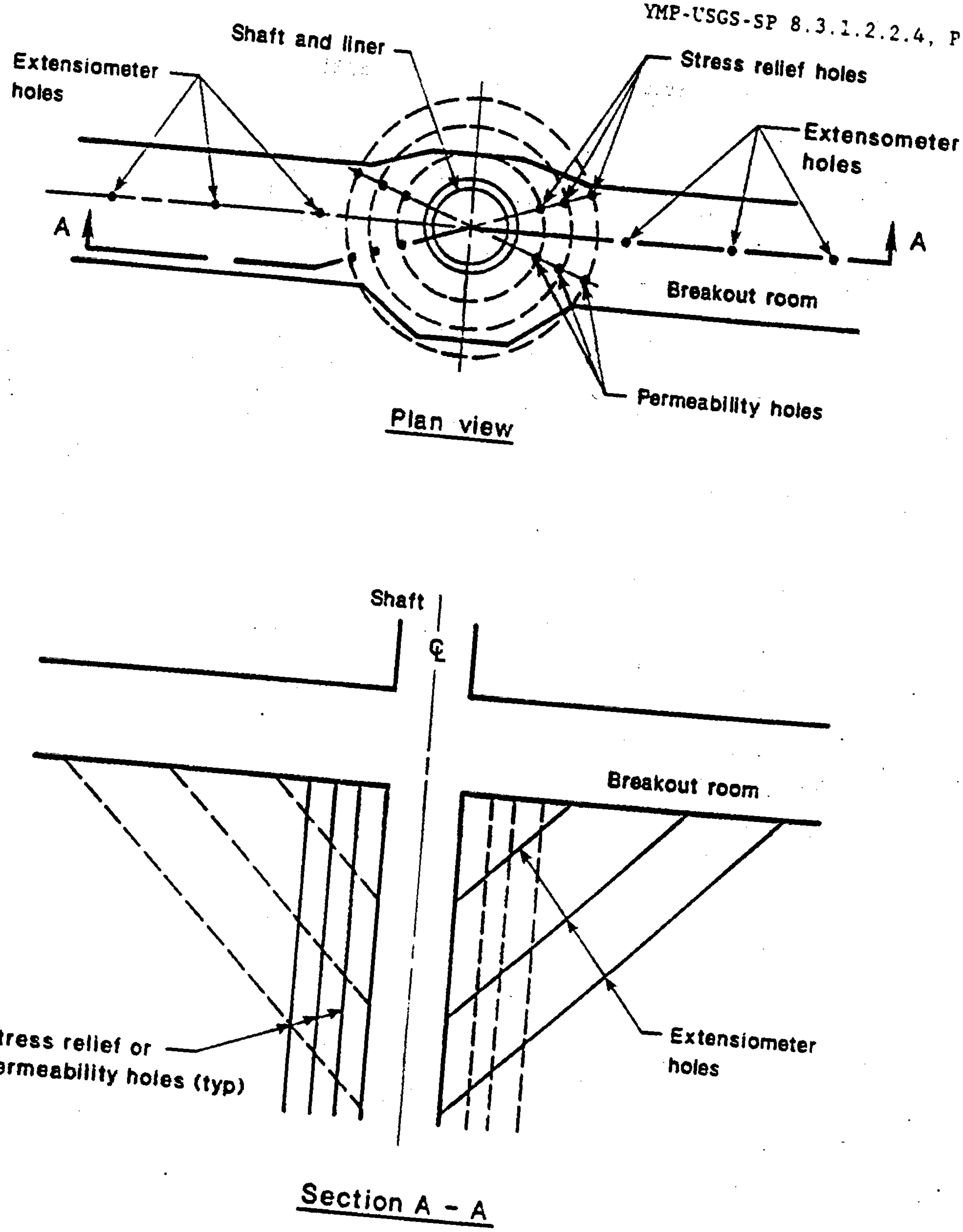



Figure 3.5-3. Plan and section view of the lower-breakout room showing the location of the boreholes for the excavation-effects tests.

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

The stress-relief boreholes will be instrumented after they are logged for fractures with a video camera. Stress-measuring gages will be installed at 5-m (16.4-ft) intervals in these boreholes to measure the stress in at least two perpendicular directions (Figure 3.5-4). These gages will be permanently cemented inside the boreholes and monitored during excavation of the shaft and placement of the lining.

The permeability boreholes will be logged with geophysical equipment and tested for permeability with packer air-injection techniques before excavation of the shaft below the breakout level and after every two rounds of excavation until changes in permeability are no longer detected. Various stages of the shaft excavation, during which these tests will be conducted, are shown in Figure 3.5-5. The permeability boreholes will be completed in a manner similar to that of the radial boreholes (Section 3.4) for long-term monitoring.

Instruments for measuring permeability will be constructed and tested in conjunction with the testing of the infiltration and radial-boreholes prototype tests. The type of instrument to be used for measuring stress changes will be determined from the excavation-effects prototype test.

The extensometer boreholes will be logged with a borehole deviatometer and a video camera to determine the setting depths of the extensometer anchors. Five to six setting depths in each borehole will be chosen.

### 3.5.3.1 Borehole drilling and coring

The upper breakout room will be excavated immediately prior to initiation of work on this activity (see Figure 3.5-5). The tentative borehole locations are shown in Figure 3.5-3 and described in Section 3.5.3. The final locations will be based on fracture data from shaft-wall mapping (8.3.1.4.2.2.4, ESF geologic mapping). A random drilling scheme will not be used because a limited number of boreholes will be drilled. A limited number of boreholes may not have a uniform distribution of boreholes within the area proximate to the shaft. The issue of wet versus dry drilling and coring is still being reviewed at this time. The same test is repeated in the lower breakout room. Table 3.5-1 in Section 3.5.3.8 presents the different methods associated with this activity.

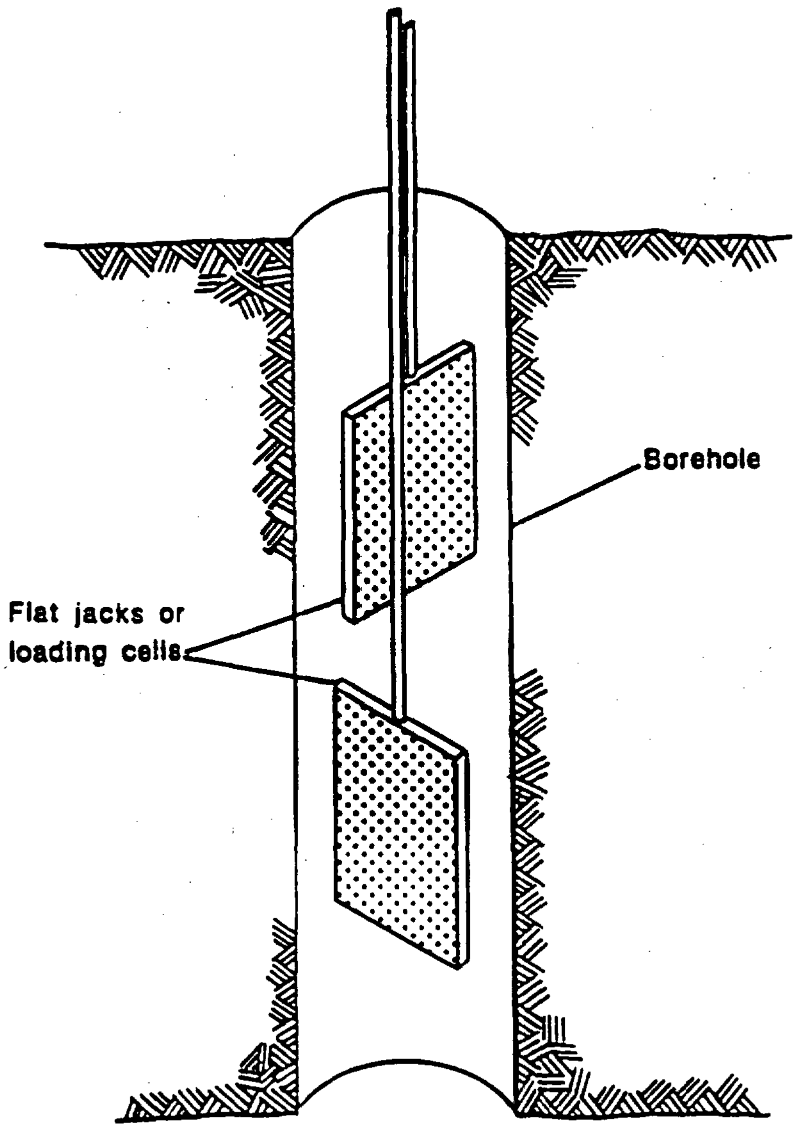



**Figure 3.5-4. Schematic diagram of instrumentation of a stress-monitoring borehole in the excavation-effects test.**

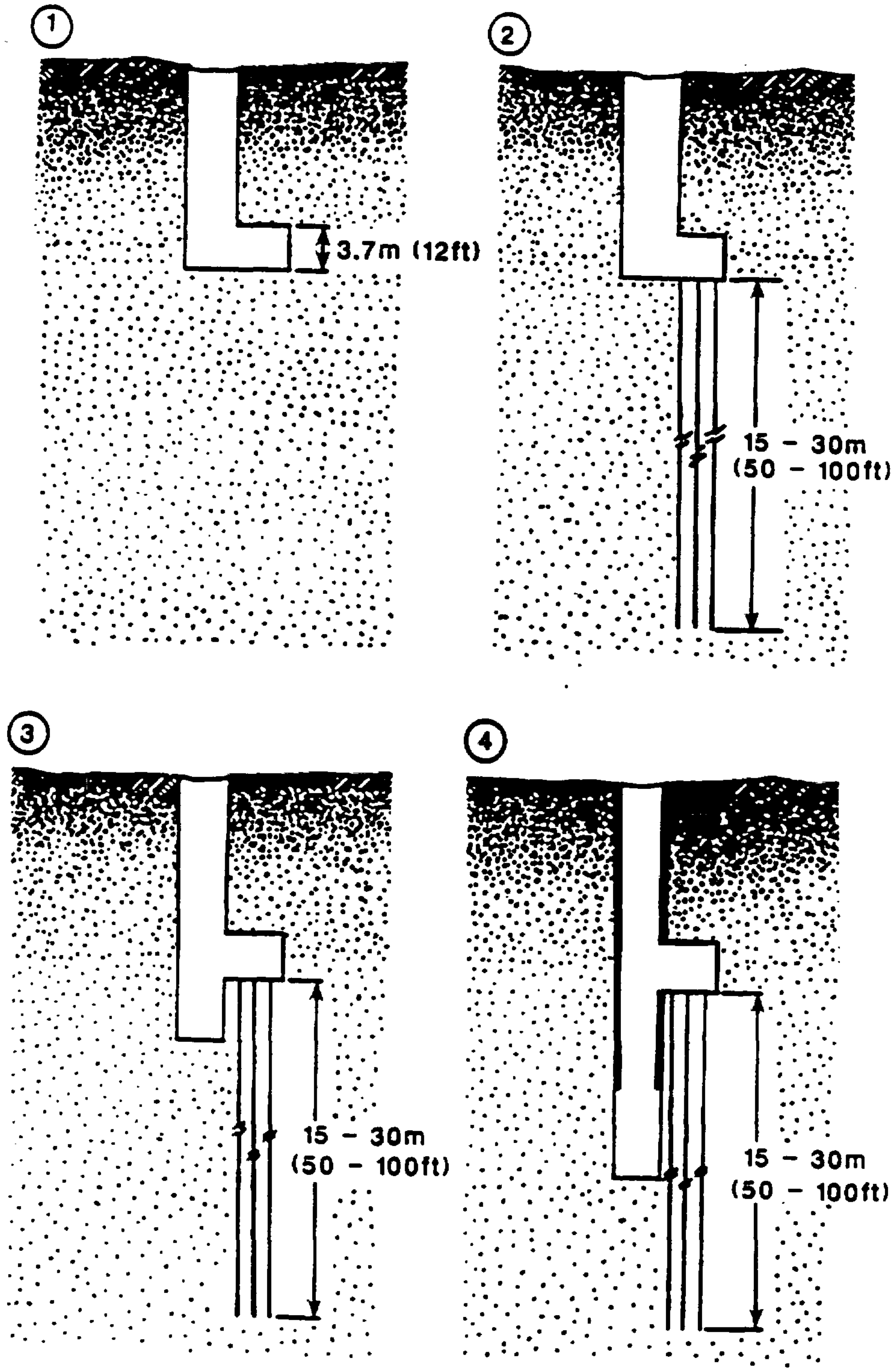



**Figure 3.5-5.** Stages of the excavation-effects test: (1) excavation of breakout room, (2) vertical borehole drilling, (3) excavation of shelf, and (4) lining of the shaft and continuing excavation.

### 3.5.3.2 Borehole-deviation survey

Under the supervision of the USGS, the logging contractor will log all permeability, stress, and strain boreholes using a deviatometer. This is essential for the analyses stage of this test where the location of the instruments, installed later, relative to the shaft is required. The line-of-sight method will be used for boreholes that appear to be straight and vertical.

### 3.5.3.3 Borehole fracture logging

Under the supervision of the USGS, the logging contractor will log all permeability, stress, and strain boreholes using a television camera. USGS personnel will log the cores of the same boreholes for sections that cannot be viewed clearly with the television camera. This is required in order to determine the setting depths of the different instruments needed for this test and for updating the shaft-wall fracture map which is required for the modeling stage. The television log is preferred over the core-logging method where wall smoothness can be observed. Additionally, some of the fractures seen on cores may be induced by drilling rather than being natural fractures.

### 3.5.3.4 Borehole geophysical surveys

Under the supervision of the USGS, the logging contractor will log all permeability, stress, and strain boreholes using neutron-moisture, porosity (epithermal neutron), and gamma-gamma tools. Borehole geophysical surveys are described in borehole geophysical surveys, Activity 8.3.1.4.2.1.3, in Study Plan 8.3.1.4.2.1. These parameters will be needed for the modeling stage of this test. Laboratory methods will be used to determine more accurate estimates for porosity and density, if required. Laboratory determination of water content in cores will not be used because it requires special core drilling and storage procedures.

### 3.5.3.5 Packer air-injection tests

Based on the television log, the setting depths of the packers will be determined. This is done in order to monitor fracture permeability in the permeability boreholes. Permeability will be measured after the boreholes are completed and after every two rounds of excavation. This will continue until the shaft is excavated past the deepest permeability borehole or until significant changes in permeability are no longer detectable. The testing methods are described in Sections 3.4.3.7 and 3.4.3.10, *in situ* pneumatic and cross-hole testing.

### 3.5.3.6 Borehole instrumentation and monitoring

Boreholes for monitoring stress and strains will be drilled and instrumented after the completion of the breakout rooms. Stress changes and axial borehole deformation are required for the modeling stage of this test. The type of stress-measuring instrument will be identified following the excavation-effects prototype test in G-tunnel. The U.S. Bureau of Mines gage cannot be utilized to measure stress for this study because this type of gage is not fixed to the borehole walls, and blasting vibrations will affect the readings. Borehole extensometers will be utilized to monitor axial deformation (strain) in the angled boreholes (Figure 3.5-3). All instruments will be connected to a data-acquisition system for continuous monitoring.

### 3.5.3.7 Excavation-effects test modeling

Fracture data (statistical and mechanical parameters) permeability profiles, stress and deformation data, and rock properties will be utilized to calibrate linked hydrologic and mechanical models to predict permeability changes around different underground openings in the repository rock. This model will be developed by the USGS by modifying existing structural and hydrologic analyses computer codes during the excavation-effects prototype test in G-tunnel. The structural analysis code that will be used is the ADINA (Bathe, 1978) code, which is a structural-analysis finite element for automatic incremental nonlinear analysis. The hydrologic analysis code is the UNSAT2 (Davis and Neuman, 1983) which is a finite-element, variably saturated flow model.

### 3.5.3.8 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.5-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be utilized only if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, there are many approaches to conducting the test. In those cases, only the most common methods are included in the tables. The selected methods in Table 3.5-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site-characterization parameter. Models and analytical techniques have been or will be developed to be consistent with test results. The expected ranges of the site-characterization parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.5-1.

## 3.5.4 Technical procedures and quality-assurance levels

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment, justification, and documentation of quality levels to activities that affect quality; and documentation of technical procedures for all technical activities that require quality assurance.

Table 3.5-2 provides a complete tabulation of quality-assurance level-assignment (YMP-QALA-) numbers and technical procedures applicable to this activity. Approved procedures are identified with a USGS number and a procedure effective date. Procedures that require preparation do not have procedure numbers.

Procedures that are identified as "needed" in the table will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started. Many of the needed technical procedures depend on the results of ongoing prototype testing and cannot be completed until work is done.

Applicable quality-assurance procedures are presented in Appendix 7.1. Completed quality-assurance level assignments are presented in Appendix 7.2.

Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Table 3.5-1. Summary of tests and methods for the excavation-effects test (SCP 8.3.1.2.2.4.5) in the exploratory shaft for the Topopah Spring welded unit
[Note: Dashes (--) indicate information is not available and to be determined.]

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | **Borehole fracture logging** | |
| Borehole television survey for locating setting depths of instruments (selected) | Fracture aperture | -- |
| " | Fracture distribution | -- |
| " | Fracture orientation | -- |
| Oriented-core for locating setting depths of instruments (alternate) | Fracture distribution | -- |
| " | Fracture orientation | -- |
| " | Fracture roughness | -- |
| | **Borehole geophysical surveys** | |
| Neutron logging to estimate water content (selected) | Moisture content, in situ degree of saturation | 0-100% |
| Laboratory determination of water content from cores (alternate) | " | " |
| Porosity (epithermal neutron) logging to estimate in situ porosity (selected) | Porosity | 0-65% |
| Laboratory determination of porosity (alternate) | " | " |
| Gamma-gamma (density) logging (selected) | Density | 0.8-2.6 gm/cm$^3$ |
| Density determination from laboratory measurements (alternate) | " | " |

Table 3.5-1. Summary of tests and methods for the excavation-effects test (SCP 8.3.1.2.2.4.5) in the exploratory shaft for the Topopah Spring welded unit--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | **Packer air-injection tests** | |
| Cross-hole pneumatic and hydrologic tests (selected) | Air permeability profiles | -- |
| | **Borehole instrumentation and monitoring** | |
| In situ measurements of stress, using borehole stress meters or borehole pressure cells (selected) | In situ stress, magnitude and orientation | -- |
| In situ measurements of stress, using U.S. Bureau of Mines gauge (alternate) | " | -- |
| Measurement of longitudinal deformation using borehole extensometers (selected) | Fracture deformation | -- |
| | **Excavation-effects test modeling** | |
| Test using numerical hydrologic-mechanical model (selected) | Air permeability profiles | -- |

Table 3.5-2. Technical procedures and quality-assurance level assignments for excavation-effects test (8.3.1.2.2.4.5)
[Dashes (--) indicate information is not available and to be determined. Quality-assurance level-assignment numbers are listed with the test/analysis title.]

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | Borehole drilling and coring<br>NNWSI-QALA-6922G-01-08, R0 | |
| HP-12,R3 | Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS | 06/08/88 |
| HP-38,R0 | Method for measuring humidity, pressure, and temperature of intake and exhaust air during vacuum drilling | In prep. |
| Needed | Drilling and coring (REECo) | -- |
| Needed | Borehole logging in the exploratory shaft and drifts | -- |
| | Borehole-deviation surveys<br>NNWSI-QALA-6922G-01-08, R0 | |
| Needed | Borehole deviation surveys | -- |
| Needed | Oriented core logging | -- |
| | Borehole fracture logging<br>NNWSI-QALA-6922G-01-08, R0 | |
| GP-10,R0 | Borehole video fracture logging | 04/12/85 |
| Needed | Borehole fracture logging | -- |
| | Borehole geophysical surveys<br>NNWSI-QALA-6922G-01-08, R0 | |
| Needed | Gamma-gamma meter calibration | -- |
| Needed | Porosity meter calibration | -- |

Table 3.5-2. Technical procedures and quality-ass...ance level assignments for excavation-effects test (8.3.1.2.2.4.5)--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Borehole geophysical surveys** NNWSI-QALA-6922G-01-08, R0 | |
| Needed | Porosity meter operation | -- |
| Needed | Method for measuring in situ porosity, using porosity (epithermal neutron) logs | -- |
| Needed | Method for measuring in situ density, using gamma-gamma logs | -- |
| HP-62,R4 | Method for measuring subsurface moisture content, using a neutron moisture meter | 11/02/88 |
| | **Packer air-injection tests** NNWSI-QALA-6922G-01-09, R0 | |
| HP-14,R1 | Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media | 07/09/84 |
| HP-15,R2 | Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media | 07/09/84 |
| HP-17,R0 | Method of calibration and testing for operation of pressure transducers for air-permeability studies in the unsaturated zone | 08/14/84 |
| HP-18,R0 | Frequency of equipment calibration for unsaturated-zone testing, Nevada Test Site | 07/20/84 |
| HP-19,R0 | Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at NTS | 07/20/84 |
| Needed | Method for calibrating gas-flow meters | -- |
| Needed | Method for calibrating thermocouples | -- |
| Needed | Method for construction of air-injection packer system and air-leak detection | -- |

Table 3.5-2. Technical procedures and quality-assurance level assignments for excavation-effects test (8.3.1.2.2.4.5)--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Packer air-injection tests** NNWSI-QALA-6922G-01-09, R0 | |
| Needed | Method for operation of packer air-injection string | -- |
| Needed | Method for calibrating temperature sensors | -- |
| | **Borehole instrumentation and monitoring** NNWSI-QALA-6922G-01-10, R0 | |
| GPP-04,R0 | In situ stress investigations | 06/27/83 |
| HP-17,R0 | Method of calibration and testing for operation of pressure transducers for air-permeability studies in the unsaturated zone | 08/14/84 |
| HP-18,R0 | Frequency of equipment calibration for unsaturated-zone testing, Nevada Test Site | 07/20/84 |
| HP-19,R0 | Method for identification, transport, and handling of instrumentation packages and equipment for field testing in the unsaturated zone at NTS | 07/20/84 |
| Needed | Data-acquisition system for monitoring borehole deformation gages, flatjacks, and load cells | -- |
| Needed | Method for calibrating a coupled-hydraulic-mechanical finite-element model | -- |
| Needed | Method of calibrating flatjacks and loading cells | -- |
| Needed | Method of emplacement of borehole stress gauges | -- |
| Needed | Method of emplacement of flatjacks and loaded cells | -- |
| Needed | Method of emplacement of multiposition borehole extensometers | -- |
| Needed | Method for calibration of borehole stress gauges | -- |

Table 3.5-2. Technical procedures and quality-assurance level assignments for excavation-effects test (8.3.1.2.2.4.5)--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Borehole instrumentation and monitoring**<br>NNWSI-QALA-6922G-01-10, R0 | |
| Needed | Method of calibration of multiposition borehole extensometers | -- |
| | **Excavation-effects test modeling**<br>NNWSI-QALA-6922G-01-11, R0 | |
| Needed | Method for evaluating the correctness of a coupled-hydraulic-mechanical finite-element model (bench-mark problems) | -- |
| Needed | Reference software documentation | -- |

### 3.6 Calico Hills test

Plans for the Calico Hills test are in the preliminary planning stage. Because the test is not part of the exploratory-shaft construction-phase testing, the plan for this activity will be presented in a subsequent revision of this study plan.

## 3.7 Perched-water test

### 3.7.1 Objectives of activity

The objectives of this activity are to

1. detect the occurrence of any perched water;

2. estimate the hydraulic properties of the zones; and

3. determine the implication of the existence of such zones on water flux, flow paths, and travel times.

### 3.7.2 Rationale for activity selection

Perched water in the geohydrologic system may imply a particular flow path for water (Montazer and Wilson, 1984). In addition, temporal variations in occurrence and characteristics of such perched water could indicate dynamic or static conditions of the unsaturated zone. Therefore, analysis of the spatial and temporal occurrence of perched water would help identify various flow paths of water. When the flow paths are identified, calculations of flux and travel time become possible. The Darcian flux is determined by dividing the flow rate by the cross-sectional area that is perpendicular to the direction of flow (Freeze and Cherry, 1979). Travel time is estimated by dividing the length of the flow path by the flux and estimated effective porosity. Direct estimation of the travel time from land surface to the perched water is also possible through analysis of the ages of pore, fracture, and perched water at known depths. The age-dating methods are described in hydrochemistry tests in Section 3.8.3.

The activity 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.

It is anticipated that any significant amount of perched water in the vicinity of the ESF will have been detected during multipurpose-borehole testing near the exploratory shafts (8.3.1.2.2.4.9). If perched water has been detected, it 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, and to sample and test, if any is encountered.

At the Nevada Test Site and vicinity, perched water is known to occur principally within or above the tuff and lava-flow aquitards, as described by Winograd and Thordarson (1975). In the underground workings beneath Rainier Mesa, the perched water occurs only within the tuff aquitard. Nine perched springs occur within the tuff aquitard and lava-flow aquitard. Perched water has not been positively identified in the bedded- or welded-tuff aquifers. Perched water within or above the tuff aquitard generally occurs in poorly connected fractures. The general absence of perched water in the welded-tuff aquifer is attributed to both abundant hydraulically connected fractures and absence of a perching bed; these prevent accumulation of perched water.

Beneath Yucca Mountain, man-induced or natural perched water has been encountered during drilling of test well USW H-1 (Rush et al., 1984) and during drilling of test hole USW UZ-1 (Whitfield, 1985). In test well USW H-1, water was perched above an underlying 5-m-thick bedded or reworked ash-flow tuff at the base of the Topopah Spring Member of the Paintbrush Tuff. This may have been contaminated water resulting from the large amount of water used during drilling, with water and detergent as the circulating media. In test hole USW UZ-1, drilling in the Topopah Spring Member was discontinued at a depth of 387 m (1,269 ft) because a large volume of water was encountered, and the water level could not be lowered significantly. All of this water may be contamination from geologic test hole USW G-1 located 305 m (1,000 ft) to the southeast of test hole USW UZ-1.

The conceptual model of flow in the unsaturated zone indicates that perched water may occur within or immediately above the Paintbrush Tuff nonwelded unit (PTn) and the Calico Hills nonwelded unit (CHn) (Montazer and Wilson, 1984). This water could occur where displacement along faults has created permeability contrasts on opposite sides of the fault. The occurrence of perched water would probably be by percolation downward into underlying units, by flow down the fault planes or zones, by lateral flow along contacts, or by combinations of these pathways.

No perched water is expected in the host rock, except perhaps immediately above the CHn. 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 PTn, 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 CHn 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.

Because the ES-1 has not been constructed at Yucca Mountain, geologic and hydrologic prototype testing will be conducted at G-tunnel in Rainier Mesa, which is located at the Nevada Test Site about 60 k (40 mi) from Mercury, Nevada. This prototype test will develop and test hydraulic methods for determining the rate of flow, hydraulic head, and procedures for collecting representative water samples from a mined shaft or drift wall. In addition, instrumentation needed to provide long-term geohydrologic data in perched-water zones will be identified. Established procedures will minimize shaft construction delays and provide quality-assured data in the licensing process.

3.7.3 General approach and summary of tests and analyses

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 flow-rate measurement will precede the borehole drilling if the flow rate into the shaft is sufficiently large.

Data from hydraulic tests of the perched-water zone will be analyzed in the field to determine the hydraulic characteristics of the zone and to estimate its lateral extent. These hydraulic tests will help to define the occurrence and to estimate the hydraulic properties of the zone so that the hydrologic conditions and flow characteristics of the perched-water zone can be modeled. Various conditions occur under which water may perch in the unsaturated zone beneath Yucca Mountain. Two possibilities are (1) as saturated zones within porous nonwelded tuffs and (2) within isolated single fractures that are poorly connected or are truncated against some network overlying relatively impermeable material. Depending on the geohydrologic characteristics of each zone, the rate of discharge into ES-1 may vary significantly; in fact, this rate of discharge will determine the type of hydraulic tests required. For example, a saturated zone within a porous nonwelded tuff and an isolated single fracture may yield only seeps or wet zones that require boreholes and piezometers for hydraulic tests. A saturated zone in a well-connected fracture network may yield appreciable flows of water and can be tested by pumping.

Excavation of the shaft may affect the interpretation of the geohydrology of the perched-water test. The disturbed zone around the shaft and the stress changes caused by drilling and blasting that alter the bulk permeability and porosity of the rock may create new pathways for flow, thereby altering the performance and results of the pumping and borehole tests. If possible, different scenarios for studying the effects of excavation on pumping and borehole tests will be explored during the prototype testing. In addition to excavation effects, lining the shaft with concrete may modify the geohydrologic properties of the rocks surrounding the shaft. Water from the wet concrete may enter fractures in the shaft wall and may invade fractures, altering flow paths.

Uncertainties and limitations which effect interpretation of data may result from perched-water zones of limited areal extent and/or loss of early-time data because of drainage into the shaft bottom. It will be necessary to assess the magnitude of these effects during analysis and interpretation of test results.

The perched-water test, conducted with either pumping or borehole tests, will determine both the type of occurrence of any perched water and the hydraulic properties necessary to predict flux, flow paths, and travel times through the unsaturated zone as influenced by intervening perched water. The effects of perched-water bodies on the construction and operation of a repository would be estimated, as would the potential for existing or future perched water near the repository. In addition, the possibility of a small-conductivity unit, above the repository, that directed water away from the repository would be evaluated. The perched-water data would also be important in formulating mathematical models of the unsaturated zone.

Any perched water encountered by the shaft will be sampled and analyzed for water quality and for stable and radioactive isotopes. Relative ages of pore and fracture water will be estimated from these data in the hydrochemistry tests. These data will help determine flow paths, flux, and travel times, as described in Section 3.8.3.

Figure 3.7-1 summarizes the organization of the perched-water test. A descriptive heading for each test and analysis appears in the shadowed boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized during testing. Cross-references to other study plans which provide input to the perched-water tests also appear in Figure 3.7.1. Figure 3.7-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed test/analysis boxes, respectively, in Figure 3.7-2.

The two figures summarize the overall structure of the planned activity in terms of methods to be employed and measurements to be made. The descriptions of the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) the site parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

The methods utilized in this activity will provide information that is approximately representative of the repository area. The spatial variabilities of existing conditions within the repository block, and the correlations to present and potential future repository conditions are represented by the perched-water tests.

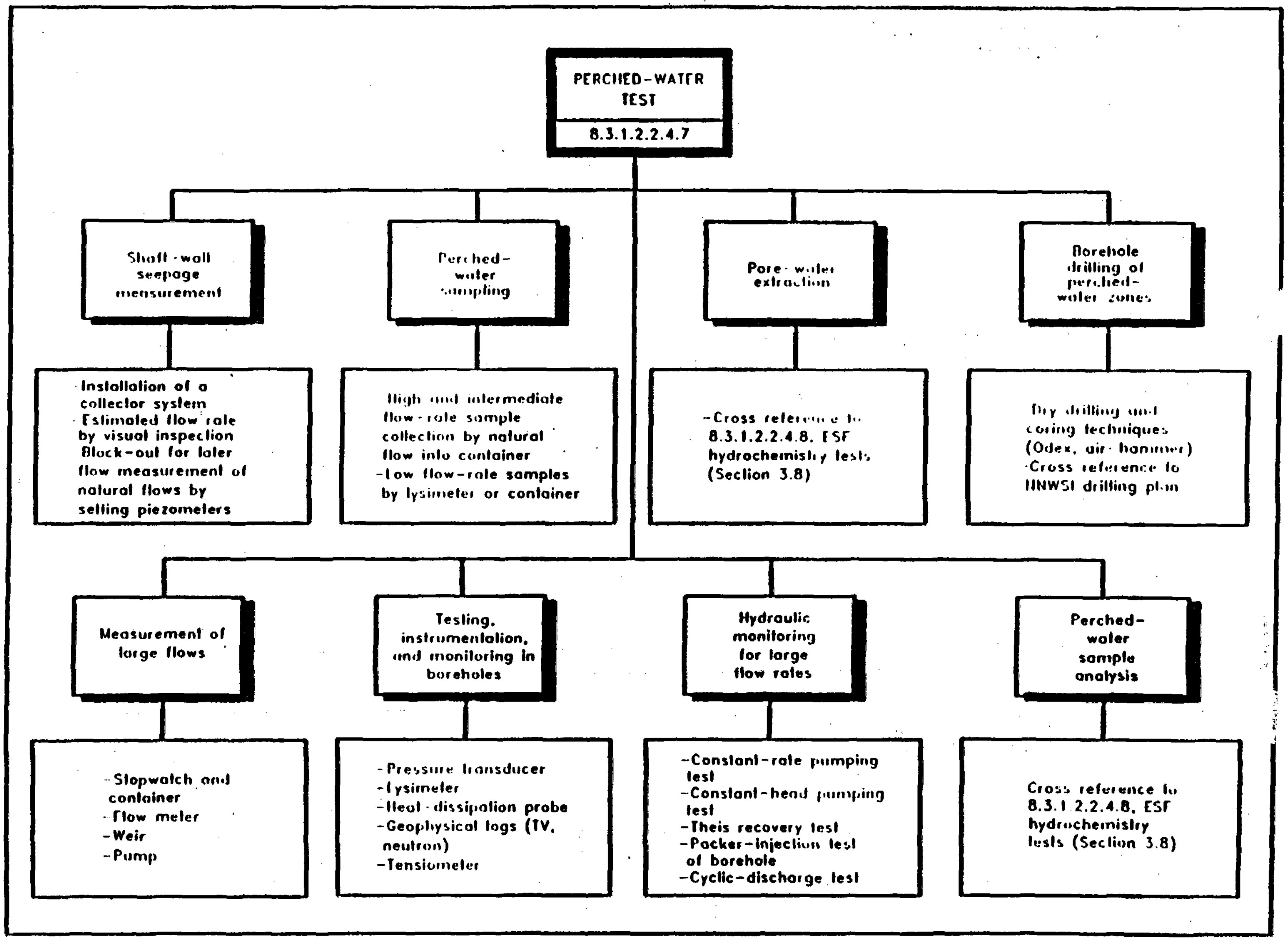



**Figure 3.7-1. Organization of the perched-water activity, showing tests, analyses, and methods.**

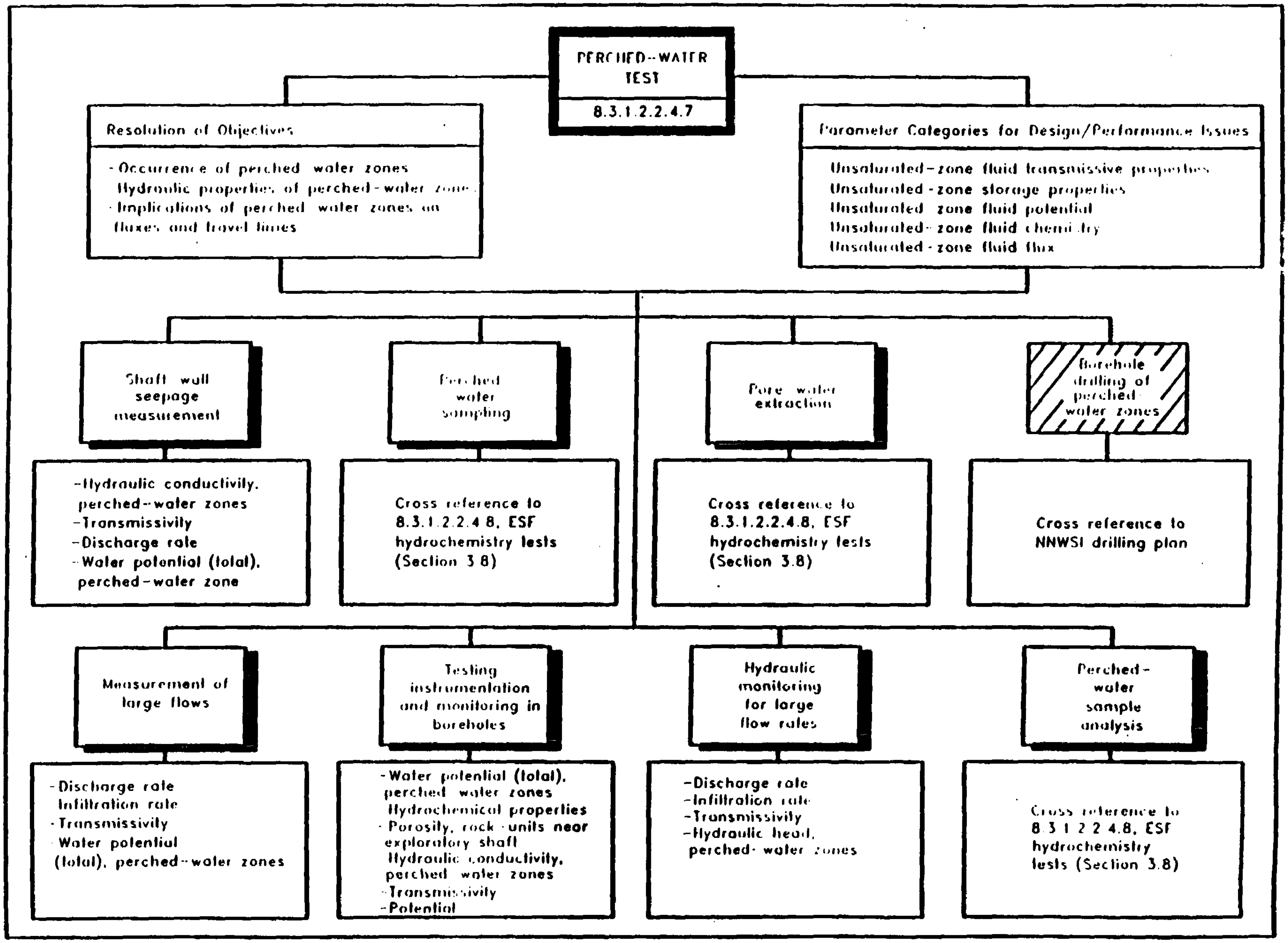



**Figure 3.7-2. Organization of the perched-water activity, showing tests, analyses, and site parameters. The cross-hatched box indicates that no site parameters will be generated.**

The perched-water tests will be conducted in the ESF which will penetrate the same geohydrologic units as does the repository. Because of this, the environment in which these tests will be conducted is an approximate representation of the repository area. The perched-water tests will help identify various flow paths of water in the repository block. When the flow paths are identified, calculations of the spatial and temporal occurrence of perched water and travel times within the repository become possible. Furthermore, an understanding of the TSw geohydrologic conditions causing the accumulation of perched water, whether perched water is a permanent or transient feature, and the implications of such a zone on flux, flow paths, and travel times will be useful in predicting potential future hydrologic conditions within the repository.

### 3.7.3.1 Shaft-wall seepage measurement

After each excavation round, rate of seepage from the shaft wall will be measured or estimated before any holes are drilled. One method of seepage measurement is installation of a small collector system such as a small inclined ledge to concentrate small flows of water in order to facilitate measurements with a container. A second method of seepage measurement is estimation of flow rate that is made by visual inspection. Finally, block-outs in the shaft wall and subsequent boreholes will allow easy access for later instrumentation and seepage measurements. No viable alternatives are available in place of the three methods that were selected. A summary of the tests, analyses, and methods is presented in Table 3.7-1 (Section 3.7.3.9).

### 3.7.3.2 Perched-water sampling

Any perched water found in the shaft will be sampled. These samples will be analyzed for water quality and for stable and radioactive isotopes. Relative ages of pore and fracture water will be estimated from these data in the hydrochemistry tests. These data will help determine flow paths, flux, and travel times, as described in Section 3.8.3.

One method is perched-water sample collection by natural large or intermediate flow into a container. A second method is small-flow-rate sample collection by lysimeter or container. The third, fourth, and fifth tests are to use methods to sample water quality, radioactive isotopes, and stable isotopes by cross reference to Section 3.8.3. As in Section 3.7.3.1, there are no viable alternate methods to use in place of the five methods that were selected. The five selected methods are presented in Table 3.7-1 in Section 3.7.3.9.

### 3.7.3.3 Pore-water extraction

Pore-water samples will be obtained from core. The pore water will be extracted from the core by methods indicated by cross reference to Section 3.8.3.6. There are no alternate methods to the methods selected (Table 3.7-1 in Section 3.7.3.9).

### 3.7.3.4 Borehole drilling of perched-water zones

The drilling of holes into perched-water zones will probably be accomplished using dry-drilling methods. These dry-drilling and coring methods will be developed during prototype testing. Dry drilling and coring is the selected method because representative rock samples and cores that are uncontaminated by drilling liquid can be obtained and because positive identification of perched-water zones is obtainable.

An alternate method is wet-drilling and -coring techniques, but this method is less desirable than dry drilling because the core could be contaminated by drilling liquid, and identification of perched-water zones would be more difficult. Another alternate method is drilling and coring with liquified gas, but this method is not desirable because the liquified gas could condense water in the air, resulting in an altered sample, and gas would be introduced into the rock, interfering with gas sampling. The selected method and the alternate method are presented in Table 3.7-1 in Section 3.7.3.9.

### 3.7.3.5 Measurement of large flows

The selected methods of measuring the rate of perched water flowing from either the shaft wall or a borehole are using a stopwatch and container, flow meter, or a weir. These data will be used to estimate hydraulic conductivity and transmissivity. There are no viable alternate methods to use in place of the three methods selected. The three selected methods are presented in Table 3.7-1 in Section 3.7.3.9.

### 3.7.3.6 Testing, instrumentation, and monitoring in boreholes

If a wet zone or seep is encountered, and if the amount of water is inadequate to justify a pumping test, a hole will be drilled into it to increase flow; this hole will penetrate beyond the region disturbed by mining of the shaft and will be cased to the outer edge of the zone. If an isolated water-bearing fracture is encountered, holes will be drilled to intersect the fracture and possibly, along and perpendicular to, the fracture plane.

Following any pumping test, two to four lateral holes will be drilled and completed with piezometers and/or lysimeters to further test and sample at a later time. If the amount of water is inadequate to justify a pumping test, short boreholes will be drilled into the walls of the shaft for testing of the water-bearing zone after completion of the shaft.

In addition to easily measurable yields of perched water, wet zones or seeps may be encountered, or the water saturation in the rock may be so large (for example, 95 or 100 percent water saturation) that a search for perched water of small yield may be necessary. If a wet zone or seep of small discharge is found, a long or short borehole will be drilled in the general direction of production in an effort to develop and concentrate the flow. The length of the hole will depend on the width of the disturbed zone as determined by other tests (Sections 3.4 and 3.5). Long lateral boreholes 33 to 66 m (108 to 216 ft) long may be drilled and completed with piezometers for long-term monitoring. The diameter of the borehole will be small but still allow installation of a piezometer. Piezometers will be designed to enable monitoring of the *in situ* pressure, sampling of the water, and testing of the perched zone. The decision on whether to drill a borehole will be made on site by a USGS hydrologist. The direction of the borehole will be guided by the direction of the apparent fracture system from which water is being produced. The borehole should penetrate beyond the disturbed zone and be cased to its outer edge. If the developed water flow is sufficiently large, it will be sampled upon completion of the lateral borehole; if not, it will be plugged and sampled later. The casing will be capped and will protrude through the concrete shaft lining for later sampling. A special block-out will be necessary to protect the casing and allow access to the casing cap.

The selected methods for testing boreholes include using instruments to monitor saturated and unsaturated conditions to insure the detection of transient boundaries. These include (1) pressure transducers to measure hydraulic head; (2) lysimeters for collecting water samples; (3) heat-dissipation probes and tensiometers to measure matric potential; (4) hydraulic tests similar to those used in Section 3.7.3.7 to determine hydraulic conductivity, transmissivity, and storage coefficient; and (5) geophysical logging. There are two alternate methods. The first alternate method involves using the thermocouple psychrometer, but this was not selected because it is used to measure matric potential in rocks that contain less water than the rocks expected there. The second alternate method consists of periodic visual observations of the borehole, but this is less satisfactory than using borehole instruments. The selected methods and the alternate methods are presented in Table 3.7-1 in Section 3.7.3.9.

The boreholes will be especially useful if pumping tests of long duration are not practical during ESF excavation. All boreholes will be subjected to long-term hydraulic tests and monitoring in order to estimate the extent and hydraulic properties of the zone. Monitoring of the boreholes may also be useful in measuring temporal changes in a perched zone due to changes in percolation rates. Although the infiltration rate is estimated to range from 0.5 to 4.5 mm/yr (Montazer and Wilson, 1984), temporal changes that might occur due to locally large infiltration along a fault zone may cause increased hydraulic head in a borehole after heavy rainfall or snowmelt. This probably would indicate that a perched-water zone is directly influenced by recharge. If the perched-water zone in a borehole decreased in hydraulic head during a period of drought, a possible change of the flow path, flux, and travel time through the unsaturated zone might be determined.

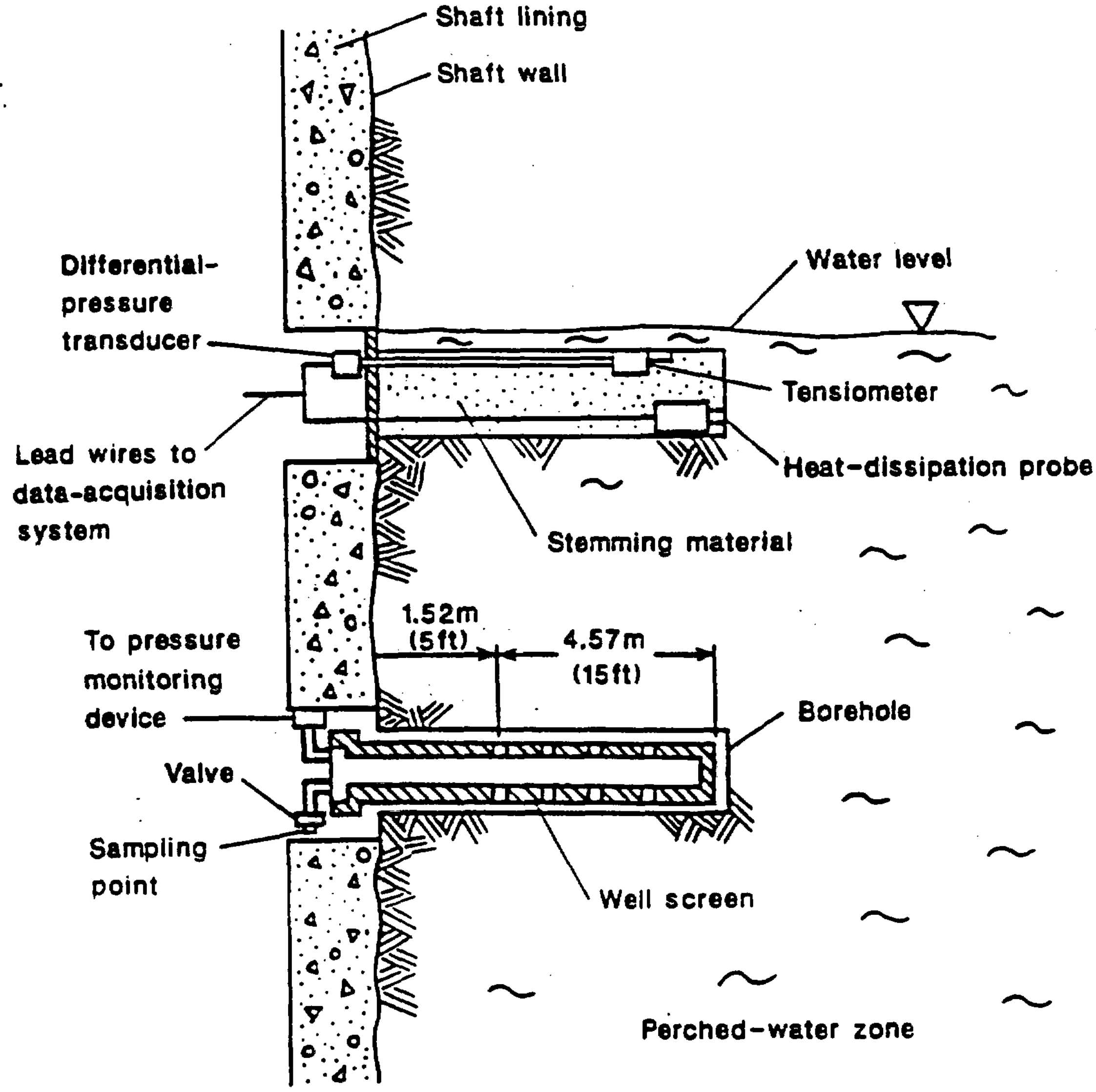
Hydraulic-head data from boreholes may provide information on the vertical component of percolation within a perched-water zone. This measurement may be accomplished by horizontal boreholes spaced vertically throughout a perched-water zone (Figure 3.7-3).

All tests will provide water samples for chemical and isotopic analyses. Boreholes that are cased will be capped for later sampling; a special block-out will be used to protect the casing and allow later access to the casing cap. All boreholes will be subjected to long-term hydraulic monitoring to estimate the extent and hydrologic properties of the zone.

### 3.7.3.7 Hydraulic tests for large flow rates

Pumping tests will be conducted in the shaft if water flows at a sufficient rate into the shaft. Pumping tests will be designed to determine the yield of the perched water. Extent of perched-water zones will be determined by a combination of surface and subsurface testing. For example, a long-term test might detect a decreasing rate of inflow, with a change in chemical constituents in the water; or a decline in static water level after repeated pumping might indicate that the perched water is of limited extent. If pumping tests show a constant rate of inflow and a constant static water level, a perched-water zone of great extent would be indicated. These pumping tests must be conducted with great care because a pumping rate that is too large might flush out sediment or clay from a weak zone or form a clay gouge within a fault; thus, hydraulic properties such as transmissivity and the storage coefficient would be increased or decreased artificially, as noted by Stuart (1955). A pumping rate that is too small, however, might indicate only storage of water within the shaft due to its large diameter, which is similar to the effects of well-bore storage. Following any pumping test, two to four lateral boreholes will be drilled and completed with piezometers and/or lysimeters to further test and sample for perched water at a later time.

Hydraulic-test methods, such as pumping tests and injection tests, will be analyzed using standard analytical methods for these tests. Pumping tests with constant discharge will be analyzed using the type-curve method (Lohman, 1972); the straight-line solution (Cooper and Jacob, 1946; Ferris and others, 1962), and the Theis recovery formula (Ferris and others, 1962). Pumping tests that are made using constant drawdown will be analyzed using Jacob and Lohman's method (Jacob and Lohman, 1952; Lohman, 1972). Pumping tests that are made using cyclic intervals of discharge will be analyzed using Brown's method (Bentall, 1963). For pumping tests in wells of large diameter, the methods of




Note: Figure not to scale

Figure 3.7-3. Schematic diagram of instrumentation of perched-water zone within the exploratory shaft.

Papadopulos and Cooper (1967) or Goodman and others (1965) will be used. Injection tests will be analyzed using the method of Cooper and others (1967) and Papadopulos and others (1973). It will be necessary to consider the effects of free-surface boundaries during the application of the proposed methods of analyses. The selected methods are presented in Table 3.7-1 in Section 3.7.3.9.

### 3.7.3.8 Perched-water sample analysis

Any perched water encountered in the shaft will be sampled. These samples will be analyzed using methods for water quality and for stable and radioactive isotopes. The methods of analysis of the hydrochemical and age-dating data will be done as part of the perched-water test. Relative ages of pore and fracture water will be estimated in the hydrochemistry tests. These data will help determine flow paths, flux, and travel times (Section 3.8.2).

There are no viable alternate methods to use in place of the selected methods which are presented in Table 3.7-1.

### 3.7.3.9 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.7-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be utilized only if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, there are many approaches to conducting the test. In those cases, only the most common methods are included in the tables. The selected methods in Table 3.7-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods. expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they feel are suitable to provide accurate data within the expected range of the site-characterization parameter. Models and analytical techniques have been or will be developed to be consistent with test results. The expected ranges of the site-characterization parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.7-1.

## 3.7.4 Technical procedures and quality-assurance levels

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment, justification, and documentation of quality levels to activities that affect quality; and documentation of technical procedures for all technical activities that require quality assurance.

Table 3.7-1. Summary of tests and methods for the perched-water test (SCP 8.3.1.2.2.4.7) in the exploratory shaft

[Note: Dashes (--) indicate information is not available and to be determined.]

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| **Shaft-wall seepage measurement** | | |
| Installation of collector system (selected) | Flow rates, perched-water zones | Small |
| Estimate flow rate by visual inspection (selected) | " | " |
| Block-out for later measurement of natural flows by setting piezometers (selected) | " | " |
| **Perched-water sampling** | | |
| Large-flow- and intermediate-flow-rate sample collection by natural flow into container (selected) | Flow rates, perched-water zones | Large |
| Small-flow-rate samples by lysimeter or container (selected) | " | " |
| Cross reference to 8.3.1.2.2.4.7 ESF hydrochemistry tests (selected) | Radioactive isotopes | -- |
| Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected) | Stable isotopes | -- |
| Cross reference to 8.3.1.2.2.4.7 ESF hydrochemistry tests (selected) | Water quality | Small |

Table 3.7-1. Summary of tests and methods for the perched-water test (SCP 8.3.1.2.2.4.7) in the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | **Pore-water extraction** | |
| Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected) | Radioactive isotopes | -- |
| Cross reference to 8.3.1.2.2.4.7 ESF hydrochemistry tests (selected) | Stable isotopes | -- |
| Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected) | Water quality | -- |
| | **Water flow-rate measurement for large flows** | |
| Stopwatch and a container (selected) | Discharge, perched-water zones | 0.0000631 $m^3/s$ to 0.00631 $m^3/s$ |
| Flow meter (selected) | " | " |
| Weir (selected) | " | " |
| | **Testing, instrumentation, and monitoring of boreholes** | |
| Pressure transducer (selected) | Water potential, total, perched-water zones | -- |
| Lysimeter (selected) | Hydrochemical properties, perched-water zones | -- |
| Heat-dissipation probe (selected) | Water potential, total, perched-water zones | -- |
| Geophysical logs (tv, neutron) (selected) | Porosity, perched-water zones | 1 to 60% |

Table 3.7-1. Summary of tests and methods for the perched-water test (SCP 8.3.1.2.2.4.7) in the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | Testing, instrumentation, and monitoring of boreholes | |
| Thermocouple psychrometer (alternate) | Water potential, total, perched-water zones | -- |
| Hydraulic tests (selected) | Hydraulic conductivity, perched-water zones | -- |
| " | Storage coefficient, perched-water zones | -- |
| " | Transmissivity, perched-water zones | -- |
| | Hydraulic tests for large flow rates | |
| Theis recovery test (selected) | Discharge, perched-water zones | 0.0000631 $m^3/s$ to 0.0252 $m^3/s$ |
| " | Hydraulic conductivity, perched-water zones | -- |
| " | Storage coefficient, perched-water zones | -- |
| " | Transmissivity, perched-water zones | -- |
| Packer injection test of borehole (selected) | Discharge, perched-water zones | 0.0000631 $m^3/s$ to 0.0252 $m^3/s$ |
| " | Hydraulic conductivity, perched-water zones | -- |
| " | Storage coefficient, perched-water zones | -- |
| " | Transmissivity, perched-water zones | -- |

Table 3.7-1. Summary of tests and methods for the perched-water test (SCP 8.3.1.2.2.4.7) in the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | Hydraulic tests for large flow rates | |
| Cyclic-discharge test (selected) | Discharge, perched-water zones | 0.0000631 $m^3/s$ to 0.0252 $m^3/s$ |
| " | Hydraulic conductivity, perched-water zones | -- |
| " | Storage coefficient, perched-water zones | -- |
| " | Transmissivity, perched-water zones | -- |
| Constant-drawdown pumping test (selected) | Discharge, perched-water zones | 0.0000631 $m^3/s$ to 0.0252 $m^3/s$ |
| " | Hydraulic conductivity, perched-water zones | -- |
| " | Storage coefficient, perched-water zones | -- |
| " | Transmissivity, perched-water zones | -- |
| Constant-rate pumping test (selected) | Discharge, perched-water zones | 0.0000631 $m^3/s$ to 0.0252 $m^3/s$ |
| " | Hydraulic conductivity, perched-water zones | -- |
| " | Transmissivity, perched-water zones | 0.0000631 $m^3/s$ to 0.0252 $m^3/s$ |
| | Perched-water sample analysis | |
| Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected) | Radioactive isotopes | -- |

Table 3.7-1. Summary of tests and methods for the perched-water test (SCP 8.3.1.2.2.4.7) in the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | Perched-water sample analysis | |
| Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected) | Stable isotopes | -- |
| Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (alternate) | Water quality | -- |

Table 3.7-2 provides a complete tabulation of quality-assurance level-assignment (YMP-QALA-) numbers and technical procedures applicable to this activity. Approved procedures are identified with a USGS number and a procedure effective date. Procedures that require preparation do not have procedure numbers.

Procedures that are identified as "needed" in the table will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started. Many of the needed technical procedures depend on the results of ongoing prototype testing and cannot be completed until work is done.

Applicable quality-assurance procedures are presented in Appendix 7.1. Completed quality-assurance level assignments are presented in Appendix 7.2.

Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Table 3.7-2. Technical procedures and quality-assurance level assignments for perched-water test (8.3.1.2.2.4.7)
[Dashes (--) indicate information is not available and to be determined. Quality-assurance level-assignment numbers are listed with the test/analysis title.]

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Shaft-wall seepage measurement** NNWSI-QALA-6922G-01-13, R0 | |
| 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 | In prep. |
| HP-107,R0 | Testing and sampling wet zones and seeps in the exploratory shaft at Yucca Mountain, NTS | In prep. |
| | **Perched-water sampling** NNWSI-QALA-6922G-01-14, R0 | |
| HP-90,R0 | Sampling and field testing of perched water in the exploratory shaft at Yucca Mountain, NTS | In prep. |
| HP-98,R0 | Procedure for recognition of perched water in the exploratory shaft at Yucca Mountain, NTS | In prep. |
| HP-104,R0 | Sampling perched water for chemical and isotopic analysis in the exploratory shaft at Yucca Mountain, NTS | In prep. |
| | **Pore-water extraction** NNWSI-QALA-6922G-01-15, R0 | |
| Needed | Pore-water extraction | -- |
| | **Borehole drilling of perched-water zones** NNWSI-QALA-6922G-01-12, R0 | |
| HP-12,R3 | Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS | 06/08/88 |
| HP-33,R0 | Preliminary method for monitoring and testing perched-water zones in a borehole drilled with the reverse-vacuum method | 05/15/85 |

Table 3.7-2. Technical procedures and quality-assurance level assignments for perched-water test (8.3.1.2.2.4.7)--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Borehole drilling of perched-water zones**<br>NNWSI-QALA-6922G-01-12, R0 | |
| HP-109,R0 | Boreholes drilled in perched-water zones after a liner is installed in the exploratory shaft at Yucca Mountain, NTS | In prep. |
| Needed | Borehole dry drilling and coring (perched-water zones) | -- |
| | **Measurement of large flows**<br>NNWSI-QALA-6922G-01-13, R0 | |
| HP-06,R0 | Hydrologic pumping test | 01/11/82 |
| HP-53,R0 | Method for calibrating digital and analog watches | 11/15/84 |
| | **Testing, instrumentation, and monitoring of boreholes**<br>NNWSI-QALA-6922G-01-12, R0 | |
| HP-14,R1 | Method for calibrating Peltier-type thermocouple psychrometers for measuring water potential of partially saturated media | 07/09/84 |
| HP-15,R2 | Method for calibrating heat-dissipation sensors for measuring in situ matric potential within porous media | 07/09/84 |
| HP-17,R0 | Method of calibration and testing for operation of pressure transducers for air-permeability studies in the unsaturated zone | 08/14/84 |
| HP-105,R0 | Borehole sampling and field testing of perched water in the exploratory shaft at Yucca Mountain, NTS | In prep. |
| HP-108,R0 | Long-term monitoring of boreholes in perched-water zones in the exploratory shaft at Yucca Mountain, NTS | In prep. |

Table 3.: . Technical procedures and quality-assurance level assignments for perched-water test (8.3.1.2.2.4.7)--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Hydraulic tests for large flow rates** NNWSI-QALA-6922G-01-13, R0 | |
| HP-53,R0 | Method for calibrating digital and analog watches | 11/15/84 |
| HP-103,R0 | Pumping tests of perched water in the exploratory shaft at Yucca Mountain, NTS | In prep. |
| | **Perched-water sample analysis** NNWSI-QALA-6922G-01-14, R0 | |
| Needed | Perched-water sample analysis | -- |

## 3.8 Hydrochemistry tests

### 3.8.1 Objectives of activity

The objectives of this activity are to

1. implement methods, designed in the prototype tests, for extracting uncontaminated pore water from mining rubble; and

2. generate hydrochemical data that will help determine the flow direction and travel time of gas and water in the unsaturated zone by hydrochemical and isotopic techniques.

### 3.8.2 Rationale for activity selection

The inorganic composition of Yucca Mountain unsaturated-zone water indicates the types of chemical processes within the unsaturated zone. The chemistry of pore water reflects the results of rock-water interactions within the matrix of the rock, and the chemistry of fracture water reflects the results of chemical processes along the rock-water interface. If fracture and matrix water have similar chemical constituents, the amounts of dissolved species may be different due to different lengths of contact time. These processes also affect the transport behavior of radionuclides leached from the waste package. Processes and conditions that may affect the precipitation, sorption, and mobility of radionuclides can, therefore, be inferred from the inorganic composition of the unsaturated-zone water.

Pore-water chemistry data and mineralogic data for the matrix and fractures in the unsaturated zone will be input to geochemical models (WATEQ, PHREEQE, EQ3/6) to provide additional information from which to infer the water-rock reactions occurring in the unsaturated zone. For example, the degree to which a theoretical water composition (calculated to be in equilibrium with a known mineral assemblage) matches the measured data can be used to infer the extent of mineral/ground-water reactions operating in the system. A close match supports a long contact time (long residence time), whereas a poor match suggests a more dynamic system and indicates the relative importance of reaction kinetics in controlling vadose-zone water composition.

Other chemical parameters, such as ionic strength and ranges of Eh/pH, will provide information on solubility and reactivity of the natural geochemical environment beneath Yucca Mountain and of the artificial environment created by the engineered-barrier systems.

A progressive change in pore-water inorganic composition is expected with depth in the unsaturated zone. This compositional variation probably can be related to variations in the types and compositions of primary minerals with which the pore water may come in contact and to the duration of contact time. The composition of fracture water may be useful in determining the degree of interconnectivity of the fractures. Certain fractures may not extend over long distances and hence may not intersect major water pathways. The water composition in such fractures may be similar to adjacent pore water, which has had long periods of rock/water interaction. Water within interconnected fractures, however, probably has had relatively short residence times and should be relatively dilute compared with water from poorly interconnected fractures. This dilute chemical concentration in water at great depths combined with younger $^{14}C$ age of water would imply a relatively fast travel time in the unsaturated zone, or periods of intense recharge at the land surface. Conversely, large concentrations at a great depth and old $^{14}C$ age of water would imply a slow travel time or overall minor recharge at the site.

Isotopic composition data can be used to interpret paleohydrologic conditions, including sources, times, and climate of recharge. When ocean water evaporates, the lighter $H_2{}^{16}O$ water molecules are preferentially evaporated compared with $H_2{}^{18}O$ or $HD^{16}O$, and the atmosphere becomes relatively depleted in the heavy isotopes. When poleward- or landward-driven water condenses, the first precipitation is enriched in the more condensable heavy isotopes. The remaining water becomes further depleted of heavy isotopes, which causes successive precipitation water to be progressively lighter. As a result, precipitation is lighter farther inland, higher in the mountains, and toward both poles. Thus, precipitation at various distances from the coast and at various altitudes and latitudes can be differentiated by the stable hydrogen- and oxygen-isotope compositions.

Although individual precipitation at the same location varies greatly in composition with time due to local weather fluctuations (temperature, humidity, and wind), water infiltrating the ground has relatively small isotopic compositional variation with time due to an averaging effect. Thus, only long-term climatic changes can be recognized by significant differences in isotopic composition of unsaturated-zone water. Precipitation at the Nevada Test Site during a cooler climate is comparatively more depleted in heavy isotopes than that from a warmer climate. Therefore, by analyzing the compositions of oxygen-18 and deuterium in the unsaturated-zone water, it is possible to identify the climate at the time of recharge (that is, recharged during the warm- or cold-climatic regime). The isotope ratios of oxygen and hydrogen recharged during the last ice age (about 10,000 years ago) were significantly depleted compared to isotope ratios of different sources. Therefore, when stable-isotope compositions of oxygen and hydrogen are compared with the climates of the past, flow paths of the water can be identified. The sources of recharge can be identified from the differences in stable-isotope ratios due to altitude effect (the higher the altitude, the cooler the condensation temperature, hence the lower the isotopic ratios). The possible sources of Yucca Mountain's precipitation are the Pacific Northwest, California coast, Gulf of California, and the Gulf of Mexico. Each is probably tagged with different stable oxygen- and hydrogen-isotope ratios. When the isotopic composition of unsaturated-zone waters is compared with precipitation collected at Yucca Mountain from these four sources, the water source possibly can be implied. Furthermore, from the age of water determined by carbon-14 and tritium methods, it is likely to identify the time of recharge, travel, and residence time (Yang and others, 1985).

Hydrochemical data and interpretations will be used as a cross-check on travel times computed from hydraulic parameters. Tritium (hydrogen-3) analyses will be used to determine the residence time of pore and fracture water up to about 100 years; carbon-14 analyses will extend the determination range from 100 to 40,000 years, and chlorine-36 yields dates from 50,000 to about 900,000 years. If caliches are dissolved into the unsaturated-zone water, carbon-14 ages can be corrected by measurements of carbon-13/carbon-12 ratios in the carbonate water because caliche has a $^{13}C/^{12}C$ ratio of about 5°/oo, while biogenic $CO_2$ has $^{13}C/^{12}C$ ratio of about 22 to 24°/oo. Therefore, the amount of caliche dissolved can be estimated, and $^{14}C$ age corrected. Four relative-age scenarios will be tested:

(a) Very young (<200 years) fracture water and relatively old (>5,000 years) pore water. This scenario implies a short residence time for fracture water and that most of the flow through the unsaturated zone is through the fracture network.

(b) Relatively young (<1,000 years) pore water and relatively old (>5,000 years) fracture water, and most fractures are air filled. This unlikely situation implies that most of the flow is through the matrix network and that the fractures are poorly connected.

(c) Pore- and fracture-water samples having the same age at a common depth, and age increasing with depth. This situation implies that fractures are poorly connected and behave as enlarged pores. It also implies the presence of relatively static perched water within the unsaturated zone.

(d) General absence of fracture water, and the occurrence of relatively old (>5,000 years) pore water. This scenario implies that the residence time of water entering the fracture system is extremely short or that all water transported by fractures is drawn into the matrix system by capillary action.

If enough pore water can be extracted from unsaturated-rock samples (in addition to the amount required for hydrochemistry tests, as described herein), pore-water samples will be sent to Los Alamos National Laboratory (LANL), and in turn sent to an outside contract laboratory, for chlorine-36/chlorine ratio analysis (see Study Plan 8.3.1.2.2.2).

When water percolates downward, travel time can be estimated from the ages of pore, fracture, and perched water at known depths. In more complicated scenarios, when water moves tortuously, the flow paths may be assessed from the oxygen-18/16 and deuterium/hydrogen ratios in water, as recharge waters in different climates have different ratios of these isotopes. When water composition of the same stable-isotope ratios is traced, it is possible to identify the flow path and path length. After this flow path is combined with water age, travel time can be calculated and compared with the value calculated from hydraulic parameters.

The Calico Hills nonwelded unit (CHn) is a nearly saturated zeolitized geohydrologic unit that probably functions as a porous medium. The water table is in this unit beneath some parts of Yucca Mountain. This unit probably retards the downward movement of pore and fracture water. Radiocarbon ages of water determined for this zone will allow an estimation of the residence time of water in the deepest part of the unsaturated zone.

Three prototype tests will be undertaken prior to the ESF hydrochemistry tests to design and validate methods of pore-water and gas collection. The optimal rubble size test, the dry coring of rubble, and the pore-water extraction by triaxial compression are described in more detail in Sections 3.8.3.4, 3.8.3.5, and 3.8.3.6. If prototype tests indicate that uncontaminated pore-water samples cannot be obtained from mining rubble, core samples must be obtained in advance of blasting in the ESF for pore-water collection. If required, one additional short borehole will be cored every 10th-blast round to obtain a sample. If the dry-coring prototype test indicates that pore-water chemistry is affected by the coring technique, the effect must be determined so that adjustments can be made for ESF testing. If the pore-water extraction prototype tests demonstrate more efficient water collection from welded tuff cannot be made, leaching of the crushed-core sample with a known amount of distilled water will be carried out in the laboratory, and leachable cation and anion concentrations will be calculated.

### 3.8.3 General approach and summary of tests and analyses

The activity is 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. Table 3.8-1 summarizes chemical and isotope analyses. The information that can be derived from these tests and how they can help to resolve issues of site-characterization are described in detail under the previous heading, Rationale for activity selection.

Gas samples will be collected twice a year for three years from the radial boreholes (Section 3.4) and two excavation-effects test holes (Figure 3.8-1). Pore water will be extracted from cores removed from the ESF test boreholes and from rubble collected from approximately 30 locations during shaft construction (Figure 3.8-2). Fracture- and perched-water samples will be collected where available.

Table 3.8-1. Chemical and isotopic analyses

| Parameter | Chemical Species | Information |
|---|---|---|
| Inorganic cations and anions | Na, Ca, Mg, K, $HCO_3$, $SO_4$, Cl, pH, $SiO_2$, Mn, Fe, Al | Types of ongoing chemical reactions. Residence times of fracture fluids. |
| Organic compounds | Organic compounds (trace amounts) | Forming of organometallic complexes that change the mobility of radionuclides. |
| Stable isotopes | Oxygen-18/oxygen-16 deuterium/hydrogen ratio | Timing of major recharge events. |
| Age dating | Carbon-14, tritium, carbon-13/carbon-12 ratio, argon-39 | Age and travel time of unsaturated zone waters. Style and pattern of fluid flow in the unsaturated zone. |
| Gas diffusion | Freon-11, Freon-12, $CO_2$, $H_2O$, $SF_6$, $CH_4$, Ar, $O_2$, $N_2$, $^3He/^4He$ | Diffusion of gasses ($^{14}C$, $^3H$, $^{39}Ar$) into the unsaturated zone. |
| Contamination check | Li, Br, I, $NO_3$, $BO_3$ | Washdown of tracers. |

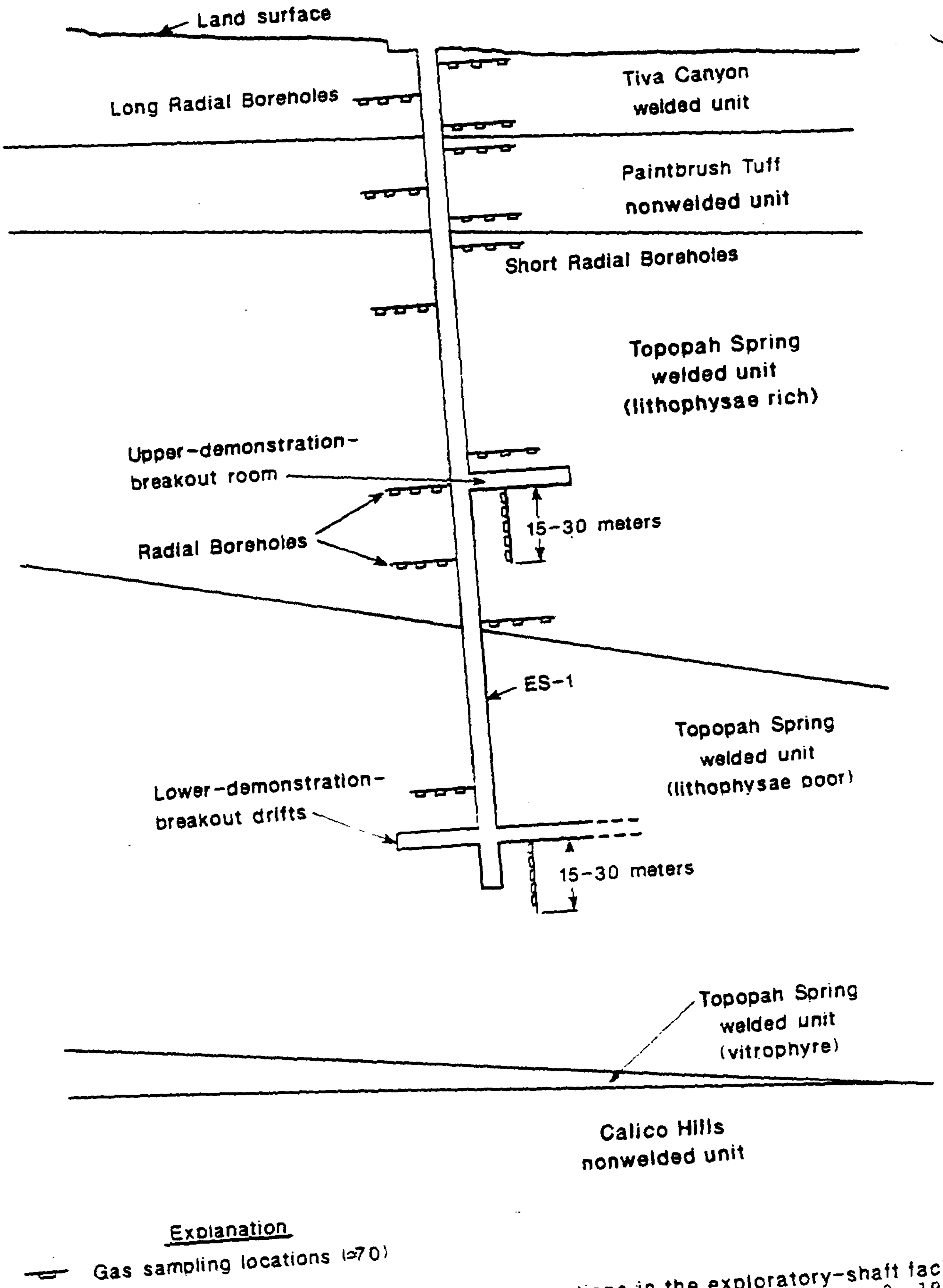
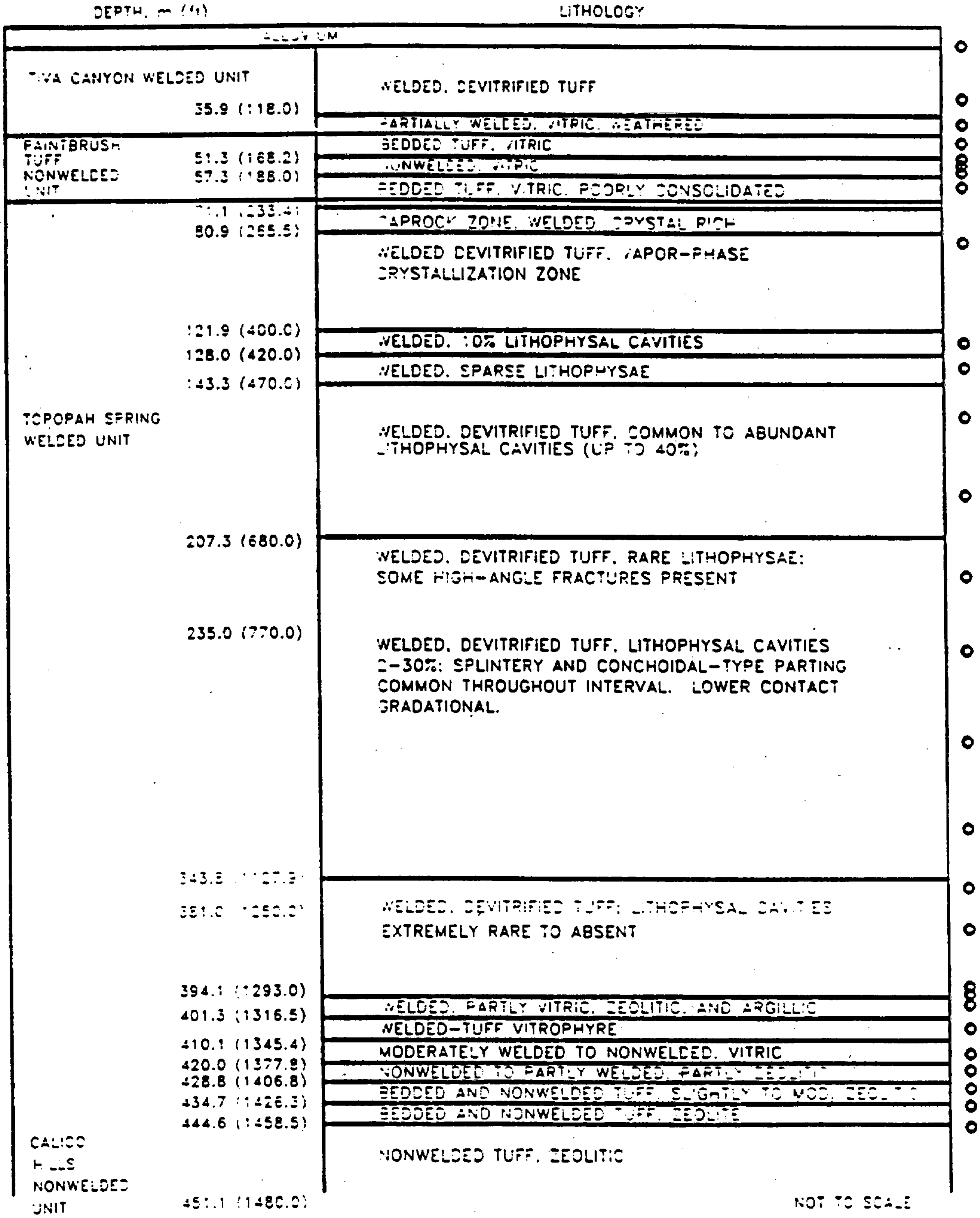



Figure 3.8-1. Diagram showing gas-sampling locations in the exploratory-shaft facility.




NOTE: GEOHYDROLOGIC UNIT THICKNESS AND DEPTHS ARE ESTIMATES.

**Figure 3.8-2. Geohydrologic unit near the exploratory-shaft facility with sampling locations (circles on right) for hydrochemistry tests.**

The activity will be performed throughout the construction phase of ES-1 and breakout zones. Samples will be collected after designated blasting rounds during shaft construction. The samples will be taken at about 30-m (100-ft) intervals. When wet zones (water content of >50%) are encountered as the shaft is being mined, additional samples will be collected. Samples will be collected by a Fenix and Scisson geologist accompanied by a subcontractor miner. They will select the rubble pieces for transport to the surface before the customary washdown. The aggregate rock samples taken from any one depth will total approximately 50 kg (110 lb), and each rock will have a minimum diameter of 300 mm (11.8 in.). Samples will immediately be sealed in beeswax for shipment to the USGS in Denver. The effects of gas and water exchange caused by blasting will be assessed during prototype testing. Additionally, tracer gas $SF_6$ will be added in the compressed-air system for borehole drilling. Chemical compositions of blasting explosives will be known in advance (such as nitrate). Any contamination from atmospheric air (Freon-11) or explosives will be checked before the data from rubble samples will be used for site characterization.

If during shaft construction a thick zone of perched water is penetrated, and the system is both simple and self-cleansing, a 4-liter- (1-gal-) water sample or sequence of samples will be taken at the time of first production.

Figure 3.8-3 summarizes the organization of the activity. A descriptive heading for each test and analysis appears in the shadowed boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized. Cross-references to other study plans which provide input to the activity also appear in Figure 3.8.3. Figure 3.8-4 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed test/analysis boxes, respectively, in Figure 3.8-4.

The two figures summarize the overall structure of the planned activity in terms of methods to be employed and measurements to be made. The descriptions of the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) the site parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

The methods utilized in this activity will provide information that is approximately representative of the repository area. The spatial variabilities of existing conditions within the repository block, and the correlations to present and potential future repository conditions are represented by the activity.

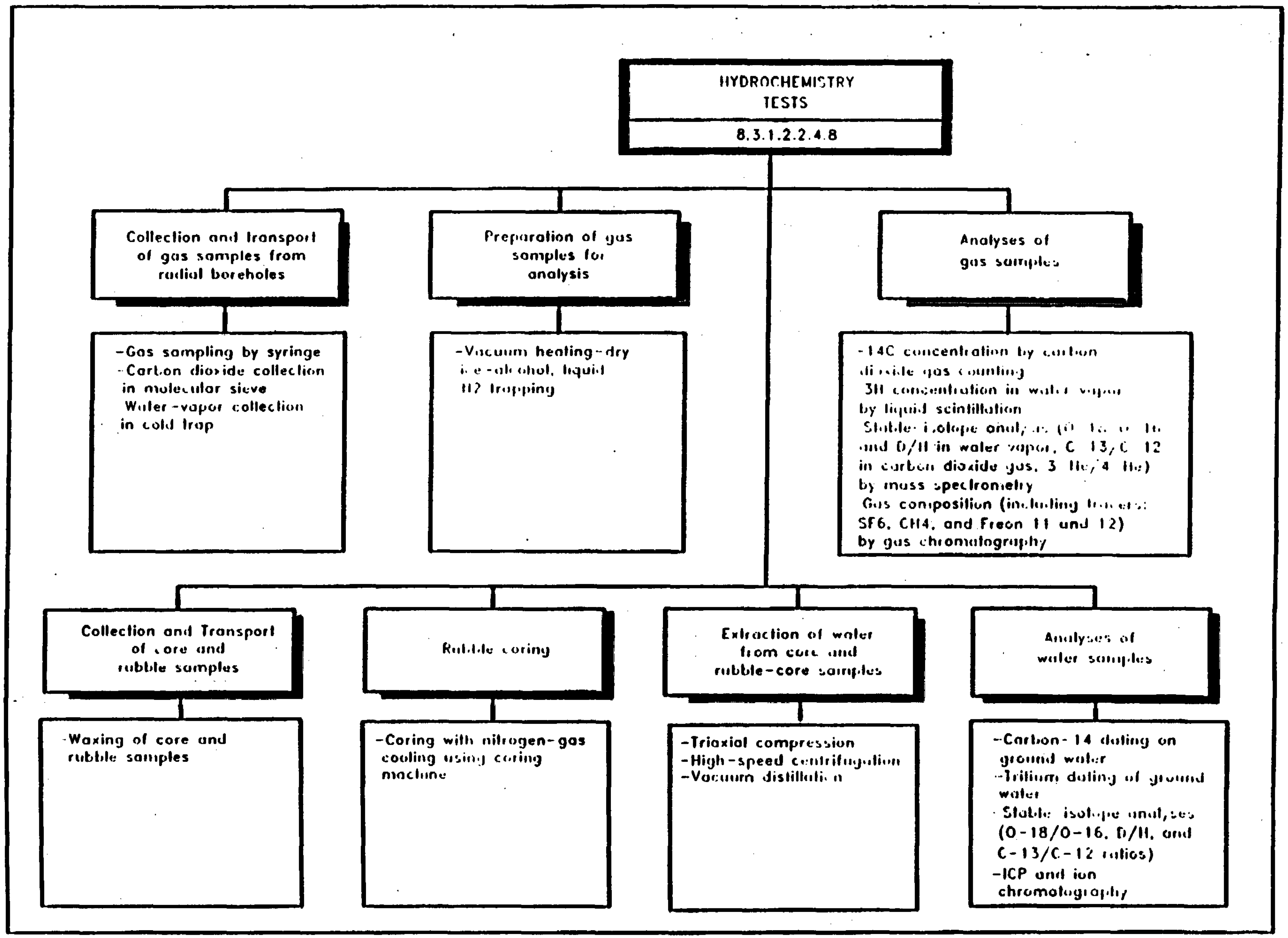



**Figure 3.8-3. Organization of the ESF hydrochemistry activity, showing tests, analyses, and methods.**

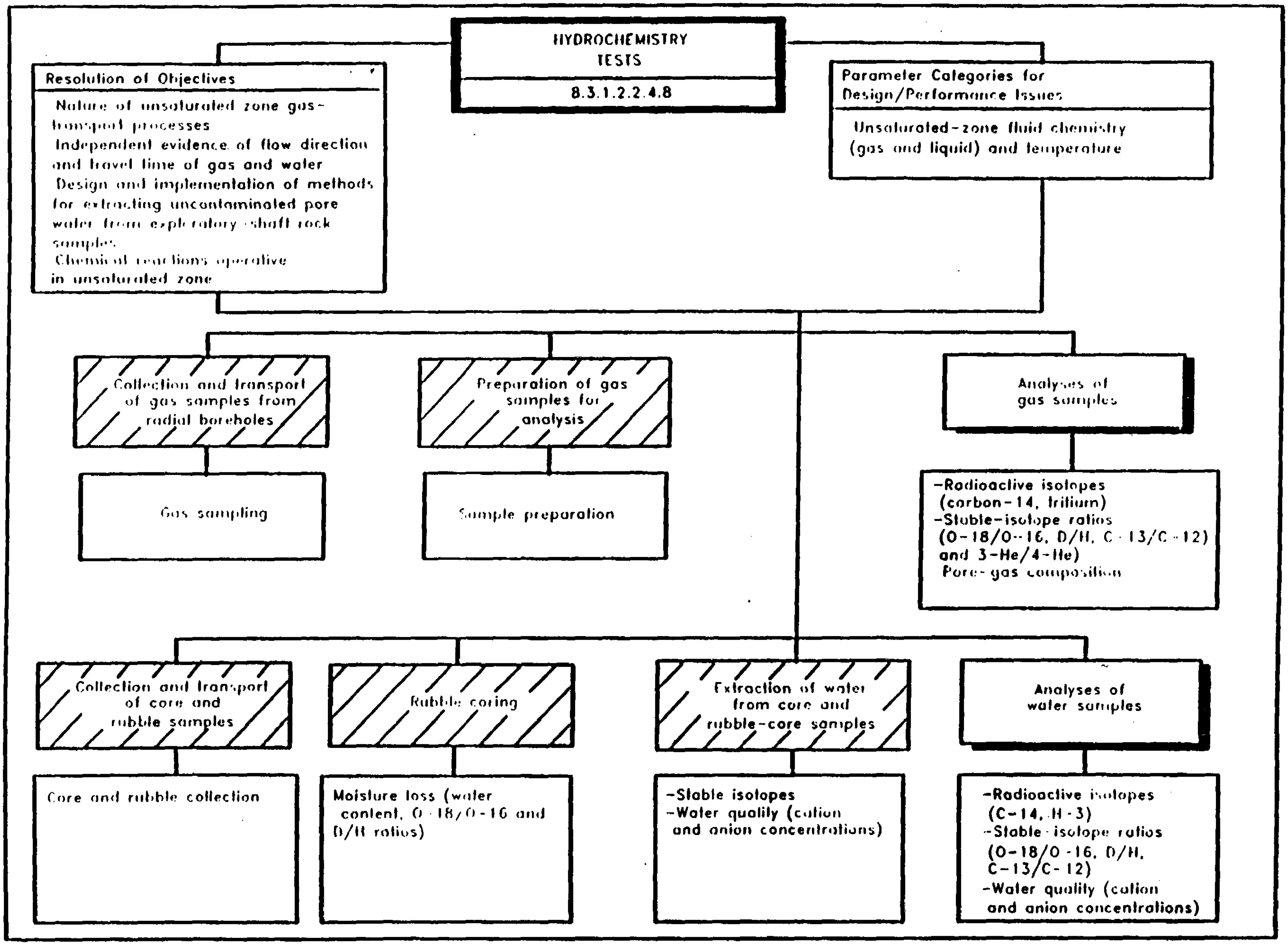



**Figure 3.8-4. Organization of the ESF hydrochemistry activity, showing tests, analyses, and site parameters. The cross-hatched boxes indicate that no site parameter will be generated.**

The hydrochemistry tests will be conducted in the ESF which will penetrate the same geohydrologic units as does the repository. Because of this, the environment in which these tests will be conducted is an approximate representation of the repository area. Furthermore, gaseous and aqueous chemical samples will be collected within radiating boreholes from ES-1, providing information on lateral variability of the host-rock hydrochemistry away from the ESF. Data from the hydrochemistry tests will be used to model (1) the geochemical evolution of ground water and (2) the gas-transport mechanisms, leading to a better understanding of water (liquid and vapor) movement within the repository host rock.

### 3.8.3.1 Collection and transport of gas samples from radial boreholes

Four types of gas samples will be collected from radial boreholes: (1) gas-composition samples, (2) carbon-13/carbon-12 ratio samples, (3) carbon-14 samples, and (4) water vapor samples. Radial-borehole dimensions, orientation, and instrumentation configurations are discussed in Section 3.4.3.1 and illustrated in Figure 3.4-5. Sampling tubes will be pumped before sample collection to purge the tubes of any atmospheric air that might have been introduced while connecting the pumps to the system. Gases sampled from the ESF boreholes will be analyzed for gas tracers introduced during the construction phase. During sample collection, the sample gas will be pumped at a flow rate of 500 mm per minute. (See Figure 3.8-5 for system apparatus.)

1) Gas composition samples -- two methods will be used for gas-composition sample collection. The first method uses a syringe inserted in the line of gas tubing pumped by the peristaltic pump; gas is allowed to flow directly into the syringe. The second method involves pumping the gas sample into a 250-ml flow-through glass container. Gas-composition sampling by syringe is preferred over collection in a flow-through cylinder; the syringe method is easier to perform and allows the sample to be injected directly from the syringe into a gas chromatograph for analysis. Gas-composition samples require no transportation because they are analyzed in the field.

(2) Carbon-13/carbon-12 ratio samples -- two methods will be used. The first method uses 5A molecular- sieve pellets to trap the $CO_2$ gas. The gas sample is allowed to flow into a 300-ml stainless-steel cylinder containing the 5A molecular-sieve pellets which trap the $CO_2$. The second method involves allowing the $CO_2$ gas to flow into a 250-ml flow-through glass container. Carbon-13/carbon-12 sampling uses both molecular-sieve and collection in a flow-through cylinder method because it is important to check by both methods.

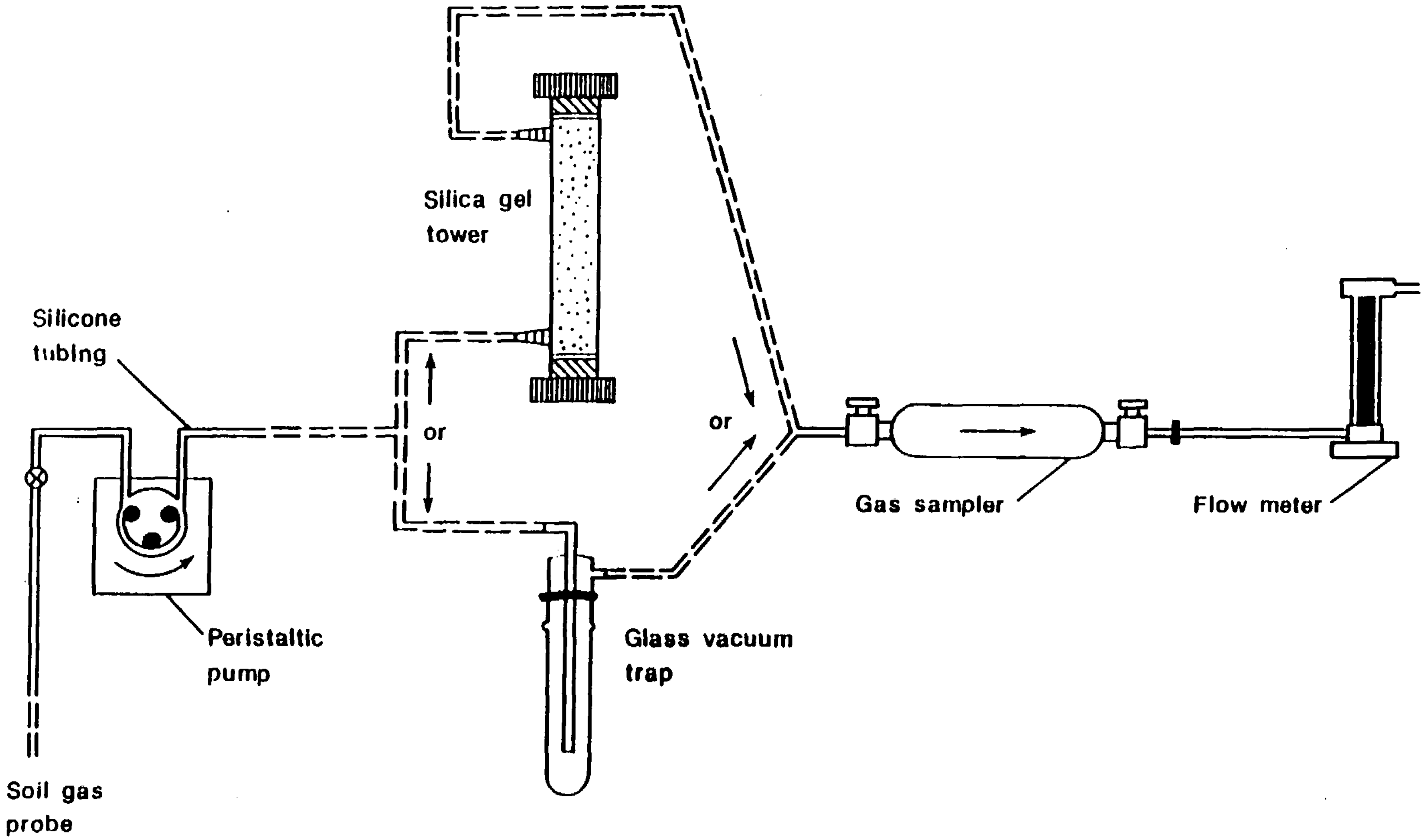



Figure 3.8-5. Diagram showing apparatus for on-site soil-gas collection for hydrochemistry tests.

(3) Carbon-14 samples -- two methods will be used for carbon-14 sample collection. The first method employs a 5A molecular sieve as discussed in (2) above. The second method (KOH method) allows the gas to disperse through a fritted plate and bubble into a container of 5 molar KOH solution. The KOH solution traps the $CO_2$ by converting it to potassium carbonate ($K_2CO_3$). The principal advantage of the molecular-sieve method of carbon-14 sampling over the KOH method is its simple design and insured, nonbreakable transport between the sampling site and the laboratory.

Carbon-14 and carbon-13/carbon-12 ratio samples will be packed in a cardboard box and mailed directly from the field to the Denver Federal Center laboratory for processing.

(4) Water-vapor samples -- three methods will be used: cold trap, silica gel, and molecular sieve. The first method involves pumping the gas sample through a cold trap cooled by a dry-ice-alcohol slurry to remove the water vapor. The second method allows the gas to flow through a tower filled with silica gel to remove the water vapor. The third method uses a 5A molecular sieve similar to (2) above to collect the water vapor. Water-vapor sampling using a cold trap is preferred over collection by silica gel tower or molecular sieve. During degas heating of the water vapor from the silica gel or molecular sieve, oxygen atoms in the water vapor exchange with oxygen atoms in the silicate minerals of the silica gel and molecular sieve, causing errors in oxygen-isotope measurements; the cold trap method is not subject to this problem. Condensed water-vapor samples (in vials) are hand-carried to Denver.

All data obtained by each group of methods (selected or alternate) should be compared to insure the validity of the selected method.

### 3.8.3.2 Preparation of gas samples for analysis

Two methods are available for preparing gas samples for analysis: (1) degassing of $CO_2$ samples trapped in molecular sieves by heating under a vacuum and collecting the released gases in cold traps using liquid nitrogen, and (2) adding acid to a potassium hydroxide (KOH) solution containing $CO_2$ to release the $CO_2$ gas from potassium carbonate ($K_2CO_3$). The first method involves heating the molecular sieve gas-collection cylinder to 300° C to drive off the captured gases, collecting the water vapor as ice in a cold trap cooled to -78° C by a dry-ice-alcohol slurry, collecting the $CO_2$ as a solid in a cold trap cooled by liquid nitrogen and storing the $CO_2$ in a storage cylinder. A simplified diagram of the degassing system

system is shown in Figure 3.8-6. The KOH method of releasing the col-lected $CO_2$ is performed by acidifying the solution; the $CO_2$ is then reacted with hydrogen gas using ruthenium pellets as a catalyst to form methane ($CH_4$) gas for gas counting. Water vapor collected in 3.8.3.1 requires no further preparation.

Sample collection and degassing using the molecular sieve/vacuum-heating method is much easier to perform (no chemical involved). The apparatus involved is simpler, easier to operate, and less subject to malfunctions during the procedure.

Internal checks assure release of all of the carbon dioxide gas. For example, near the end of the degassing procedure, the liquid-nitrogen level is raised around the carbon dioxide cold trap. This exposes a clean section of the collection tube in the trap to liquid nitrogen; any carbon dioxide still solidifying in the trap will form a ring of new white solid on this section of the tube--indicating that the degassing process is not yet complete. No formation of new carbon-dioxide solid ensures that all of the carbon dioxide has been trapped.

### 3.8.3.3 Analyses of gas samples

Stable-isotope ratios (oxygen-18/oxygen-16, carbon-13/carbon-12, deuterium/hydrogen, and helium-3/helium-4) will be analyzed using mass spectrometry by the U.S. Geological Survey Research Laboratory, Reston, Virginia. Low-level gas counters will be used to determine tritium activity in water vapor at the University of Miami, Miami, Florida. Large carbon-14 samples (carbon-14 dioxide gas) will be analyzed using conventional gas-counting methods by Geochron, Inc. in Boston, Massachusetts. Small carbon-14 samples will be analyzed by tandem accelerator mass spectrometry (TAMS) at the University of Arizona, Tucson, Arizona. Argon-39 will be separated out from other gases in the samples, processed, and measured by proportional counter at the University of Bern, Switzerland, the only available facility for analysis. All gas samples will be analyzed for the presence of construction-phase tracers (sulfur hexafluoride, methane, freon, etc.), using gas chromatography-mass spectrometry (GCMS).

Carbon-14 and tritium concentration measurements are preferred over argon-39 and krypton-81. Because argon and krypton are rare gases, their natural concentrations are very small; therefore, a very large volume of sample gas would be necessary for conventional gas counting, which requires some type of gas-separation system. Such a system would be difficult to handle. Carbon-14 requires much smaller sample volumes because it is measured by the TAMS method. Furthermore, argon-39 has an additional drawback in that it can also be produced by *in situ* neutron activation in the subsurface which may interfere with the measurement of cosmogenic argon-39. Feasibility of dating gas samples with krypton-81 remains to be seen. Oxygen-18/oxygen-16,

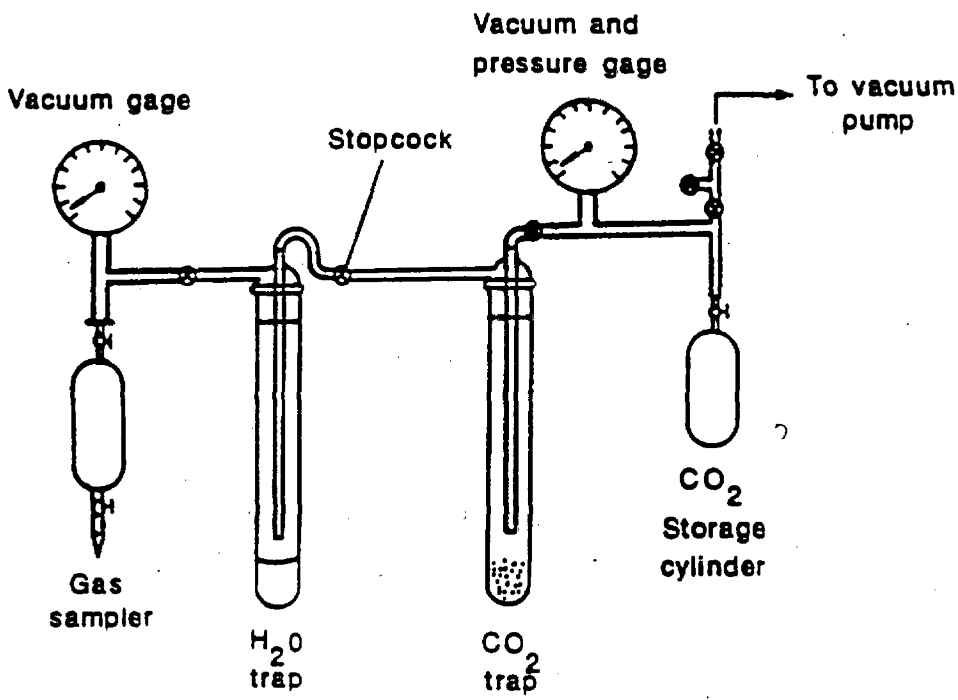



Figure 3.8-6. Diagram showing degassing system for hydrochemistry tests.

stable-isotope ratios are preferred over other stable isotope ratios because more background data are available, and standard analysis techniques already exist for these isotopes.

Carbon-14 and tritium concentration measurements will determine the residence time of the gases in the unsaturated zone. Stable-isotope ratios will provide information on the flow path of the gases through the unsaturated zone as well as their interactions with other minerals or transport properties. Tracer concentrations will help determine the effects of excavation operations of the exploratory shaft on *in situ* gases in the unsaturated zone. Refer also to Section 3.8.3 for more detail concerning the uses of the chemical and isotopic analyses of pore gases.

3.8.3.4 Collection and transport of core and rubble samples

The optimal rubble-size prototype test will develop procedures to collect, seal, and transport mining rubble and will determine the optimal size mining rubble needed to avoid blast contamination.

The two different methods of obtaining rock samples which will be tested are the following:

1. Rubble samples -- two sizes of rock rubble will be collected after blast rounds and prior to washdown. A minimum dimension of 15 cm (6 in.) for the bulk samples is suggested. Samples of both welded and nonwelded tuffs will be required. Because blasting variables, such as charge, spacing, pattern, delay sequence, and type of explosive may be nonuniform, the effect of blasting on contamination may also be nonuniform. After the blasting variables are fixed, 50 pieces of 12-in. diameter rubble (40 welded and 10 nonwelded) and 20 pieces of 6-in. diameter rubble (16 welded and 4 nonwelded) will be collected. An equal number of rubble pieces will be collected from each blast round. The degree with which the rubble pieces meet the two primary criteria, degree of wetness (visually observable) and proximity to preblasting core samples, will be determined by the field coordinator.

2. Coring in advance of blasting -- core samples can be collected by dry coring into the face of the controlled-blast demonstration room. Such samples should be collected at least the distance of two blast rounds in front of the face to ensure that they are unaffected by previous blasting. The samples for this activity will be obtained by a dry-coring technique and will be 6.1 cm (2.4 in.) in diameter. Core samples obtained at this time by coring in advance of blasting will have been

baselined by the dry-coring prototype test and will reflect the preblast rock chemistry.

When samples are available after blasting or coring, procedures for handling those samples are as follows.

A. The preserved samples will be sealed in cellophane, marked with indelible marker on tape, and placed in storage containers. Methods to minimize the time spent on these activities will be determined. At the same time and location, complementary rubble will be collected, sealed, marked, and placed in containers for archiving at the Nevada Test Site.

B. The rubble will be transported to Mercury, Nevada, as soon as possible after collection. A portion of the rubble will be cored at the Holmes and Narver Laboratory. The cores will be sealed in aluminum foil, capped, waxed and packaged in containers for delivery to the Denver Federal Center (DFC).

C. The rubble which is not cored at the Nevada Test Site will be sealed in aluminum foil and waxed to preserve the ambient pore-water characteristics and to minimize evaporative losses. The rubble will be placed in containers and placed on a vehicle for transportation to the Denver Federal Center.

D. The sealed and containerized core and rubble samples will be transported to the Denver Federal Center in an air-conditioned vehicle to insure core-water preservation during the movement of the core from the Nevada Test Site to the permanent storage facility in Denver. The methods for transportation are detailed in Hydrologic Procedure HP-131. Such procedures should be formulated prior to ESF construction so that construction delays and costs are minimized, and the samples obtained are of value. Coordination with the sample overview committee is required in order to preclude sample-handling and custody conflicts in the ESF.

As a first appraisal of the chemical analyses of the water, the data will be checked for evidence of the components of the explosive elements.

Stable hydrogen- and oxygen-isotope data can be plotted on deuterium/oxygen-18 ratio diagrams in order to determine the heating effect of the blasts on evaporation. This will be accomplished by comparing these data with those obtained from coring in advance of blasting. Isotopic data can also be plotted against chemical composition as a check on trends determined separately.

Methods developed in the optimal rubble size prototype test will be implemented in the ESF hydrochemistry tests.

**3.8.3.5 Rubble coring**

The purpose of the dry coring of rubble prototype test is to develop procedures to obtain cored samples from rubble pieces using dry-coring techniques. In order to determine the effect of the coring technique on the pore-water chemistry, two different categories of rubble pieces will be used. The first is a reference rubble piece which will be obtained by chipping a sample from the unblasted rock prior to the mining demonstration. From this large rock piece, cores will be obtained both by dry coring and by chipping with a chisel. The second category is rubble produced by the mining demonstration. When the required number of rubble pieces are obtained from the mining-demonstration spoil, this rubble will be sealed and shipped to the USGS Denver laboratory for dry coring. Upon receipt of the rubble pieces at the Denver laboratory, coring will be performed. In order to prevent excessive heat build-up and potential damage to the core bit, slow coring rates must be used. The final coring rate will be determined from trial runs; however, a coring rate of 400 r/min with an advancement rate of 0.003 cm (0.001 in.) per revolution has been found to be successful.

Coring with nitrogen-gas cooling using a coring machine is preferred over the chipping method because the latter method is labor-intensive. The latter method, however, is required for a few samples to compare the water loss after coring and chipping for verifying the coring method.

Analysis of the test will be done by measuring water content of nearby pieces before and after the coring and chipping. The chipping method assumes no water loss. Furthermore, water loss can also be checked by $^{18}O/^{16}O$ and D/H ratios of water before and after coring and chipping. If significant water loss occurs during coring, the stable-isotope ratio will become heavier compared with the water before coring.

The techniques designed in the dry coring of rubble prototype test will be used in the ESF hydrochemistry test.

**3.8.3.6 Extraction of water from core and rubble-core samples**

Four methods are available to extract water from unsaturated tuffs: (1) triaxial compression, (2) high-speed centrifugation, (3) vacuum distillation, and (4) immiscible displacement. Triaxial compression involves placing a core sample in a compression chamber and applying axial and confining pressures in step increases to force water and air from the pore space (see Figure 3.8-7). Using a sequence of step increases allows a maximum amount of water to be recovered with a minimum potential for rock/water interactions which might alter the original pore-

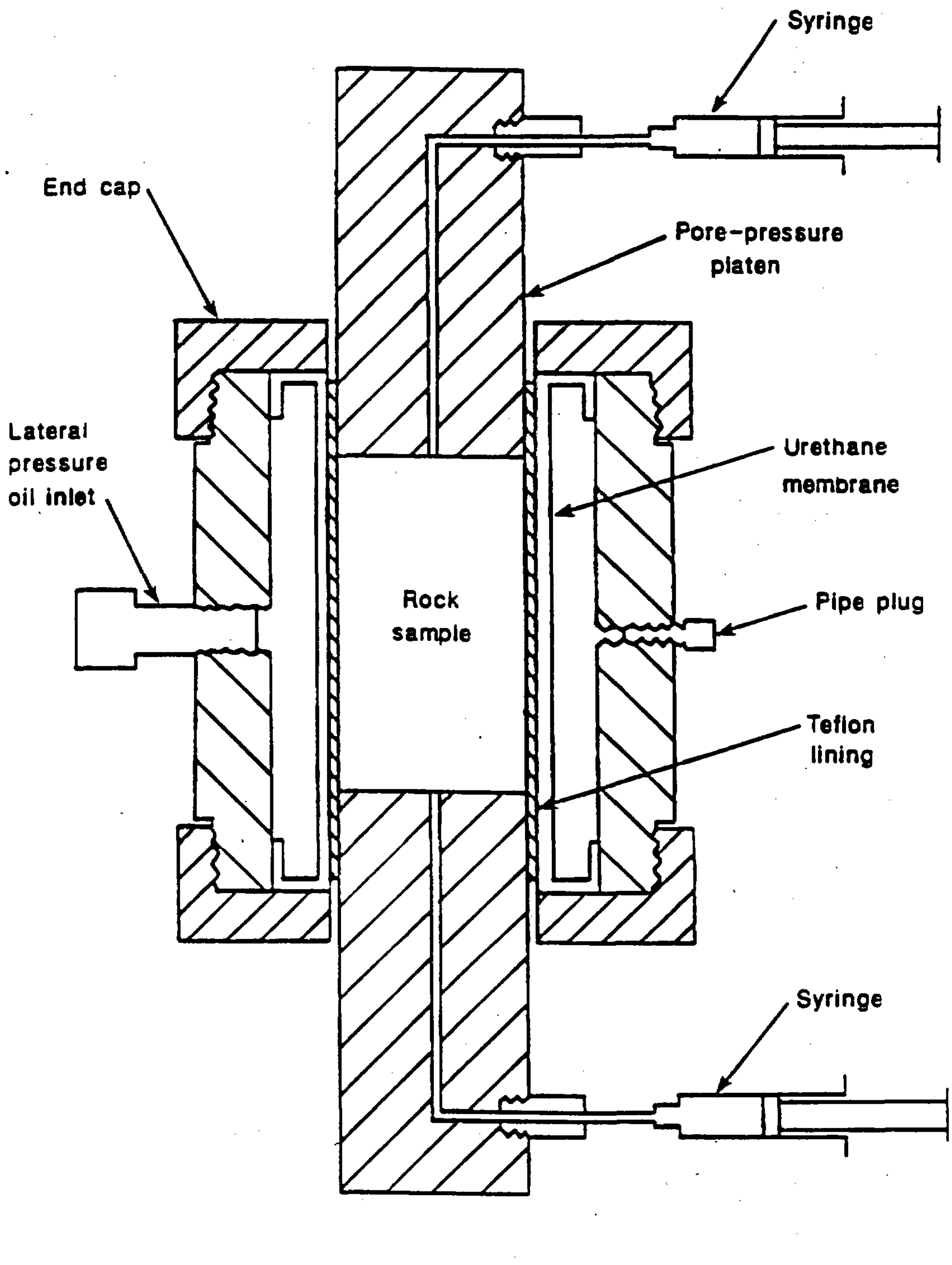



Figure 3.8-7. Diagram showing apparatus for pore-water extraction by triaxial compression for hydrochemistry tests.

pore-water composition. [Axial pressure is increased in three steps: $7.58 \times 10^4$, $1.17 \times 10^5$, and $1.52 \times 10^5$ J/kg (kPa) (758, $1.17 \times 10^3$, and $1.52 \times 10^3$ bar) 11,000, 17,000, and 22,000 PSI; at the same time, confining pressure is increased from 8,000 to 9,000 PSI, $5.52 \times 10^4$ to $6.21 \times 10^4$ J/kg (552 to 621).] Different core orientations (in relation to the tuff fabric) can also be tested to optimize water recovery. The centrifugation method uses the large centrifugal force developed in a high-speed (8,000 to 18,000 rpm) centrifuge to drive pore water out of a core (see Figure 3.8-8). The removal process can be simple drainage, or an immiscible fluid can be introduced to displace the pore water during centrifugation. Centrifugation can be used on crushed or broken samples as well as on intact core pieces. The distillation method involves heating the core under a vacuum and capturing the vaporized pore water in a low-temperature (-78 °C) cold trap. The immiscible-displacement method uses an immiscible fluid (usually a halogenated hydrocarbon) to displace pore water from the core in a leaching process.

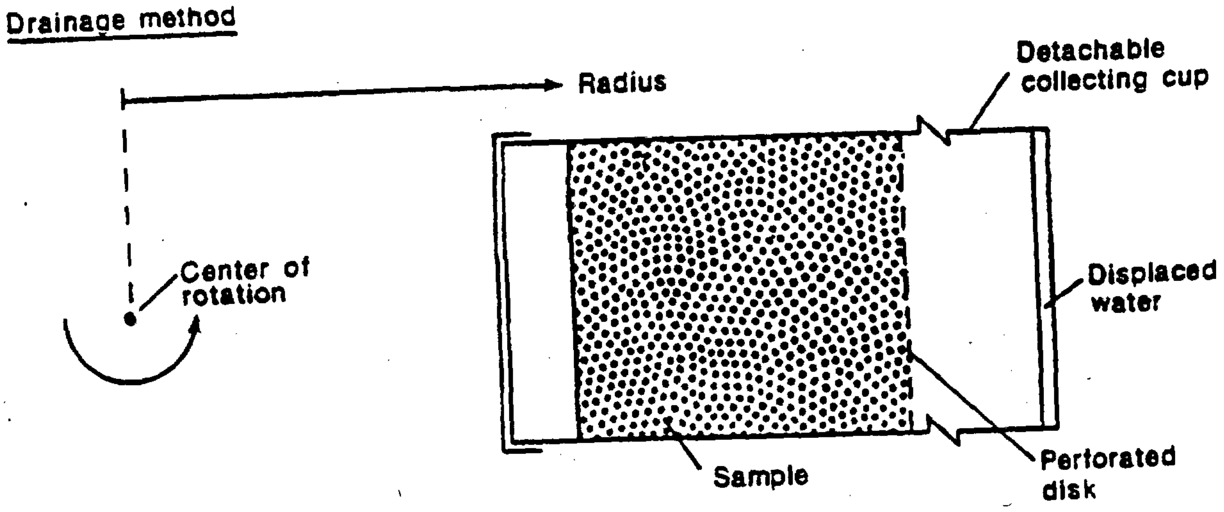
In extracting pore water from tuff samples, several of the above methods can be used in sequence to achieve maximum water recovery. A progression from triaxial compression to centrifugation and finally to vacuum distillation for a single sample ensures optimum water removal. This sequence also represents a ranking from most desirable to least preferred of the pore-water extraction methods. Triaxial compression is favored over centrifugation for two major reasons.

(1) The forces acting on the core are much better understood for triaxial compression than centrifugation; therefore, more information about the actual pore-volume reduction process that occurs within the core will be gained from triaxial compression.

(2) The triaxial-compression method recovers gas from the sample pore space, which is not possible using centrifugation. The isotopic composition of the gas in the sample is also useful in pore-fluid characterization.

Centrifugation, however, can be used on broken cores which are unsuitable for triaxial compression. Triaxial compression and centrifugation are preferred over vacuum distillation pore water because cation and anion concentrations are needed for pore-water characterization. Immiscible displacement is the least favored method, because by forcing a new fluid through the sample, it introduces additional potential for error--either by adding trace water present in the immiscible fluid or by chemical reactions between the immiscible fluid and the core. (Centrifugation would be performed only using simple drainage and not incorporating an immiscible fluid for this same reason.)

A representative water sample extracted from the core can be verified in two ways. First, by taking water samples at each



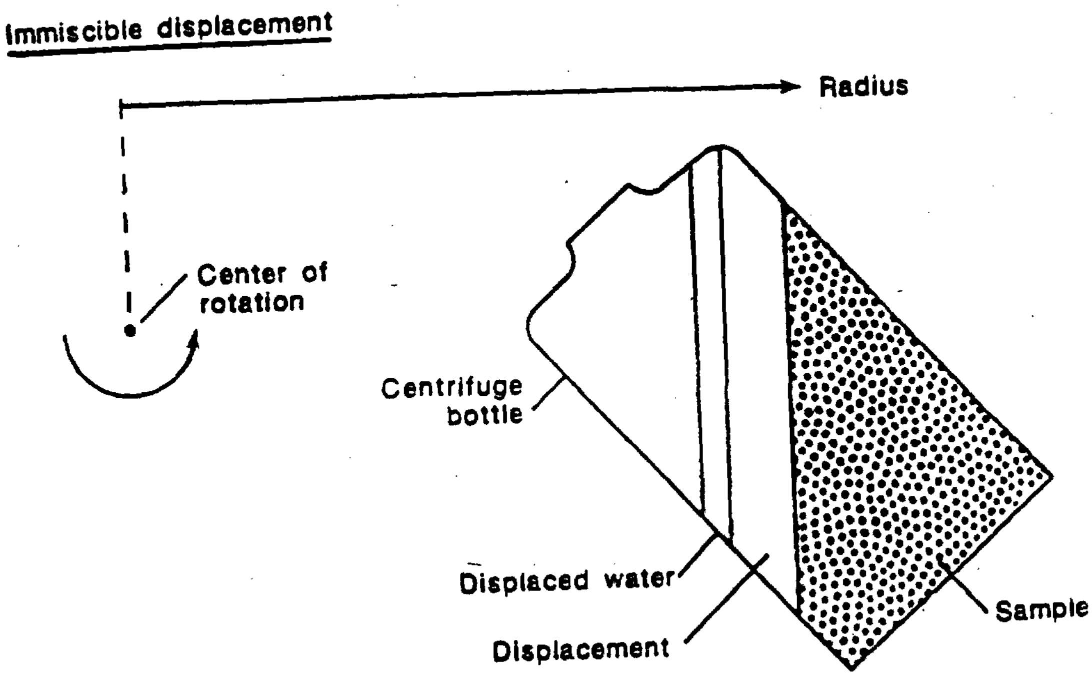




Figure 3.8-8. Diagram showing methods of centrifugation for hydrochemistry tests.

pressure level during the triaxial compression procedure, a set of chemical-concentration data relating cation and anion concentrations to axial pressure will be available. If the ion concentrations do not increase with increasing pressure, then the triaxial compression process is not affecting the original pore-water composition. (Also, if a sharp increase in concentration is noted at a higher pressure level, future testing can secure representative samples by holding pressures below that level.) Present data do not indicate any correlation between increased pressures and pore-water composition or spin rates and pore-water composition, but that possibility is being assessed in the prototype testing. Second, water-sample analyses from a core which was extracted by centrifugation can be compared to analyses from a nearby core used for triaxial compression. Although not an unequivocal demonstration, similar chemical concentrations obtained by both methods would, again, support the validity of triaxial compression in producing representative samples (Yang and others, in prep.).

The pore-water extraction by triaxial-compression prototype test will determine proper extraction procedures to produce representative water samples and will determine if a particular rock-core orientation is more favorable than another for water extraction. The methods developed during the prototype test will be implemented during ESF hydrochemistry testing.

### 3.8.3.7 Analyses of water samples

Cation concentrations will be determined by using inductively coupled plasma (ICP), and anion concentrations will be determined using ion chromatography at the U.S. Geological Survey Central Laboratory, Denver, Colorado. Stable-isotope ratios will be analyzed using mass spectrometry by the U.S. Geological Survey Research Laboratory, Reston, Virginia. Low-level-concentration gas counters or liquid scintillation counters will be used to determine tritium activity at the University of Miami, Miami, Florida. Large carbon-14 samples will be analyzed using conventional gas-counting methods by Geochron, Inc. in Boston, Massachusetts. Small carbon-14 samples will be analyzed by tandem-accelerator mass spectrometry (TAMS) at the University of Arizona, Tucson, Arizona. Chlorine-36 will be analyzed using TAMS at the University of Rochester, Rochester, New York. Argon-39 and krypton-81 will be purged out of the water samples and processed and measured by proportional counter at the University of Bern, Switzerland. All water samples will be analyzed for the presence of tracers (chloride, bromide, nitrate, borate, etc.), using gas chromatography-mass spectrometry (GCMS) and high-pressure liquid chromatography (HPLC) by a subcontractor laboratory.

For water sample dating, carbon-14 and tritium are preferred over argon-39 and krypton-81. Because argon and krypton are so insoluble in water, a very large volume of water would be necessary to use these isotopes for sample-age dating. It is doubtful that such a large amount of water could be obtained. In addition, argon-39 and krypton-81 are counted in a conventional gas counter; small sample volumes cannot be measured. Carbon-14 and tritium require much smaller sample volumes because they are measured by the TAMS method. Furthermore, argon-39 has an additional drawback in that it can also be produced by *in situ* neutron activation in the subsurface which may interfere with the measurement of cosmogenic argon-39. Chlorine-36 for age dating is also dependent on the extent of *in situ* production in the subsurface. If this interference is minimal, chlorine-36 will be used for water-age dating. Oxygen-18/oxygen-16, carbon-13/carbon-12, and deuterium/hydrogen stable-isotope ratios are preferred over other stable-isotope ratios because more background data are available, and standard analysis techniques already exist for these isotopes. Use of ICP, ion chromatography, GCMS, HPLC, and TAMS are preferred over atomic adsorption because these techniques can analyze more than one element at a time, whereas atomic adsorption must determine each element individually and so would require much more time to complete an analysis.

Carbon-14 dating will determine the age of the water in the unsaturated zone, and tritium will be analyzed for use as an indicator of recent meteoric water. Stable-isotope ratios will provide information on the flow path of the water through the unsaturated zone and any high-temperature rock/water interactions. Age and flow-path length together will be used to estimate travel times of water in the unsaturated zone. Ion concentrations will provide information about chemical processes involving the rock matrix and pore water. Tracer concentrations will help determine the effects of excavation/operations of the exploratory shaft on water in the unsaturated zone. Refer also to Section 3.8.2 for more detail concerning the uses of the chemical and isotopic analyses of pore water.

### 3.8.3.8 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.8-2. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be utilized only if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, there are many approaches to conducting the test. In those cases, only the most common methods are included in the tables. The selected methods in Table 3.8-2 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they feel are suitable to provide accurate data within the expected range

Table 3.8-2. Summary of tests and methods for the hydrochemistry-tests (SCP 8.3.1.2.2.4.8) in the exploratory shaft

[Note: Dashes (--) indicate information is not available and to be determined.]

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| **Analyses of gas samples** | | |
| Age dating of carbon dioxide gas samples using conventional gas counter (selected) | Radioactive-isotope activity | 1,000 yr to 50,000 yr |
| Age dating by scintillation counting of tritium in water vapor (selected) | " | Up to 150 yr |
| Stable-isotopes analyses (O-18/O-16 and D/H in water vapor, C-13/C-12 in carbon dioxide gas) (selected) | Stable isotopes | $^{18}O/^{16}O$: 0 to -20 per mil<br>D/H: 0 to -200 per mil<br>$^{13}C/^{12}C$: -7 to -28 per mil |
| Gas composition (including tracers) by gas chromatography (selected) | Pore-gas composition | $CO_2$ - 0 to 2%<br>$CH_4$ - 0 to 5 ppm<br>$H_2$ - 0 to 5 ppm |
| Argon-39 dating of gas (alternate) | Radioactive-isotope activity | Up to 1,000 yr |
| Hydrochemical determination by sample analysis and modeling (selected) | Flow paths, hydrochemical determination | -- |
| Hydrologic determination, other activities (alternate) | " | -- |
| Mass spectrometry (alternate) | Stable isotopes | $CO_2$ - 0 to 2%<br>$CH_4$ - 0 to 5 ppm<br>$H_2$ - 0 to 5 ppm |
| Hydrochemical determination by sample analysis and modeling (selected) | Travel times, hydrochemical determination | -- |
| Hydrologic determination, other activities (alternate) | " | -- |

Table 3.8-2. Summary of tests and methods for the hydrochemistry-tests (SCP 8.3.1.2.2.4.8) in the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | Rubble coring | |
| Coring with nitrogen-gas cooling using coring machine (selected) | Moisture loss (water content, $^{18}O/^{16}O$ and D/H ratios) | $^{18}O/^{16}O$: 0 to -20 per mil<br>D/H: 0 to -200 per mil |
| Chip cores with chisel and saw (alternate) | Moisture loss (water content $^{18}O/^{16}O$ and D/H ratios) | $^{18}O/^{16}O$: 0 to -20 per mil<br>D/H: 0 to -220 per mil |
| | Analyses of water samples | |
| Carbon-14 dating on ground water (selected) | Radioactive-isotope activity | 1,000 to 50,000 yr |
| Age-dating of carbon dioxide in water samples using tandem-accelerator mass spectometry (selected) | " | " |
| Tritium dating of ground water (selected) | " | Up to 150 yr |
| Stable-isotope analyses ($^{18}O/^{16}O$, D/H, and C-13/C-12 ratios) (selected) | Stable-isotope ratio analyses | $^{18}O/^{16}O$: 0 to -20 per mil<br>D/H: 0 to -200 per mil |
| ICP and ion chromatography (selected) | Water quality, cations and anions | 0 to 500 mg/l |
| Chlorine-36 dating of ground water (alternate) | Radioactive-isotope activity | Up to 900,000 yr |
| Argon-39 dating of ground water (alternate) | " | Up to 1,000 yr |
| Mass spectrometry for other stable isotopes (alternate) | Stable isotopes | -- |

Table 3.8-2. Summary of tests and methods for the hydrochemistry-tests (SCP 8.3.1.2.2.4.8) in the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | Analyses of water samples | |
| Atomic adsorption (alternate) | Water quality, cations and anions | 0 to 500 mg/l |

of the site-characterization parameter. Models and analytical techniques have been or will be developed to be consistent with test results. The expected ranges of the site-characterization parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.8-2.

### 3.8.4 Technical procedures and quality-assurance levels

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment, justification, and documentation of quality levels to activities that affect quality; and documentation of technical procedures for all technical activities that require quality assurance.

Table 3.8-3 provides a complete tabulation of quality-assurance level-assignment (YMP-QALA-) numbers and technical procedures applicable to this activity. Approved procedures are identified with a USGS number and a procedure effective date. Procedures that require preparation do not have procedure numbers.

Procedures that are identified as "needed" in the table will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started. Many of the needed technical procedures depend on the results of ongoing prototype testing and cannot be completed until work is done.

Applicable quality-assurance procedures are presented in Appendix 7.1. Completed quality-assurance level assignments are presented in Appendix 7.2.

Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Table 3.8-3. Technical procedures and quality-assurance level assignments for hydrochemistry tests (8.3.1.2.2.4.8)

[Dashes (--) indicate information is not available and to be determined. Quality-assurance level-assignment numbers are listed with the test/analysis title.]

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | Collection and transport of gas samples from radial boreholes<br>NNWSI-QALA-6922G-01-16, R0 | |
| HP-56,R1 | Gas and water-vapor sampling from unsaturated-zone test holes | 04/15/88 |
| Needed | Data archiving, shipping, and handling procedure | -- |
| | Preparation of gas samples for analysis<br>NNWSI-QALA-6922G-01-16, R0 | |
| HP-86,R0 | Method for degassing carbon dioxide and water (vapor) samples from unsaturated-zone test holes | 05/16/88 |
| | Analyses of gas samples<br>NNWSI-QALA-6922G-01-16, R0 | |
| HP-07,R0 | Use of a trace gas for determining atmospheric contamination in a dry-drilled borehole | 09/30/87 |
| HP-127,R0 | Carbon-14 dating by tandem acceleration mass spectrometer | In prep. |
| Needed | Data archiving, shipping, and handling procedure | -- |
| Needed | Procedure for analysis of constituent stable isotopes of water | -- |
| HP-160,R0 | Methods for collection and analysis of samples for gas composition by gas chromatography | 06/16/88 |
| | Collection and transport of core and rubble samples<br>NNWSI-QALA-6922G-01-17, R0 | |
| HP-12,R3 | Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS | 06/08/88 |

Table 3.8-3. Technical procedures and quality-assurance level assignments for hydrochemistry tests (8.3.1.2.2.4.8)--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | Collection and transport of core and rubble samples<br>NNWSI-QALA-6922G-01-17, R0 | |
| HP-131,R0 | Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis | 06/13/88 |
| | Rubble coring<br>NNWSI-QALA-6922G-01-17, R0 | |
| Needed | Air coring of 6.35-cm cores from rubble | -- |
| | Extraction of water from core and rubble-core samples<br>NNWSI-QALA-6922G-01-17, R0 | |
| HP-110,R0 | Extraction of pore waters by centrifuge methods | 06/08/88 |
| HP-125,R0 | Method for extraction of pore water from tuff cores by triaxial compression | 05/20/88 |
| HP-126,R0 | Extraction of residual water from tuff samples by vacuum distillation | 06/15/88 |
| | Analyses of water samples<br>NNWSI-QALA-6922G-01-17, R0 | |
| HP-08,R0 | Methods for determination of inorganic substances in water | 08/06/82 |
| HP-11,R0 | Methods for determination of radioactive substances in water | 06/18/82 |
| HP-127,R0 | Carbon-14 dating by tandem acceleration mass spectrometer | In prep. |
| Needed | Data archiving, shipping, and handling procedure | -- |
| Needed | Method for analyzing water samples for Cl-36 | -- |

Table 3.8-3. Technical procedures and quality-assurance level assignments for hydrochemistry tests (8.3.1.2.2.4.8)--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | Analyses of water samples<br>NNWSI-OALA-6922G-01-17, R0 | |
| Needed | Procedure for analysis of constituent stable isotopes of water | -- |
| Needed | Procedure for determining the presence of tracers in pore-water samples | -- |

## 3.9 Multipurpose-borehole testing near the exploratory shafts

### 3.9.1 Objectives

The objectives of this activity are to

1. monitor and evaluate potential hydrologic and engineering interference effects from exploratory-shaft (ES) construction on ES testing;

2. evaluate the effects of site (surface) preparation and exploratory-shaft facility (ESF) construction on ambient site conditions, to provide hydrogeologic data for preliminary site-characterization and performance assessment calculations;

3. identify possible intervals of perched water in the portion of the unsaturated zone penetrated by the boreholes;

4. sample and test such intervals if present; and

5. confirm engineering and hydrologic properties upon which the ESF design is based, and to identify any anomalous conditions in the vicinity of the ESF.

### 3.9.2 Rationale for activity selection

The multipurpose-borehole activity has been incorporated with the present study to augment reference hydrologic and engineering properties data in the immediate areas of ES-1 and ES-2 prior to their construction; and to have monitoring holes in place, adjacent to each shaft and below the area disturbed by surface construction activities, that will allow the observation and measurement of any changes in nearby ambient conditions that may result from shaft construction.

USW MP-1, adjacent to ES-1, is planned to be drilled first, followed by USW MP-2, which will be adjacent to ES-2. Construction of the ES-1 collar is planned to start after the completion of USW MP-2 and is planned to precede the collar construction of ES-2 by about two months. Construction of ES-2 is planned to proceed ahead of ES-1 after the first few tens of meters to allow early access to the main test levels. Information obtained in the boreholes may prevent potentially costly delays in shaft construction if unexpected conditions are encountered. The responses observed in USW MP-2 caused by the construction of ES-2 are expected to be similar to those that might be later observed in USW MP-1 caused by the construction of ES-1. Therefore, USW MP-2 may provide some lead time, so that construction effects can be considered before ES-1 testing. The boreholes will be drilled concurrently if scheduling problems dictate as long as there is a short lag time (such as a few weeks) between common events of the two drilling activities. The preferred schedule was constructed to facilitate a hydrogeologic knowledge transfer for completing USW MP-1 prior to the drilling/coring of USW MP-2 (such as identifying perched-water zones, geologic structure, and significant lithologic variations in USW MP-1; and attempting to stratigraphically locate those same features in USW MP-2). A shortened lag time could still facilitate this need, but completion of one borehole prior to the initiation of drilling the other would provide the most comprehensive knowledge base of what to expect in the second borehole.

A third multipurpose borehole may be drilled midway between ES-1 and ES-2, if further study demonstrates a need for direct observation of the effects (shaft construction) between the two shafts. The primary purpose of this borehole would be to attempt to identify, if present, the impacts of construction activities in ES-2 on scientific investigations in ES-1.

### 3.9.3 General approach and summary of tests and analyses

The organization of the multipurpose-borehole activity is summarized in Figure 3.9-1. A descriptive heading for the tests and analyses appears in the shadowed boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized during testing. Cross references to other study plans which provide input to the tests also appear in Figure 3.9-1. The objectives of the activity, parameter categories for design and performance which are addressed by the activity, and the site parameters measured during testing are summarized in Figure 3.9-2. These appear in the boxes in the top left side, top right side, and below the shadowed test/analysis boxes, respectively, in Figure 3.9-2.

The overall structure of the planned activity in terms of methods to be employed and measurements to be made is summarized in Figures 3.9-1 and 3.9-2. Descriptions in the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) the site parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

Following the successful completion of the dry-drilled and/or dry-cored prototype borehole, two multipurpose boreholes are planned to be dry-drilled and spot-cored to achieve the objectives of this activity. Construction activities are scheduled so that USW MP-1 is planned to be drilled first, followed by USW MP-2. Construction of the ES-1 collar is planned to start after completion of USW MP-2, approximately 2 months before collar construction of ES-2. Depth penetration of ES-1 will precede ES-2 until a depth of about 30 m (100 ft) is reached. At this level, tests will be conducted in the radial boreholes in ES-1 ( see Section 3.4, radial borehole set numbers 2 and 3) near 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, its construction will proceed

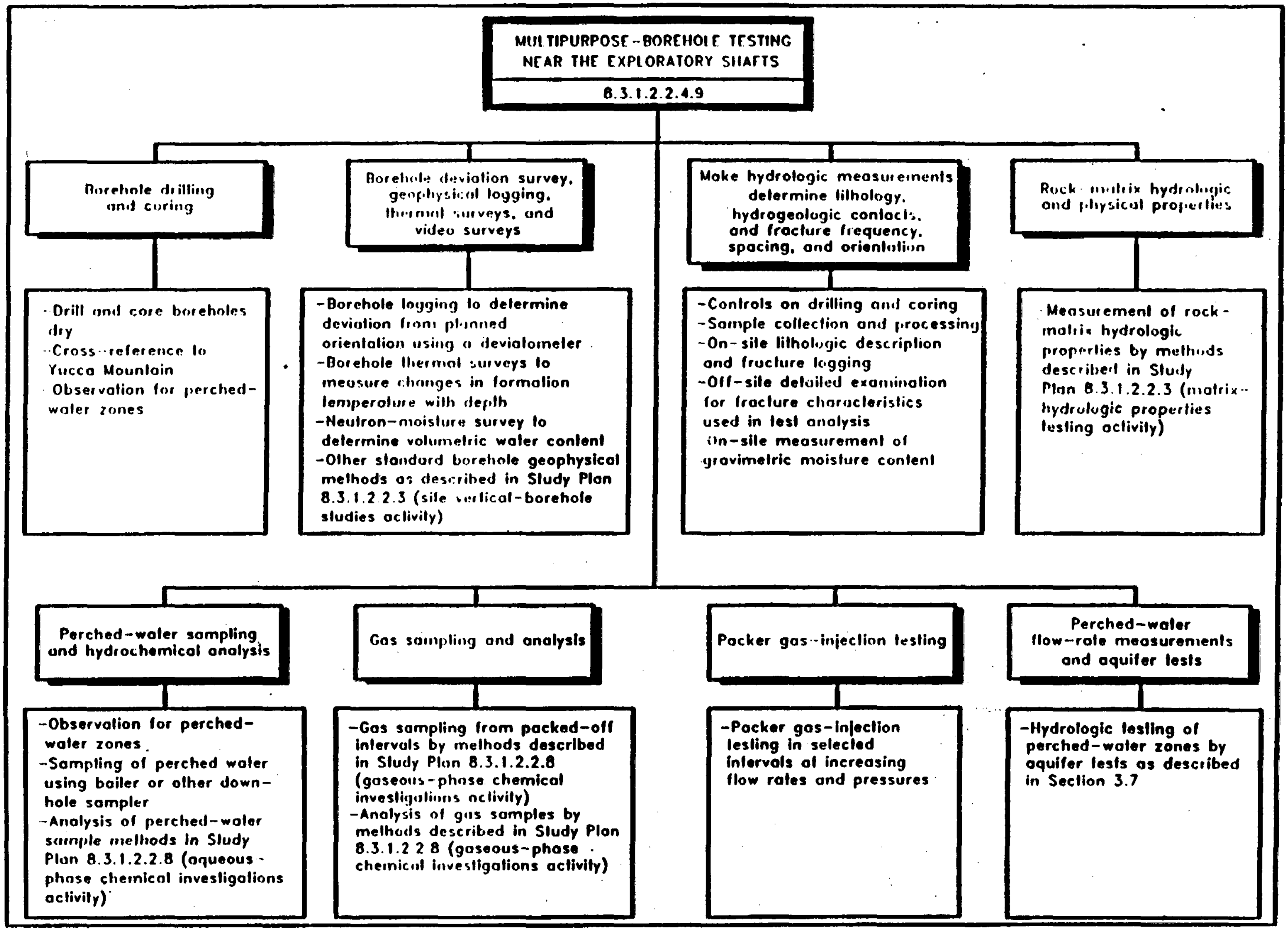



Figure 3.9-1. Organization of the multipurpose-borehole activity, showing tests, analyses, and methods.

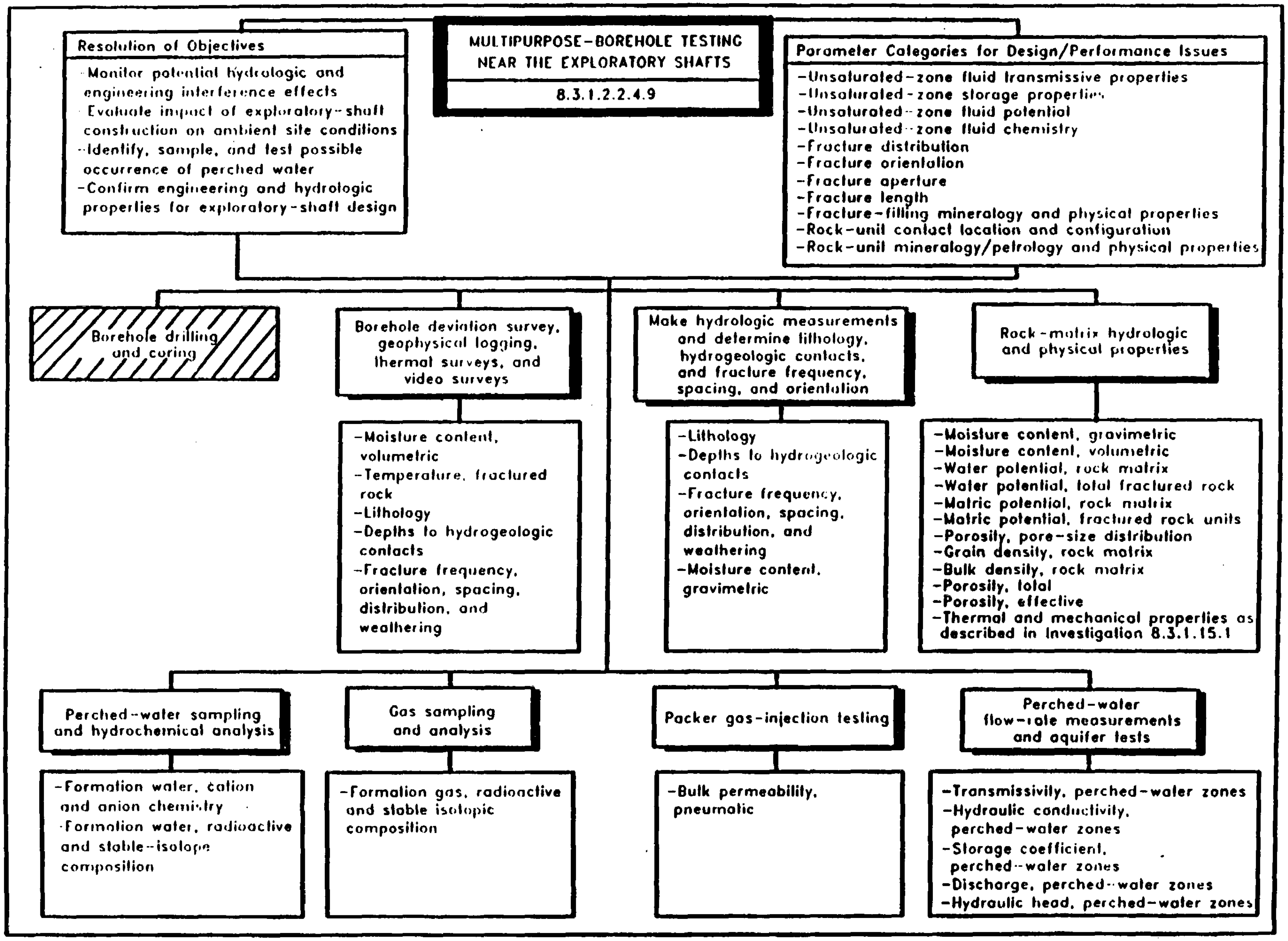



**Figure 3.9-2. Organization of the multipurpose-borehole activity, showing tests, analyses, and site parameters. The cross-hatched box indicates that no site parameters will be generated.**

ahead of ES-1 after these first few tens of meters due to testing scheduled for ES-1. A third multipurpose borehole may be drilled midway between ES-1 and ES-2, as stated previously, and would be completed as far ahead as practicable to the completed construction of ES-2.

Construction activities at and near the exploratory-shaft facility are expected to disturb local rock mechanical and hydrologic properties during blasting and excavation and to introduce significant quantities of water to the site surface for compaction of the ESF pad, dust control, drilling, and mining. SCP Section 8.4.2.2 describes the planned activities. During the construction of the ESF pad and shafts, the addition of fluids may result in areas of local recharge and increases in flux rates near the surface. Preliminary analyses of the infiltration of large amounts of added ponded surface water through the unsaturated zone have been performed, and results are summarized in SCP Section 8.4.3.2.1.1. Additional analyses of the movement of added construction water distant from the shaft are described in SCP Section 8.4.3.2.1.3. In both cases, the preliminary analyses suggest that the movement of fluids will be limited and that the ability of the site to isolate waste will not be compromised.

The drilling of the multipurpose boreholes and the excavation of the shafts will provide an opportunity to confirm the models of fluid migration described above. The downward migration of surface water will be evaluated by compiling saturation profiles for the multipurpose boreholes through the upper unsaturated zone and by analyzing samples for tracers added to the water. In addition, sampling and observation in the exploratory shafts will provide information on the extent of fluid migration. Because of wall exposures, observations in the shafts may also provide data on flow mechanisms (i.e., whether fracture or matrix flow is dominant).

The multipurpose boreholes are located to provide reference information in the vicinity of ES-1 before shaft construction activities and to provide a monitoring hole after shaft construction activities begin. The pre-shaft-sinking results of the planned neutron-moisture logging will serve as a baseline against which construction-induced variations in moisture content may be assessed. If amounts of water are introduced by construction such that water migrates outward from the shaft, or if water introduced at the surface migrates downward, periodic logs may detect the moisture front. Pneumatic testing will be conducted periodically to determine resultant changes in bulk pneumatic permeability due to shaft construction. USW MP-1 will provide for sampling and testing of any perched-water zones encountered and for fluids introduced during the construction of the pad or shafts, if saturated conditions are reached. This borehole will be located outside the anticipated modified permeability zone (MPZ) caused by construction of ES-1. Analysis of the core samples obtained from USW MP-1 and USW MP-2 will provide data for establishing pre-shaft *in situ* ambient conditions and will 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, samples will be analyzed for the parameters listed under this activity. In particular, matrix hydrologic properties and moisture conditions will be characterized to establish *in situ* conditions that can be correlated with the results of geophysical testing.

USW MP-2 is 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 will likely have been 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 will be conducted in USW MP-2.

Neither of the two multipurpose boreholes will be permanently instrumented. Although a permanently instrumented borehole could provide a more sensitive means of monitoring moisture changes than could neutron-moisture logs, the great length of time required to establish re-equilibration makes such an approach impractical. The open boreholes will allow flexibility in terms of follow-up packer testing and neutron-moisture logging that a permanently instrumented borehole could not accommodate. In addition, if saturated conditions are present following the initiation of shaft construction, an open borehole will allow access for the collection of water samples.

Drilling the boreholes will disturb *in situ* conditions in the near-field rock mass adjacent to the boreholes. In addition, nitrogen-injection testing could drive moisture away from the near-field environment of the borehole. The dry drilling and coring methods that will be used, however, are expected to minimize the disturbance to the hydrologic system, and preinjection reference information will be collected before nitrogen-injection testing. This information will consist of laboratory measurements of moisture content and matric potential from core and cuttings, and the geophysical logging records correlated with these data. Although these data will not directly address changes in moisture in fractures, results of neutron-moisture logging may provide some indication of moisture contents in fracture zones when compared to fracture logs, video logs, and other geophysical logs.

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

A third multipurpose borehole may be drilled as close as practicable to the midpoint 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 (SCP Section 8.4.3.3) results indicate that any expected fluid loss from construction activities in ES-2 would not migrate the 30 to 45 m (100 to 150 ft) from the shaft to the additional borehole. Direct measurements of the effects of ES-2, if present, and confirmation of modeling results, however, are possible; and other effects might be detectable by a multipurpose borehole at this location, such as changes in bulk pneumatic permeability. A decision on the need for a third multipurpose borehole will be made, based on additional analyses, prior to construction of ES-2. This decision will be based on the results of further study that may demonstrate the need for direct observation of the effects (shaft construction) between the two shafts.

Immediately after the drilling, a standard suite of geophysical logs will be run in each borehole. The primary purpose of geophysical logs is to obtain a continuous record of the properties of each geohydrologic unit penetrated during drilling and to document borehole conditions. These records will be correlated with rock matrix-hydrologic and physical properties data to evaluate the distribution of the values of these properties in the geohydrologic units encountered, to assist in identifying and characterizing possible perched-water zones, and to assist in choosing intervals for packer gas-injection tests. Outside this study, the geophysical logs will be used for correlation of hydrogeologic units (8.3.1.2.2.3.2) and geologic units (8.3.1.4.2.1.3).

A borehole lithologic log will be compiled from examination of drill-bit cuttings and core. A core fracture log of observed fracture characteristics will also be prepared. Both logs will provide input data for the evaluation of hydrologic- and engineering-properties conditions at the ES-1 and ES-2 sites. On-site observations of core fractures, in conjunction with down-hole television logs, will aid in selection of packer gas-injection testing intervals.

Values of rock-matrix hydrologic and physical properties testing will augment the reference data base upon which the ESF design is based and will indicate zones of unexpected or anomalous values of these properties that may exist at the shaft sites.

In the event that perched-water zones are encountered in the boreholes, water samples will be collected, flow-rate measurements will be made, and hydrologic and hydrochemical properties of the zones will be determined. The resulting data will be of importance to shaft construction and performance assessment.

Following borehole completion, formation-gas sampling and analysis will be conducted to evaluate gaseous-phase chemistry in the vicinity of the boreholes so that a baseline can be established.

Following drilling, geophysical logging, gas sampling, and packer gas-injection testing in each hydrogeologic unit will be conducted to establish a reference pre-construction data base for bulk pneumatic permeabilities of the units. Periodic retesting will be conducted to determine if pneumatic permeability changes occur due to shaft construction.

### 3.9.3.1 Borehole drilling and coring

Drilling will provide access to the unsaturated zone adjacent to ES-1 and ES-2, thus making it possible to (1) define structure and stratigraphy; (2) recover cores and drill-bit cuttings for laboratory measurement of matrix-hydrologic, chemical, and physical properties; (3) determine saturation of each geohydrologic unit as a function of depth; (4) perform *in situ* pneumatic tests to evaluate gas-permeability characteristics of the combined matrix and fracture systems; (5) recover matrix pore water and *in situ* gases for age dating and hydrochemical analysis; (6) visually observe and record the density and orientation of fractures with depth; and (7) conduct geophysical logging, thermal surveys, and borehole video surveys.

Two multipurpose boreholes (USW MP-1 and USW MP-2) will be emplaced using dry-drilling and spot-coring techniques. Both boreholes will be located and constructed such that they do not penetrate within a distance of either of the two shaft or drift diameters of any planned man-made underground openings. USW MP-1 will be located near ES-1 and USW MP-2 near ES-2 (Figure 3.9-3). Each will be approximately 15 to 18 m (50 to 60 ft) 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 will be approximately 20 cm (8 in.) in diameter and will be drilled approximately to the corresponding shaft depths, with walls as smooth as practicable 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 will be drilled first, spot-cored throughout (approximately 0.3 to 0.6 m [1 to 2 ft] of each 3 m [10 ft] will be cored) and continuously cored, if feasible, through the Yucca Mountain and Pah Canyon members of the Paintbrush Tuff, through intervals bracketing the upper demonstration breakout room and the MTL, and through intervals with potential for perched water (see Figures 3.4-3 and 3.4-4). The amount of coring planned in USW MP-1 is estimated to be 128 m (420 ft) of the total 335 m (1,100 ft) drilled. USW MP-2 will 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.

Both boreholes will be drilled such that the drilling system employed will minimize changes in the water content of cores.

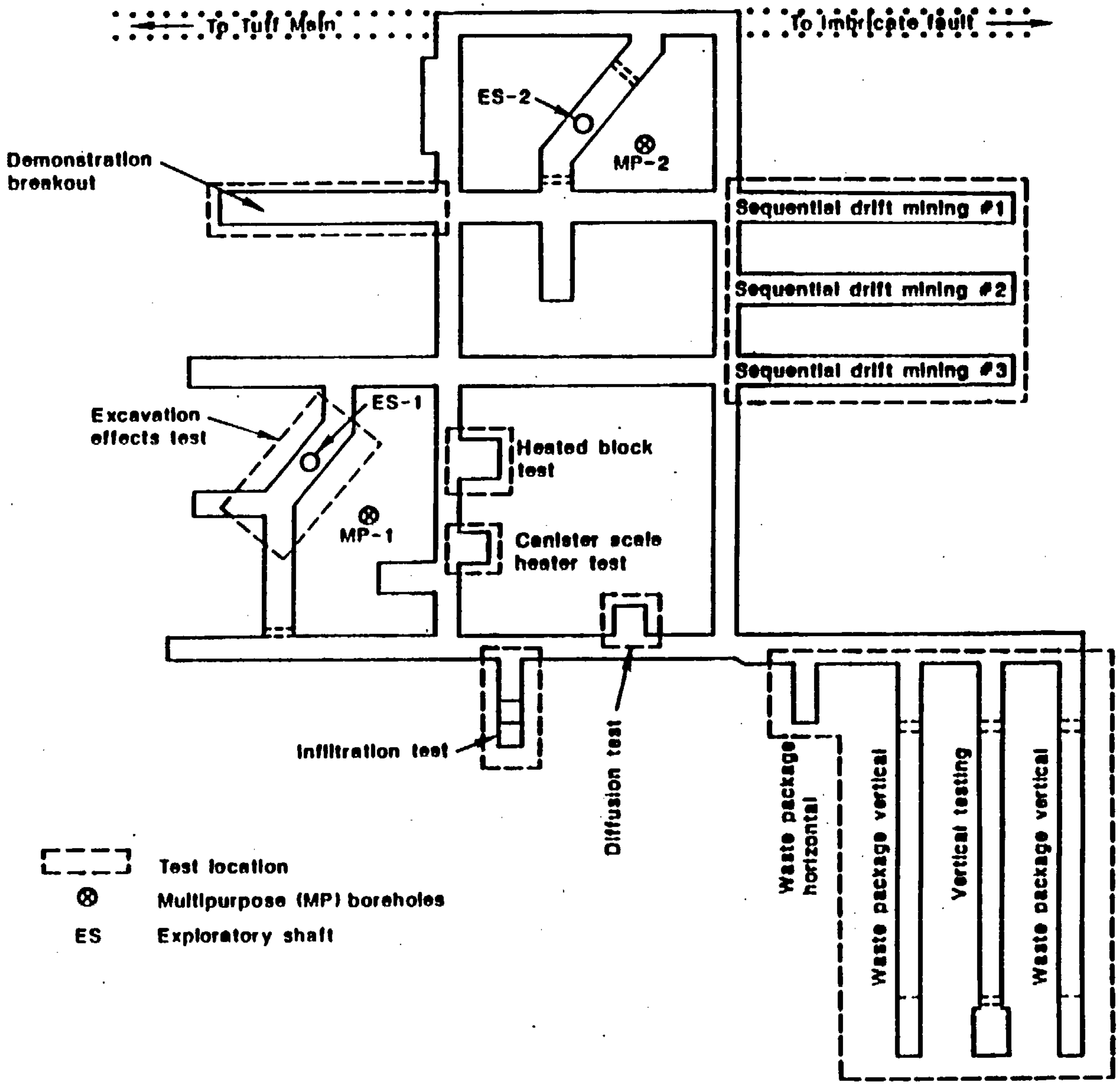



Figure 3.9-3. Proposed location of multipurpose boreholes at the main test level.

drill-bit cuttings, and the rock mass adjacent to the borehole. There are two proven methods of drilling with air in the unsaturated zone at the Nevada Test Site; the dual-wall, reverse-vacuum, rotary system and the Odex system. A third method of dry drilling and coring which uses a dual-wall, reverse-circulation, down-hole hammer technique may also prove to be suited to drilling needs at Yucca Mountain. At present, only the dual-wall, reverse-vacuum, rotary system has been used at the Nevada Test Site to reach depths necessary for the boreholes (about 335 m [1,100 ft]). It is difficult to obtain suitable core samples using this method, however. The Odex system has been used to depths of 158 m with excellent coring results, but some doubt exists as to the feasibility of reaching depths in excess of 300 m (1,000 ft). Standard drilling technology is capable of drilling dry holes to the depths planned for the multipurpose boreholes, but the amount of core obtained may be a function of the selected drilling/coring method. For this reason, prototype testing of the downhole-hammer method may be conducted prior to the initiation of the multipurpose borehole drilling/coring program to assist in method selection. Greater numbers of core samples obtained will enhance correlations of *in situ* measurements with geophysical-logging data.

### 3.9.3.2 Borehole deviation survey, geophysical logging, thermal surveys, and video surveys

Both USW MP-1 and USW MP-2 will be logged with a deviatometer. This procedure is essential for plotting the three-dimensional locations of the boreholes relative to ES-1 and ES-2, as input to observations and measurements carried out in the multipurpose boreholes during the construction of the shafts. If survey results indicate that the boreholes have diverted from their target locations, standard drilling techniques (such as setting wedges or utilizing gyroscopic drilling measures) will be used to ensure proper orientation of the borehole.

A standard suite of geophysical logs will be run in each of the boreholes following completion of drilling. Included in this suite will be the following log types: caliper, neutron, gamma-gamma (density), induction, gamma-ray (natural), gamma-ray (spectral), temperature, and dielectric logs. The uses of the above logs, their operational principles, and required borehole conditions are discussed in the Site Vertical Borehole Studies Activity of Study Plan 8.3.1.2.2.3. Radially (side scan viewing) and axially (forward viewing) oriented television camera logs of each borehole will also be run. These will be used for mapping fracture orientations, distributions, and densities. Neutron-moisture logs will be run periodically during and after the drilling period to monitor any changes in water-content profiles.

**3.9.3.3 Determination of lithology, hydrogeologic contacts, hydrologic measurements, and fracture frequency, spacing, and orientation**

Controls will be implemented during drilling to insure that (1) cuttings and core samples are representative of natural conditions in sampled intervals; (2) drilling progress is monitored in a timely fashion so that sampling adequately characterizes lithologic and hydrologic variations with depth; and (3) samples are properly identified, labeled, and controlled. The controls are designed to minimize information loss and the introduction of spurious and misleading information. These controls are treated in detail in the Site Vertical Boreholes Activity of Study Plan 8.3.1.2.2.3 and are summarized briefly below.

Preliminary sample depth, number, and type will be determined by the Principal Investigator in coordination with the Sample Oversight Committee and recorded in the drilling criteria letter and work plan prior to the start of drilling. The drilling contractor will be responsible for producing samples of drill-bit cuttings and cores as specified in the work plan. After the samples are obtained by the drilling contractor, logged and photographed by staff of the Sample Management Facility, and provided on site to the USGS, necessary steps to prevent evaporation from the samples will be taken. Both drill-bit cuttings and core will be processed in a manner such that evaporation is minimized. On-site lithologic descriptions will be done to guide the collection of core samples. A current on-site lithologic log will be used to determine when the borehole has reached a predetermined unit where cores are to be collected.

On-site hydrologic measurements will consist of the determination of gravimetric moisture content from a small but adequate amount of drill-bit cuttings taken for this purpose. This is accomplished on site in order to minimize evaporation prior to obtaining the *wet* weight of the cuttings. The cuttings will then be dried in an oven to obtain the *dry* weight. After the sample has been weighed, it will be discarded.

A lithologic log will be compiled by examining and testing drill-bit cuttings and cores collected from USW MP-1 and USW MP-2. The descriptive log for the rocks penetrated in each borehole will include a lithologic description versus depth, thickness and depth of each unit, and a description of associated physical and hydrologic characteristics. A core fracture log for each borehole will include a description of observed fractures, to include depth, abundance, geometry, and physical and mineralogical characteristics. This information will be combined with the results of downhole television surveys to produce a fracture log for each borehole.

### 3.9.3.4 Rock-matrix hydrologic and physical properties

The determination of rock-matrix hydrologic and physical properties by laboratory analysis is essential to characterizing the ambient hydrologic and physical properties of the unsaturated zone near the sites of ES-1 and ES-2. Matrix-hydrologic properties will play an important role in interpreting the results of the packer gas-injection tests, neutron logs, and other hydrologic tests conducted in perched-water zones. Data collected in this test will also augment the matrix-hydrologic data base in Study 8.3.1.2.3.3 (Yucca Mountain unsaturated-zone percolation, surface-based studies) and the physical-properties data base of Investigation 8.3.1.15.1 (Spatial distribution of thermal and mechanical properties).

Matrix hydrologic properties (including water content, permeability, and storage properties) and physical-rock properties (such as bulk density and fracture frequency, orientation, and spacing) for each geohydrologic unit will be measured in the laboratory. In the initial stages of these tests, the results of analyses will be compared to the results of borehole-geophysical logging in order to establish a quantitative correlation between measured laboratory values and geophysical logs. After the geophysical logs are calibrated for the physical and hydrologic parameters of interest, it is envisioned that geophysical logging can be used to support studies of conditions in the shaft, and monitoring of USW MP-1 and USW MP-2 during shaft construction.

Matrix hydrologic-properties testing will be performed according to the laboratory procedures described in the matrix-hydrologic-properties testing activity of Study Plan 8.3.1.2.2.3. Properties measured will include gravimetric and volumetric water content, bulk and grain density, water potential, matric potential, matrix permeability, relative permeability, moisture retention, total porosity, and effective porosity.

Thermal and mechanical rock properties testing will be performed according to laboratory procedures described in SCP Investigation 8.3.1.15.1. Properties measured will include thermal conductivity, heat capacity, coefficient of thermal expansion, Poisson's ratio, Young's modulus, deformation modulus, compressive strength, angle of internal friction, and various fracture mechanical properties.

### 3.9.3.5 Perched-water sampling and hydrochemical analysis

If perched water is detected during the process of drilling either of the two multipurpose boreholes, drilling operations will be interrupted, and a program of sampling and testing within the perched-water zone will be implemented (as defined in Study Plan 8.3.1.2.2.3). The occurrence of perched water may be first detected by a change in drilling response such as the bit "balling up." This condition may be due to moisture and fine particles collating to form a mud which causes a reduction in drill-bit cuttings being removed from the borehole, and results in slower drilling rates. Other evidence includes cuttings clogging parts of the return lines or separator due to moisture, and cuttings appearing to be moist or wet or feeling damp when squeezed in an observer's hand.

The first course of action in the event perched water is encountered would be to attempt to obtain a water sample, possibly by means of a bailer or other type of down-hole sampler. A water sample must be collected with minimal delay before 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 collected periodically.

Because of the loss of large quantities of drilling fluid used during construction of a nearby test hole (USW G-4), it is possible that if perched water is detected in either of the two multipurpose boreholes, it may be the result of lost drilling fluids from USW G-4. Drilling fluids used in USW G-4 contained 20 ppm LiBr tracer, and 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 the ESF. The multipurpose boreholes may provide data to support the finalization of plans for the perched-water activity (Section 3.7).

Analysis of perched-water samples for ionic concentrations, stable-isotope ratios, radioactive isotopes, and tracers will be performed according to the procedures specified in the aqueous-phase chemical investigations activity of Study Plan 8.3.1.2.2.8 (Hydrochemical characterization of the unsaturated zone).

### 3.9.3.6 Gas sampling and analysis

Formation gas sampling will be undertaken in order to characterize preconstruction gaseous-phase chemistry in USW MP-1 and USW MP-2. This information will be used as a baseline condition for multipurpose-borehole monitoring during the construction of the shafts and also will augment the hydrochemistry data base of the gaseous-phase chemical investigations activity of Study Plan 8.3.1.2.2.8.

Gas samples from selected packed-off intervals of both multipurpose boreholes will be extracted and prepared for analysis according to procedures specified in the above activity. The types of samples collected will be gas composition, carbon-13/carbon-12 ratios, carbon-14, and water-vapor samples. Analysis for air-coring contamination, stable-isotope ratios, radioactive isotopes, and tracers will be performed in the laboratories and according to the procedures specified in the above activity in Study Plan 8.3.1.2.2.8.

### 3.9.3.7 Packer gas-injection testing

To establish a preconstruction data set for bulk pneumatic permeabilities, packer nitrogen-injection tests will be performed in each of the boreholes following completion of drilling 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 observation intervals. All three intervals will be equipped with thermocouple psychrometers (or other humidity sensors), thermocouples, and pressure transducers. Observation intervals will be monitored for evidence of bypass of the packers from the injection interval. Flow rate and injection pressure of the nitrogen gas will be monitored in either transient or steady-state tests. The same procedure will 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 and after construction of the exploratory shafts, additional periodic packer tests will be conducted to determine any changes in gas permeabilities due to shaft construction.

Intervals within the radial boreholes may be used as observation points for gas-injection tests conducted in USW MP-1 and USW MP-2 in the multipurpose-borehole testing activity. Conversely, intervals in USW MP-1 and USW MP-2 may be used to observe *in situ* pneumatic testing in radial-borehole tests. The observations will aid in evaluating anisotropy in air permeability, and asymmetry in air permeability in different directions along the same flow paths.

### 3.9.3.8 Flow-rate measurements and aquifer tests

Flow-rate measurements and aquifer tests will be conducted in perched-water zones (if encountered) if flow is sufficient. Types of tests performed could include (but not be limited to) constant-drawdown and constant-rate pumping tests and Theis recovery tests. Tests would be conducted according to the applicable procedures discussed in the perched-water test activity (Section 3.7) of this study plan and in Study Plan 8.3.1.2.2.3, Unsaturated-zone percolation surface-based study.

### 3.9.3.9 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.9-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. Alternate methods may be utilized only if selected methods are impractical to measure the parameter(s) of interest. The selected methods in Table 3.9-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. Models and analytical techniques have been or will be developed to be consistent with test results. The expected ranges of the site-characterization parameter shall be bracketed by previous data collection and computer modeling.

### 3.9.4 Technical procedures and quality-assurance levels

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment, justification, and documentation of quality levels to activities that affect quality; and documentation of technical procedures for all technical activities that require quality assurance.

Table 3.9-2 provides a tabulation of quality-assurance level-assignment (YMP-QALA-) numbers and technical procedures applicable to this activity. Approved procedures are identified with a USGS number and a procedure effective date. Procedures that require preparation do not have procedure numbers.

Procedures that are identified as "needed" in the table will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started. Many of the needed technical procedures depend on the results of ongoing prototype testing and cannot be completed until work is done.

Applicable quality-assurance procedures are presented in Appendix 7.1. Completed quality-assurance level assignments are presented in Appendix 7.2.

Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Table 3.9-1. Summary of tests and methods for the multipurpose-borehole testing (SCP 8.3.1.2.2.4.9) near the exploratory shaft
[Note: Dashes (--) indicate information is not available and to be determined.]

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| **Borehole-deviation survey, geophysical logging, thermal surveys, and video surveys** | | |
| Borehole thermal surveys to measure changes in formation temperature with depth (selected) | Temperature, fractured rock | -- |
| Neutron-moisture survey to determine volumetric water content (selected) | Moisture content, volumetric | -- |
| Borehole video surveys (selected) | Fracture frequency, orientation, spacing, distribution, and weathering | -- |
| Other standard borehole geophysical methods as described in SP 8.3.1.2.2.3.2 (site vertical-borehole studies) (selected) | Depths to hydrogeologic contacts | -- |
| " | Lithology | -- |
| **Determination of lithology, hydrogeologic contacts, hydrologic measurements, and fracture frequency, spacing, and orientation** | | |
| On-site lithologic description and fracture logging from cuttings and cores (selected) | Depths to hydrogeologic contacts | -- |
| " | Fracture frequency, orientation, spacing, distribution, and weathering | -- |
| " | Lithology | -- |
| Off-site detailed examination for fracture characteristics from core samples (selected) | Fracture frequency, orientation, spacing, distribution, and weathering | -- |

Table 3.9-1. Summary of tests and methods for the multipurpose-borehole testing (SCP 8.3.1.2.2.4.9) near the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| **Determination of lithology, hydrogeologic contacts, hydrologic measurements, and fracture frequency, spacing, and orientation** | | |
| On-site measurement of gravimetric moisture content of cuttings and cores. (selected) | Moisture content, gravimetric | -- |
| **Rock-matrix hydrologic and physical properties** | | |
| Measurement of rock-matrix hydrologic properties by methods described in SP 8.3.1.2.2.3.1 (matrix-hydrologic properties testing) (selected) | Bulk density, rock matrix | -- |
| " | Grain density, rock matrix | -- |
| " | Matric potential, fractured rock units | -- |
| " | Matric potential, rock matrix | -- |
| " | Moisture content, gravimetric | -- |
| " | Moisture content, volumetric | -- |
| " | Porosity pore-size distribution | -- |
| " | Porosity, effective | -- |
| " | Porosity, total | -- |
| " | Water potential, rock matrix | -- |
| " | Water potential, total fractured rock | -- |

Table 3.9-1. Summary of tests and methods for the multipurpose-borehole testing (SCP 8.3.1.2.2.4.9) near the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | **Perched-water sampling and analysis** | |
| Perched-water sample collection by methods described in Section 3.7 and analysis of perched-water samples by methods applicable to vertical boreholes, as described in SP 8.3.1.2.2.7 (selected) | Formation water, cation and anion chemistry | -- |
| " | Formation water, radioactive and stable-isotope composition | -- |
| | **Gas sampling and analysis** | |
| Gas-sample collection and analysis of samples by methods described in SP 8.3.1.2.2.7 (gaseous-phase chemical investigations activity) (selected) | Formation gas, radioactive and stable-isotope composition | -- |
| | **Packer gas-injection testing** | |
| Packer gas-injection testing (selected) | Bulk permeability, pneumatic | -- |
| | **Flow-rate measurements and aquifer tests** | |
| Hydrologic testing of perched-water zones by aquifer tests and packer-injection tests (selected) | Discharge, perched-water zones | -- |
| " | Hydraulic conductivity, perched-water zones | -- |
| " | Hydraulic head, perched-water zones | -- |

Table 3.9-1. Summary of tests and methods for the multipurpose-borehole testing (SCP 8.3.1.2.2.4.9) near the exploratory shaft--Continued

| Methods (selected and alternate) | Site-characterization parameter | Expected range |
|---|---|---|
| | Flow-rate measurements and aquifer tests | |
| Hydrologic testing of perched-water zones by aquifer tests and packer-injection tests (selected) | Storage coefficient, perched-water zones | -- |
| " | Transmissivity, perched-water zones | -- |

Table 3.9-2. Technical procedures and quality-assurance level assignments for multipurpose-borehole testing (8.3.1.2.2.4.9) near the exploratory shaft
[Dashes (--) indicate information is not available or to be determined. Quality-assurance level-assignment numbers are listed with the test/analysis title.]

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Borehole drilling and coring** YMP-QALA-6922-01-18,R0 | |
| Needed | Borehole cleaning and verification techniques | -- |
| Needed | Borehole drilling of perched-water zones | -- |
| Needed | Borehole dry drilling and coring procedure: horizontal and vertical holes | -- |
| | **Borehole-deviation survey, geophysical logging, thermal surveys, and video surveys** YMP-QALA-6922-01-19,R0 | |
| GP-10,R0 | Borehole video fracture logging | 04/12/85 |
| GPP-12,R0 | Borehole gravity measurement and data reduction | 03/20/85 |
| GPP-14,R0 | Induced-polarization borehole logging operations | 05/27/86 |
| GPP-15,R0 | Magnetic-susceptibility borehole logging operations | 05/27/86 |
| GPP-17,R0 | Magnetometer borehole logging operations | 05/27/86 |
| HP-72,R0 | Operation of the Mt. Sopris II geophysical logging unit, USGS Logging Van (I-139055) | In prep. |
| Needed | Borehole deviation surveys | -- |
| Needed | Calibration of noncommercial logging tools | -- |
| Needed | Depth calibration of noncommercial logging tools | -- |
| Needed | Method for calibrating temperature sensors | -- |
| Needed | Borehole video survey | -- |
| HP-62,R4 | Method for measuring subsurface moisture content, using a neutron moisture meter | 11/02/88 |

Table 3.9-2. Technical procedures and quality-assurance level assignments for multipurpose-borehole testing (8.3.1.2.2.4.9) near the exploratory shaft--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Borehole-deviation survey, geophysical logging, thermal surveys, and video surveys**<br>YMP-QALA-6922-01-19,R0 | |
| Needed | Borehole thermal surveys | -- |
| Needed | Borehole video and logging survey procedure: horizontal and vertical holes | -- |
| Needed | Borehole geophysical logging procedure for horizontal and vertical holes (F&S) | -- |
| HP-96,R0 | Neutron-moisture meter calibration (vertical holes) | -- |
| | **Determination of lithology, hydrogeologic contacts, hydrologic measurements, and fracture frequency, spacing, and orientation**<br>YMP-QALA-6922-01-20,R0 | |
| GP-11,R0 | Logging fractures in core | 05/15/85 |
| HP-12,R3 | Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS | 06/08/88 |
| HP-32,R0 | Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone | 05/15/85 |
| HP-73,R0 | Calibration and use of the Sartorius Electronic Toploader (balance) Model 1507 MP8 | 03/29/85 |
| 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 | 09/30/87 |
| | **Rock-matrix hydrologic and physical properties**<br>YMP-QALA-6922-01-21,R0 | |
| GPP-22,R0 | Determining porosity and density of rock samples and calibration of associated instruments | 10/29/87 |

Table 3.9-2. Technical procedures and quality-assurance level assignments for multipurpose-borehole testing (8.3.1.2.2.4.9) near the exploratory shaft--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Rock-matrix hydrologic and physical properties** YMP-QALA-6922-01-21,R0 | |
| HP-28,R0 | Laboratory procedures for the determination of moisture-retention curves on rock core | 05/15/85 |
| HP-55,R0 | Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated-zone test holes | 09/09/85 |
| Needed | Determination of effective porosity from core samples | -- |
| Needed | Determination of grain density from core samples | -- |
| | **Perched-water sampling and analysis** YMP-QALA-6922-01-22,R0 | |
| HP-33,R0 | Preliminary method for monitoring and testing perched-water zones in a borehole drilled with the reverse-vacuum method | 05/15/85 |
| Needed | Perched-water sampling | -- |
| Needed | Perched-water sample analysis | -- |
| Needed | Perched-water sampling and chemical/age-dating analysis | -- |
| | **Gas sampling and analysis** YMP-QALA-6922-01-23,R0 | |
| HP-56,R1 | Gas and water-vapor sampling from unsaturated-zone test holes | 04/15/88 |
| | **Packer gas-injection testing** YMP-QALA-6922-01-24,R0 | |
| HP-10,R1 | Packer-injection and shut-in tests | 07/09/84 |

Table 3.9-2. Technical procedures and quality-assurance level assignments for multipurpose-borehole testing (8.3.1.2.2.4.9) near the exploratory shaft--Continued

| Technical procedure number (NWM-USGS-) | Technical procedure | Effective date |
|---|---|---|
| | **Packer gas-injection testing** YMP-QALA-6922-01-24,R0 | |
| Needed | Method for construction of air-injection packer system and air-leak detection | -- |
| Needed | Single-hole, gas-injection tests | -- |
| Needed | Method for determining fracture geometric parameters from air-injection tests | -- |
| | **Flow-rate measurements and aquifer tests** YMP-QALA-6922-01-25,R0 | |
| HP-06,R0 | Hydrologic pumping test | 01/11/82 |

## 3.10 Hydrologic properties of major faults encountered in main test level of ESF

The major-fault hydrologic properties testing will be focused on the Ghost Dance fault, a major fault near Drill Hole Wash, and the imbricate fault zone, with other faults tested if flow is observed. Because this test is not part of the ES construction-phase testing, the plans for this activity will be presented in a subsequent revision of this study plan.

# 4 APPLICATION OF STUDY RESULTS

## 4.1 Application of results to resolution of design and performance issues

The results of this study will be used in the resolution of NNWSI performance and design issues concerned with fluid flow (both liquid and gas) within the unsaturated zone beneath Yucca Mountain. The principal applications will be in assessments of ground-water and gas travel times (Issues 1.1 and 1.6), and design analyses related to the underground-repository facilities (Issues 1.10, 1.11, and 4.4). Issues concerned with the waste-package containment and engineered-barrier system releases (Issue 1.4 and 1.5) and repository seals (Issue 1.12) will also use the hydrologic information resulting from this study.

The application of site information from this study to design- and performance-parameter needs required for the resolution of design and performance issues is addressed in Section 1.3. Logic diagrams and tables are used to summarize specific relations between performance- and design-parameter needs and site parameters determined from this study. Section 7.3 provides additional detailed parameter relations.

## 4.2 Application of results to support other site-characterization investigations and studies

Data collected in this study will be employed in other studies in Investigation 8.3.1.2.2 (Description of the unsaturated-zone hydrologic system at the site), as well as in studies concerning the following investigations:

- 8.3.1.3.1 - Studies to provide the information on water chemistry within the potential emplacement horizon and along potential flow paths;
- 8.3.1.3.8 - Studies to provide the required information on retardation of gaseous radionuclides along flow paths to the accessible environment;
- 8.3.1.4.2 - Geologic framework of the Yucca Mountain site;
- 8.3.1.15.1 - Studies to provide the required information for spatial distribution of thermal and mechanical properties;
- 8.3.1.15.2 - Studies to provide the required information for spatial distribution of ambient stress and thermal conditions; and
- 8.3.1.16.3 - Ground-water conditions within and above the potential host rock.

In Investigation 8.3.1.2.2, of which Study 8.3.1.2.2.4 is a component, several other studies will employ data generated in this study.

Study 8.3.1.2.2.6 (Characteristics of gaseous-phase movement in the unsaturated zone) will employ gaseous-phase movement data generated in Activities 8.3.1.2.2.4.4 (Radial-borehole tests) and 8.3.1.2.2.4.9 (Multipurpose-borehole tests) in the description of the pre-waste-emplacement gas-flow field at Yucca Mountain, identifying structural controls on fluid flow, determining the conductive properties of the unsaturated zone for gas flow, and modeling the transport of water and tracers in the gas phase. Among the data contributed would be unsaturated-zone fluid-transmissive properties, fluid potential, fluid flux, and fracture geometry and characteristics.

Study 8.3.1.2.2.7 (Hydrochemical characterization of the unsaturated zone) will employ gas- and water-analysis data for radioactive isotopes, stable-isotope ratios, pore-gas composition, and cation/anion concentrations generated in Activities 8.3.1.2.2.4.8 (Hydrochemistry tests in the ESF) and 8.3.1.2.2.4.9 (Multipurpose-borehole tests). The data will be used both in gas-phase chemical investigations (gas-transport mechanism, flow direction, flux, and travel time) and aqueous-phase chemical investigations (ground-water flow direction, flux, travel time, and water-rock interaction. Data on unsaturated-zone ground-water compositions resulting from the hydrochemistry tests (8.3.1.2.2.4.8) will also be used to support assumptions about ground-water compositions in the laboratory sorption tests (Investigation 8.3.1.3.4). The water composition used in sorption testing must be compared to that determined by the hydrochemistry activity to assure that the laboratory-sorption data are valid.

Study 8.3.1.2.2.8 (Fluid flow in unsaturated, fractured rock) will receive important information from Study 8.3.1.2.2.4 in order to select, develop, verify, and validate numerical codes for modeling fluid flow in the unsaturated zone. Virtually all data on unsaturated-zone hydrologic processes collected in the five activities described in this study plan will be used as input to the fracture-flow modeling in the unsaturated zone.

In Study 8.3.1.2.2.9 (Site unsaturated-zone modeling, and synthesis), the unsaturated-zone hydraulic properties listed above and derived in part from Study 8.3.1.2.2.4 will be employed in the development of an evolving conceptual model of their spatial distribution, the selection, development, and testing of hydrologic-modeling computer codes, simulation of the natural hydrogeologic system, and stochastic modeling and uncertainty analysis.

In Investigation 8.3.1.3.1, Study 8.3.1.3.1.1 (Ground-water chemistry model) will employ water-analysis data for radioactive isotopes, stable-isotope ratios, and cation/anion concentrations measured in Activities 8.3.1.2.2.4.8 (Hydrochemistry tests in the ESF and 8.3.1.2.2.4.9 (Multipurpose-borehole tests) as data for the unsaturated-zone ground-water composition model.

In Investigation 8.3.1.3.8, Study 8.3.1.3.8.1 (Gaseous radionuclide transport calculations and measurements) will employ the same gaseous-flow analysis data from Activities 8.3.1.2.2.4.8 and 8.3.1.2.2.4.9 as data required for water chemistry. The study will also employ analyses of gas samples from this activity for radioactive isotopes, stable-isotope ratios, and pore-gas composition as data required for identification of gaseous radionuclide species and gas-phase composition. From Activity 8.3.1.2.2.4.4 (Radial-borehole), the above study will employ data on unsaturated-zone transmissive properties, fluid potential and temperature, and fluid flux, as well as fracture geometry and properties as required data for determining flow paths for gaseous transport.

In Investigation 8.3.1.4.2, both the component stratigraphic and structural studies will employ geologic information generated in the exploratory-shaft percolation study. Study 8.3.1.4.2.1 (Characterization of the vertical and lateral distribution of stratigraphic units within the site area) will be the principal means of investigating the stratigraphy of the site and will receive some lithostratigraphic data from Study 8.3.1.2.2.4. Among these data will be rock-unit contact locations and configurations and rock-unit vertical and lateral variability from Activity 8.3.1.2.2.4.4, Radial-borehole tests. Study 8.3.1.4.2.2 (Characterization of structural features within the site area) will employ data on fracture geometry and characteristics collected in Activities 8.3.1.2.2.4.4 (Radial-borehole tests), 8.3.2.2.4.5 (Excavation-effects test), and 8.3.1.2.2.4.9 (multipurpose-borehole test).

Investigation 8.3.1.15.1 (Spatial distribution of thermal and mechanical properties) will employ laboratory data on thermal and mechanical rock properties generated from samples provided by Activity 8.3.1.2.2.4.9 (Multipurpose-borehole tests).

Investigation 8.3.1.15.2 (Spatial distribution of ambient stress and thermal conditions) will employ data generated in Activity 8.3.1.2.2.4.5 on *in situ* stress magnitude and orientation and fracture deformation.

In Investigation 8.3.1.16.3, Study 8.3.1.16.3.1 (Determination of the preclosure hydrologic conditions of the unsaturated zone at Yucca Mountain, Nevada) will compile and synthesize data collected in Study 8.3.1.2.2.4 for use in addressing preclosure repository design requirements, design analyses, and underground-facilities technology.

# 5 SCHEDULES AND MILESTONES

## 5.1 Schedules

The proposed schedule presented in Figure 5.1-1 summarizes the logic network and reports for the five activities of the ESF construction-phase hydrologic testing. This figure represents a summary of the schedule information which includes the sequencing, interrelations, and relative durations of the activities described in this study. Specific durations and start and finish dates for the activities are being developed as part of ongoing planning efforts. The development of the schedule for the present study has taken into account how the study will be affected by contributions of data or interferences from other studies, and also how the present study will contribute or may interfere with other studies.

The *in situ* hydrologic activities described in this study plan will be dependent on the construction schedules of the multipurpose boreholes, exploratory-shaft facility, and the underground drifts. The radial-borehole, hydrochemistry, and perched-water tests will begin shortly after initiation of construction of shaft ES-1, but the excavation-effects test will not begin until after construction of the ES-1 upper breakout room. All four of these tests will continue following the completion of the exploratory-shaft facility and drifts. The remaining four tests of this study (not shown on Figure 5.1-1) will also be conducted at this time.

Accurate characterization of unsaturated-zone percolation will require several years of hydrologic testing and monitoring. Because of the relatively long period of time needed, the planned activities provide little time for delay.

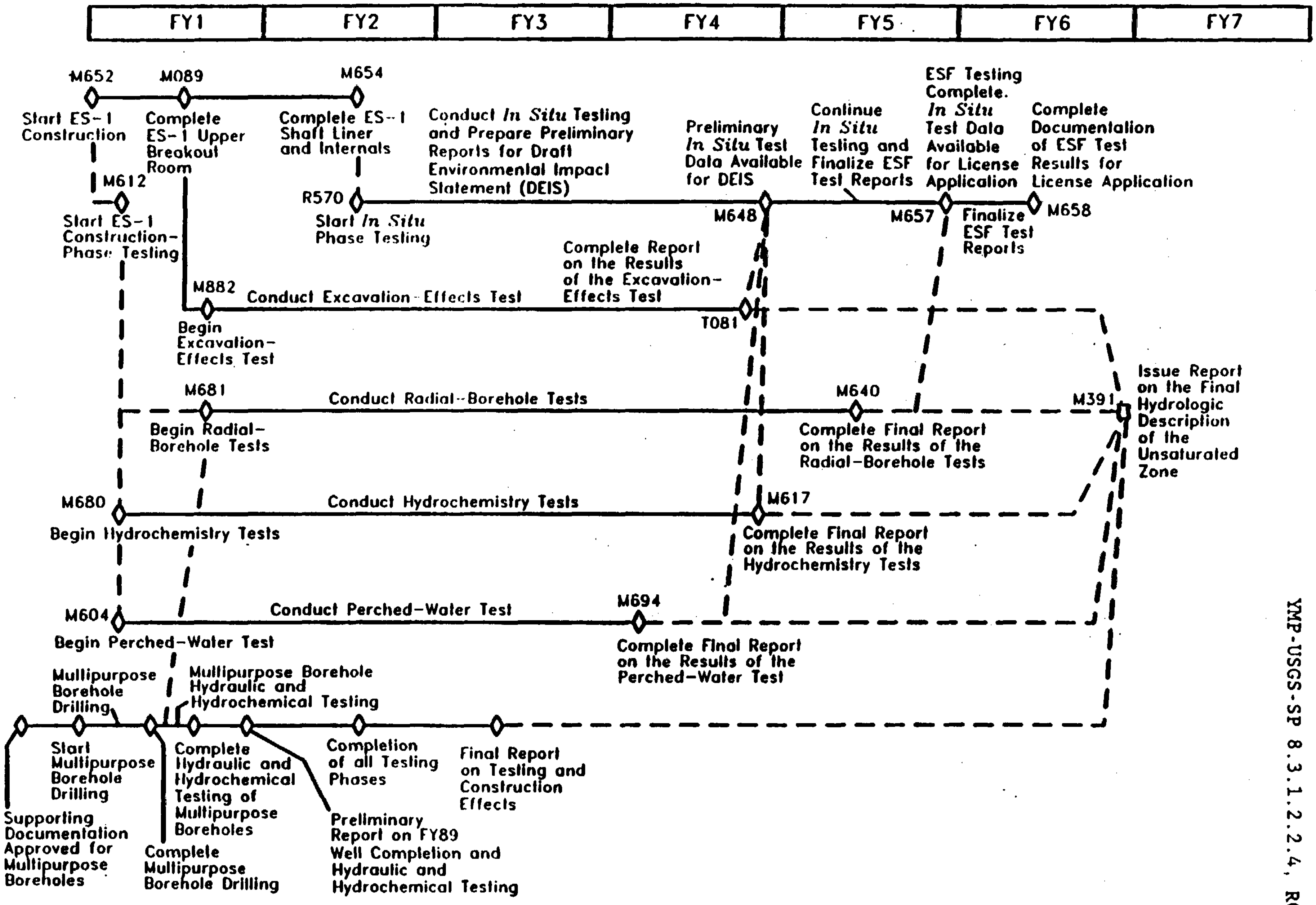



**Figure 5.1-1. Summary network of ESF construction-phase hydrologic tests.**

## 5.2 Milestones

The milestone number, title, and corresponding work-breakdown-structure (WBS) number associated with the five activities of the ESF construction-phase hydrologic testing are summarized in Table 5.2-1.

The information presented in Table 5.2-1 represents major events or important summary milestones associated with the activities presented in this study plan as shown in Figure 5.1-1. Specific dates for the milestone are not included in the tables, as these dates are subject to change due to ongoing planning efforts.

Table 5.2-1. Milestone list for study (SCP 8.3.1.2.2.4), exploratory-shaft facility
[Note: Dashes (--) indicate information is not available and to be determined.

| Milestone number | Milestone description | Work breakdown structure number |
|---|---|---|
| Study: Characterization of Yucca Mountain percolation in the unsaturated-zone--exploratory-shaft-facility study: 8.3.1.2.2.4 | | |
| M652 | Start ES-1 shaft construction | 1.2.6 |
| R570 | Start ESF in situ testing | 1.2.6 |
| M612 | Start ES-1 construction-phase testing | 1.2.6 |
| Activity: Radial-borehole tests in the exploratory-shaft facility: 8.3.1.2.2.4.4 | | |
| M681 | Begin radial-borehole sampling test | 1.2.6.9.2.2.5.G |
| M640 | Issue report on the results of radial-borehole tests in the exploratory-shaft facility | 1.2.6.9.2.2.5.G |
| Activity: Excavation-effects test in the exploratory-shaft facility: 8.3.1.2.2.4.5 | | |
| M882 | Begin excavation-effects test | 1.2.6.9.2.2.6.G |
| M089 | Complete ES-1 upper breakout room (520 ft level) | 1.2.6 |
| T081 | Complete report on the results of the excavation-effects test | 1.2.6.9.2.2.6.G |
| 2196 | Complete excavation-effects test | 1.2.6.9.2.2.6.G |
| Activity: Perched-water test in the exploratory-shaft facility: 8.3.1.2.2.4.7 | | |
| M604 | Begin perched-water test | 1.2.6.9.2.2.8.G |
| M694 | Issue final report on the results of perched-water test in the exploratory-shaft facility | 1.2.6.9.2.2.8.G |

Table 5.2-1. Milestone list for study (SCP 8.3.1.2.2.4), exploratory-shaft facility--Continued

| Milestone number | Milestone description | Work breakdown structure number |
|---|---|---|
| Activity: Hydrochemistry tests in the exploratory-shaft facility: 8.3.1.2.2.4.8 | | |
| M680 | Begin exploratory-shaft-facility hydrochemistry test of the unsaturated zone | 1.2.6.9.2.2.9.G |
| M617 | Issue final report on the results of the hydrochemistry tests in the exploratory-shaft facility | 1.2.6.9.2.2.9.G |
| Activity: Multipurpose-borehole testing near the exploratory shafts: 8.3.1.2.2.4.9 | | |
| -- | Supporting documentation in place and approved | -- |
| -- | Start USW MP-1 | -- |
| -- | Start USW MP-2 | -- |
| -- | Complete USW MP-1 | |
| -- | Complete USW MP-2 | -- |
| -- | Final report on testing and construction effects | -- |
| -- | Resubmittal of SP 8.3.1.2.2.4 to DOE-YMPO | -- |
| -- | Preliminary report in FY90 on well completion and hydraulic testing completed in FY89 | -- |
| -- | Complete hydraulic testing of USW MP-1 and MP-2 | -- |
| -- | Completion of all testing phases | -- |

## 6 REFERENCES

Aronofsky, J. S., and Jenkins, R., 1954, A simplified analysis of unsteady radial-gas flow: Trans. AIME, 201: 149.

Bathe, K. L., 1978, ADINA/BM - A general computer program for nonlinear analysis of mine structures: U. S. Bureau of Mines contract No. J0255008.

Bear, J., 1979, Hydraulics of ground water: New York, McGraw-Hill, Inc. 2. 1972, Dynamics of fluids in porous media: New York, American Elsevier.

Bruce, G., Peaceman, D., Rachford, H. H., and Rice, J., 1953, Calculations of unsteady-state gas flow through porous media: Trans. AIME, 198: 79 (1953).

Bentall, Ray, compiler, 1963, Shortcuts and special problems in aquifer tests: U.S. Geological Survey Water-Supply Paper 1545-C, p. C10-C15.

Cooper, H. H., Jr., and Jacobs, C. E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union Transactions, v. 27, no. 4, p. 526-534.

Cooper, H. H., Jr., Bredehoeft, J. D., and Papadopulos, S. S., 1967, Response of a finite-diameter well to an instantaneous charge of water: Water Resources Research, v. 3, no. 1, p. 263-269.

Davis, G. S., Marvil, J. D., and Runnells, D. D., 1985, Hydrogeochemical feasibility studies related to subsurface flow on Yucca Mountain, Nevada Test Site. USGS Contract No. 14-08-0001-10190 Final Report: Boulder, Colorado, Department of Geological Science, University of Colorado, p. 3.8-8.

Davis, L. A. and Neuman, S. P., 1983, Documentation and user's guide: UNSAT2 - Variably Saturated Flow Model, NUREG/CR-3390.

Earlougher, R. C., Jr., 1977, Advances in well test analysis: Society of Petroleum Engineers of AIME, Monograph vol. 5 of the Henry L. Doherty series, second printing.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geological Survey Water-Supply Paper 1536-E, 174 p.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, 603 p.

Goodman, R. E., Moye, D. G., Van Schalwyk, A., Jarandel, I., 1965, Groundwater inflows during tunnel driving: Eng. Geol. v. 2, no. 1, p. 39-56.

Haas, H. H., Fisher, D. W., Thorsten, D. C., and Weeks, E. P., 1983, 13-CO2 and 14-CO2 measurements on soil atmosphere sampled in the sub-surface unsaturated zone in the western Great Plains of the U.S. Radiocarbon, v. 25, no. 2, pp. 301-314.

Hantush, M. S., 1966, Analysis of data from pumping test in anisotropic aquifers: Journal of Geophysical Research, v. 71 (2), p. 421-426.

Hillel, D., 1971, Soil and water: Physical principles and processes: New York, Academic Press, Physiological Ecology series.

----- 1980, Fundamentals of soil physics: New York, Academic Press.

Hsieh, P. A., and Neuman, S. P., 1985, Field determination of the three-dimensional hydraulic conductivity tensor of anisotropic media: 1. Theory: Water Resources Research, v. 21, no. 11, p. 1655-1665.

Hsieh, P. A., Neuman S. P., Stiles, G. K. and Simpson, E. S., 1985, Field determination of the three-dimensional hydraulic conductivity tensor of anisotropic media: 2. Methodology and application of fractured rocks: Water Resources Research, v. 21, no. 11, p. 1667-1676.

Jacob, C. E., and Lohman, S. W., 1952. Nonsteady flow to a well of constant drawdown in an extensive aquifer: American Geophysical Union Transactions, v. 33, p. 559-569.

Katz, D. L., Cornell, D., Kobayashi, R., Poettmann, F. H., Vary, J. A., Elenbaas, J. R., and Weinaug, C. F., 1959, Handbook of natural gas engineering: New York, McGraw-Hill Book Co., Inc.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Long, J. C. S., Remer, J. S., Wilson, C. R., and Witherspoon, T. A., 1982, Porous media equivalents for networks of discontinuous fractures, Water Resources Research, 18(3), p. 645-658.

Mishra S., Bodvarsson, G. S., and Attanayake, M. P., 1987, Estimating properties of unsaturated-fractured formations from injection and falloff tests: to be published as an LBL report.

Montazer, P., 1982, Permeability of unsaturated fractured metamorphic rocks near an underground opening [Ph.D. thesis]: Colorado School of Mines, Golden, Colorado.

----- 1983, Demonstrative finite element modeling of the influence of a borehole on the permeability of a single fracture: Internal Report to Karnobransleosakerhet, Sweden: Denver, Colorado, U.S. Geological Survey.

Montazer, P., and Wilson, W. E., 1984, Conceptual hydrologic model of flow in the unsaturated zone, Yucca Mountain, Nevada, USGS-OFR-84-4345: U.S. Geological Survey, Denver, Colorado, Water-Resources Investigations Report.

Muskat, M., 1937, The flow of homogeneous fluids through porous media: New York, McGraw-Hill Book Co., Inc.

Papadopulos, I. S., 1965, Nonsteady flow to a well in an infinite anisotropic aquifer, in Dubrovnik Symposium on Hydrology of Fracture Rocks, Proceedings, p. 21-31, International Association of Scientific Hydrology, Dubrovnik, Yugoslavia, 1965.

Papadopulos, I. S., and Cooper, J. J., Jr., 1967, Drawdown in a well of large diameter: Water Resources Research, v. 3, no. 1, p. 241-244.

Papadopulos, S. S., Bredehoeft, J. D., and Cooper, H. H., Jr., 1973, On the analysis of "slug test" data: Water Resources Research, v. 9, no. 4, p. 1087-1089.

Rush, F. E., Thordarson, W., and Pyles, D. G., 1984, Geohydrology of test well USW H-1, Yucca Mountain, Nye County, Nevada, Water-Resources Investigations Report 84-4032.

Rissler, P., 1978. Determination of water permeability of jointed rock: Publications of the Institute for Foundation Engineering, Soil Mechanics, Rock Mechanics, and Water Way Construction, RWTH (university) Aachen, Federal Republic of Germany, English edition of volume 5, ISSN 0341-7972.

Sass, J. H., and Lachenbruch, A. H., 1982, Preliminary interpretation of thermal data from the Nevada Test Site, USGS-OFR-82-973: Denver, Colorado, U.S. Geological Survey, Open-File Report.

Schrauf, T. W., and Evans, D. D., April 1984, Relationship between the good conductivity and geometry of a natural fracture: U.S. Nuclear Regulatory Commission, NUREG/CR-3680.

Snow, D. T., 1965, A parallel model of fractured permeable media, [Ph.D. thesis]: Berkeley, California, University of California.

----- 1966, Three-hole pressure test for anisotropic foundation permeability: Fels. U. Ing. Geology, v. 4, p. 298.

Stuart, W. T., 1955, Pumping test evaluates water problems at Eureka, Nevada: American Institute of Mining, Metallurgical, and Petroleum Engineers Transactions, v. 202, p. 148-156.

Theis, C. F., 1935, The relation between the lowering of the Piezometric surface and the rate and duration of discharge of a well using ground-water storage: Trans., AGU, 519-524.

Trautz, R. C., 1984, Rock fracture aperture and gas conductivity measurements *in situ* [M. S. thesis]: Tucson, Arizona, University of Arizona.

U.S. Department of Energy, 1985, Mission Plan for the Civilian Radioactive Waste Management Program, Overview and Current Program Plan, DOE/RW-0005, Washington D. C., three volumes.

U.S. Department of Energy, 1988, Draft Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada, Washington, D. C.

U.S. Geological Survey, 1986, Quality-assurance-program plan for Nevada Nuclear Waste Storage Investigations, NNWSI-USGS-QAPP-01, R4, USGS QA level assignment (QALA), NNWSI-USGS-QMP-3.02, R1, and Preparation of technical procedures, NNWSI-USGS-QCMP-5.01, R1.

Van Golf-Racht, T. D., 1982, Fundamentals of fractured reservoir engineering: Developments in petroleum science, v. 12: New York, Elsevier Scientific Publishing Co.

Wang, I. S. Y., and Narasimhan, T. N., 1985, Hydrologic mechanisms governing fluid flow in a partially saturated, fractured, porous medium: Water Resource Res., v. 21, no. 12, pp. 1861-1874.

Weeks, E. P., 1978, Field determination of vertical permeability to air in the unsaturated zone: Washington, D.C., U.S. Geological Survey Professional Paper 1051.

Weeks, E. P., Earp, D. E., and Thomson, G. N., 1982, Use of atmospheric fluorocarbons F-11 and F-12 to determine the diffusion parameters of the unsaturated zone in the southern high plains of Texas: Water Resources Research, v. 18, no. 5, p. 1345-1378.

Whitfield, M. S., 1985, Vacuum drilling of unsaturated tuffs at a potential radioactive waste repository, Yucca Mountain, Nevada; Denver, Colorado, Proceedings National Water Well Association, November 19-21.

Winograd, I. J., and Thordarson, W., 1975, Hydrogeologic and hydrochemical framework, South-Central Great Basin, Nevada-California, with special reference to the Nevada Test Site; Washington, D.C., U.S. Geological Survey Professional Paper 712-C.

Yang, I. C., Sayre, T. M., Turner, A. K., and Montazer, P., in prep., Pore-water extraction by triaxial compression from unsaturated tuff, Yucca Mountain, Nevada; U.S. Geological Survey Water-Resources Investigation Report.

Yang, I. C., Haas, H. H., Weeks, E. P., and Thorstenson, D. C., 1985, Analyses of gaseous-phase stable and radioactive isotopes in the unsaturated zone, Yucca Mountain, Nevada: Proceedings of NWWA Conference, Denver, Colorado, p. 488.

# 7. APPENDICES

## 7.1. Quality-assurance requirements matrix and quality-assurance level assignment sheets for the five activities in present revision of study plan

### 7.1.1. Quality-assurance requirements matrix

**Quality-assurance requirements**

The activities in this study plan have been assigned as Quality Level I in accordance with procedure USGS QMP-3.02. These data may be used in the license application in assessing ground-water travel times and ground-water flow rates which have a direct bearing on site assessments concerning waste isolation to be used in the license application. The applicable criteria from NQA-1 that apply to this study are shown below, along with the procedures and other documents that will satisfy these criteria.

**Applicable NQA-1 criteria for Study 8.3.1.2.2.4 and how they will be satisfied**

| NQA-1 Criteria # | Documents addressing these requirements |
|---|---|
| 1. Organization and interfaces | The organization of the OCRWM program is described in the Mission Plan (DOE/RW-005, June 1985) and further described in Section 8.6 of the SCP. Organization of the USGS-YMP is described in the following:<br><br>QMP-1.01 (Organization Procedure) |
| 2. Quality-assurance program | The Quality-Assurance Programs for the OCRWM are described in YMP-QA Plan-88-9, and OGR/83, for the Project Office and HQ, respectively. The USGS QA Program is described in the following:<br><br>QMP-2.01 (Management Assessment of the YMP-USGS Quality-Assurance Program)<br><br>QMP-2.02 (Personnel Qualification and Training Program)<br><br>QMP-2.05 (Qualification of Audit and Surveillance Personnel)<br><br>QMP-2.06 (Control of Readiness Review) |

| | | |
|---|---|---|
| | | QMP-5.02 (Preparation and Control of Drawings and Sketches) |
| | | QMP-5.03 (Development and Maintenance of Management Procedures) |
| | | QMP-5.04 (Preparation and Control of the USGS QA Program Plan) |
| | | QMP-5.05 (Preparation and Issuance of Tentative Technical Procedures [Replaces QMP-11.01]) |
| 6. | Document control | QMP-6.01 (Document Control); |
| 7. | Control of purchased items and services | QMP-7.01 (Supplier Evaluation, Selection and Control) |
| 8. | Identification and control of items, samples, and data | QMP-8.01 (Identification and Control of Samples)<br><br>QMP-8.03 (Control of Data) |
| 9. | Control of processes | Not applicable |
| 10. | Inspection | Not applicable |
| 11. | Test control | Not applicable |
| 12. | Control of measuring and test equipment | QMP-12.01 (Instrument Calibration) |
| 13. | Handling, shipping, and storage | QMP-13.01 (Handling, Storage, and Shipping of Instruments) |
| 14. | Inspection, test, and operating status | Not applicable |
| 15. | Control of nonconforming items | QMP-15.01 (Control of Nonconforming Items) |
| 16. | Corrective action | QMP-16.01 (Control of Corrective Action Reports)<br><br>QMP-16.02 (Control of Stop-Work Orders)<br><br>QMP-16-03 (Trend Analysis) |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)
Activity - Radial Borehole Tests in the Exploratory Shaft Facility
Method Borehole drilling and coring

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Shaft wall fracture mapping | I | 1,2,3,5,6,10, 13,15,16,17,18 | Meets step No. 5 of the QA Level Checklist wherein the location of the radial boreholes and interpretation of the pneumatic and hydraulic tests is based on information from this activity. Criteria excluded: 4,7,12 - no equipment or purchased samples required; 8 - no samples anticipated; 9 - not a special process; 11 - no experiments or research involved; 14 not part of the USGS QA Program. |
| Locating radial boreholes in the shaft | I | 1,2,3,5,6,10, 13,15,16,17,18 | Meets step No. 5 of the QA Level Checklist wherein the location of the borehole could affect the outcome of the pneumatic and hydraulic tests. Criteria excluded: 4,7,12 - no equipment or purchased samples required; 8 - no samples anticipated; 9 - not a special process; 11 - no experiments or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| A. D. Jenkins (signature) | 01-12-88 | (signature) | 2/5/88 | for D. H. Hardy (signature) | 2/5/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| James Blaylock (signature) | 3/11/88 | W. Blanchard (signature) | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

Activity - Radial Borehole Tests in the Exploratory Shaft Facility
Method Borehole drilling and coring

| Method/Item Breakdown | QA Level | NQA 1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Retrieval of core and drill bit cuttings | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is the first step in providing data that provides site characterization data that has a significant impact on the database that supports the final repository design and assessment of the repository performance. Exceptions for additional methods or items may be identified or broken out in criteria letters or during criteria meetings. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Labeling, processing, lithologic examination, and sampling of core and drill bit cuttings | I | 1,2,3,5,6,8,10, 13,15,16,17,18 | Meets step No. 5 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Lithologic analysis on-site is a Level I because descriptions at the site can critically affect collection of other data during coring and drilling activities. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program; - 4,7,12 - no equipment or purchased services required. |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)

Activity - Radial Borehole Tests in the Exploratory Shaft Facilities

Method - Determination of hydraulic and physical properties of core

| Method/Item Breakdown | QA Level | NQA 1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| On site determination of moisture content | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the database that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Laboratory determination of hydraulic and physical properti[illegible] core | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the database that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Fracture logging of core | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist wherein the failure of this item could result in mislocating pneumatic and hydraulic tests. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program; 4,7,12 no equipment or purchased services required. |

*LEGEND OF 18 QA CRITERIA of NQA 1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCT[illegible], PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B. D. [signature] | 01-12-88 | [signature] | 1/5/88 | For D. H. [signature] | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/11/88 | M. [signature] | 3/1/88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

Activity Radial Borehole Tests in the Exploratory Shaft Facility
Method Borehole surveys

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Calibration of logging tools (both commercial and noncommercial), depth calibration of logging tools (both commercial and noncommercial) | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets steps 2, 5, and 11 of QA Checklist wherein if the tools are not properly calibrated, incorrect or misleading conclusions can be drawn from the data and the item can impact this and other Level I activities. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Removal of obstructions from drillhole for interval to be logged | III | NA | Meets none of the attributes of Levels I or II; if obstructions are not adequately removed, additional attempts can be made until obstructions are cleared. |
| Borehole survey, including geophysical video | I | 1,2,3,4,5,6,7, 10,12,13,15,16, 17,18 | Meets step No. 5 of QA Checklist wherein failure of this activity could result in the irretrievable loss of QA Level I data. Criteria excluded: 8 - no samples involved; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| W. L. Jenkins | 01-12-88 | J.E. Willmon | 2/2/88 | for R. H. Handy | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/11/88 | M. Blanchard | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

| Method/Item Breakdown | QA Level | NQA 1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Log fractures from video tape | I | 1,2,3,4,5,6,7, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 8 - no samples involved. 9 not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

NNWSI USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS) NNWSI-QALA 69226 01 04, R0

Activity - Radial Borehole Tests in the Exploratory Shaft Facility



Method In situ pneumatic testing

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| General description of straddle packer components, how to set up the system, adjust the guard and test interval lengths. | III | NA | Meets none of the QA Level I or II requirements. No data is collected and the integrity of the equipment (leak free) is tested under other breakdown items. |
| Determine the location of flow test using borehole logs (lithologic, fracture, and geophysical) | I | 1,2,3,4,5,6,7, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist wherein the location of the test could affect the data collected during the test and data analyses. Criteria excluded: 8 - no samples taken; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Test straddle packer for leaks and set system at target depth | I | 1,2,3,4,5,6,7, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Checklist wherein if instrument performance is not controlled, incorrect conclusions can be drawn from the data collected during other QA Level I items. Criteria excluded: 8 - no samples taken; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| G.D. Leaks | 01-12-88 | [signature] | 2/2/88 | for [signature] | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/11/88 | M. [signature] | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

Activity - Radial Borehole Tests in the Exploratory Shaft Facility
Method In situ pneumatic testing

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Perform flow tests. Tests to be conducted include: 1) single hole gas injection 2) single hole gas withdrawal 3) pressure pulse gas injection | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein data from the test will be used for site characterization and could significantly affect the data base that directly supports the final design and performance of the repository. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

Activity: Radial Borehole Test in the Exploratory Shaft Facility

Method: Borehole instrumentation and monitoring

| Method/Item Breakdown | QA Level | NQA 1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Prepare borehole stemming design; locate instrument stations using geologic and geophysical logs, camera and fracture mapping surveys, and results of pneumatic testing | I | 1,2,3,4,5,6,7, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this is a preliminary step of a data gathering activity. Criteria excluded: 8 - no samples taken; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Develop methods for in situ verification of sensor output or recalibration of downhole sensors | III | NA | Meets none of the QA Level I or II requirements. Item describes prototype testing; successful methods will be used for subsequent monitoring and data collection in the field. |
| Perform in situ verification of downhole sensor and stem and instrument boreholes in accordance with borehole stemming design | I | 1,2,3,4,5,6,7, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist wherein the failure to provide a means to periodically recalibrate and/or verify sensor performance in situ could result in the irretrievable loss of QA Level I data either because of sensor malfunctions and/or drift. Criteria excluded: 8 - no samples taken; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B.D. Lewis | 01-12-88 | [signature] | 2/5/88 | [signature] for | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/11/88 | [signature] | 3/11/88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

Activity - Radial Borehole Test in the Exploratory Shaft Facility
Method Borehole instrumentation and monitoring

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Collecting data | I | 1,2,3,4,5,6,7, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist insofar as misidentified terminal connections caused by improper labeling or identification of leads, tubing, logging terminals could result in the irretrievable loss of QA Level I data. Criteria excluded: 8 - no samples taken; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

Activity - Radial Borehole Test in the Exploratory Shaft Facility
Method Collect and transport gas samples

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Collect and transport gas samples | 1 | 1,2,3,5,6,8,10, 12,13,15,16,17, 18 | Meets step No. 5 of the QA Level Checklist wherein failure to properly collect and transport gas samples can impact the entire activity and other related Level I activities if performed incorrectly. Criteria excluded: 4 - no procurement involved, equipment already exists; 7 - does not involve receipt of materials or equipment; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B. D. Jewkes | 01-12-88 | W. Willmon | 2/5/88 | D. H. Dandy (for) | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| James Blaylock | 3/11/88 | M. Blanchard | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)



Activity - Radial Borehole Test in the Exploratory Shaft Facility
Method Cross-hole pneumatic and hydraulic testing

| Method/Item Breakdown | QA Level | NQA 1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Conduct water injection cross-hole tests | I | 1,2,3,4,5,6,7, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein the data from the test will be used for site characterization and could significantly affect the data base that supports the design and performance of the repository. Criteria excluded: 8 - no samples taken; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Conduct tracer test | I | 1,2,3,5,6,10, 12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist wherein if the incorrect tracer is used, the data can be adversely affected. Criteria excluded; 4,7 no equipment or purchased service required; 8 - no samples are taken; 9 not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Analyze gas or water samples | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that supports the final repository design and assessment of repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA 1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B.D. J'Leslie | 01-12-88 | [signature] | 2/5/88 | for [signature] | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/14/88 | [signature] | 3/1/88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

Activity - Excavation Effects Test in the Exploratory Shaft Facility
Method Borehole survey

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole drilling and coring | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist. This item has a significant impact on the data collected to evaluate the excavatin effects where the initial moisture conditions may be minimally disturbed. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Borehole deviation survey | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist. This item has a direct impact on the data collected to evaluate the effects of excavation where the exact location of the stress and strain measuring instruments relative to the shaft needs to be known. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Borehole fracture logging | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist. This item has a significant impact on the data collected to evaluate the excavation effects. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B D Jenkins | 01-12-88 | [signature] | 2/5/88 | [signature] for | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| James Blaylock | 3/14/88 | M Blanchard | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole geophysical survey | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist. This item has a significant impact on the data collected to evaluate the excavation effects where the in-situ rock condition around the shaft need to be known. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)
Activity - Excavation Effects Test in the Exploratory Shaft Facility
Method Packer air injection testing

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Packer air injection testing | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist. This item has a significant impact on the data collected to evaluate the excavation effects where the permeability changes due to excavation need to be estimated. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| B.D. Jardie | 01-12-88 | J. Willmon | 4/5/88 | for R.H. [signature] | 2/8/88 |
|---|---|---|---|---|---|
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/11/88 | M. [signature] | 3/11/88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)

Activity - Excavation Effects Test in the Exploratory Shaft Facility

Method Borehole instrumentation and monitoring

| Method/Item Breakdown | QA Level | NQA 1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole instrumentation and monitoring | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist. This item has a significant impact on the data collected to evaluate the excavation effects where this information will be used to evaluate thhe excavation effects model. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA 1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| D. D. Jenkin | 01-12-88 | K. Wellman | 2/5/88 | D. H. Appel for Chief | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| James Blaylock | 3/11/88 | M. Blanchard | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)



Activity - Excavation Effects Test in the Exploratory Shaft Facility
Method - Excavation effects test modeling

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Excavation effects test modeling | I | 1,2,3,5,6,10, 13,15,16,17,18 | Meets step No. 2 of the QA Level Checklist wherein this item provides site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 4,7,12 - no equipment or purchased services required; 8 - no samples required; 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| [signature] | 01-12-88 | [signature] | 2/9/88 | for [signature] | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/4/88 | [signature] | 3/11/88 | 3-16-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)



Activity - Perched Water Tests in the Exploratory Shaft Facility

Method Borehole drilling and testing

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole dry drilling and coring (perched-water zones) | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |
| Boreholes drilled after liner is installed | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |
| Borehole instrumentation, sampling, testing and monitoring of water-bearing isolated fractures, low productivity zones, wet zones, and seeps | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctl Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| [signature] | 01-12-88 | [signature] | 2/5/88 | for [signature] | 2/8/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/11/88 | [signature] | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

Activity - Perched Water Tests in the Exploratory Shaft Facility
Method Borehole drilling and testing

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
| --- | --- | --- | --- |
| Long term monitoring | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)

Activity - Perched Water Tests in the Exploratory Shaft Facility

Method - Flow measurement



| Method/Item Breakdown | QA Level | NQA 1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Shaft wall seepage or small flow measurement | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |
| Water flow rate measurement for moderate to large flows | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |
| Hydraulic tests for large flow rates | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA 1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| W. D. Jandro | 01-12-88 | [signature] | 1/13/88 | [signature] for | 2/5/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| James Blaylock | 3/11/88 | M. Blanchard | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)



Activity - Perched Water Tests in the Exploratory Shaft Facility

Method Perched water sampling

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Recognition of occurrence of perched water | I | 1,2,3,5,6,8,10, 13,15,16,17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 4,7,12 - no equipment or purchased services required; 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |
| Perched water sampling | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |
| Perched water sample analysis | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| A.D. Fenelio | 01-12-88 | [signature] | 2/5/88 | A.H. Handy for | 2/5/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/11/88 | M. [signature] | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

Method Pore water extraction

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Pore water extraction | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item can impact the entire activity and other related activities if not performed correctly. Criteria excluded: 9 - not a special process, 11 - no experimental tests of research, 14 - not part of USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B. R. [signature] | 01-12-88 | [signature] | 2/5/88 | [signature] for | 2/5/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| [signature] | 3/11/88 | [signature] | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)



Activity - Hydrochemistry Tests in the Exploratory Shaft Facility
Method - Collecting, transporting, preparing and analyzing gas samples from radial boreholes

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Collecting, transporting, preparing and sending gas samples from radial boreholes for analyses | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist whereing failure to properly collect and transport gas samples can impact the entire activity and other related Level I activities if performed incorrectly. Criteria excluded: 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program. |
| Analyzing gas samples | I | 1,2,3,4,5,6,7,8, 10,13,15,16,17, 18 | Meets step No. 5 of the QA Level Checklist wherein failure to properly analyze gas samples can impact the entire activity and other related Level I activities if performed incorrectly. Criteria excluded: 9 - not a special process; 11 - no tests or research involved; 12 - does not require instrument calibration; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B. D. Jenkins | 01-12-88 | [signature] for | 3/5/88 | [signature] | 2/5/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, Branch of NNWSI | Date |
| James Blaylock | 3/11/88 | M. Blanchard | 3-11-88 | 3-14-88 | |
| WMPO Quality Assurance | Date | WMPO Technical | Date | Effective Date | |

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS) NNWSI-QALA-6922G 01 17, R0



Activity - Hydrochemistry Tests in the Exploratory Shaft Facility

Method Collecting, transporting, preparing, and analyzing core and rubble samples

| Method/Item Breakdown | QA Level | NQA 1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Collecting and transporting core and rubble samples | 1 | 1,2,3,4,5,6,7,8, 9,10,12,13,15, 16,17,18 | Meets step No. 5 of the QA Level Checklist wherein failure to properly collect core and rubble samples can impact the entire activity and other related Level 1 activities if performed incorrectly. Criteria excluded: 11 - no tests or research involved; 14 - not part of the USGS QA Program. |
| Coring rubble and extracting water from core and sending water samples for analyses | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist wherein failure to properly extract water from core samples can impact the entire activity and other related Level 1 activities if performed incorrectly. Criteria excluded: 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program. |
| Analyze pore water samples | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist wherein failure to properly analyze water samples can impact the entire activity and other related Level 1 activities if performed incorrectly. Criteria excluded: 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

W D, Jenkins 01-12-88 , [signature] 2/2/88 A W Dandy 2/5/88

Activity · Multipurpose·Borehole Testing near the Exploratory Shaft
Method · Borehole drilling and coring

| Method/Item Breakdown | QA Level | NQA·1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole dry drilling and coring procedure: Horizontal and vertical holes (REECo) | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item is the first step in providing data that provides site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Exceptions for additional methods or items may be identified or broken out in criteria letters or during criteria meetings. Criteria excluded: 9 · not a special process; 11 · no experimental tests or research involved; 14 · not part of the USGS QA Program. |
| Borehole cleaning and verification techniques | I | 1,2,3,4,5,6,7, 10,15,16,17,18 | Meets step No. 5 of the QA Level Checklist wherein this item can impact the entire activity and other related Level I activities if performed incorrectly. Criteria excluded: 8 · no samples collected; 9 · not a special process; 11 · no experimental tests or research involved; 12 · calibration of instruments not required; 13 · no shipment of instrumentation; 14 · not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA·1 as incorporated in NVO·196·17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B. D. Jenkins | 12/09/88 | J. A. Waldman | 12/15/88 | for A. H. Handy | 12/15/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, YMP Branch | Date |
| James Blaylock | 1/12/89 | M. Blanchard | 1-12-89 | | |
| YMPO Quality Assurance | Date | YMPO Technical | Date | Effective Date | |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole drilling of perched-water zones | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 4 of the QA Level Checklist wherein this item is the first step in providing data that provides site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Exceptions for additional methods or items may be identified or broken out in criteria letters or during criteria meetings. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

YMP - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)

Activity - Multipurpose-Borehole Testing near the Exploratory Shaft

Method - Borehole deviation surveys, geophysical logging, thermal surveys, and video surveys

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole video fracture logging | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Borehole gravity measurement and data reduction | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B.D. Leslie | 12/09/88 | J.L. Willmon | 12/13/88 | for Al Hardy | 12/15/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, YMP Branch | Date |
| James Blaylock | 1/12/89 | M. Blanchard | 1-12-89 | | |
| YMPO Quality Assurance | Date | YMPO Technical | Date | Effective Date | |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Induced-polarization borehole logging operations | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Magnetic-susceptibility borehole logging operations | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Magnetometer borehole logging operations | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Operation of the Mt. Sopris II geophysical logging unit, USGS logging Van (I-139055) | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole deviation surveys | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Calibration of noncommercial logging tools | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Depth calibration of non-commercial logging tools | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Method for calibrating temperature sensors | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole video survey | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Method for measuring sub-surface moisture content using a neutron moisture meter | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Borehole thermal surveys | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Borehole geophysical logging procedure for horizontal and vertical holes (F&S) | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Borehole video and logging survey procedure: Horizontal and vertical holes | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Method for geophysical logging in horizontal and vertical boreholes | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Neutron moisture meter calibration (vertical boreholes) | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

YMP - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)



Activity - Multipurpose-Borehole Testing near the Exploratory Shaft

Method - Determine lithology, hydrogeologic contacts, hydrologic measurements, and fracture frequency, spacing, and orientation

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Logging fractures in core | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist wherein this item can impact the entire activity and other related Level I activities if performed incorrectly. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, Nevada Test Site (NTS) | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 5 of the QA Level Checklist wherein this item can impact the entire activity and other related Level I activities if performed incorrectly. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B.D. [signature] | 12/09/88 | [signature] | 12/15/88 | for [signature] | 12/15/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, YMP Branch | Date |
| James Blaylock | 1/12/89 | M. Blanchard | 1-12-89 | | |
| YMPO Quality Assurance | Date | YMPO Technical | Date | Effective Date | |

Activity - Multipurpose-Borehole Testing near the Exploratory Shaft

Method - Determine lithology, hydrogeologic contacts, hydrologic measurements, and fracture frequency, spacing, and orientation

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Calibration and use of the Sartorius electronic top loader (balance) Model 1507 MPS | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Method for the operation and maintenance of the stabil-therm miniature batch oven in the determination of gravimetric water content in test-hole samples | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

YMP - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)



Activity - Multipurpose-Borehole Testing near the Exploratory Shaft
Method - Rock-matrix hydrologic and physical properties

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Determining porosity and density of rock samples and calibration of associated instruments | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Laboratory procedures for the determination of moisture-retention curves on rock core | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B.D. Leedie (signature) | 12/09/88 | (signature) | 12/15/88 | for (signature) | 12/15/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, YMP Branch | Date |
| James Blaylock (signature) | 1/12/89 | M. Blanchard (signature) | 1-12-89 | | |
| YMPO Quality Assurance | Date | YMPO Technical | Date | Effective Date | |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Hydrologic-laboratory testing of core and drill-cutting samples from unsaturated zone test holes | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Determination of effective porosity from core samples | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Determination of grain density from core samples | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

YMP - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)

Activity - Multipurpose-Borehole Testing near the Exploratory Shaft

Method - Perched-water sampling and analysis



| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Preliminary method for monitoring and testing perched-water zones in a borehole drilled with the reverse-vacuum method | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Perched-water sampling | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B D Lewis | 12/09/88 | [signature] | 12/15/88 | [signature] for | 12/15/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, YMP Branch | Date |
| James Blaylock | 1/12/89 | M. Blanchard | 1-12-89 | | |
| YMPO Quality Assurance | Date | YMPO Technical | Date | Effective Date | |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Perched-water sample analysis | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Perched-water sampling and chemical/age dating analysis | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

YMP - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS) YMP-QALA-6922G-01-23, R0



Activity - Multipurpose-Borehole Testing near the Exploratory Shaft

Method - Gas sampling and anlaysis

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Gas and water vapor sampling from unsaturated zone test holes | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION
2 QA PROGRAM
3 DESIGN & SITE INVESTIGATION CONTROL
4 PROCUREMENT DOCUMENT CONTROL
5 INSTRUCTIONS, PROCEDURES & DRAWINGS
6 DOCUMENT CONTROL
7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES
8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES
9 CONTROL OF SPECIAL PROCESSES
10 INSPECTION (SURVEILLANCE)
11 TEST & EXPERIMENT/RESEARCH CONTROL
12 CONTROL OF MEASURING & TEST EQUIPMENT
13 HANDLING, STORAGE & SHIPPING
14 INSPECTION, TEST, & OP. STATUS
15 CONTROL OF NONCONFORMING ITEMS
16 CORRECTIVE ACTION
17 QA RECORDS
18 AUDITS

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| B.D. [signature] | 12/09/88 | [signature] | 12/13/88 | for [signature] | 12/15/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, YMP Branch | Date |
| James Blaylock | 1/12/89 | [signature] | 1-12-89 | | |
| YMPO Quality Assurance | Date | YMPO Technical | Date | Effective Date | |

YMP - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)

Activity - Multipurpose-Borehole Testing near the Exploratory Shaft

Method - Packer gas-injection testing

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Packer-injection and shut-in tests | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Method for construction of air-injection packer system and air-leak detection | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| G.D. Lewis (signature) | 12/09/88 | J.R. Willmon (signature) | 12/15/88 | for A.H. Dandy (signature) | 12/15/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, YMP Branch | Date |
| James Blaylock (signature) | 1/12/89 | Maxwell Blanchard (signature) | 1-12-89 | | |
| YMPO Quality Assurance | Date | YMPO Technical | Date | Effective Date | |

| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Single-hole gas injection tests | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |
| Method for determining fracture geometric parameters from air-injection tests | I | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

YMP - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)

Activity - Multipurpose-Borehole Testing near the Exploratory Shaft

Method - Flow-rate measurements and pumping tests



| Method/Item Breakdown | QA Level | NQA-1 Criteria Requirements* | Justification of Level & QA Criteria Exceptions |
|---|---|---|---|
| Hydrologic pu^m^ping tests | 1 | 1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18 | Meets step No. 2 of the QA Level Checklist wherein this item is a step in providing site characterization data that has a significant impact on the data base that supports the final repository design and assessment of the repository performance. Criteria excluded: 9 - not a special process; 11 - no experimental tests or research involved; 14 - not part of the USGS QA Program. |

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

| | | |
|---|---|---|
| 1 ORGANIZATION | 7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES | 13 HANDLING, STORAGE & SHIPPING |
| 2 QA PROGRAM | 8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES | 14 INSPECTION, TEST, & OP. STATUS |
| 3 DESIGN & SITE INVESTIGATION CONTROL | 9 CONTROL OF SPECIAL PROCESSES | 15 CONTROL OF NONCONFORMING ITEMS |
| 4 PROCUREMENT DOCUMENT CONTROL | 10 INSPECTION (SURVEILLANCE) | 16 CORRECTIVE ACTION |
| 5 INSTRUCTIONS, PROCEDURES & DRAWINGS | 11 TEST & EXPERIMENT/RESEARCH CONTROL | 17 QA RECORDS |
| 6 DOCUMENT CONTROL | 12 CONTROL OF MEASURING & TEST EQUIPMENT | 18 AUDITS |

APPROVALS

| | | | | | |
|---|---|---|---|---|---|
| R. D. Joulin (signature) | 12/08/88 | J. E. Kellman (signature) | 12/15/88 | for R. H. Handy (signature) | 12/15/88 |
| Originator | Date | Quality Assurance Manager | Date | Chief, YMP Branch | Date |
| James Blaylock (signature) | 1/12/89 | M. Blanchard (signature) | 1-12-89 | | |
| YMPO Quality Assurance | Date | YMPO Technical | Date | Effective Date | |

## 7.2 Analytical discussion of specific-storativity and porosity determinations for gas-injection tests

During transient-gas injection testing, the permeability and storativity of a porous medium are readily measured. In addition, an evaluation of bulk porosity is possible, as storativity is directly proportional to the porosity of the medium, and the viscosity and compressibility of the gas for an isothermal expansion process.

Ground-water hydrologists use the following form of the continuity equation to express mathematically the physical process of a slightly compressible or noncompressible fluid flowing through a homogeneous, isotropic, deformable, porous medium.

$$\nabla \cdot (K \nabla h) = S_s \frac{\partial h}{\partial t} \qquad (1)$$

where h = hydraulic head
K = hydraulic conductivity
t = time
$S_s$ = specific (volume) storativity.

Bear (1979) has shown theoretically that the specific storativity in equation (1) is equal to

$$S_s = \gamma [\phi \beta + (1 - \phi) \alpha] \qquad (2)$$

where $\gamma$ = specific weight of fluid
$\phi$ = porosity
$\beta$ = isothermal fluid compressibility = $\frac{1}{\rho} \frac{\partial \rho}{\partial p}$
$\alpha$ = coefficient of compressibility for the matrix
$\rho$ = fluid density
p = fluid pressure.

For a compressible fluid, the continuity equation is different from that of equation (1), namely

$$\nabla (\rho \frac{k}{\mu} \nabla p) = \rho [\phi \beta + (1 - \phi) \alpha] \frac{\partial p}{\partial t} \qquad (3)$$

where $\mu$ = viscosity of the fluid
k = intrinsic permeability.

Equation (3) assumes that the effects of gravity on the fluid are negligible. This is a reasonable assumption for gas-flow analyses. A review of the petroleum literature reveals that petroleum engineers use a slightly different form of equation (3), the difference arising from the way in which bulk-rock compressibility ( [1 - $\phi$] $\alpha$ ) is defined. Petroleum engineers often use pore compressibility, $C_p$, defined as

$$C_p = \frac{1}{V_p} \frac{\partial V_p}{\partial p} \qquad (4)$$

where $V_p$ = pore volume, in place of [1 - $\phi$) $\alpha$ . Using this definition, equation (4) can be expressed in the following form:

$$\nabla \cdot (\rho \frac{k}{\mu} \nabla \rho h) = \rho \phi [\beta + C_p] \frac{\partial p}{\partial t} . \qquad (5)$$

This is the starting point for the derivation of the isothermal gas flow continuity equation. The equation of state n for an ideal gas undergoing isothermal expansion is

$$\rho = \frac{P\, m}{R\, T} \qquad (6)$$

where m is the molecular weight of the gas, R is the universal gas constant, T equals absolute temperature of the gas, and P is the absolute pressure. In addition, the fluid compressibility, $\beta$ , becomes 1/p and is two to three orders of magnitude greater than the pore compressibility, $C_p$, for a given pressure. (See T. D. Van Golf-Racht, 1982, p. 199-208.) Using the fact that $\beta >> C_p$, and $\gamma h = p$, that is, assuming $\gamma z$ is negligible, which is reasonable because $\gamma$ for a gas is very small, equation (5) can be rewritten as follows:

$$\nabla \cdot (\frac{k}{\mu}\ p\ \nabla p) = \frac{\partial p}{\partial t} . \qquad (7)$$

In addition, $\mu$ is not very sensitive to changes in pressure, and so it is often treated as a constant and placed on the right side of equation (6). Implicit differentiation can be employed to put equation (7) in the following form:

$$\nabla \cdot ( k\ \nabla p^2 ) = \frac{\phi \mu}{p^{\rho}} \frac{\partial p^2}{\partial t} . \qquad (8)$$

The gas storativity can now be defined as $S_g = \phi \mu \beta$, which shows that it is a function of pressure because $\beta = 1/p$.

Steady-state analytical solutions to equation (8) are readily obtainable (Muskat, 1937). Time-dependent analytical solutions, however, cannot be obtained due to the nonlinear nature of this partial differential equation. Solutions have been derived numerically using various codes (Bruce and others, 1953; Aronofsky and Jenkins, 1954) or by linearizing the partial differential equation (Katz and others, 1959). Linearizing equation (8) simply involves setting 1/p equal to a constant, 1/p, where p is the average reservoir pressure. When 1/p is set equal to a constant, the gas equation becomes linear with respect to $p^2$, making it readily solvable by analytical techniques developed for slightly compressible fluids. Mishra and others (1987) showed that, as long as the pressure changes during a gas-injection test were below 202 J/kg (kPa) (2.02 bar), the linearization assumption yielded very good results.

Solutions to various well-hydraulics problems for slightly compressible fluids, such as the line-source or Theis solution (Theis, 1935; Earlougher, 1977), become solutions to the linearized gas-flow equation. The form of the solutions is modified in that pressure squared replaces hydraulic head. Values of dimensionless time and flow-rate can be calculated using gas formulas given by Katz and others (1959). Earlougher (1977) presents in great detail methods of analyzing transient-test data from single-hole and multi-hole (interference), slightly compressible fluid, flow tests. Formation permeability can be obtained from either borehole configuration; however, the storage coefficient cannot be determined from a single-hole test when the skin factor (i.e., degree of borehole damage or improvement) is significant. If the skin factor is negligible, then an estimate of porosity can be determined from a gas-injection test.

It should be noted that equation (8) is for single-phase gas flow only. It does not account for the presence of formation water, which can impede gas movement and complicate gas-test results. It should, therefore, be applied with caution when water saturations are high, such as in the Calico Hills nonwelded unit, where the average saturation is 91% (Montazer and Wilson, 1984). Highly fractured geohydrologic units, such as the Topopah Springs or Tiva Canyon welded units, are probably drained, and so gas-injection tests performed in these units will produce estimates of fracture permeability and porosity. In any event, the permeabilities and porosities determined for a partially saturated medium using gas-injection tests will be drained effective (permeability/porosity) values.

7.3 Relations between the site information to be developed in this study and the design and performance information needs specified in the SCP

This section tabulates in Table 7.3.1 the specific technical information relations between SCP design- and performance-parameters needs and site parameters to be determined in this study. The relations were developed using model-based parameter categories (see Figure 2.1-1) that provide common terminology and organization for evaluation of site, design, and performance information relations.

All design and performance issues that obtain data from this study are noted in the table. For each issue, the site parameters (from SCP 8.3.1.2) are related to the design and performance parameters reported in the performance allocation tables (from SCP 8.3.2 - 8.3.5). At the beginning of each issue group, the performance measures addressed by the design or performance parameters for the issue are listed. Parameter categories, as noted above, are used to group the design and performance parameters with the site parameters so that comparisons of information requirement (design and performance) with information source (site study) can be made.

For each design and performance parameter noted in the table, the associated goal and confidence (current and needed) and site location are listed. For each parameter category, the associated site parameters are listed with information about the site location and the site activity providing the information.

Note - Comparison of the information relations (site parameters with design/performance parameters) must be done as sets of parameters in a given parameter category. Line-by-line comparisons from the left side of the table (design/performance parameters) with the right side of the table (site parameters) within a parameter category should <u>not</u> be made.

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| **Issue 1.1** | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| Performance Measures: (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.); EPPH[a], nominal case, release scenario class E, water pathway release; EPPH[a], nominal case, release scenario class E, gas pathway release | | | | | |
| **Parameter Category: Rock-unit contact location and configuration** | | | | | |
| Altitudes of geohydrologic-unit contacts; as a function of lateral-spatial location | Controlled area; Unsaturated-zone units, overburden | Goal: Mean, Variance<br>Current: Medium, Medium<br>Needed: High, Medium | Depth to hydrogeologic contacts | Exploratory shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| **Parameter Category: Rock-unit mineralogy/petrology and physical properties** | | | | | |
| Bulk density (Rock matrix) | Controlled area; All units | Goal: Mean, Variance<br>Current: Medium, Low<br>Needed: Medium, Medium | Bulk density, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Grain density, rock matrix | " | " |
| | | | Density | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Porosity | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | | | |
| | | | Porosity, perched water zones | Exploratory shaft (ES 1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Bulk density, rock matrix | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Grain density, rock matrix | " | " |
| | | | Lithology | " | " |
| Parameter Category: Fracture distribution | | | | | |
| Fracture frequency (Fracture networks) | Controlled area; All units | Goal: Mean, Variance, Autocorrelation length<br>Current: Low, Low, Low<br>Needed: Medium, Low, Low | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Fracture distribution | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| | | Parameter Category: Fracture distribution | | | |
| | | | Fracture freq[uency], orientation, spacing, distribution, and weathering | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | Parameter Category: Fracture-filling mineralogy and physical properties | | | |
| Fracture compressibility (Fracture networks) | Controlled area; All units | Goal: Mean<br>Current: Low<br>Needed: Low | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Fracture roughness | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Relative liquid permeability (wetting and draining) (Rock matrix) | Repository area; Unsaturated-zone units, overburden | Goal: Mean, Variance<br>Current: NA, NA<br>Needed: Medium, Low | Bulk permeability | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| **Issue 1.1** | Total system performance for limiting radionuclide releases to accessible environment | | | (SCP 8.3.5.13) | |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Relative liquid permeability (wetting and draining) (Fracture network) | Repository area; Unsaturated-zone units, overburden | Goal: Mean, Variance<br>Current: NA, NA<br>Needed: Low, Low | Bulk permeability, pneumatic | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Effective porosity (Rock matrix) | " | Goal: Mean, Variance, Autocorrelation length<br>Current: NA, NA, NA<br>Needed: High, Medium, Low | Bulk porosity | " | " |
| Effective porosity (Fracture network) | " | Goal: Mean, Variance, Autocorrelation length<br>Current: NA, NA, NA<br>Needed: Low, Low, Low | Fracture permeability | " | " |
| Saturated permeability (Fault-zone rock mass) | Controlled area; Unsaturated-zone units, overburden | Goal: Mean, Variance<br>Current: NA<br>Needed: Medium, Low | Gas permeability, excavation effects | " | " |
| Effective porosity (Fault-zone rock mass) | " | Goal: Mean, Variance<br>Current: NA<br>Needed: Low, Low | Permeability, relative, gas, rock matrix | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Matrix-fracture interface permeabilities (Not applicable) | Controlled area; All units | Goal: Not significantly different from matrix values<br>Current: Low<br>Needed: High | Permeability, relative, water, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Matrix-fracture interface constrictivity (MF-CT factors) | " | Goal: Not significantly different from matrix factors<br>Current: Low<br>Needed: High | Permeability, saturated, gas, rock matrix | " | " |
| Relative pneumatic permeability (wetting and draining) (Rock matrix) | Repository area; Overburden | Goal: Mean, Variance<br>Current: Low, Low<br>Needed: Medium, Low | Pneumatic permeability, bulk, fractured rock | " | " |
| Relative pneumatic permeability (wetting and draining) (Fracture network) | " | " | Air-permeability profiles | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Effective pneumatic porosity (Rock matrix) | " | Goal: Mean, Variance, Autocorrelation length<br>Current: Low, Low, Low<br>Needed: Low, Low, Low | " | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

**Issue 1.1** Total system performance for limiting radionuclide releases to accessible environment (SCP 8.3.5.13)

Parameter Category: Unsaturated-zone transmissive properties

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Effective pneumatic porosity (Fracture network) | Repository area; Overburden | Goal: Mean, Variance, Autocorrelation length<br>Current: Low, Low, Low<br>Needed: High, Low, Low | Hydraulic conductivity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| Profiles of Darcy velocity of air flow (Ambient, rock mass pore spaces) | Repository area; Unsaturated-zone units, overburden | Goal: To be determined<br>Current: Low<br>Needed: High | Transmissivity, perched-water zones | " | " |
| | | | Bulk permeability, pneumatic | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Hydraulic conductivity, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | " |
| | | | Transmissivity, perched-water zones | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| | | Parameter Category: Unsaturated-zone storage properties | | | |
| $n_e$: average effective matrix porosity, repository area unsaturated zone (scenario class E, nominal case)[b] | Repository area; Unsaturated zone | Goal: >0.1<br>Current: Low<br>Needed: High | Moisture retention, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Moisture retention (wetting and draining) (Rock matrix) | Repository area; Unsaturated-zone units, overburden | Goal: Mean, Variance<br>Current: Medium, Medium<br>Needed: Low, Low | Porosity pore-size distribution, matrix | " | " |
| Moisture retention (wetting and draining) (Fracture network) | " | Goal: Mean, Variance<br>Current: NA<br>Needed: Low, Low | Porosity, bulk, fractured rock | " | " |
| | | | Porosity, matrix | " | " |
| | | | Storage coefficient, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Porosity pore-size distribution | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| | | Parameter Category: Unsaturated-zone storage properties | | | |
| | | | Porosity, effective | Exploratory-shaft facility; All units penetrated by ES-1, and ES 2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Porosity, total | " | " |
| | | | Storage coefficient, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | " |
| | | Parameter Category: Unsaturated-zone dispersive properties | | | |
| Liquid constrictivity, tortuosity factor (Rock matrix) | Controlled area; All units | Goal: Mean, Variance<br>Current: Low, Low<br>Needed: Medium, Low | Diffusive tortuosity, fractured rock and rock mass | Exploratory shaft (ES 1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Liquid constrictivity, tortuosity factor (Fracture networks) | " | Goal: Mean, Variance<br>Current: Low, Low<br>Needed: Low, Low | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| | | Parameter Category: Unsaturated-zone dispersive properties | | | |
| Liquid constrictivity, tortuosity factor (Fault-zone rock mass) | Controlled area; All units | Goal: Mean, Variance<br>Current: Low, Low<br>Needed: Low, Low | | | |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| Profile of partial pressure of $CO_2$ (Ambient rock mass) | Repository area; Unsaturated-zone units, overburden | Goal: No goal<br>Current: Low<br>Needed: Medium | Pore-gas composition | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Profiles of bicarbonate concentration, calcium-ion concentration, pH, in liquid phase (Ambient rock mass) | " | " | Radioactive isotopes | " | " |
| Profile of temperature; as a function of time, including effects of heat from repository | " | Goal: Predict profiles where temperature change exceeds 10% of ambient (° C)<br>Current: Low<br>Needed: Medium | Stable isotopes | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | (SCP 8.3.5.13) | |
| Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | | | |
| Profile of carbon-14 concentration (Ambient, rock mass pore spaces) | Repository area; Unsaturated-zone units, overburden | Goal: To be determined<br>Current: Low<br>Needed: Medium | Temperature, fractured rock | Exploratory shaft (ES 1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Major-ion water chemistry (composition, Eh, pH); ambient rock-mass pore fluids | " | " | Water content, volumetric | " | " |
| | | | Hydrochemical properties, perched-water zones | Exploratory shaft (ES 1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Radioactive isotopes | " | " |
| | | | Stable isotopes | " | " |
| | | | Water quality | " | " |
| | | | Moisture loss (water content, $^{18}O/^{16}O$ and D/H ratios) | Exploratory shaft (ES-1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Pore-gas composition | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Radioactive-isotope activity | Exploratory shaft (ES-1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Stable isotopes | " | " |
| | | | Stable-isotope ratio analyses | " | " |
| | | | Water quality, cations and anions | " | " |
| | | | Formation gas, radioactive- and stable-isotope composition | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Formation water, cation and anion chemistry | Exploratory-shaft facility; Perched-water zones | " |
| | | | Formation water, radioactive and stable isotope composition | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Temperature, fractured rock | Exploratory shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4 |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| Profile of near-field saturation;as a function of time, including effects of heat from repository | Repository area; Unsaturated-zone units, overburden | Goal: Prediction consistent with temperature profile (above)<br>Current: Low<br>Needed: Medium | Water content, gravimetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Water content, volumetric, rock matrix | " | " |
| | | | Moisture content, in situ degree of saturation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Moisture content, gravimetric | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | | (SCP 8.3.5.13) |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| | | | Moisture content, volumetric | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | Parameter Category: Unsaturated-zone fluid flux | | | |
| $q_w$: average flux through repository area in unsaturated zone (scenario class E, nominal case)[b] | Repository area; Unsaturated zone | Goal: <0.5 mm/yr<br>Current: Medium<br>Needed: High | Discharge, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| Mean residence time of released carbon-14 dioxide in unsaturated-zone units | Controlled area; Unsaturated zone | Goal: Show residence time >10,000 yr<br>Current: Low<br>Needed: High | Flow rates, perched-water zones | " | " |
| | | | Flow paths, hydrochemical determination | Exploratory shaft (ES-1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Travel times, hydrochemical determination | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.1 | Total system performance for limiting radionuclide releases to accessible environment | | | (SCP 8.3.5.13) | |
| | | Parameter Category: Unsaturated-zone fluid flux | | | |
| | | | Discharge, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | 8.3.1.2.2.4.9 |
| Issue 1.5 | Waste package and repository engineered-barrier system release rates | | | (SCP 8.3.5.10) | |
| Performance Measures: Concentrations of radionuclide species in gas phase, liquid water, and adsorbed to solid phases within the near-field host rock. | | | | | |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Host-rock hydrologic properties (waste package environment) | Primary area; TSw2 | Goal: Properties known with accuracy sufficient to calculate differences in flow through the near-field rock resulting from anticipated and unanticipated events<br>Current: Low<br>Needed: High | Bulk permeability | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4 |
| | | | Bulk permeability, pneumatic | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.5 | Waste package and repository engineered-barrier system release rates | | | | (SCP 8.3.5.10) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| | | | Bulk porosity | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Fracture permeability | " | " |
| | | | Gas permeability, excavation effects | " | " |
| | | | Permeability, relative, gas, rock matrix | " | " |
| | | | Permeability, relative, water, rock matrix | " | " |
| | | | Permeability, saturated, gas, rock matrix | " | " |
| | | | Pneumatic permeability, bulk, fractured rock | " | " |
| | | | Air-permeability profiles | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| **Issue 1.5** | **Waste package and repository engineered-barrier system release rates** | | | | **(SCP 8.3.5.10)** |
| | | **Parameter Category: Unsaturated-zone transmissive properties** | | | |
| | | | Air-permeability profiles | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Hydraulic conductivity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Transmissivity, perched-water zones | " | " |
| | | | Bulk permeability, pneumatic | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Hydraulic conductivity, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | " |
| | | | Transmissivity, perched-water zones | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| Performance Measures: (Supporting parameters used in calculating performance parameters for ground-water travel time.); Boundary of repository-induced changes in effective fracture porosity; Ground-water travel time[e], Topopah Spring welded unit (secondary reliance); Ground-water travel time[e], Calico Hills non-welded, vitric unit (primary reliance); Ground-water travel time[e], Calico Hills non-welded, zeolitized unit (primary reliance) | | | | | |
| Parameter Category: Rock-unit contact location and configuration | | | | | |
| Contact altitude, hydrologic units (Rock mass) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev<br>Current: Medium, NA, NA<br>Needed: High, Low, Medium | Depth to hydrogeologic contacts | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| Contact altitude, lithologic units (Rock mass) | Controlled area; Saturated zone, each litho unit in upper 100 m | Goal: Mean<br>Current: Low<br>Needed: Medium | | | |
| Altitude of the hydrogeologic unit contacts | Repository area; Subsurface | Goal: --<br>Current: --<br>Needed: -- | | | |
| Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | | | |
| Density, bulk (Rock matrix) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev<br>Current: Medium, NA, NA<br>Needed: Medium, Medium, Medium | Bulk density, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | |
| Bulk density | Repository area; Subsurface | Goal: --<br>Current: --<br>Needed: -- | Grain density, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Density | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Porosity | " | " |
| | | | Porosity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Bulk density, rock matrix | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Grain density, rock matrix | " | " |
| | | | Lithology | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | **Parameter Category: Fracture distribution** | | | |
| Fracture frequency (Fractures) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor SDev<br>Current: Low, NA, NA<br>Needed: Medium, Low, Low | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Fracture distribution | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Fracture frequency, orientation, spacing, distribution, and weathering | Exploratory shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | **Parameter Category: Fracture orientation** | | | |
| Fracture orientation (Fault zones) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SDev<br>Current: NA, NA<br>Needed: Low, Low | Fracture orientation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Fracture orientation (Fractures) | " | Goal: Mean SCor, SDev<br>Current: NA, NA, NA<br>Needed: Low, Low, Low | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| Parameter Category: Fracture aperture | | | | | |
| Fracture aperture (Fault zones) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SDev<br>Current: NA, NA<br>Needed: Low, Low | Fracture aperture | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Fracture aperture (Fractures) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Low | " | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Parameter Category: Unsaturated-zone transmissive properties | | | | | |
| Permeability, relative (Fault zones) | " | Goal: Mean, SDev<br>Current: NA, NA<br>Needed: Low, Low | Bulk permeability | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Permeability, relative (Fractures) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Low, Low, Low | Bulk permeability, pneumatic | " | " |
| Permeability, relative (Rock mass) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Low | Bulk porosity | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5 12) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Permeability, relative (Rock matrix) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Low | Fracture permeability | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Permeability, relative pneumatic (Fault zones) | Repository area; Unsaturated zone, each geohydrologic unit | Goal: Mean<br>Current: NA<br>Needed: Medium | Gas permeability, excavation effects | " | " |
| Permeability, relative pneumatic (Fractures) | " | Goal: Mean, SDev<br>Current: NA, NA<br>Needed: Medium, Low | Permeability, relative, gas, rock matrix | " | " |
| Permeability, relative pneumatic (Rock matrix) | " | " | Permeability, relative, water, rock matrix | " | " |
| Permeability, saturated (Fault zones) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean SDev<br>Current: NA, NA<br>Needed: Medium, Low | Permeability, saturated, gas, rock matrix | " | " |
| Permeability, saturated (Fractures) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Medium | Pneumatic permeability, bulk, fractured rock | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Permeability, saturated (Rock mass) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: High, Low, Medium | Air-permeability profiles | Exploratory shaft (ES 1), upper and lower breakout rooms; ISw | 8.3.1.2.2.4.5 |
| Permeability, saturated (Rock matrix) | " | Goal: Mean, SCor, SDev<br>Current: Low, NA, NA<br>Needed: High, High, High | " | " | " |
| Porosity, effective (Fault zones) | " | Goal: Mean, SDev<br>Current: NA, NA<br>Needed: Low, Low | Hydraulic conductivity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| Porosity, effective (Fractures) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Low, Low, Low | Transmissivity, perched-water zones | " | " |
| Porosity, effective (Rock mass) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: High, Medium, Medium | Bulk permeability, pneumatic | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES 2 | 8.3.1.2.2.4.9 |
| Porosity, effective (Rock matrix) | " | " | Hydraulic conductivity, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Fracture and matrix saturated permeability | Repository area; Subsurface | Goal: --<br>Current: --<br>Needed: -- | Transmissivity, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | 8.3.1.2.2.4.9 |
| Relative permeability for the fracture network and matrix as a function of temperature | * | * | | | |
| Gas relative conductivity for the fracture network and matrix as a function of temperature | * | * | | | |
| Effective porosity and porosity of the fracture network, fault zones, rock mass, and matrix | * | * | | | |
| Changes in porosity and permeability of matrix due to construction and heat from waste emplacement | * | * | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone storage properties | | | |
| Moisture retention curve (Fault zones) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SDev<br>Current: NA, NA<br>Needed: Low, Low | Moisture retention, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Moisture retention curve (Fractures) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Low, Low, Low | Porosity pore-size distribution, matrix | " | " |
| Moisture retention curve (Rock mass) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Medium | Porosity, bulk, fractured rock | " | " |
| Moisture retention curve (Rock matrix) | " | Goal: Mean, SCor, SDev<br>Current: Low, NA, NA<br>Needed: Medium, Low, Medium | Porosity, matrix | " | " |
| Porosity, total (Fault zones) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Medium | Storage coefficient, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone storage properties | | | |
| Porosity, total (Fractures) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Medium | Porosity pore-size distribution | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| Porosity, total (Rock matrix) | " | Goal: Mean, SCor<br>Current: NA, NA<br>Needed: High, High | Porosity, effective | " | " |
| | | | Porosity, total | " | " |
| | | | Storage coefficient, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | " |
| | | Parameter Category: Unsaturated-zone fluid potential | | | |
| Pressure head, matric potential (Fault zones) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Low | Matric potential, fractured rock and rock units | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Pressure head, matric potential (Fractures) | " | " | Pneumatic potential distribution | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone fluid potential | | | |
| Pressure head, matric potential (Rock matrix) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev Current: Low, NA, NA Needed: Medium, Low, Medium | Water potential, rock matrix, and total fractured rock | Exploratory shaft (ES 1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Saturation (and moisture content) values as a function of depth and lateral spatial location | Repository area; Subsurface | Goal: -- Current: -- Needed: -- | Water potential, total, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| Pressure head values as a function of depth and lateral spatial location | " | " | Hydraulic head, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | 8.3.1.2.2.4.9 |
| | | | Matric potential, fractured rock units | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw, | " |
| | | | Matric potential, rock matrix | " | " |
| | | | Water potential, rock matrix | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone fluid potential | | | |
| | | | Water potential, total fractured rock | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| Isotopic ratios, ground-water residence time (Fault zone) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SDev<br>Current: NA, NA<br>Needed: Medium, Low | Pore-gas composition | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Isotopic ratios, ground-water residence time (Fractures) | " | " | Radioactive isotopes | " | " |
| Isotopic ratios, ground-water residence time (Rock matrix) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Low | Stable isotopes | " | " |
| | | | Temperature, fractured rock | " | " |
| | | | Water content, volumetric | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Hydrochemical properties, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Radioactive isotopes | " | " |
| | | | Stable isotopes | " | " |
| | | | Water quality | " | " |
| | | | Moisture loss (water content, $^{18}O/^{16}O$ and D/H ratios) | Exploratory shaft (ES-1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Pore-gas composition | " | " |
| | | | Radioactive isotope activity | " | " |
| | | | Stable isotopes | " | " |
| | | | Stable-isotope ratio analyses | " | " |
| | | | Water quality, cations and anions | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Formation gas, radioactive- and stable-isotope composition | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Formation water, cation and anion chemistry | Exploratory-shaft facility; Perched-water zones | " |
| | | | Formation water, radioactive and stable isotope composition | " | " |
| | | | Temperature, fractured rock | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | " |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| Moisture content, volumetric (Fault zones) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Low | Water content, gravimetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| Moisture content, volumetric (Fractures) | Repository area; Unsaturated zone, each geohydrologic unit below repository | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Low | Water content, volumetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Moisture content, volumetric (Rock matrix) | " | Goal: Mean, SCor, SDev<br>Current: Low, Low, Low<br>Needed: High High, High | Moisture content, in situ degree of saturation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Saturation (Fault zones) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: Medium, Low, Low | Moisture content, gravimetric | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| Saturation (Fractures) | " | " | Moisture content, volumetric | " | " |
| Saturation (Rock matrix) | " | Goal: Mean, SCor, SDev<br>Current: Low, NA, NA<br>Needed: High, Medium, Medium | | | |
| Moisture retention curves for wetting and draining | Repository area; Subsurface | Goal: --<br>Current: --<br>Needed: -- | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground-water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone fluid flux | | | |
| Flux (q)[b] | Controlled area; TSw[a] | Goal: <0.5 mm/yr[de]<br>Current: Low<br>Needed: Low | Discharge, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| Distance along flow paths | Controlled area; TSw | Goal: >10 m (100%)<br>Current: Medium<br>Needed: Low | Flow rates, perched water zones | " | " |
| Flux (q) | Controlled area; | Goal: <0.5 mm/yr<br>Current: Low<br>Needed: High | Flow paths, hydrochemical determination | Exploratory shaft (ES-1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| Distance along flow paths | " | Goal: >2.5 m (100%), >25 m (80%)<br>Current: Low, Low[f]<br>Needed: High, Medium | Travel times, hydrochemical determination | " | " |
| Flux (q) | Controlled area; CHnz | Goal: <0.5 mm/yr<br>Current: Medium<br>Needed: High | Discharge, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | 8.3.1.2.2.4.9 |
| Distance along flow paths | " | Goal: >2.5 m (100%), >25 m (80%)<br>Current: Low, Low[f]<br>Needed: High, Medium | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.6 | Pre-waste-emplacement ground water travel time | | | | (SCP 8.3.5.12) |
| | | Parameter Category: Unsaturated-zone fluid flux | | | |
| Flux, percolation rate (fault zones) | Repository area; Unsaturated zone, TSw2, repository level | Goal: Mean, SCor, SDev<br>Current: NA, NA, Low<br>Needed: Medium, Low, Low | | | |
| Flux, percolation rate (Fractures) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, Medium<br>Needed: Medium, Low, Low | | | |
| Flux, percolation rate (Rock matrix) | " | Goal: Mean, SCor, SDev<br>Current: NA, NA, NA<br>Needed: High, Medium, Medium | | | |
| Ground-water percolation flux at the top of TSw2 (portion of Topopah Spring welded unit proposed for repository unit) | Repository area; Subsurface | Goal: --<br>Current: --<br>Needed: -- | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| **Issue 1.10** | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| Performance Measures: Rock-induced load on waste package; Temperature vs. time in waste package environment; Quantity of liquid water that can contact the container; Quality of liquid water that can contact the container | | | | | |
| Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | | | |
| Mechanical and thermal stress loading: unit weight | Repository area; Repository block: TSw2 | Current: Needed: Medium | Bulk density, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: bulk density of matrix | Repository area; Repository block: TSw2 | Current: Needed: High | Grain density, rock matrix | " | " |
| | | | Density | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Porosity | " | " |
| | | | Porosity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | |
| | | | Bulk density, rock matrix | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Grain density, rock matrix | " | " |
| | | | Lithology | " | " |
| | | Parameter Category: Fracture distribution | | | |
| Fracture orientation and density: average spacing within each borehole | Repository area; Repository block: TSw2 | Current: Needed: High | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Fracture orientation and density: set identification | " | " | Fracture distribution | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: fracture spacing | " | Current: Needed: Medium | Fracture frequency, orientation, spacing, distribution, and weathering | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Fracture orientation | | | |
| Fracture orientation and density: distribution of orientation | Repository area; Repository block: TSw2 | Current: Needed: High | Fracture orientation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Fracture orientation and density: average dip of set | " | " | | | |
| Fracture orientation and density: average azimuth of set | " | " | | | |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: fracture orientation | " | Current: Needed: Medium | | | |
| | | Parameter Category: Fracture aperture | | | |
| Fracture stiffness: aperture | " | " | Fracture aperture | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Fracture aperture | | | |
| | | | Fracture aperture | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | Parameter Category: Fracture-filling mineralogy and physical properties | | | |
| Mechanical and thermal stress loading: joint roughness | Repository area; Repository block: TSw2 | Current: Needed: High | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Fracture stiffness: joint roughness coefficient | " | Current: Needed: Medium | Fracture roughness | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Fracture shear strength: joint roughness coefficient | " | Current: Needed: High | | | |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: fracture porosity | " | " | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: hydraulic conductivity of matrix for liquid phase | Repository area; Repository block: TSw2 | Current: Needed: High | Bulk permeability | Exploratory shaft (ES 1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: porosity of matrix | " | " | Bulk permeability, pneumatic | " | " |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: relative permeability curves | " | " | Bulk porosity | " | " |
| Single-phase fluid flow;relative permeability (water quantity) | Waste package near-field environment; TSw2 | Goal: +/- 20% Current: -- Needed: -- | Fracture permeability | " | " |
| Single-phase fluid flow; fracture permeability (water quantity) | " | " | Gas permeability, excavation effects | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Two-phase fluid flow; relative permeability (water quantity) | Waste package near-field environment; TSw2 | Goal: +/- 20% Current: -- Needed: -- | Permeability, relative, gas, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Two-phase fluid flow; fracture permeability (water quantity) | " | " | Permeability, relative, water, rock matrix | " | " |
| | | | Permeability, saturated, gas, rock matrix | " | " |
| | | | Pneumatic permeability, bulk, fractured rock | " | " |
| | | | Air-permeability profiles | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | " | " | " |
| | | | Hydraulic conductivity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| | | | Transmissivity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Bulk permeability, pneumatic | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Hydraulic conductivity, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | " |
| | | | Transmissivity, perched-water zones | " | " |
| | | Parameter Category: Unsaturated-zone dispersive properties | | | |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: dispersivity for radionuclides in rock matrix | Repository area; Repository block: TSw2 | Current: Needed: Medium | Diffusive tortuosity, fractured rock and rock mass | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Unsaturated-zone dispersive properties | | | |
| Near-field temperature distribution; thermal properties (initial temperature, heat capacity, thermal conductivity) for TSw2 as identified in SCP Section 8.3.2.2 (Issue 1.11) (thermal loading) | Waste package near-field environment; TSw2 | Goal: See SCP Table 8.3.2.2-5<br>Current: --<br>Needed: -- | | | |
| | | Parameter Category: Unsaturated-zone diffusive properties | | | |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: Knudsen diffusion coefficients | Repository area; Repository block: TSw2 | Current:<br>Needed: Medium | Gaseous-diffusion coefficient, fractured rock units | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: diffusion coefficients for radionuclides in rock matrix | " | Current:<br>Needed: High | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | | | |
| Mineralogy and water quality: rock-water interaction at elevated temperature | Repository area; Repository block: TSw2 | Current: Needed: High | Pore-gas composition | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Mineralogy and water quality: vadose water composition | " | " | Radioactive isotopes | " | " |
| | | | Stable isotopes | " | " |
| | | | Temperature, fractured rock | " | " |
| | | | Water content, volumetric | " | " |
| | | | Hydrochemical properties, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Radioactive isotopes | " | " |
| | | | Stable isotopes | " | " |
| | | | Water quality | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Moisture loss (water content, $^{18}O/^{16}O$ and D/H ratios) | Exploratory shaft (ES 1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Pore-gas composition | " | " |
| | | | Radioactive isotope activity | " | " |
| | | | Stable isotopes | " | " |
| | | | Stable-isotope ratio analyses | " | " |
| | | | Water quality, cations and anions | " | " |
| | | | Formation gas, radioactive- and stable-isotope composition | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Formation water, cation and anion chemistry | Exploratory-shaft facility; Perched-water zones | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Formation water, radioactive and stable isotope composition | Exploratory-shaft facility; Perched water zones | 8.3.1.2.2.4.- |
| | | | Temperature, fractured rock | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | " |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| For Topopah Spring Tuff at repository horizon (TSw2)[b]: water retention curves | Repository area; Repository block: TSw2 | Current:<br>Needed: High | Water content, gravimetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Single-phase fluid flow; degree of saturation (water quantity) | Waste package near-field environment; TSw2 | Goal: +/- 50%<br>Current: --<br>Needed: -- | Water content, volumetric, rock matrix | " | " |
| Two-phase fluid flow; degree of saturation (water quantity) | " | " | Moisture content, in situ degree of saturation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | (SCP 8.3.4.2) | |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| | | | Moisture content, gravimetric | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Moisture content, volumetric | " | " |
| | | Parameter Category: Unsaturated-zone fluid flux | | | |
| Water quantity: single-phase fluid flow | Repository area; Repository block: TSw2 | Current: Needed: High | Discharge, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| Water quantity: two-phase fluid flow | " | " | Flow rates, perched-water zones | " | " |
| | | | Flow paths, hydrochemical determination | Exploratory shaft (ES-1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Travel times, hydrochemical determination | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Unsaturated-zone fluid flux | | | |
| | | | Discharge, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | 8.3.1.2.2.4.9 |
| | | Parameter Category: Rock deformation | | | |
| Mechanical and thermal stress loading: Poisson's ratio | Repository area; Repository block: TSw2 | Current:<br>Needed: Medium | Fracture deformation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Borehole stability: near-field mechanical properties | " | Current:<br>Needed: High | | | |
| Near-field stress distribution and rock displacements; mechanical properties (Young's modulus, Poisson's ratio, compressive strength, etc.) for TSw2 as identified in SCP Section 8.3.2.2 (Issue 1.11) (rock-induced loading) | Waste package near-field environment; TSw2 | Goal: See SCP Table 8.3.2.2-5<br>Current: --<br>Needed: -- | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| | | Parameter Category: Rock in situ stress, repository area | | | |
| Mechanical and thermal stress loading: principal stress magnitude | Repository area; Repository block: TSw2 | Current: Needed: Medium | In situ stress, magnitude, and orientation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Mechanical and thermal stress loading: principal stress orientations | " | " | | | |
| Fracture stiffness: normal stress | " | Current: Needed: High | | | |
| Fracture stiffness: shear stress | " | " | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.10 | Characteristics and configurations of waste packages (postclosure) | | | | (SCP 8.3.4.2) |
| Parameter Category: Rock in situ stress, repository area | | | | | |
| Near-field stress distribution and rock displacements; fracture (joint) characteristics (shear/normal stiffness, orientation, frequency, etc.) for TSw2 as identified in SCP Section 8.3.2.2 (Issue 1.11) (rock-induced loading) | Waste package near-field environment; TSw2 | Goal: See SCP Table 8.3.2.2-5<br>Current: --<br>Needed: -- | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | (SCP 8.3.2.2) | |
| Performance Measures: Usable area: Is usable area adequate for 70,000 metric tons of uranium (MTU) waste?; Temperature; Temperature; Temperature; Potential for significant displacement (see Issue 1.1); Stress, deformation, factor of safety, and potential rock fall; Extent of change in saturation and water chemistry | | | | | |
| Parameter Category: Rock-unit contact location and configuration | | | | | |
| Elevation of unit contacts for positioning underground facility[f] (Structure contour maps on upper and lower contacts of TSw2 in primary area and extensions) | Primary area and extensions; TSw2 | Goal: Contours accurate to 30 m +/- Current: Low Needed: Medium | Depth to hydrogeologic contacts | Exploratory shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| Elevation of unit contacts for positioning underground facility (Structure contour map on lower contact of TSw2, minimum overburden) | " | Goal: Contours accurate to 10 m +/- Current: Low Needed: High | | | |
| Elevation of unit contacts for positioning underground facility (Structure contour map on upper contact of TSw2, minimum overburden) | " | Goal: Contours accurate to 10 m +/- Current: Low Needed: Medium | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | | (SCP 8.3.2.2) |
| Parameter Category: Rock-unit contact location and configuration | | | | | |
| Geologic stratigraphy to water table (location of unit contacts for thermal modeling) (Structure contour maps on upper and lower contacts of TSw2 in primary area and extensions) | Primary area and extensions; TSw2 | Goal: Contours accurate to 30 m +/-<br>Current: Low<br>Needed: Medium | | | |
| Geologic stratigraphy to water table (location of unit contacts for thermal modeling) (Structure contour map on lower contact of TSw2 in areas with minimum overburden) | Primary area and extensions; Unsaturated zone | Goal: Contours accurate to 10 m +/-<br>Current: Low<br>Needed: Medium | | | |
| Geologic stratigraphy to water table (location of unit contacts for thermal modeling) (Structure contour map on upper contact of TSw2 in areas with minimum overburden) | " | " | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | | (SCP 8.3.2.2) |
| | | Parameter Category: Rock-unit contact location and configuration | | | |
| Geologic stratigraphy to water table (Structure contour map on upper and lower contacts of other units in primary area and extensions) | Primary area and extensions; TCw, PTn, TSw | Goal: Contours accurate to 60 m +/-<br>Current: Low<br>Needed: Medium | | | |
| | | Parameter Category: Fracture distribution | | | |
| Joint abundance (TSw2) | Primary area and extensions; TSw2 | Goal: See SCP Table 6-15[5]<br>Current: Low<br>Needed: Medium | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Joint abundance (TSw1, and TSw3) | Primary area and extensions; TSw1, TSw3 | Goal: See SCP Table 6-15[5]<br>Current: Low<br>Needed: Low | Fracture distribution | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Fracture frequency, orientation, spacing, distribution, and weathering | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | | (SCP 8.3.2.2) |
| | | Parameter Category: Fracture orientation | | | |
| Joint spatial orientation (TSw2) | Primary area and extensions; TSw2 | Goal: See SCP Table 6-15[$]<br>Current: Low<br>Needed: Medium | Fracture orientation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Joint spatial orientation (TSw1, and TSw3) | Primary area and extensions; TSw1, TSw3 | Goal: See SCP Table 6-15<br>Current: Low<br>Needed: Low | | | |
| | | Parameter Category: Fracture-filling mineralogy and physical properties | | | |
| Joint roughness coefficient (TSw2) | Primary area and extensions; TSw2 | Goal: See SCP Table 6-15[$]<br>Current: Low<br>Needed: Medium | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Joint roughness coefficient (TSw1, and TSw3) | Primary area and extensions; TSw1, TSw3 | Goal: See SCP Table 6-15[$]<br>Current: Low<br>Needed: Low | Fracture roughness | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | | (SCP 8.3.2.2) |
| Parameter Category: Unsaturated-zone moisture conditions | | | | | |
| Saturation (During development around the excavations) | Primary area and extensions; TSw2 | Goal: <90%<br>Current: Low<br>Needed: High | Water content, gravimetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Water content, volumetric, rock matrix | " | " |
| | | | Moisture content, in situ degree of saturation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Moisture content, gravimetric | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Moisture content, volumetric | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | | (SCP 8.3.2.2) |
| | | Parameter Category: Rock deformation | | | |
| Young's modulus (TSw2 for 0-100 MPa) | Primary area and extensions; TSw2 | Goal: Current mean[o] +/- 15%<br>Current: Medium<br>Needed: High | Fracture deformation | Exploratory shaft (ES 1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Young's modulus (TSw1 for 0-100 MPa) | Primary area and extensions; TSw1 | Goal: Current mean[o] +/- 15%<br>Current: Medium<br>Needed: Medium | | | |
| Young's modulus (Above TSw1[q]) | Primary area and extensions; TCw, PTn | Goal: Current mean[o] +/- 15%<br>Current: Low to medium<br>Needed: Low | | | |
| Deformation modulus (TSw2 for 0-100 MPa) | Primary area and extensions; TSw2 | Goal: Current mean[o] +/- 15%<br>Current: Low<br>Needed: High | | | |
| Deformation modulus (TSw3 | Primary area and extensions; TSw3 | Goal: Current mean[o] +/- 15%<br>Current: Low<br>Needed: Medium | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | | (SCP 8.3.2.2) |
| | | Parameter Category: Rock deformation | | | |
| Deformation modulus (TSw1 for 0-100 MPa) | Primary area and extensions; TSw1 | Goal: Current mean[a] +/- 15%<br>Current: Low<br>Needed: Medium | | | |
| Deformation modulus (Above TSw1[a]) | Primary area and extensions; TCw, PTn | Goal: Current mean[a] +/- 15%<br>Current: Low<br>Needed: Low | | | |
| Poisson's ratio (TSw2 for 0-100 MPa) | Primary area and extensions; TSw2 | Goal: Current mean[a] +/- 20%<br>Current: Medium<br>Needed: Medium | | | |
| Poisson's ratio (TSw1 for 0-100 MPa) | Primary area and extensions; TSw1 | Goal: Current mean[a] +/- 20%<br>Current: Low to medium<br>Needed: Low | | | |
| Poisson's ratio (Above TSw1[a]) | Primary area and extensions; TCw, PTn | Goal: Current mean[a] +/- 20%<br>Current: Low<br>Needed: Low | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | | (SCP 8.3.2.2) |
| | | Parameter Category: Rock deformation | | | |
| Joint normal stiffness (TSw2) | Primary area and extensions; TSw2 | Goal: See SCP Table 6-13[$]<br>Current: Low<br>Needed: Medium | | | |
| Joint normal stiffness (TSw1, and TSw3) | Primary area and extensions; TSw1, TSw3 | Goal: See SCP Table 6-13[$]<br>Current: Low<br>Needed: Low | | | |
| Joint shear stiffness (TSw2) | Primary area and extensions; TSw2 | Goal: See SCP Table 6-13[$]<br>Current: Low<br>Needed: Medium | | | |
| Joint shear stiffness (TSw1, and TSw3) | Primary area and extensions; TSw1, TSw3 | Goal: See SCP Table 6-13[$]<br>Current: Low<br>Needed: Low | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.11 | Characteristics and configurations of repository and engineered barriers (postclosure) | | | (SCP 8.3.2.2) | |
| | | Parameter Category: Rock in situ stress, repository area | | | |
| Initial stress state for primary area and extensions (Vertical stresses, and magnitude and direction of minimum and maximum horizontal stresses) | Primary area and extensions; TSw | Goal: Vertical stress[m] accurate to +/- 1 MPa<br>Current: Low to medium<br>Needed: Medium | In situ stress, magnitude, and orientation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Initial stress state for primary area and extensions (Vertical stresses and magnitude and direction of minimum and maximum horizontal stresses) | " | Goal: Horizontal stress[m] accurate to +/- 2 MPa<br>Current: Low<br>Needed: Low | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | | (SCP 8.3.3.2) |
| Performance Measures: Quantity of water; Drainage capacity; Amount of fill | | | | | |
| Parameter Category: Rock-unit contact location and configuration | | | | | |
| Morphology of bedrock surface; in order of priority - downgradient, ingradient, and about 160m from shaft locations | Vicinity of shaft locations; Near surface | Goal: Determine contours to within +/- 3 m<br>Current: Low<br>Needed: Medium | Depth to hydrogeologic contacts | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| Thickness of alluvium | Within 75m of shaft and borehole locations; Near surface | Goal: Determine thickness to within +/- 10%<br>Current: Low<br>Needed: Medium | | | |
| Unit contacts in exploratory boreholes; all boreholes (see SCP Table 8.3.3.2-4) | All boreholes in categories A and B[d]; | Goal: Contact location +/- 5 m<br>Current: Low<br>Needed: High | | | |
| Parameter Category: Fracture distribution | | | | | |
| Fracture characteristics | Repository area; TCw | Goal: <20 fractures/m<br>Current: Low<br>Needed: High | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | (SCP 8.3.3.2) | |
| | | Parameter Category: Fracture distribution | | | |
| Fracture characteristics | At base of ES-1; TSw2 | Goal: <40 fractures/m<br>Current: Low<br>Needed: High | Fracture distribution | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| " | At base of ES-1 | Goal: <5 fractures/m<br>Current: Low<br>Needed: High | Fracture frequency, orientation, spacing, distribution, and weathering | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| " | PTn | Goal: <10 fractures/m<br>Current: Low<br>Needed: High | | | |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Saturated bulk-rock hydraulic conductivity of Tiva Canyon Member | Vicinity of shaft locations; TCw | Goal: 1 x $10^{-5}$ to 1 x $10^{2}$ cm/s<br>Current: Low<br>Needed: Medium | Bulk permeability | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | | (SCP 8.3.3.2) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Extent and hydraulic conductivity of modified permeability zone (MPZ) | Vicinity of shaft locations; TCu;TSw2 | Goal: Less than or equal to 60 times the undisturbed, rock-mass saturated hydraulic conductivity, averaged over one radius from the wall of the shaft<br>Current: Low<br>Needed: Medium | Bulk permeability, pneumatic | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Unsaturated hydraulic, matrix properties | Vicinity of shaft locations; TSw2 | Goal: $1 \times 10^{-8}$ to $1 \times 10^{-15}$ m/s in vicinity of shafts<br>Current: Low<br>Needed: Medium | Bulk porosity | " | " |
| Drainage capacity | Selected drift-floor locations; TSw2 | Goal: Saturated, bulk-rock hydraulic conductivity $k_{SAT}{}^{d} > 1 \times 10^{-5}$ cm/s<br>Current: Low<br>Needed: High | Fracture permeability | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | | (SCP 8.3.3.2) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Drainage capacity | Base of shafts; TSw2 | Goal: Saturated, bulk-rock hydraulic conductivity $k_{SAT} > 1 \times 10^{-5}$ cm/s<br>Current: Low<br>Needed: High | Gas permeability, excavation effects | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Permeability, relative, gas, rock matrix | " | " |
| | | | Permeability, relative, water, rock matrix | " | " |
| | | | Permeability, saturated, gas, rock matrix | " | " |
| | | | Pneumatic permeability, bulk, fractured rock | " | " |
| | | | Air-permeability profiles | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | " | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | | (SCP 8.3.3.2) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| | | | Hydraulic conductivity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Transmissivity, perched-water zones | " | " |
| | | | Bulk permeability, pneumatic | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Hydraulic conductivity, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | " |
| | | | Transmissivity, perched-water zones | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | | (SCP 8.3.3.2) |
| | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | | |
| Chemistry of waters (if any); in faults, including sediment content | | Goal: Elemental concentration similar to those contained in SCP Table 4-6<br>Current: Low<br>Needed: Medium | Pore-gas composition | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Radioactive isotopes | " | " |
| | | | Stable isotopes | " | " |
| | | | Temperature, fractured rock | " | " |
| | | | Water content, volumetric | " | " |
| | | | Hydrochemical properties, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Radioactive isotopes | " | " |
| | | | Stable isotopes | " | " |
| | | | Water quality | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | | (SCP 8.3.3.2) |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Moisture loss (water content, $^{18}O/^{16}O$ and D/H ratios) | Exploratory shaft (ES-1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Pore-gas composition | " | " |
| | | | Radioactive-isotope activity | " | " |
| | | | Stable isotopes | " | " |
| | | | Stable-isotope ratio analyses | " | " |
| | | | Water quality, cations and anions | " | " |
| | | | Formation gas, radioactive- and stable-isotope composition | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Formation water, cation and anion chemistry | Exploratory-shaft facility; Perched-water zones | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | | (SCP 8.3.3.2) |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Formation water, radioactive and stable isotope composition | Exploratory-shaft facility; Perched-water zones | 8.3.1.2.2.4.9 |
| | | | Temperature, fractured rock | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | " |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| Continuous saturation profile of alluvium to bedrock interface | Shaft and borehole locations; Near surface | Goal: +/- 10% of natural saturation every meter<br>Current: Low<br>Needed: Medium | Water content, gravimetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Water content, volumetric, rock matrix | " | " |
| | | | Moisture content, in situ degree of saturation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 1.12 | Characteristics and configurations of shaft and borehole seals | | | | (SCP 8.3.3.2) |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| | | | Moisture content, gravimetric | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Moisture content, volumetric | " | " |
| | | Parameter Category: Rock in situ stress, repository area | | | |
| In situ stresses | TCw, TSw2 | Goal: Vertical stress accurate to +/- 1 MPa;horizontal stresses accurate to +/- 2 MPa<br>Current: Low<br>Needed: Low | In situ stress, magnitude, and orientation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 2.2 | Worker radiological safety under normal operating conditions | | | | (SCP 8.3.5.4) |
| Performance Measures: Effective attenuation of direct radiation by host rock | | | | | |
| Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | | | |
| Bulk density of host rock | TSw2 | Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here<br>Current: Medium<br>Needed: High | Bulk density, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Grain density, rock matrix | " | " |
| | | | Density | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Porosity | " | " |
| | | | Porosity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 2.2 | Worker radiological safety under normal operating conditions | | | | (SCP 8.3.5.4) |
| | | Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | |
| | | | Bulk density, rock matrix | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Grain density, rock matrix | " | " |
| | | | Lithology | " | " |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| Water content of host rock | TSw2 | Goal: Tentative goal is to have further measurements of this parameter verify the range of expected values listed here<br>Current: Medium<br>Needed: High | Water content, gravimetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Water content, volumetric, rock matrix | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 2.2 | Worker radiological safety under normal operating conditions | | | | (SCP 8.3.5.4) |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| | | | Moisture content, in situ degree of saturation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Moisture content, gravimetric | Exploratory shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Moisture content, volumetric | " | " |
| Issue 2.7 | Characteristics and configurations of the repository (preclosure) | | | | (SCP 8.3.2.3) |
| Performance Measures: See performance measures of subfunction C of Issue 2.7; Moderating materials in or around emplaced waste | | | | | |
| | | Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | |
| Bulk density of host rock (TSw2 unit) | Primary area and extensions; TSw2 | Goal: See footnote (d)<br>Current: Medium<br>Needed: High | Bulk density, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 2.7 | Characteristics and configurations of the repository (preclosure) | | | | (SCP 8.3.2.3) |
| | | Parameter Category: Rock-unit mineralogy/petrology and physical properties | | | |
| | | | Grain density, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Density | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Porosity | " | " |
| | | | Porosity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Bulk density, rock matrix | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Grain density, rock matrix | " | " |
| | | | Lithology | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 2.7 | Characteristics and configurations of the repository (preclosure) | | | | (SCP 8.3.2.3) |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| Water content of host rock as a function of temperature and time (TSw2 unit) | Primary area and extensions; TSw2 | Goal: See footnote (d)<br>Current: Medium<br>Needed: High | Water content, gravimetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Water content, volumetric, rock matrix | " | " |
| | | | Moisture content, in situ degree of saturation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Moisture content, gravimetric | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Moisture content, volumetric | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | (SCP 8.3.2.5) | |

Performance Measures: Thickness for drift construction and waste emplacement; Shafts and ramps compatible with requirements for repository sealing; Drift sizes and slopes compatible with requirements for personnel and material transport and utility routing; Drifts (underground layout) compatible with repository sealing; Usable openings of required size; Compliance with 10 CFR 60.133 (g); Space to accomodate surface facilities (with contingency); Removal rate equal to rate of condensation; Removal rate equal to rate of inflow; Constructability of usable borehole for waste disposal envelope

Parameter Category: Rock-unit contact location and configuration

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Stratigraphic contacts for top and bottom of the TSw2 formation within candidate areas for repository | Primary area and extensions; TSw2 | Goal: Determine elevation of stratigraphic contacts at selected points within candidate repository area to accuracy of +/- 10 m<br>Current: Low<br>Needed: High | Depth to hydrogeologic contacts | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| Elevation of upper Calico Hills | Exploratory shafts; CHn | Goal: Elevation within 5 m<br>Current: High<br>Needed: High | | | |
| Upper- and lower-contact elevations for TSw2 formation over the entire repository area | Primary area; TSw2 | Goal: Upper- and lower-contact elevations for the TSw2 within 20 m<br>Current: --<br>Needed: Medium | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | | Parameter Category: Rock-unit contact location and configuration | | | |
| Upper- and lower-contact elevations for the TSw2 unit within the potential repository area | Primary area and extensions; TSw2 | Goal: Upper- and lower-contact elevations for the TSw2 within 20 m<br>Current: Medium<br>Needed: Medium | | | |
| | | Parameter Category: Fracture distribution | | | |
| Number of joint sets | Primary area; Repository block, TSw2 | Goal: TSw2, 2 - 3 sets<br>Current: Medium<br>Needed: High | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Fracture frequency and spacing | " | Goal: TSw2, 20 - 40 per $m^3$<br>Current: Medium<br>Needed: Medium | Fracture distribution | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Fracture frequency, orientation, spacing, distribution, and weathering | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | | Parameter Category: Fracture orientation | | | |
| Joint orientation | Primary area; Repository block, TSw2 | Goal: TSw2, identify joint sets and orientation<br>Current: Medium<br>Needed: Medium | Fracture orientation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | Parameter Category: Fracture-filling mineralogy and physical properties | | | |
| Joint roughness coefficient (fracture surfaces) | " | Goal: TSw2<br>Current: (see footnote e)<br>Needed: (see footnote e) | Fracture characteristics: distribution, aperture, weathering | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| Joint roughness and condition of joints | " | Goal: TSw2, discontinuous to smooth undulating<br>Current: Medium<br>Needed: Medium | Fracture roughness | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| Joint alteration | " | Goal: TSw2 softening or low friction with clay mineral coatings<br>Current: Medium<br>Needed: Medium | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| Permeability of disturbed rock | Primary area; Underground facility | Goal: Permeability of rock affected by mining operations (blasting)<br>Current: Low<br>Needed: Low | Bulk permeability | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Bulk permeability, pneumatic | " | " |
| | | | Bulk porosity | " | " |
| | | | Fracture permeability | " | " |
| | | | Gas permeability, excavation effects | " | " |
| | | | Permeability, relative, gas, rock matrix | " | " |
| | | | Permeability, relative, water, rock matrix | " | " |
| | | | Permeability, saturated, gas, rock matrix | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | (SCP 8.3.2.5) | |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| | | | Pneumatic permeability, bulk, fractured rock | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Air-permeability profiles | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | " | " | " |
| | | | Hydraulic conductivity, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Transmissivity, perched-water zones | " | " |
| | | | Bulk permeability, pneumatic | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | | Parameter Category: Unsaturated-zone transmissive properties | | | |
| | | | Hydraulic conductivity, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | 8.3.1.2.2.4.9 |
| | | | Transmissivity, perched-water zones | " | " |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| Water and formation chemistry | Primary area; Repository block | Goal: Quantitative and qualitative analysis of formation and water<br>Current: Medium<br>Needed: Medium | Pore-gas composition | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Radioactive isotopes | " | " |
| | | | Stable isotopes | " | " |
| | | | Temperature, fractured rock | " | " |
| | | | Water content, volumetric | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | (SCP 8.3.2.5) | |
| | | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | |
| | | | Hydrochemical properties, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Radioactive isotopes | " | " |
| | | | Stable isotopes | " | " |
| | | | Water quality | " | " |
| | | | Moisture loss (water content, $^{18}O/^{16}O$ and D/H ratios) | Exploratory shaft (ES-1), 30-m depth intervals; TCw, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Pore-gas composition | " | " |
| | | | Radioactive-isotope activity | " | " |
| | | | Stable isotopes | " | " |
| | | | Stable-isotope ratio analyses | " | " |
| | | | Water quality, cations and anions | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age | | | | |
| | | | Formation gas, radioactive- and stable-isotope composition | Exploratory-shaft facility; Selected units penetrated by ES-1, and ES-2 | 8.3.1.2.2.4.9 |
| | | | Formation water, cation and anion chemistry | Exploratory-shaft facility; Perched-water zones | " |
| | | | Formation water, radioactive and stable isotope composition | " | " |
| | | | Temperature, fractured rock | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | | Parameter Category: Unsaturated-zone moisture conditions | | | |
| Condensate quantity | Repository facilities; | Goal: Determined using parameters specified in System Elements 1.1.2 (subsurface), 1.2.1.6 (mine ventilation), and 1.2.2.7 (waste handling ventilation)<br>Current: --<br>Needed: -- | Water content, gravimetric, rock matrix | Exploratory shaft (ES-1), eight depth locations; TCw, PTn, TSw, contacts between units | 8.3.1.2.2.4.4 |
| | | | Water content, volumetric, rock matrix | " | " |
| | | | Moisture content, in situ degree of saturation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| | | | Moisture content, gravimetric | Exploratory-shaft facility; All units penetrated by ES-1, and ES-2, TCw, PTn, TSw | 8.3.1.2.2.4.9 |
| | | | Moisture content, volumetric | " | " |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | | Parameter Category: Rock deformation | | | |
| Rock properties in primary area; Poisson's ratio (intact rock) | Primary area; Repository block, TSw1 | Goal: TSw1, 0.20 - 0.30 (NL)[c]<br>Current: Low to medium<br>Needed: Low | Fracture deformation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |
| " | Primary area; Repository block | Goal: TSw1, 0.13 - 0.19 (L)[d]<br>Current: Low<br>Needed: Low | | | |
| " | Primary area; Repository block, TSw2 | Goal: TSw2, 0.19 - 0.29<br>Current: Medium<br>Needed: Medium | | | |
| Rock properties in primary area; Young's modulus (intact rock) | Primary area; Repository block, TSw1 | Goal: TSw1, 12 - 54 GPa (NL)<br>Current: Medium<br>Needed: Medium | | | |
| " | Primary area; Repository block, Tsw1 | Goal: TSw1, 14 - 17 GPa (L)<br>Current: Low<br>Needed: Medium | | | |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | | Parameter Category: Unsaturated-zone fluid flux | | | |
| Natural-water inflow | Repository facilities; | Goal: Actual inflow rate to accuracy of +/- 10 gpm<br><br>Current: Low<br>Needed: Medium | Discharge, perched-water zones | Exploratory shaft (ES-1); When perched water is encountered | 8.3.1.2.2.4.7 |
| | | | Flow rates, perched-water zones | " | " |
| | | | Flow paths, hydrochemical determination | Exploratory shaft (ES-1), 30-m depth intervals; TCu, PTn, TSw | 8.3.1.2.2.4.8 |
| | | | Travel times, hydrochemical determination | " | " |
| | | | Discharge, perched-water zones | Exploratory-shaft facility; To be determined when perched water is encountered | 8.3.1.2.2.4.9 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | | (SCP 8.3.2.5) |
| | | Parameter Category: Rock in situ stress, repository area | | | |
| Rock properties in primary area; in situ stress (rock mass) | Primary area; Repository block | Goal: Vertical, 6.3 - 7.7 MPa (average value for 300 m)<br>Current: Low to medium<br>Needed: Medium | In situ stress, magnitude, and orientation | Exploratory shaft (ES-1), upper and lower breakout rooms; TSw | 8.3.1.2.2.4.5 |

Table 7.3-1 Design and performance issues and parameters supported by results of this study

| Design and Performance Parameters | Parameter Location | Parameter Goal and Confidence (Current and Needed) | Site Parameters | Parameter Location | Site Activity |
|---|---|---|---|---|---|
| Issue 4.4 | Repository construction, operation, closure, and decommissioning technologies | | | (SCP 8.3.2.5) | |
| | | Parameter Category: Rock deformation | | | |
| Rock properties in primary area;Young's modulus (intact rock) | Primary area; Repository block, TSw2 | Goal: TSw2, 29 - 33 GPa<br>Current: Medium<br>Needed: Medium | | | |
| Rock properties in primary area;deformation modulus (rpck mass) | Primary area; Repository block, TSw1 | Goal: TSw1, 12 - 20 GPa (NL)<br>Current: Low<br>Needed: Medium | | | |
| " | " | Goal: TSw1, 4 - 11 GPa (L)<br>Current: Medium<br>Needed: Medium | | | |
| " | Primary area; Repository block, TSw2 | Goal: TSw2, 11 - 19 GPa<br>Current: Low<br>Needed: Medium | | | |
| Joint normal- and shear-stiffness properties (fractures) | " | Goal: TSw2<br>Current: (see footnote e)<br>Needed: (see footnote e) | | | |
| Abrasiveness of rock | Primary area; Repository block | Goal: Reasonable cutter life<br>Current: Medium<br>Needed: Medium | | | |

The following number is for Office of Civilian Radioactive Waste Management Records Management purposes only and should not be used when ordering this document:

Accession Number: NNA.890106.0031