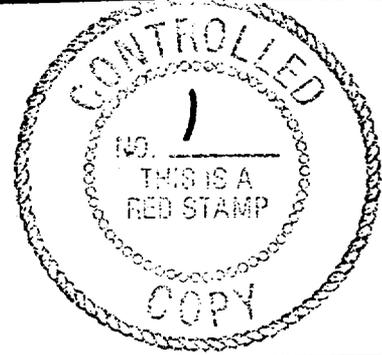


YMP-021-R1
4/15/92

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT STUDY PLAN APPROVAL FORM



Study Plan Number 8.3.1.2.2.4

Study Plan Title CHARACTERIZATION OF THE YUCCA MOUNTAIN UNSATURATED ZONE IN THE
EXPLORATORY STUDIES FACILITY

Revision Number 1

Prepared by: USGS

Date: 12/28/92

Approved:

J. Timothy Sullivan 1/14/93
Director, Regulatory and Site Evaluation Division / Date

Effective Date: 1/15/93

102-8

ABSTRACT

This study plan describes the plans for four of the five unsaturated-zone hydrologic site-characterization activities to be performed in and adjacent to the Yucca Mountain exploratory-studies facility (ESF) during construction. These USGS underground activities are expected to contribute to an understanding of the *in-situ* hydrologic characteristics of the unsaturated zone, to provide an understanding of the impacts of the ramps and drifts construction on the *in-situ* characteristics, and to provide hydrologic-parameter input for the resolution of design and performance issues. The four activities include:

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

Plans for the fifth activity, hydrologic properties of major faults, will be included in a subsequent revision of the study plan.

The plans for *in-situ* hydrologic testing in the ramps and drifts of the ESF will be included in a subsequent revision of the study plan. These three activities include:

- o Intact fracture tests,
- o Percolation tests, and
- o Bulk-permeability tests.

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.

RECORD OF REVISIONS

<u>REVISION NUMBER</u>	<u>REVISION</u>	<u>DATE</u>
R0	<p>Study rationale and plans for four construction-phase activities</p> <ul style="list-style-type: none"> Radial-borehole tests (Section 3.4) Excavation-effects tests (Section 3.5) Perched-water tests (Section 3.7) Hydrochemistry tests (Section 3.8) 	3-24-88
	<p>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.</p>	1-03-89
R1	<p>Study rationale and plans for four construction-phase activities</p> <ul style="list-style-type: none"> Radial-borehole tests (Section 3.4) Excavation-effects tests (Section 3.5) Perched-water tests (Section 3.7) Hydrochemistry tests (Section 3.8) <p>Deletion of Calico Hills tests and multipurpose-borehole tests</p>	12-92

CHARACTERIZATION OF THE YUCCA MOUNTAIN
UNSATURATED ZONE IN THE
EXPLORATORY STUDIES FACILITY

YMP - USGS - SP 8.3.1.2.2.4, R1

STUDY PLAN

DECEMBER 1992

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1 PURPOSE AND OBJECTIVES OF STUDY

1.1 Purpose of the study plan

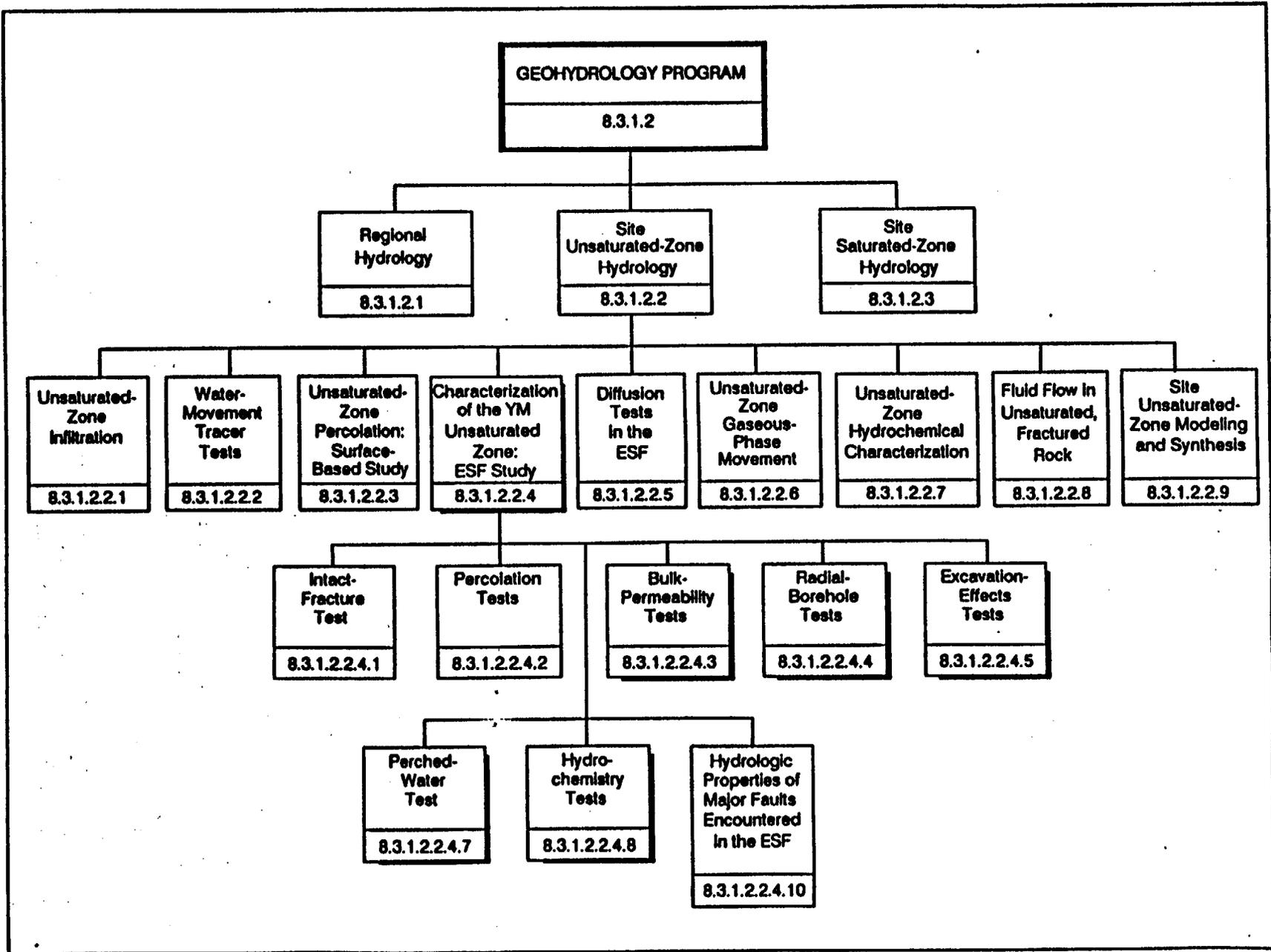
The U.S. Geological Survey (USGS) is conducting studies at Yucca Mountain, Nevada, as part of the Yucca Mountain Project (YMP). The purposes of the USGS studies are to provide geologic and hydrologic information to evaluate the suitability of Yucca Mountain for development of a geologic high-level nuclear-waste repository and the ability of the mined geologic-disposal system (MGDS) to isolate the waste in compliance with regulatory requirements. In particular, the project is designed to acquire information necessary for the U.S. Department of Energy (DOE) to demonstrate in its environmental-impact statement and license application that the MGDS can meet the requirements of federal regulations 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191.

This study plan describes the USGS plans for *in-situ* hydrologic characterization of Yucca Mountain from the ramps, drifts, and associated boreholes of the exploratory-studies facility (ESF). The study is now organized into eight activities:

- 8.3.1.2.2.4.1 - Intact-fracture test,
- 8.3.1.2.2.4.2 - Percolation test,
- 8.3.1.2.2.4.3 - Bulk-permeability test
- 8.3.1.2.2.4.4 - Radial-borehole test,
- 8.3.1.2.2.4.5 - Excavation-effects test,
- 8.3.1.2.2.4.6 - Calico Hills test
(ACTIVITY DELETED)
- 8.3.1.2.2.4.7 - Perched-water test,
- 8.3.1.2.2.4.8 - Hydrochemistry tests,
- 8.3.1.2.2.4.9 - Multipurpose-boreholes testing near the
exploratory shafts (ACTIVITY DELETED), and
- 8.3.1.2.2.4.10 - Hydrologic properties of major faults
encountered in the ESF.

Note that the numbers (e.g., 8.3.1.2.2.4.1) used throughout this plan provide references to specific sections of the YMP Site Characterization Plan (SCP) (U.S. DOE, 1988). The SCP describes the technical rationale of the overall site-characterization program and provides general descriptions of the activities described in detail in Section 3 of this study plan.

Figure 1.1-1 illustrates the location of the study within the SCP Geohydrology Program. This study in the ESF is one of nine studies planned to characterize the unsaturated zone at Yucca Mountain; the



1.1-2

December 28, 1992

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Figure 1.1-1. Diagram showing the location of the ESF characterization of the YM unsaturated zone study within the unsaturated-zone investigation and the Geohydrology Program.

others are part of the surface-based evaluations. The eight activities in the study were selected on the basis of various factors. Time and schedule requirements were considered in determining the number and types of tests chosen to obtain the required data. Tests were designed on the basis of design and performance parameter needs, available test and analysis methods, and test scale and interference. These factors are described in Sections 2 and 3.

The descriptions and plans for each activity are presented in Section 3. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) tests and analyses. Alternate test and analysis methods are summarized, and cross references are provided for technical procedures.

Five hydrologic test activities are planned during the ESF construction phase. They are the radial-borehole tests (Activity 8.3.1.2.2.4.4), excavation-effects tests (Activity 8.3.1.2.2.4.5), perched-water tests (Activity 8.3.1.2.2.4.7), hydrochemistry tests (Activity 8.3.1.2.2.4.8), and hydrologic properties of major faults (Activity 8.3.1.2.2.4.10). Revised plans for the first four of these activities are included in the present version of the study plan, in Sections 3.4, 3.5, 3.7, and 3.8, respectively. Plans for the major-faults activity will be included in a subsequent revision of the study plan. Three other activities will be conducted as part of the *in-situ* testing in the drifts of the ESF: the intact-fracture tests (Activity 8.3.1.2.2.4.1), percolation tests (8.3.1.2.2.4.2), and bulk-permeability tests (Activity 8.3.1.2.2.4.3). The plans for these activities will also be presented in a subsequent revision.

The Calico Hills tests (Activity 8.3.1.2.2.4.6) and the multipurpose-borehole testing (Activity 8.3.1.2.2.4.9) have been dropped from the study, for reasons presented in Sections 3.6 and 3.9, respectively.

Application of the study results is summarized in Sections 1.3 and 4, schedules and milestones are presented in Section 5, and a study-plan reference list is presented in Section 6.

1.1.1 Objectives of the study

Hydrologic evaluation of the unsaturated zone will be conducted as an integrated set of surface-based and ESF activities with a common objective to provide an understanding of the past, present, and future fluid flow characteristics in the unsaturated zone at Yucca Mountain.

Surface-based testing will be conducted on the land surface and in vertical and horizontal holes drilled into the repository host rock and surrounding units. Surface-based borehole studies designed to investigate the deep unsaturated zone are described in YMP-USGS SP 8.3.1.2.2.3 (Unsaturated-zone percolation - surface-based studies), and are integrated with the ESF activities (described in this plan) in terms of technical objectives, spatial locations, and parameter determinations. (Parameter is used in this plan to mean a property,

characteristic, and/or the numerical value of a constant that is used to describe the unsaturated-zone hydrologic system).

The north and south ramps, underground drifts, and associated boreholes of the ESF will provide (1) an opportunity to evaluate the in-situ unsaturated-zone hydrologic properties in orientations not achievable from surface-based boreholes, (2) an opportunity to directly inspect the structure and stratigraphy of the rock walls of the ramps and drifts, and (3) an opportunity to evaluate the rock-matrix and fracture-hydrologic parameters for a wide range of test scales. Figure 1.1-2 illustrates the map location of the ESF at Yucca Mountain. Figure 1.1-3 illustrates the conceptual layout of the ESF.

The objective of this ESF unsaturated-zone study is to understand the spatial distribution of present water flow within the unsaturated zone. Plans for studies of past and future unsaturated-zone flow characteristics are described in YMP-USGS SP 8.3.1.2.2.7 (Unsaturated-zone hydrochemistry) and YMP-USGS SP 8.3.1.2.2.9 (Unsaturated-zone modeling and synthesis). Hydrologic studies of infiltration from the land surface (YMP-USGS SP 8.3.1.2.2.1), and site-saturated zone studies (YMP-USGS SP 8.3.1.2.3.1), provide boundary condition information for models of unsaturated-zone percolation.

The salient conditions to be characterized in the unsaturated zone include the hydraulic and pneumatic potential gradients that extend from the land surface to the water table (350 to 750 m; 1,150 to 2,460 ft beneath Yucca Mountain). These potential gradients may vary discontinuously between geohydrologic units. Figure 1.1-4 shows the relation between the stratigraphic and geohydrologic units at Yucca Mountain. The characterization of flow beneath Yucca Mountain must include, for all geohydrologic units, the determination of flow distribution under a variety of conditions. As flux is difficult to measure at either the infiltration boundary (land surface) or the water table, it must be estimated from either the potential water distribution and the conductive properties of the rocks or by other indirect methods.

From the viewpoint of waste isolation, the most significant site-characterization findings will be to predict the transport of radionuclides from the repository, beneath Yucca Mountain, to the water table. SCP Sections 8.3.5.12 (Ground-water travel time) and 8.3.5.13 (Total-system performance) describe the need for this essential information. The hydraulic-properties data that will be used for these unsaturated-flux calculations will be collected by the USGS in the surface-based and ESF unsaturated-zone percolation studies.

Gas flow in the unsaturated zone has an important hydrologic role, as well as providing a mechanism for transport of gaseous radionuclides to the accessible environment. Whereas the coexisting matrix pores and fractures greatly complicate computations of total-system behavior under present or estimated future conditions, the

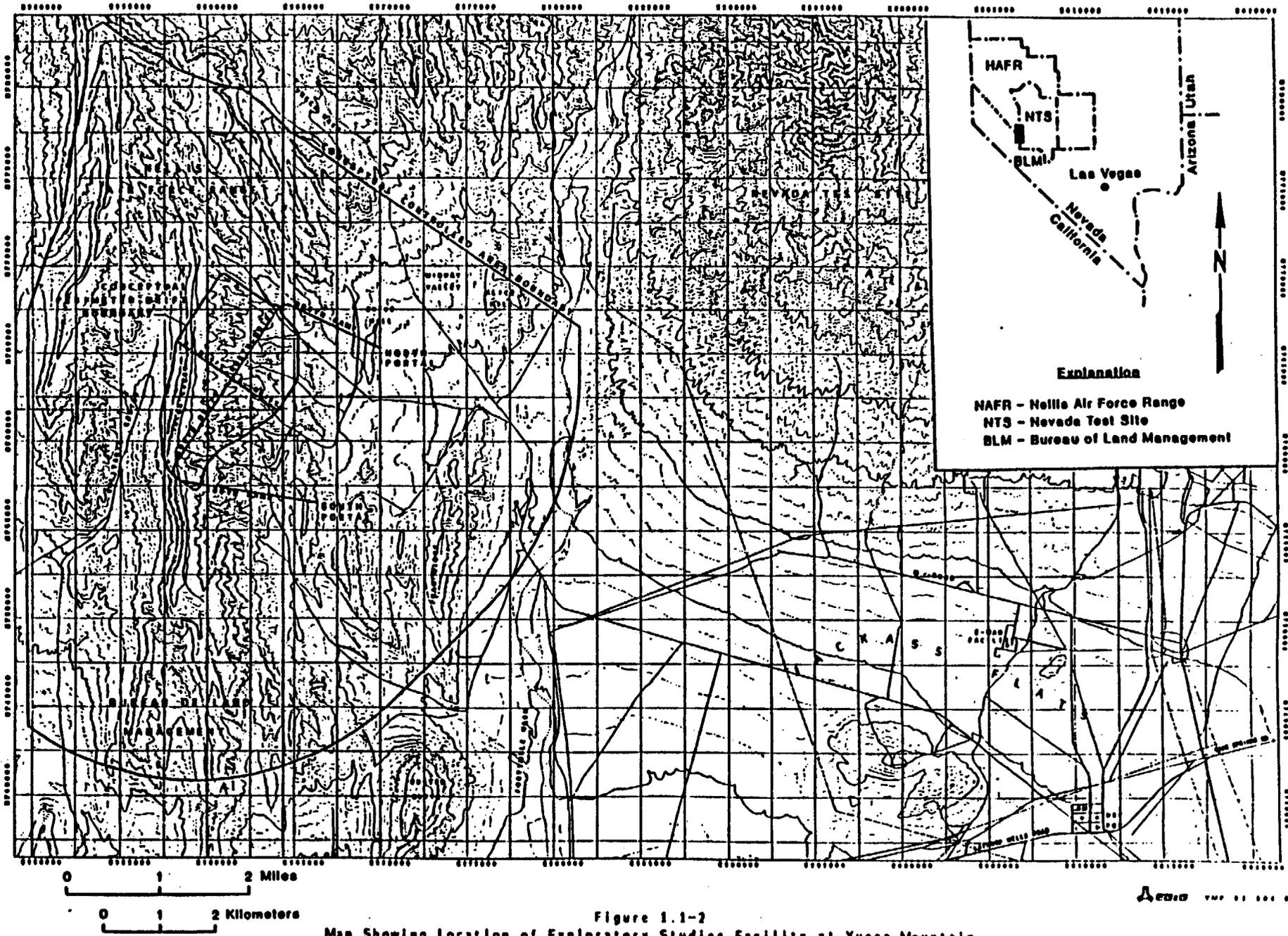


Figure 1.1-2
Map Showing Location of Exploratory Studies Facility at Yucca Mountain

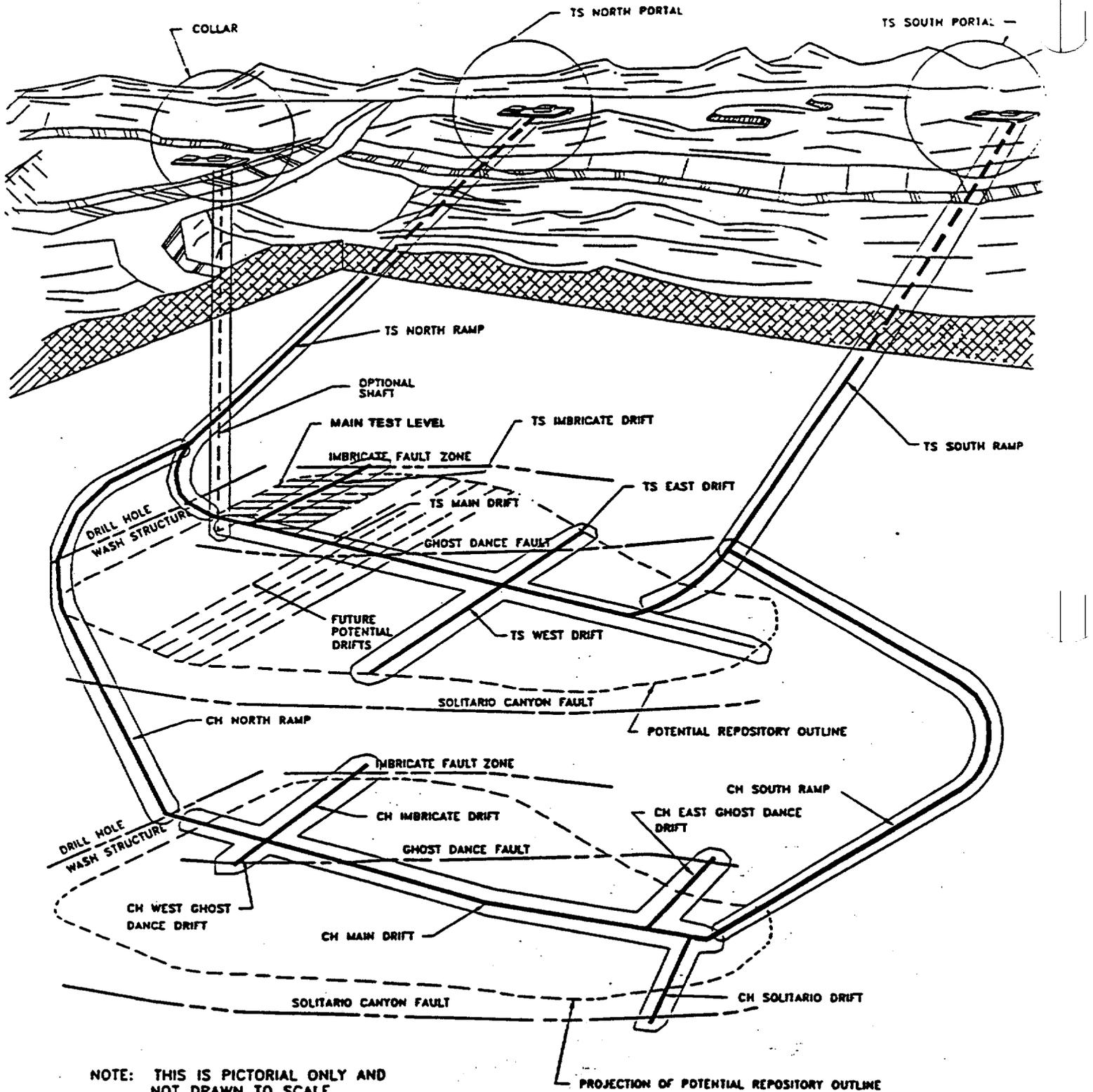


Figure 1.1-3. Conceptual illustration of the exploratory studies facility.

Stratigraphic unit		Geohydrologic unit (where unsaturated)
Alluvium		Alluvium (QAL)
Paintbrush Tuff	Tiva Canyon Member	Tiva Canyon welded unit (TCw)
	Yucca Mountain Member	Paintbrush Tuff nonwelded unit (PTn)
	Pah Canyon Member	
	Topopah Spring Member	Topopah Spring welded unit (TSw)
	Tuffaceous beds of Calico Hills	
Crater Flat Tuff	Prow Pass Member	Zeolitized (CHnz)
	Bullfrog Member	
		Crater Flat unit (CFu)

Note: Figure not to scale

Figure 1.1-4. Diagram showing the relation of geohydrologic units to stratigraphic units (modified from Montazer and Wilson, 1984).

existence of large-aperture fractures provides not only conduits for potential future drainage in the unsaturated zone, but also large relative gas permeability. Natural gas-phase flow is driven by seasonal atmospheric-density differences between the mountain slopes and mountain summit, and by geothermal heat. Vapor discharges from the air-filled fractures may inhibit water percolation from rain and snow melt because of convective and diffusive vapor discharge to the land surface. If air flow reduces the matrix water content, the resulting increased water tension would aid in damping infiltration pulses that may be channeled in fractures. It is important to be able to quantify vapor flow because it may be opposite in direction to liquid flow, and of similar flux. Current knowledge of and site-characterization efforts for unsaturated-zone gas flow appear in YMP-USGS SP 8.3.1.2.2.6 (Yucca Mountain unsaturated-zone gaseous-phase movement).

Hydraulic, pneumatic, and hydrochemical testing and analysis will be conducted as part of this ESF unsaturated-zone study to provide an understanding of the conditions and processes described above. Integration of this information with the results of other hydrologic studies (Figure 1.1-1) will provide the basis for the development of the unsaturated-zone hydrologic model described in Section 2.

1.2 Regulatory rationale and justification

The results of unsaturated-zone testing conducted in the ESF ramps and drifts will provide hydrologic data for calculations of the unsaturated-zone ground-water travel time and the predictions of radionuclide releases to the accessible environment. Hydrologic properties determined in the study will be used in design analyses of the underground facility, repository seals, and waste packages.

The overall regulatory-technical relations between the SCP design and performance information needs and the data collected in this study are presented in the geohydrology testing strategy presented in SCP Section 8.3.1.2 and the issue-resolution strategies (repository, seals, waste package, and performance assessment) presented in SCP Sections 8.3.2 through 8.3.5. The description presented below provides a more specific identification of these relations as they apply to this study.

Project-organization interfaces between this ESF unsaturated-zone study and the YMP performance and design issues are illustrated in Figure 1.2-1. The figure also indicates project interfaces with other site studies; these relations are described further in Section 4.2. The relations between the design and performance issues noted below and the regulatory requirements of 10 CFR 60 and 10 CFR 960 are described in Section 8.2.1 of the SCP.

Information derived from the study will principally support the determinations of pre-waste-emplacment, ground-water travel time (Issue 1.6) and the predictions of radionuclide releases to the accessible environment (Issue 1.1). Study results will also provide information for the resolution of the issues concerned with the near-field hydrologic environment of the waste-package emplacement holes (Issue 1.4) and releases from the repository engineered-barrier system (Issue 1.5).

Physical, hydrologic, and hydrochemical information about the unsaturated-zone rocks obtained from this study will be used in the analyses for repository design (Issue 4.4) and in the assessments of repository post-closure performance (Issue 1.11). Unsaturated-zone information on fracture characteristics and hydrologic conditions will be used in developing the design requirements for ramp and borehole seals (Issue 1.12). Information on the moisture conditions and chemistry of the unsaturated-zone water will be used in the analyses of waste-package performance (Issue 1.10).

The following portion of this section summarizes from the SCP the study-level interfaces between this study and the performance and design issues. The discussion of the uses of site-characterization data from this study in resolving those issues is based upon performance measures and performance parameters identified in SCP Sections 8.3.2 through 8.3.5.

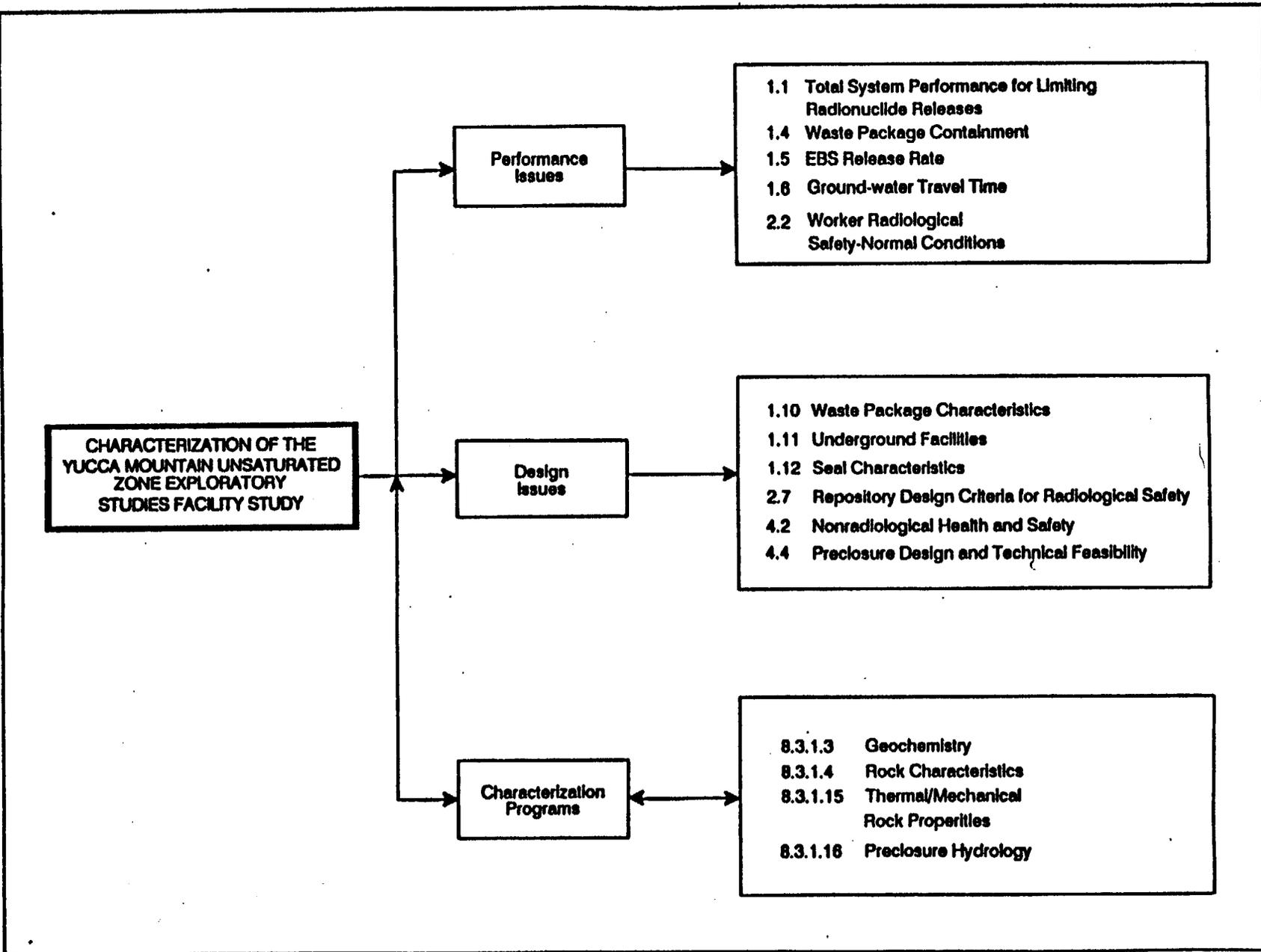


Figure 1.2-1. Diagram showing interfaces of the ESF characterization of the YM unsaturated-zone study with YMP performance and design issues and other site-characterization programs.

Performance Issue 1.1.

(Total-system radionuclide release to the accessible environment;
10 CFR 60.112 and 40 CFR 191.13)

In calculating the complementary cumulative distribution function (CCDF) for estimating radionuclide releases after repository closure, the DOE intends to take into account all those natural processes and events that are sufficiently credible to warrant consideration. Impacts of processes and events initiated by human activities will also be considered in the system-performance assessments for Issue 1.1. Selection of processes and events considered credible enough to affect future repository performance has resulted in the identification of a set of scenarios grouped in scenario classes, according to features which the scenarios have in common. The expected partial-performance measure (EPPM) for a scenarios class is a term that expresses the probability of occurrence of that scenario class. Significant scenario classes are those which have the highest EPPM values. (A detailed treatment of scenario classes and the EPPM concept appears in SCP Section 8.3.5.13.)

Scenario Class E, also called the nominal case, describes the undisturbed performance of the repository; it takes into account the legitimate, distinguishable alternative conceptual models that are supported by the available information. This class is associated with anticipated or expected conditions, and it describes the predicted behavior of the repository and the uncertainties in predicted behavior, considering only likely natural events.

Disruptive scenario classes (disturbed cases) are also developed in Issue 1.1. These classes are considered sufficiently credible to warrant consideration, but are outside the range of probability considered for the nominal case.

Site information resulting from this study will be used to satisfy the requirements of numerous supporting parameters needed to evaluate the nominal case of Scenario Class E of the issue-resolution strategy for total system performance. The study results will also provide baseline data for the disturbed cases. These supporting parameters (e.g., hydrologic characteristics of the rock matrix, fracture network, or fault zones specific to the repository area) are used in calculations of the performance parameters for the different scenarios.

In Scenario Class E, the unsaturated and saturated zones are considered the primary barriers to radionuclide migration, and the engineered barrier system is considered as a backup. SCP Table 8.3.5.13-9 is a description of the performance parameters for this scenario. Examples of performance parameters for the nominal case to which site-characterization data from the present study can contribute include average flux and average effective porosity in the unsaturated zone in the repository area. Supporting performance parameters needed to evaluate the nominal case and to serve as baseline data for the disturbed cases are listed in SCP Table 8.3.5.13-17. Supporting parameters pertaining to the unsaturated zone include effective porosity, relative

liquid permeability, and saturated permeability. Site data from the present study also contribute to these supporting parameters.

Unsaturated-zone hydrologic properties measured in this study (e.g., matrix and fracture permeability, porosity, and water content), as well as altitudes of stratigraphic contacts, contribute to the Issue 1.1 supporting parameters employed in the following calculations.

- Calculation of the specific-discharge field in the unsaturated zone, moisture content of unsaturated-zone units, and hydrodynamic response times in the overburden units.
- Calculation of the specific-discharge field in fault zones in the unsaturated zone, moisture content in fault zones, and hydrodynamic response times of fault zones.
- Calculation of coupling factors and radionuclide retardation factors in the unsaturated zone.
- Calculation of model validation coupling factors in the unsaturated zone.
- Calculation of gas-phase carbon-14 transport in the overburden units.
- Model calibration and validation of gas-phase carbon-14 transport in the unsaturated-zone overburden units.

Performance Issue 1.6

(Pre-waste-emplacement ground-water travel time; 10 CFR 60.113)

Issue 1.6 addresses the question of whether or not the candidate repository site can meet the Nuclear Regulatory Commission (NRC) performance objective for ground-water travel time. The performance objective is that the geologic repository shall be located so that the pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 yr (or such other time approved or specified by the NRC). Briefly, the qualitative description of the disturbed zone is the part of the controlled area where physical and chemical properties are expected to change due to underground facilities construction or the effects of waste-generated heat, such that the properties changed may have a significant effect on repository performance. The controlled area is a location which on the surface encompasses no more than 100 km² and extends no further than 5 km from the outer boundary of the radioactive wastes, and which includes the subsurface underlying the area defined by these limits. The accessible environment is the atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that is outside the controlled area.

As in Issue 1.1, site information from the study will be used to satisfy numerous supporting performance parameters needed to assess

ground-water travel time in individual unsaturated-zone units. These supporting parameters (e.g., unsaturated-zone rock matrix permeability in the repository area) are used to define various aspects of the unsaturated-zone model, spatial correlation structure model, and fracture-hydrologic-characteristics model. These aspects include initial and boundary conditions, material properties, system geometry, and validation of model concepts. The results of the ground-water travel-time model calculations yield performance parameters for each of the unsaturated-zone units. Examples of these performance parameters are discharge and distances along flow paths; these are applied to the performance measure of ground-water travel time for each of the hydrogeologic components of the ground-water regime.

Rock hydrologic and physical properties (e.g., rock matrix bulk density, bulk permeability), altitudes of geohydrologic-unit contacts, and water chemistry measured in this study are required as input for the supporting parameters for the unsaturated-zone ground-water travel-time model initial and boundary conditions, material properties, and system geometry. Porosity and fracture properties (e.g., fracture orientation, fracture distribution) are required in the fracture-hydrologic-properties model for supporting parameters for validation, material properties, and system geometry.

Performance Issues 1.8 and 1.9

(Favorable and potentially adverse conditions; 10 CFR 60.122)
(Qualifying and disqualifying conditions; 10 CFR 960.3-1-5)

The results of this study have indirect applications to the NRC siting criteria - Favorable Condition 7 (pre-waste-emplacment, ground-water travel time) through Issue 1.6, and Favorable Condition 8 (unsaturated-zone hydrogeologic conditions) through Issue 1.1. The study also has indirect applications to the higher-level findings for the geohydrology qualifying and disqualifying conditions through Issues 1.1 and 1.6.

Design Issue 1.10

(Characteristics and configuration of the waste package; 10 CFR 60.135)

Unsaturated-zone water chemistry, transmissive properties (e.g., transmissivity, hydraulic conductivity), and water-content information obtained from this study will be used to characterize the near-field (pre-waste-emplacment) environment of the waste packages.

Information on the quantity and quality of unsaturated-zone water obtained from this study will be used in assessing the performance of the engineered-barrier system in limiting the release of radionuclides. Hydrologic properties data (e.g., bulk permeability) of the Topopah Spring welded unit will be obtained from this study and will be used in calculating the flow and transport in the near-field host rock. The applicable performance

measures are concentrations of radionuclide species in the gas phase, liquid water, and adsorbed to solid phases within the near-field host rock. The performance parameters receiving site information are host-rock hydrologic properties.

The results of the this study will also support (indirectly through Issue 1.10) resolution of performance issues concerned with releases from the engineered-barrier system (Issue 1.5) and the performance of the waste package (Issue 1.4), where the applicable performance measure is the quality of water that can contact the waste container. The water-chemistry data collected in the study will apply to the hydrochemical performance parameters of the issue.

Design Issue 1.11

(Characteristics and configurations of repository and engineered barriers - post closure; 10 CFR 60.133)

The characteristics and configurations of the repository underground openings will rely, in part, on the rock physical, thermal, mechanical, and hydrologic properties information derived from this study. These information will be used in (a) assessments of the layout of the underground facility and the thermal-mechanical stability of the repository underground openings and (b) drainage and moisture control plans.

The rock physical (e.g., fracture aperture, fracture weathering), thermal (e.g., fractured-rock temperature), mechanical (e.g., fracture deformation), and hydrologic (e.g., volumetric rock matrix water content) properties derived from the matrix-properties testing for the radial-boreholes tests (Activity 8.3.1.2.2.4.4) and excavation-effects tests (Activity 8.3.1.2.2.4.5) will support assessments of the usable underground area for waste emplacement. Water-seepage and perched-water testing parameters (e.g., flow rates in the perched-water zones, discharge in the perched-water zones) in the ramps, drifts, and boreholes (Activity 8.3.1.2.2.4.7) and hydrologic-properties testing of major faults (Activity 8.3.1.2.2.4.10) will support the design of drainage and moisture-control systems for the repository underground facilities. Information (e.g., fracture orientation, fracture deformation) derived from the excavation-effects tests (Activity 8.3.1.2.2.4.5) will be used in evaluations of design constraints to limit excavation-induced changes in the rock-mass permeability.

Unsaturated-zone physical and hydrologic properties (e.g., rock matrix bulk density, rock matrix gravimetric water content) derived from this study indirectly support the assessment of the underground safety of the repository workers (Issue 2.2 and 4.2) and repository design criteria (Issue 2.7).

Design Issue 1.12

(Characteristics and configuration of repository and borehole seals; 10 CFR 60.134)

Unsaturated-zone information derived from this study will be used in the design of repository seals. Information on rock-hydrologic properties (e.g., hydraulic conductivity), *in-situ* stress, rock-mechanical properties (e.g., bulk permeability), fracture characteristics, and water chemistry will be obtained from ramp and drift construction-phase testing and borehole testing within the ESF.

Bulk-rock conductivity, extent and conductivity of the modified-permeability zone around the ramps and drifts, rock-mass fracture characteristics, and hydrogeologic contact information will be obtained from the radial-borehole tests (Activity 8.3.1.2.2.4.4). Information obtained about the extent and hydraulic conductivity of permeability zones in tuff units in the repository will be used for the design of borehole and ramp seals.

The excavation-effects tests (Activity 8.3.1.2.2.4.5) will provide information on the *in-situ* stress, the modified-permeability zones around the ramps and drifts, and the unsaturated hydraulic conductivity and fracture characteristics of the rock mass around the openings. These data will be used in the design of ramp and drift seals.

Results of water-sample analysis (Activity 8.3.1.2.2.4.8) from perched-water zones or from fractures and faults will provide hydrochemical information needed for ramp, drift, and borehole seal design. Discharge rates from perched-water zone tests results (Activity 8.3.1.2.2.4.7) will also be used in designing repository seals.

Design Issue 4.4

(Repository design and technical feasibility)

The altitudes of rock-unit contacts derived from the geologic mapping in the ramps and drifts (Activity 8.3.1.4.2.2.4) will provide information to assess the thickness of the rock units. This information will be used to determine the underground space available for repository construction and waste emplacement.

In-situ stresses, rock-mechanical properties, and fracture geometry and deformation information obtained in the excavation-effects tests (Activity 8.3.1.2.2.4.5) will support the assessments of developing usable repository underground openings (ramps, drifts, emplacement rooms, and boreholes) of required size under normal and credible abnormal conditions. Information from this activity will be used in evaluating the rock-mechanical and rock-hydrologic property changes in the disturbed rock around the underground openings and the impacts of these changes on the repository design.

Condensate from seeps and natural water inflow from perched-water zones (if encountered) will be evaluated in the ramps, drifts, and boreholes (Activity 8.3.1.2.2.4.7), and the radial boreholes (Activity 8.3.1.2.2.4.4). Water-flow rate information (e.g., discharge in perched-water zones) will be used in the design of systems for water control in the ramps, drifts, boreholes and repository openings. Water-chemistry data (Activity 8.3.1.2.2.4.8) will also be used in underground facility design.

It should be noted that the principal data on rock-deformation properties for the resolution of design and performance issues are taken from Investigation 8.3.1.15.1 (Spatial distribution of rock thermal and mechanical properties), from Investigation 8.3.1.15.2 (Spatial distribution of ambient stress and thermal conditions), and for rock-unit contacts and fracture geometry and properties from Investigation 8.3.1.4.2 (Geologic framework of Yucca Mountain). Data acquired in Study 8.3.1.2.2.4 are primarily for the understanding of unsaturated-zone hydrologic properties and have a secondary utility in supplementing data needs outside the study. For example, in-situ stress data gathered in Activity 8.3.1.2.2.4.5 (Excavation-effects tests) are measured mainly to estimate permeability changes caused by repository construction; however, these data will also contribute to Study 8.3.1.15.2.1 (Site ambient stress conditions).

The following briefly summarizes the information to be obtained by the activities of this study. More detailed descriptions of information to be obtained are presented in Section 3.

The intact-fracture tests (Activity 8.3.1.2.2.4.1) will provide an understanding of fracture-flow processes at an in-situ scale of one to two fracture spacings. These determinations will be used to improve on estimates of matrix-fracture flow transition and flux needed for ground-water model validation.

The percolation tests (Activity 8.3.1.2.2.4.2) will provide direct evidence of water-percolation rates at an intermediate in-situ scale at several locations in the Topopah Spring welded unit (TSw). These determinations will have application to ground-water flow path and travel-time determinations.

The bulk-permeability tests (Activity 8.3.1.2.2.4.3) will provide intermediate in-situ scale measurements of the Topopah Spring welded unit conductivity. These determinations will have application to water-vapor and gas-flux calculations in the assessments of ground-water and gas travel times in the TSw. The radial-borehole tests (Activity 8.3.1.2.2.4.4) will provide cross-hole test information within each of the tuff units in the unsaturated zone and across selected contacts between these units. The permeability measurements obtained from the radial boreholes will provide, with similar scale information obtained from the bulk-permeability tests (Activity 8.3.1.2.2.4.3) and surface-based boreholes testing (Activity 8.3.1.2.2.3.2), broad spatial coverage of the hydrogeologic properties of Yucca Mountain.

The excavation-effects tests (Activity 8.3.1.2.2.4.5) will provide an estimate of stress-induced changes on permeability as a result of ramp excavation. These changes will provide estimates of flow-path adjustments for ground-water travel-time calculations as a result of excavation of the underground openings.

Perched-water zones (if encountered) will be monitored and tested (Activity 8.3.1.2.2.4.7) to determine flow paths and rates. Test results will be applicable to ground-water travel-time calculations and repository-design analyses.

Chemical testing of water and gas samples obtained from core samples and from boreholes drilled in the ESF (Activity 8.3.1.2.2.4.8) will provide independent data (from the hydraulic characteristics) of flow paths and travel times. The chemical and isotopic data will be used as means of confirming conceptual models and validating numerical models of ground-water and gas-flow paths and travel times.

The major-fault hydrologic-properties activity (Activity 8.3.1.2.2.4.10) will collect matrix, rock-mass, and chemical data to evaluate the permeability and flow conditions of principal faults encountered in the ramps and drifts of the exploratory-studies facility.

2 RATIONALE FOR STUDY

2.1 Technical rationale and justification

Section 3 of this plan provides additional detail for the specific activities, tests and analyses, and methods of this study. This section provides an overview and justification of the overall study.

2.1.1 Statement of problem and test justification

Understanding the unsaturated-zone flow system at Yucca Mountain is essential to the site-characterization program because it is within this interval of partially saturated rocks that the repository is proposed to be constructed. The geologic evaluation of the site is a multi-discipline effort. Programs and investigations are planned to study the geochemical and geologic characteristics (SCP Section 8.3.1.3, Geochemistry; 8.3.1.4.2, Stratigraphy and structure; and 8.3.1.15.1, Thermal and mechanical properties). It is not within the scope of this study plan, however, to discuss the geologic and rock-characteristics studies. The reader is referred to the SCP and associated study plans for descriptions pertaining to the particular studies or activities of interest. This study plan discusses only the unsaturated-zone hydrologic tests in the exploratory-studies facility.

In the unsaturated zone, water is presumed to be present both in liquid and vapor phases within the interstitial, fracture, and lithophysal openings. It is important to evaluate water flow and storage within the repository block because water is the expected major medium for any transport of radionuclides to the accessible environment. Water flow and storage is envisioned to be complexly three dimensional, controlled by the structural, stratigraphic, and climatological settings, and, in general, liquid-water flow is expected to occur within interconnected pores and fractures, as well as advective and diffusive vapor-phase flow within interconnected air-filled fracture openings.

In addition to understanding water movement within the repository block, there is a need to consider and account for the occurrence of dissolved constituents in both the liquid and gas phases. The concentrations and transport of solutes within the unsaturated zone are coupled to the occurrence and movement of water (liquid and vapor) and may also be affected by chemical interactions with the surrounding rock matrix. Furthermore, because liquid-water and vapor are expected to be in local thermodynamic phase equilibrium, liquid-water saturation and water-vapor and solute concentrations are coupled through the prevailing geothermal regime. Consequently, the hydrologic evaluation of the site constitutes a problem of two-phase, multi-component, coupled heat (geothermal) and water flow within a layered sequence of tilted, faulted and fractured, variably saturated tuffaceous geohydrologic units.

Hydrologic testing in the ramps, underground drifts, and underground boreholes will (1) supplement and complement surface-

based hydrologic information with *in-situ* hydrologic characterization of the rock mass, (2) provide an opportunity for directly inspecting the structure and stratigraphy of the rock walls, and (3) provide an opportunity to evaluate rock-matrix and fracture-hydrologic parameters for a wide range of test scales. The ESF unsaturated-zone tests are designed with the objective of ultimately providing an understanding of the spatial and temporal water movement within the unsaturated zone.

The ESF unsaturated-zone tests will provide hydrologic information that is not readily obtainable from surface-based boreholes. The ESF provides a testing environment that is suitable for three-dimensional characterization of the rock mass, and the percolation tests are designed to study hydraulic parameters in multiple directions. Lateral variations will be studied through horizontal drifts and boreholes and by careful mapping of underground rock exposures. Excavation of the ramps and drifts will produce large volumes of rock that can be used for determination of water chemistry (Activity 8.3.1.2.2.4.8, Hydrochemistry tests) and for laboratory analysis of rock/hydraulic properties. Samples of rocks containing intact fractures can be readily obtained from within the ramps and drifts. Results of hydraulic tests (Activity 8.3.1.2.2.4.1, Intact-fracture tests) on such samples will be more representative of *in-situ* conditions, thereby increasing confidence in correlations between hydrologic and geologic data and, ultimately, *in-situ* characterization. Percolation tests can be conducted in a rock mass that has not been disturbed by recent weathering and is representative of the repository host rock.

In addition to determination of specific hydrologic parameters and relations, the effects of excavation on the host rock can be studied directly in the ESF. The radial-boreholes (Activity 8.3.1.2.2.4.4), percolation (Activity 8.3.1.2.2.4.2), bulk-permeability (Activity 8.3.1.2.2.4.3), and perched-water (Activity 8.3.1.2.2.4.7) tests will indirectly provide multi-scale information on geohydrologic properties invaluable to the analysis of the design and performance of the repository. The excavation-effects tests (Activity 8.3.1.2.2.4.5) will directly estimate the magnitude and extent of the modification of the TSw geohydrologic unit caused by excavation. The major-fault hydrologic properties test (Activity 8.3.1.2.2.4.10) will provide data on permeability and flow conditions of discrete major fault zones.

The ESF will provide an ideal environment for *in-situ* hydrologic tests of the unsaturated zone beneath Yucca Mountain, the objective of the tests being to quantitatively define geohydrologic parameters influencing water flow in the TSw and CHn. Because the spatial and temporal extrapolation of water flow within the unsaturated zone involves complex interactions that can only be described with the aid of hydrologic models, preliminary data from the ESF hydrologic tests will be used as a basis for multiscale, numerical modeling of the unsaturated zone. These models will provide a description of the important components of the geohydrologic system and will reflect an

understanding of the hydrologic parameters, the initial and boundary hydrologic conditions and processes, and their relations.

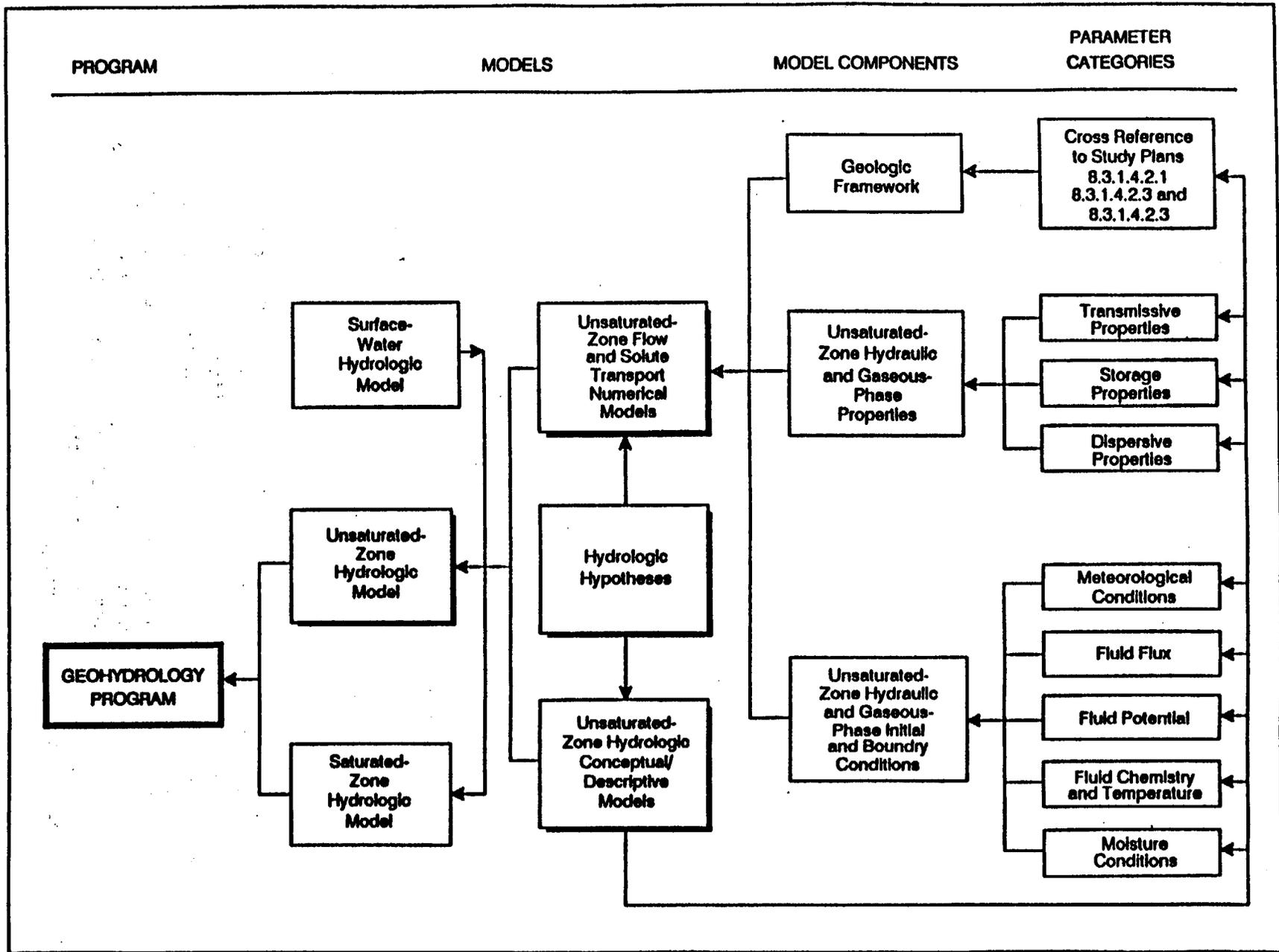
The geohydrologic program will develop two hydrologic models that will describe two distinct zones of the hydrologic system: the unsaturated zone and the saturated zone (Figure 2.1-1). A surface-water hydrologic model will be developed to provide input to these two hydrologic models. The hydrologic models will be used at many stages of site characterization to perform preliminary analyses, to design and analyze tests and experiments, and to analyze and interpret field data. The principal hydrologic modeling effort is to construct mathematical representations to simulate the natural geohydrologic system and its components.

The ESF unsaturated-zone tests and corresponding hydrologic model concentrate on the deep part of the unsaturated zone. The unsaturated-zone hydrologic model will be developed at site scale, whereas the surface-water and saturated-zone hydrologic models will be developed at both site and regional scales. The hydrologic zones described by these models are those that significantly affect the resolution of hydrologic-related design and performance issues; these zones therefore are the principal subjects of hydrologic investigations. The logic diagram of Figure 2.1-1 shows the relations among the hydrologic models and the overall geohydrologic program. The diagram expands the unsaturated-zone hydrologic model to show the components and parameters categories that are used in that model. The diagram shows that the unsaturated-zone model consists of numerical and conceptual models, which in combination will provide a hydrologic description of the unsaturated zone.

The unsaturated-zone hydrologic model consists of three major components: (1) the geohydrologic framework, (2) rock properties, and (3) initial and boundary conditions. The geohydrologic framework establishes the unsaturated-zone system geometry. Rock properties include unsaturated-zone hydraulic and gaseous-phase properties. Boundary conditions include hydrologic infiltration (land surface) and water-table boundaries. These components form the basis for developing the numerical models that quantitatively describe various aspects of the zone and are used as a basis for developing the technical rationale for the planned work.

2.1.2 Parameters and testing strategies

In SCP usage (U.S. Department of Energy, 1988) activity parameters are those parameters that are generated by testing and analysis in the field, laboratory, or office; they represent the most basic measurements that will be used to characterize the geohydrology of Yucca Mountain and vicinity. Many of the activity parameters are building blocks to support various aspects of the project. Some, such as hydraulic conductivity, support design and performance issues directly. Others primarily provide bases for analyses and evaluations to be conducted within the Geohydrology Program or within other characterization programs.



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Figure 2.1-1. Logic diagram of Geohydrology Program, including model components and parameter categories.

In SCP Table 8.3.1.2-1, activity parameters for the Geohydrology Program are grouped according to parameter categories. The activity parameters associated with activities of this study also appear in the figures and tables of Section 3 of this study plan. Parameter categories serve to group similar types of performance and design parameters supporting performance-assessment and design issues resolutions (SCP Sections 8.3.2 through 8.3.5) and match them with groups of similar types of activity or characterization parameters to be obtained during site characterization. Parameter categories in the SCP were introduced as a classification scheme to aid in assessing the appropriateness and completeness of the data collection program. In Figure 2.1-1, the parameter categories are shown supporting specific model components that make up the site unsaturated-zone model. This figure corresponds to SCP Figure 8.3.1.2-3, and in that document is accompanied by parallel logic diagrams for the surface-water and saturated-zone components of the Geohydrology Program.

In SCP usage, a characterization parameter is a parameter, obtained by a characterization program, that has a logical, direct tie to a performance or design parameter, and for which a testing basis can be defined. Most characterization parameters will be developed from some combination of activity parameters, and will be the products of data reduction, tests and analyses, and modeling. Hydrologic analyses generated in this study can be traced from activity parameters through characterization parameters and to their intended use in satisfying performance-assessment requirements for issues resolutions.

In this and other study plans, it has been useful to group the measured or calculated parameters of the various activities (activity parameters) into a limited set of characterization parameters, more broadly defined parameters that encompass activity parameter data collected in the field and laboratory, or generated by modeling. By introducing these parameters, it becomes easier to understand how the study relates to satisfying the information requirements of parameters in the design and performance issues. The grouping of activity parameters according to characterization parameters is given in Table 2.1-1. Characterization parameters also appear in the logic diagrams accompanying the activity descriptions of Sections 3.4, 3.5, 3.7, and 3.8.

Characterization parameters will be expressed as functions of space and (or) time and will be presented in formats that will facilitate use of the data in resolving design and performance issues. In future SCP progress reports, a testing basis will be developed for each characterization parameter, and will consist of some means of expressing the goals, confidence limits, and accuracy associated with each characterization parameter, so that requirements of performance parameters can be satisfied. An example of a testing basis could be that some statistical measure of the parameter, such as the mean, be known to a specific degree of accuracy.

Table 2.1-1. Association of activity parameters with site-characterization parameters

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
Activity 8.3.1.2.2.4.4 - Radial-borehole tests	Hydraulic conductivity	Permeability, water
	Gas permeability	Permeability, relative, gas, rock matrix Permeability, saturated, gas, rock matrix Pneumatic permeability, bulk, fractured rock Permeability, pneumatic Fracture permeability Gas permeability, excavation effects Porosity pore-size distribution, matrix Porosity, bulk, fractured rock Porosity, matrix Porosity Bulk density, rock matrix Grain density, rock matrix Fracture characteristics: distribution, aperture, weathering Anisotropy Fracture aperture Fracture permeability
	Water permeability	Moisture retention, rock matrix Water content, gravimetric, rock matrix Water content, volumetric, rock matrix Permeability, relative, water, rock matrix Porosity pore-size distribution, matrix Porosity, bulk, fractured rock Porosity, matrix Porosity Bulk density, rock matrix Grain density, rock matrix Anisotropy Fracture aperture Fracture permeability
	Hydraulic gradient	Water potential, distribution and fluctuation Water potential, rock matrix, and total fractured rock Pneumatic potential, distribution and fluctuation Pore-gas composition Radioactive isotopes Stable isotopes
Activity 8.3.1.2.2.4.4 - Radial-borehole tests	Gaseous diffusion	Gaseous diffusion coefficient, fractured rock units Diffusive tortuosity, fractured rock and rock mass Temperature, distribution and fluctuations

Table 2.1-1. Association of activity parameters with site-characterization parameters (continued)

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
Activity 8.3.1.2.2.4.5 - Excavation-effects tests	Fracture permeability	Initial fracture permeability around excavations Changes in fracture permeability due to excavation effects Changes in rock stress due to excavation effects Fracture locations Fracture characteristics In-situ rock stress and mechanical property measurements In-situ stress changes, magnitude and direction Fracture deformation Changes in rock stress due to excavation effects Effects of stress changes on fracture aperture Fracture aperture Fracture distribution Fracture orientation Fracture roughness
	Fracture effective porosity	Changes in fracture effective porosity due to excavation effects Rock density Rock porosity Fracture locations Fracture characteristics In-situ rock stress and mechanical property measurements Changes in rock stress due to excavation effects Effects of stress changes on fracture aperture Fracture aperture Fracture distribution Fracture orientation Fracture roughness
Activity 8.3.1.2.2.4.5 - Excavation-effects tests	Fracture saturation	Moisture content, in-situ degree of saturation Changes in fracture saturation due to excavation effects Fracture locations Fracture aperture Fracture distribution Fracture orientation Fracture roughness

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Table 2.1-1. Association of activity parameters with site-characterization parameters (continued)

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
Activity 8.3.1.2.2.4.7 - Perched-water tests	Hydraulic conductivity	Hydraulic conductivity, perched-water zones Transmissivity Porosity, rock units near ramps and drifts
	Hydraulic gradient	Water potential (total), perched-water zones Hydraulic head, perched-water zones Radioactive isotopes Stable isotopes Water quality Potential
	Ground-water flux	Infiltration rate Discharge rate Flow rates, perched-water zones
	Storage coefficient	Storage coefficient, perched-water zones
Activity 8.3.1.2.2.4.8 - Hydrochemistry tests	Flow paths, ground water and gas	Radioactive-isotope activity Stable isotopes Pore-gas composition Water quality, cations and anions Flow paths, hydrochemical determination
	Travel times, ground water and gas	Radioactive-isotope activity Stable isotopes Pore-gas composition Water quality, cations and anions Travel times, hydrochemical determination

2.1-8

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A common requirement of the activity parameters is that sufficient confidence can be placed in their numerical values and in the understanding of their relations for hydrologic modeling and hypothesis testing. That is, confidence in the calibration of a model to a given level is dependent on the extent to which the input data and observations are well characterized and credible. These empirical data are affected by uncertainties due to measurement errors and to presence of both random and correlated large-scale spatial variability (heterogeneities). The presence of these uncertainties must be considered in order to assess the accuracy with which numerical hydrologic models simulate the natural geohydrologic system. The sensitivity of the performance measure to various parameters can, nevertheless, be investigated, and such models can be used as tools to improve understanding of the functioning of each zone, to test hypotheses, and to further guide data collection.

Some of the specific parameters listed in Table 2.1-1, although not required directly for resolving performance and design issues, are required to accomplish satisfactory hydrologic modeling, which in turn increases confidence in the accuracy of the parameters that are required for performance and design analyses. Because model parameters cannot be known explicitly everywhere throughout the modeled area, the input parameters must be expressed as statistical distribution functions. Numerical models will be used as a principal approach to assess whether the data collected to describe the present and expected geohydrologic characteristics provide the information required by the performance and design issues.

A principal testing strategy of the study, therefore, is to utilize approaches that minimize uncertainty of the activity parameters and in the understanding of their relations within the constraints of available resources. Some degree of uncertainty is inevitable, because parameters vary in space and time, measurements contain errors, and hydrologic processes are slow and difficult to measure. As described below, however, the strategy of the study is to increase confidence by utilizing multiple approaches for determining parameters not readily amenable to measurement or analysis, by testing hypotheses, and by developing acceptable models.

A major advantage to using multiple approaches for determining parameters is that, in general, reliance is not placed only on one test to determine a parameter. Some tests will provide only partial information, whereas others will provide extensive information necessary for determination of a hydrologic parameter. By combining the test results and studying their relations, a greater understanding and confidence of any particular parameter can be achieved. For example, the estimation of fluid-travel times (a critical issue) can be addressed with multiple approaches. Fluid travel time can be estimated by calculating the residence of environmental tracers in the pore water or by calculating the velocity at which fluid flows through the rock from the bulk hydrologic parameters. The hydrochemistry tests will provide residence times for pore and fracture fluids at the repository site. The combination of intact-fracture, bulk-permeability, percolation,

radial-borehole, and major-fault hydrologic properties tests will provide data on permeability, effective porosity, and pore-size distribution necessary for the calculation of travel time. In addition, the percolation tests will provide velocities at various steady-state infiltration rates in small volumes of rock. Fluid potential distributions will be obtained from the radial-borehole and major-fault hydrologic-properties tests, and if perched water is encountered, hydrologic tests and hydrochemical tests will be conducted to evaluate water flux, flow paths and travel times.

Because of the nonstandard nature of some of the tests, the possibility that one or more tests may fail in achieving the desired objectives is recognized. The use of multiple approaches for determining parameters increases confidence that the failure or the partial failure of one or more tests will not severely inhibit the ability of the characterization activities in providing the information required. Prototype tests for site characterization, especially those related to characterization of the unsaturated zone, have been performed (see Dennis, 1991) which has increased the confidence level that test objectives can be achieved.

For some activity parameters, it is necessary to measure them at different scales. For example, various tests are designed to measure unsaturated fracture hydraulic conductivity, from the conductivity of discrete fractures to that of increasingly more extensive fracture networks. The smallest-scale test is the intact-fracture tests which entails direct observation and measurement of fluid and mass transport within a single fracture. The purpose of the small-scale testing is to develop an empirical foundation for modeling flow and transport through single fractures. When this discrete-fracture model is evaluated (calibrated and validated), it can be used to simulate a larger network of discrete fractures. The percolation tests will then be used to evaluate the fracture-network model. In turn, another numerical model, based on this fracture-network approach, will be applied to simulate the percolation tests. The error in evaluating flow through the percolation test block by the fracture-network modeling approach may be large, because the percolation-tests scale may not be representative of the entire rock mass. For this reason, the bulk-permeability and radial-borehole tests will be conducted to evaluate the effect of size on variations of hydrologic properties. In the bulk-permeability tests, the pneumatic permeabilities of different volumes of rock will be evaluated directly from cross-hole tests, data that will then be used to estimate the scale at which the continuum approach is valid. The variable-scale discrete model developed from intact-fracture tests will be used to predict the hydrologic properties of a large volume of rock that will be tested later in the main test level of the ESF. Results from this model will be compared with results using the fracture-network model developed from percolation tests. If predictions prove to have insignificant error, the technique can be used to extend results of the bulk-permeability tests to other parts of the ESF and repository block. In turn, the validity of this extrapolation method will be tested directly by the radial-borehole

tests (Activity 8.3.1.2.2.4.4), the surface-based vertical- and horizontal-borehole tests (Study 8.3.1.2.2.3), and gaseous-phase movement study (Study 8.3.1.2.2.6) which averages permeabilities for very large volumes of rock by recording pressure changes at various levels in boreholes caused by barometric fluctuations.

The process of variable-scale testing and modeling will delineate the scale at which the continuum approach can be used with minimum error as well as provide large-scale understanding of the host rock. The results will increase confidence that an understanding has been gained of the relations between hydraulic conductivity and fracture characteristics, and that the appropriate scale has been selected for modeling and testing of the hydrologic hypotheses. The testing and refinement of hydrologic hypotheses provide a logical and systematic approach to improving our understanding of how the geohydrologic system functions. The result will be an improved conceptual model which, in turn, leads to increased confidence in the hydrologic models and, ultimately, in the geohydrologic program (Figure 2.1-1). In turn, results of the study will provide a basis for updating and revising the hypotheses.

2.1.3 Hydrologic hypotheses

The unsaturated-zone hydrologic hypotheses describe in general terms the manner in which fluids (water and gas) may move through the unsaturated zone. The testing and refinement of hypotheses provide a logical and systematic approach to the ultimate definition of how the geohydrologic system functions. The results will be an improved conceptual model which, in turn, leads to increased confidence in the geohydrologic evaluation of the repository site.

The hypothesis component shown in Figure 2.1-1 is tied to Table 2.1-2, which lists current hypotheses for the unsaturated zone. The table also shows objectives and approaches of the activities that are directly involved in testing these hypotheses.

In conducting preliminary performance and design analyses, assumptions must be made regarding parameters and hydrologic processes and conditions. These preliminary analyses may include assumptions involving parameters such as flow paths, velocities, fluxes, gradients, conductivities, anisotropies, boundary conditions, and structural and geohydrologic-unit controls on unsaturated flow. Concepts that may affect these aspects of the hydrologic system include the potential for lateral flow and capillary barriers in the unsaturated zone, conditions under which matrix and fracture flow occur, and accumulation of perched water. The ongoing process of hypothesis testing helps to increase confidence that the assumptions made in preliminary analyses are reasonable.

2.1.4 Hydrologic modeling

In assuming that the overall hydrologic system within the unsaturated zone at Yucca Mountain can be described by conventional theories of fluid storage and movement in porous and fractured media,

Table 2.1-2. Relations between unsaturated-zone hydrologic conceptual model hypotheses and the activity objectives of Study 8.3.1.2.2.4

Hypothesis	SCP number	Activity objectives
Fractures and fracture systems and barriers to or conduits for liquid-water flow, depending on ambient matrix saturation.	8.3.1.2.2.4.1	To evaluate fluid-flow and chemical-transport properties of single, relatively undisturbed fractures.
	8.3.1.2.2.4.2	To determine the hydrologic conditions that control the occurrence of fluid flow within fractures and matrix and to provide experimental data against which the validity of numerical models can be tested.
Discrete fractures and fracture networks can be modeled as equivalent porous media.	8.3.1.2.2.4.1	See above objectives.
Orientation of fractures and faults influences degree of transmissiveness, thereby introducing a fundamental system anisotropy.	8.3.1.2.2.4.2	See above objectives.
	8.3.1.2.2.4.3	To determine the scale at which the host rock behaves as an equivalent anisotropic porous medium.
	8.3.1.2.2.4.3	To compare hydraulic test results against a distribution of simulated results calculated from a large number of realizations of the possible fracture networks conditioned on average fracture orientation and/or fracture density data.
	8.3.1.2.2.4.3	To use a numerical fracture-flow model to establish the minimum dimensions at which other rock masses with the same fracture characteristics behave as equivalent porous media and to examine the dependence of rock-mass dimensions on changing saturation.
	8.3.1.2.2.4.4	To evaluate the potential for lateral flow of water within dipping units.
	8.3.1.2.2.4.4	To evaluate the potential for lateral flow of water along geohydrologic-unit contacts.

Table 2.1-2. Relations between unsaturated-zone hydrologic conceptual model hypotheses and the activity objectives of Study 8.3.1.2.2.4 (continued)

Hypothesis	SCP number	Activity objectives
	8.3.1.2.2.4.4	To detect vertical flows of water, as both vapor and liquid, in the unsaturated zone.
Hydrologically interconnected fracture systems and rock matrix define a macroscopic composite or equivalent porous medium.	8.3.1.2.2.4.2	See above objectives.
	8.3.1.2.2.4.3	See above objectives.
Unsaturated lateral flow can occur at the contact between the Tiva Canyon welded (TCw) and Paintbrush nonwelded (PTn) units, depending on the flux and the permeability contrast across the contact.	8.3.1.2.2.4.4, 8.3.1.2.2.4.8	To evaluate the potential for lateral flow of water along geohydrologic-unit contacts, using radial borehole tests in the ESF, and to evaluate hydrochemical-isotopic data from any gas and pore water collected.
Lateral flow can occur within the PTn, because of intercalation of layers with contrasting hydraulic properties within the unit.	8.3.1.2.2.4.4	To evaluate the potential for lateral flow of water within dipping units, using radial borehole tests in the ESF.
Flow in the Topopah Spring welded unit (TSw) is downward and occurs under steady-state conditions. Flow is primarily in the matrix when the flux is less than some value related to the saturated matrix hydraulic conductivity, and flow is primarily in fractures at fluxes larger than that value.	8.3.1.2.2.4.4	To detect vertical flow of water, as both vapor and liquid, in the unsaturated zone using radial borehole tests in the ESF.
The nearly vertically oriented fault zones and their associated fractures can be highly effective pathways for vertical liquid-water flow with large flux, especially in the competent TCw and TSw. Under some conditions, faults can impede lateral flow and thus produce perched-water bodies where the faults intercept significant lateral flow.	8.3.1.2.2.4.7, 8.3.1.2.2.4.10	To detect the occurrence of any perched water, estimate the hydraulic properties of the zones, and determine the implication of existence of such zones of flux, flow paths, and travel times.
Perched-water bodies and capillary-barriers may be temporarily present within the UZ system.	8.3.1.2.2.4.7	To detect the occurrence of any perched-water zones.
	8.3.1.2.2.4.7	To estimate the hydraulic properties of the zones.
	8.3.1.2.2.4.7	To determine the implications of the existence of such zones on flux, flow paths, and travel times.

Table 2.1-2. Relations between unsaturated-zone hydrologic conceptual model hypotheses and the activity objectives of Study 8.3.1.2.2.4 (continued)

Hypothesis	SCP number	Activity objectives
Volumes containing many pores and fractures are definable such that changes in boundary fluxes equal changes in internal moisture storage.	8.3.1.2.2.4.8	To understand the gas transport processes within the unsaturated zone and to provide independent evidence of flow direction, flux, and travel time of gas.
	8.3.1.2.2.4.8	To design and implement methods for extracting uncontaminated pore fluid from rock excavated during ramp construction.
	8.3.1.2.2.4.8	To determine the flow direction, flux, and travel time of water in the unsaturated zone by isotopic geochemistry techniques.
	8.3.1.2.2.4.8	To determine the extent of water-rock interaction so that geochemical modeling can be performed to deduce the flow path and to understand the geochemical evolution of the unsaturated zone water.

the present and probable future spatial distribution and magnitude of hydrologic parameters can be predicted from appropriately constructed hydrologic models. The successful development of calibrated numerical models of the hydrologic system will increase confidence that the geohydrologic framework, distribution of input parameters, and nature of initial and boundary conditions are appropriate for utilization in performance and design analyses.

Hydrologic modeling produces the velocity field essential for defining flow paths and computing ground-water travel time. Such modeling requires sufficiently detailed knowledge of the geohydrologic framework and the three-dimensional distribution of hydrologic parameters. The importance of these ESF unsaturated-zone tests for determining the magnitude and distribution of these hydrologic parameters is emphasized. *In-situ*, underground, multiple-approach, variable-scale testing is necessary for developing a complete and accurate geohydrologic program of the repository block under Yucca Mountain.

2.2 Constraints on the study

2.2.1 Prototype testing

The USGS investigators responsible for the activities described in Section 3 have chosen and proposed testing procedures that they expect will work as planned. The investigators recognize, however, that there is a degree of risk associated with many of the tests that have not been previously tried and have therefore planned and conducted prototype tests to validate the performance of the proposed testing methods. For a summary of results of prototype tests, see Dennis (1991).

Prototype testing serves several purposes, including the development of reasonable and adequate quality-assurance procedures and an assessment of the data-acquisition and storage needs of individual tests. Primarily, prototype testing provides an opportunity to understand, implement, refine, and practice testing procedures prior to the actual testing. For example, certain hydrology tests (bulk permeability, percolation, and excavation effects) have never been performed at the proposed scales. Similarly, many of the proposed testing methods have never been applied to unsaturated, densely welded, fractured tuffs, such as the Topopah Spring welded unit at Yucca Mountain (Figure 1.1-4).

Equipment selection and development is a major objective of the prototype testing. As such, specification of equipment to be used during site characterization cannot be completely defined until this testing is done. For standard testing methods, equipment lists may be found in the technical procedures noted for each activity described in Section 3 of this plan.

Because the underground facilities have not been constructed at Yucca Mountain, geologic and hydrologic prototype testing has been conducted at G-tunnel in Rainier Mesa, which is located at the Nevada Test Site (NTS) about 60 kilometers (40 miles) from Mercury, Nevada. Prototype testing and equipment development for the air permeability testing activity was conducted at the Apache Leap Tuff site near Superior, Arizona. Prototype drilling, instrumentation, and testing established procedures that will be needed for site-characterization tests to provide quality-assured data for the licensing process.

References are made to specific prototype tests in each of the activity descriptions of Section 3.

2.2.2 Representativeness of repository-scale and correlation to repository conditions

The ESF is located within the repository area and will penetrate the same geohydrologic units as does the repository. Because of this, the environment in which ESF tests will be conducted is an approximate representation of the repository area and representativeness should be enhanced by the current ramp-based rather than shaft-based design. How well each test will represent future or present

conditions of the repository at the scale of the repository depends on a number of factors relating to the particulars of the test.

The ESF hydrologic-test results will be extrapolated across the site on the basis of an integrated drilling plan (SCP Section 8.3.1.4.1, Development of an integrated drilling program) and an integrated geologic- and hydrologic-characterization program. Geologic studies (Study 8.3.1.4.2.1, Vertical and lateral distribution of stratigraphic units within the site area; 8.3.1.4.2.2, Structural features within the site area; and 8.3.1.4.2.3, Development of a three-dimensional geologic model of the site area) will provide larger-scale models that will allow ESF-scale test results to be extrapolated across the site surface-based hydrologic testing in boreholes (Activity 8.3.1.2.2.3.2, Site vertical-borehole studies) and will also increase confidence in the ability to extrapolate across the repository site.

The representativeness of the current testing plans is considered to be much more representative than what was described in the SCP Section 8.4.2.1.5 (Representativeness of planned testing) for tests in a vertical shaft. The current ESF will have a minimum of two ramps with drifts in the TSw2, with an option for two additional ramps and drifts in the CHn. Drifts will extend from the ramps to the Ghost Dance Fault, Solitario Canyon Fault, and Imbricate Fault zone. Figure 1.1-3 illustrates the appropriate locations of where the ramps and drifts will cross major geologic structures that will allow for a visual and a hands-on inspection for geologic and hydrologic rock properties.

2.2.3 Accuracy and precision of methods

Selected and alternate methods for testing in each activity are summarized in tables at the end of each activity description (Section 3). These methods were selected on a basis of their precision and accuracy, duration, and interference with other tests and analyses. The accuracy and precision of the exploratory-studies facility hydrologic tests is difficult to quantify prior to testing and implementation of the methodology. The degree of accuracy and/or precision of each method within activities is a qualitative, relative judgement based on current knowledge and familiarity with, and understanding of, the method. Prototype testing was also helpful in assessing the accuracy and precision of the methods proposed for collecting site characterization data. For selected methods, if values for accuracy and precision exist, they will be listed in the USGS technical procedures which are referenced in the activity descriptions of Section 3.

2.2.4 Potential impacts of activities on the site

The current ESF design consists of the following:

1. Two ramps: Designated as the North and South Ramps, will extend from the surface and connect underground with the Main Drift;
2. Main Drift in the TSw2 that connects the North and South Ramps;
3. Core test area of the Main Test Level: Principal area in the Topopah Spring Member where the majority of testing will be conducted;
4. Calico Hills Ramps: Ramps that provide access from the Topopah Spring Member to the Calico Hills geologic barrier and provide access to the Imbricate, Ghost Dance, and Solitario Canyon fault zones;
5. Calico Hills Main Drift: A lateral drift through the Calico Hills unit that will provide access for the exploratory drifts to the Imbricate, Ghost Dance, and Solitario Canyon fault zones;
6. Lateral Drift Extension from Main Drift: A drift constructed by the drill and blast method. The diameter has not yet been determined;
7. East-West Drift to test Ghost Dance Fault;
8. Drifts from ramps to test Ghost Dance Fault, Solitario Canyon Fault, and Imbricate Fault zone (see Figure 1.1-3).

Surface facilities will include a power substation, sewage treatment lagoons, construction and testing-support buildings, various trailers, and an access road.

After construction is completed, additional *in-situ* tests will be conducted, principally in the Main Test Level. The *in-situ* test activities described in this plan will have relatively little impact on the natural-state site conditions. Hydrologic disturbances from ESF testing activities could potentially impact site performance by increasing the water flux at the repository horizon, changing the hydrologic properties of the unsaturated zone, and creating preferential pathways for liquid and gaseous transport of radionuclides. The only tests that currently have been identified to be performed in the ESF that may introduce water into the unsaturated zone are the percolation and the hydrologic properties of major faults tests. Since the test blocks for the percolation test will be separated from the rock mass and isolated within the drift, the water added to the rock can be recovered. If the decision to use water following air injection tests in fault zones is made, the quantity of water used will be tagged with a tracer and kept to a minimum. Test areas will be limited to fault zones away from other tests. Therefore, there is no indication that the testing activities will introduce a significant amount of water to the unsaturated zone or

that the use of water will result in permanent changes to the *in-situ* hydrologic properties of the rocks.

2.2.5 Time required versus time available

The *in-situ* hydrologic tests described in this study plan are constrained by the schedule for the start and completion of the ramps and drifts. The ESF testing is also constrained by the need to complete the *in-situ* tests for input to the YMP environmental impact statement-performance assessment and license application. Section 5.1 presents current schedules for the four activities described in this plan.

2.2.6 Limits of analytical methods

Although numerical modeling of tests planned in this study will be performed, the problem remains of identifying parameters in a distributed system with many degrees of freedom available. Measurements in the tests will be made at a few locations in a system in which the numerical mesh of the model may have thousands of unknowns. The use of all available data can reduce uncertainty, but some uncertainty will remain. Uncertainty analyses may be considered as an alternative to the solution of those problems that incorporate the unknown features of the system.

2.2.7 Potential for interference among activities, and from ESF construction

YMP requires that all construction and testing must go through analysis to evaluate test interference due to construction and interference from other tests. Such analysis will ensure that interference has been eliminated or minimized. Generally, the selected tests of this study will have little or no interference with other planned tests. In cases where tests do interfere, the USGS investigators have planned the testing sequence accordingly, in order to maximize data collection and minimize interference. All of the water that will be used in hydrologic tests will be tagged with a tracer to determine if any interference is occurring in adjacent test areas. The decision as to which tracers are to be used will be made on a case-by-case basis as part of the test planning process.

SCP Section 8.4.2.3.1, Exploratory studies facility testing operations, layout constraints, and zones of influence, discusses the constraints imposed on the underground layout by each experiment and the estimated zone of influence of each experiment. The design requirements generally arise from requirements that the *in-situ* conditions such as stress state, degree of saturation, and temperature in the region where the experiment is to be conducted not be altered by other activities in the ESF. Flexibility in choosing the final location and orientation of an experiment may also be an important constraint because of local variations in geology and fracture orientation. The zone of influence is intended to describe the extent to which each experiment alters or influences the surrounding region. In the conduct of each test, it is vital to

insure that the data derived from the test are not influenced by other experiments that may be underway at the same time. The criteria for determining if a potential interference existed was taken to be whether the zone of influence of one experiment impinged on another experimental area to such a degree that the results of the experiment could be affected. To insure conservatism in this approach, the potential for interference was considered high if the zones of influence of two experiments overlapped. Because the maximum zones of influence of each test were overlaid onto a layout to check for potential interference, timing of the test was not taken into consideration during the analysis. If interference concerns showed up during the analysis, timing of the tests involved was considered to determine if the tests were separated sufficiently in time to preclude the interference problem (i.e., one test may have been completed, leaving no permanent alteration of the rock, before the second was begun). If potential interferences were found during the analysis, the adjustments to the timing of the experiments or the layout were considered.

The test-to-test interferences concerns were evaluated (SCP Section 8.4.2.3.1) as outlined above only for the experiments proposed for the Main Test Level. Experiments and observational activities planned for the underground excavations were evaluated with regard to potential zones of influence, but further evaluation was not considered necessary due to the nature of the tests (primarily observational and sample collection) or the limited amount of rock affected, or the large physical separation between these tests and others.

The interference analysis of all experiments proposed for the Main Test Level was performed based on the current test definitions, available analysis results, and prototype test data. The designs of several of the experiments may change as site evaluation proceeds. These changes will require a reevaluation of potential interferences among the applicable tests.

On the basis of analyses presented in the SCP Section 8.4.2.3.6.1 (Potential for interference between tests), the locations and separation distances between tests are considered to be acceptable. Hydrologic interference between drifts is not likely to be observed, although the possibility of flow in large-aperture fractures from one drift to another cannot be ruled out. Additionally, no mechanical interference or unacceptable vibratory interference is expected. A portion of the hydrochemistry testing is expected to be performed at the same location as the radial boreholes tests, the use of an air tracer will enable recognition of potential interferences between these tests.

3 DESCRIPTION OF ACTIVITIES

The study is organized into ten activities:

- o 8.3.1.2.2.4.1 - Intact-fracture tests
- o 8.3.1.2.2.4.2 - Percolation tests
- o 8.3.1.2.2.4.3 - Bulk-permeability tests
- o 8.3.1.2.2.4.4 - Radial-borehole tests
- o 8.3.1.2.2.4.5 - Excavation-effects tests
- o 8.3.1.2.2.4.6 - Calico Hills tests
(ACTIVITY DELETED)
- o 8.3.1.2.2.4.7 - Perched-water tests
- o 8.3.1.2.2.4.8 - Hydrochemistry tests
- o 8.3.1.2.2.4.9 - Multipurpose-boreholes testing near the
exploratory shafts (ACTIVITY DELETED), and
- o 8.3.1.2.2.4.10 - Hydrologic properties of major faults
encountered in the ESF.

Five test activities are planned during the ESF construction phase: radial borehole, excavation effects, perched water, hydrochemistry, and hydrologic properties of major faults. This study plan includes the plans for radial-borehole, excavation-effects, perched-water, and hydrochemistry; which are described in Sections 3.4, 3.5, 3.7, and 3.8, respectively. The plans for hydrologic properties of major faults will be described in Section 3.10 in a subsequent revision of this plan. Three other activities will be conducted as a part of the *in-situ* testing in the ramps and drifts of the ESF: intact fracture, percolation, and bulk permeability. The plans for these activities will be described in a subsequent revision of this plan.

3.1 Intact-fracture test

The intact-fracture tests will be conducted in a USGS laboratory. The rock samples for this test will be obtained from the ESF. Because the test is not a part of the ESF construction-phase testing, the plan for this activity will be presented in a subsequent revision of this study plan.

3.2 Percolation test

The percolation tests will be conducted in ramps and drifts of the ESF. Because the tests are not part of the ESF construction-phase testing, the plan for this activity will be presented in a subsequent revision of this study plan.

3.3 Bulk permeability tests

The bulk permeability tests will be conducted in the ramps and drifts of the ESF. Because these tests are not part of the ESF construction-phase testing, the plan for this activity will be presented in a subsequent revision of this study plan.

3.4 Radial-borehole tests

3.4.1 Objectives

The objectives of this activity are to:

1. quantify the gas permeability and anisotropy of the geohydrologic units within the unsaturated zone.
2. evaluate the effects of excavation in the ramps and drifts on hydrologic properties of unsaturated-zone geohydrologic units.
3. estimate tortuosity and effective porosity of the drained pore spaces of the unsaturated geohydrologic units;
4. quantify the boundary effects at the geohydrologic unit contacts;
5. compare pneumatic and hydraulic test results especially at the geohydrologic unit contacts; and
6. monitor for flow of water, as both vapor and liquid, in the unsaturated zone;

3.4.2 Rationale for activity selection

It is hypothesized that most fractures in the unsaturated zone beneath Yucca Mountain probably are drained and devoid of significant liquid water (Montazer and Wilson, 1984; Wang and Narasimhan, 1985). The air in these fractures, as well as within the unsaturated pores, is nearly saturated with water vapor. This vapor-saturated air probably is mobile in the more extensively fractured tuffs and, to a lesser degree, in the moderately to nonfractured tuffs. Two mechanisms cause flow of the vapor-saturated air: the natural geothermal gradient and the transient pneumatic-potential gradient that results from atmospheric-pressure fluctuations.

Two simplified cases of water flow in the unsaturated zone include upward movement of water vapor and downward migration of liquid water. Upward migration of vapor-saturated air may indicate the potential for upward migration of gaseous radionuclides. In addition, downward water movement may be indicative of potential radionuclide-solute transport. In both cases, the natural vapor and liquid-water fluxes may be influenced by the thermal field created after emplacement of high-level radioactive waste.

Although water vapor in the unsaturated zone probably cannot transport significant amounts of radionuclides, the transport of gaseous radionuclides in the vapor-saturated air is a concern. Gaseous radionuclides, such as tritium and carbon-14, may be transported to the atmospheric environment by natural gradients or disturbed gradients imposed by repository emplacement. Therefore, permeabilities, anisotropy, porosities, travel time, and transport

mechanism in the air-filled voids of the unsaturated zone are important in assessing the performance of a potential repository. Tortuosity, air-filled effective porosity, and air permeability should be determined in order to evaluate the potential transport rate of the gaseous radionuclides. Tortuosity and air-filled effective porosity are needed to calculate the effective coefficient of diffusion of the gases through the rock and thus to evaluate diffusive transport. Gas permeability is needed to calculate flow velocity so that convective transport can be evaluated. Porosity, tortuosity, air permeability and anisotropy will be determined by testing (gas injection into the rock), passive monitoring of pneumatic pressure, and gas sampling and analysis. These activities are described in greater detail in Section 3.4.3.

Flow of liquid water in the unsaturated zone is expected to be downward; however, heterogeneity in tuff properties could result in deviation of flow from the vertical. Two situations could cause this deviation: (1) anisotropy in permeability within geohydrologic units and (2) contrasts in permeability between adjacent geohydrologic units. In the latter case, if a large contrast in permeability exists between units, then perched-water or capillary-barrier conditions may form. If these conditions occur along dipping geohydrologic-unit contacts, water may flow laterally. The existence of major structural features, such as faults, may result in diversion of water. The case of water diversion caused by marked contrasts in permeability of different geohydrologic units will be investigated by the hydrologic properties of major faults tests (Activity 8.3.1.2.2.4.10).

Understanding the potential for lateral flow of water along geohydrologic-unit contacts is crucial in calculating the rate at which water may percolate through the repository host rock and the travel time to the accessible environment. Large contrasts in hydrologic properties exist at the TCw-PTn and PTn-TSw1 contacts. The potential for a capillary barrier between the matrix of the TCw and the matrix of the PTn and a potential barrier between the matrix of the PTn and the fractures of the TSw1 will be investigated. In addition, the potential for perched water and lateral flow at the PTn-TSw1 contact and at contacts in the layered anisotropic PTn unit will be examined on both small and large scales. Diversion of downward flow by the welded unit could significantly reduce the downward flow of water to the proposed repository. The upper and lower contacts of the PTn have been identified as test sites; ramp construction may identify additional contacts of highly variable permeabilities in the PTn that will require testing. Initial testing will consist of injecting gas across the contacts followed by long term monitoring and ultimately water will be injected across the geohydrologic contact during the final phase of testing.

Free drainage of the repository host rock is considered a favorable condition for a repository in the unsaturated zone. Free drainage will assure that, with wetter climatic conditions, saturated conditions may not develop within the repository host rock. Air-filled pore and fracture space is available to transmit any recharge

pulse; hence, air permeability is an indicator of the potential for free drainage in the unsaturated zone.

Excavation of underground openings alters the natural state of stress within rock. Stress redistribution will cause fractures and pores to open or close depending upon their location in the newly established stress field. In turn, bulk permeability and porosity of the rock will change as a result of changes in fracture and pore sizes. Changes in porosity directly affect the saturation level of the rock; therefore, saturation also is sensitive to stress changes. The effects of excavation on tuff hydrologic parameters are important for two reasons: (1) the excavation of ramps and drifts may affect the interpretation of hydrologic information obtained from the radial boreholes, and (2) the disturbed zone surrounding the ramps may create new pathways for radionuclide migration and thus may require corrective measures. Gas-injection packer tests will quantify the hydrologic characteristic changes around ramps and drifts.

In order to develop a standard cross-hole pneumatic and hydraulic test system that can be used in the ESF hydrologic tests (radial-borehole tests, bulk-permeability tests, and excavation-effects tests) and also can be applicable to the surface-based air permeability testing, prototype testing was conducted at the University of Arizona's Apache Leap Tuff site located near Superior, Arizona. The test system was made up of several components, including testing and preparation of hardware, software, technical procedures, data analyses, and field-test configuration. The prototype testing identified both strong and weak components of the system. In summary, the measurement instruments, pressure transducers, thermistors, thermocouple psychrometers (TCPs), mass flow controllers, etc. all functioned well while the packer system, used to isolate test intervals, had some deficiencies. The constant-rate test methods and pressures-squared differences analysis methods (Brar, 1975) were found to work well and a Scientific Notebook Plan (HP-241T) for conducting surface-based air permeability testing has been written and approved.

3.4.3 General approach and summary of tests and analyses

The radial-borehole tests were originally conceived as construction-phase tests designed to quantify the effects of vertical shaft excavation; however, the tests have undergone several modifications in design since they were first envisioned.

The radial boreholes testing configured for two ramps, (see Figure 3.4-1), consists of four test Programs: 1) air permeability-anisotropy testing of the geohydrologic units using a three-borehole arrangement, 2) air-injection testing across the geohydrologic contacts using a four-borehole arrangement, 3) long-term monitoring of selected intervals in one or more boreholes at each site, and 4) water-injection testing at the contact sites following completion of the long-term monitoring. Because the two ramps offer some duplication of tests, one or more of the contact sites may be

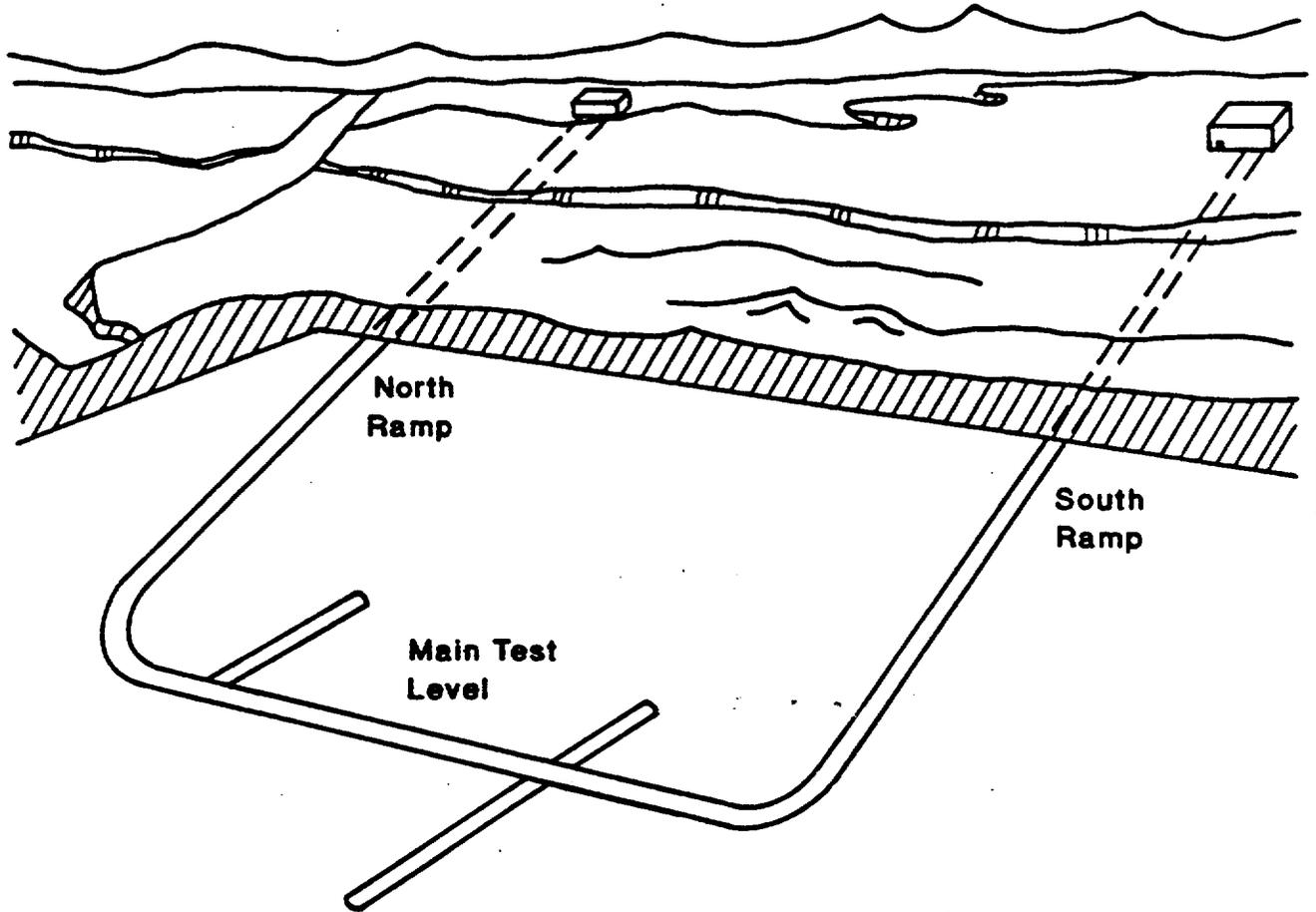


Figure 3.4-1. ESF configuration

selected for hydraulic testing before long-term monitoring. This would supply data on possible perched-lateral flow and capillary barriers sooner than originally proposed. In addition, it will allow long-term monitoring of the drying process.

Air permeability-anisotropy testing of the geohydrologic units will be conducted in a alcove perpendicular to the ramp. The alcove will contain three 30-m HQ boreholes also orientated quasi-perpendicular to the ramp. The actual location and drill angle of the boreholes will be determined after the fracture-mapping data is reviewed. The three boreholes will be instrumented with pneumatic packers and/or downhole liner system and sensors. Single and cross-hole air injection testing and cross-hole tracer testing will be conducted. The goals of the testing are to quantify the: 1) permeability, 2) anisotropy, 3) effective porosity, and 4) tortuosity of the geohydrologic units. Testing will be conducted in alcoves located in the north and south ramps (see Figure 3.4-2). The following is a list of alcove stratigraphic locations.

NORTH RAMP

1. Alcove in upper TCw
2. Alcove in lower TCw
3. Alcove in middle PTn
4. Alcove in TSw1

SOUTH RAMP

5. Alcove in upper TCw
6. Alcove in lower TCw
7. Alcove in middle PTn
8. Alcove in TSw1
9. Alcove in TSw2

Air and water injection testing across and along the geohydrologic contacts will also be conducted in alcoves perpendicular to the ramp. Testing will require four 30-m boreholes, two on each side of the contact, also drilled perpendicular to the ramp. The boreholes will be instrumented with pneumatic packers and/or a downhole liner system and sensors. Following installation, single and cross-hole air-injection testing, and possibly a limited number of water injection tests, will be conducted. At the completion of the testing all or some of the boreholes will be instrumented for long-term monitoring. The long-term monitoring instrumentation will consist of pneumatic packers, pressure transducers, thermistors, and thermocouple psychrometers (TCPs). The isolated intervals will also have surface gas lines so that gas samples can be taken. The long-term monitoring program is expected to last approximately 5 years. Following completion of the long-term monitoring program, single and cross-hole water injection tests will be conducted at all sites. The goals of the geohydrologic unit contact testing are to: 1) quantify the boundary effects of the contacts on air flow, 2) monitor for any long-term change in

Stratigraphic unit		Geohydrologic unit (where unsaturated)	
Alluvium		Alluvium (QAL)	
Paintbrush Tuff	Tiva Canyon Member	Tiva Canyon welded unit (TCw)	1, 5
	Yucca Mountain Member	Paintbrush Tuff nonwelded unit (PTn)	2, 6
	Pah Canyon Member		
	Topopah Spring Member	Topopah Spring welded unit (TSw ₁)	3, 7
		(TSw ₂)	4, 8
	Calico Hills non-welded unit (CHn)	9	
Tuffaceous beds of Calico Hills		Vitric (CHnv)	
Crater Flat Tuff	Prow Pass Member	Zeolitized (CHnz)	
	Bullfrog Member		
		Crater Flat unit (CFu)	

Note: Figure not to scale

Figure 3.4-2. Stratigraphic locations of permeability-anisotropy test sites.

pressure, temperature, or water potential at the contacts, and 3) quantify the boundary effects of the contacts on water flow. Testing will be conducted in the north and south ramps at but not limited to the following locations (see Figure 3.4-3):

NORTH RAMP

1. Alcove at TCw-PTn contact
2. Alcove at PTn-TSw1 contact

SOUTH RAMP

3. Alcove at TCw-PTn contact
4. Alcove at PTn-TSW1 contact

Because the ramp is expected to be generally unlined it will influence the moisture content, temperature, and pneumatic pressure of the surrounding rock. In order to quantify these influences on the pneumatic testing and long-term monitoring, pneumatic testing and long-term instrumentation must be conducted as soon as possible following the ramp reaching an identified test level. This early baseline data is required in order to ascertain the degree to which the moisture and temperature state of the rock is impacted by the ramps.

Figure 3.4-4 summarizes the organization of the radial-borehole activity. A descriptive heading for each test and analysis appears in the boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized during testing. Figure 3.4-5 summarizes the objectives of the activity, site-characterization parameters, and activity parameters. Cross-references to other study plans which provide input to the radial-borehole tests also appear in both figures.

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 activity 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 exact scheduling of the radial borehole testing and associated activities is dependent on the ramp construction schedule and the access provided during ramp construction.

3.4.3.1 Borehole drilling and coring

3.4.3.1.1 Permeability-anisotropy boreholes

The permeability-anisotropy borehole test sites will consist of three 30-m HQ boreholes. The boreholes will be

Stratigraphic unit		Geohydrologic unit (where unsaturated)	
Alluvium		Alluvium (QAL)	
Paintbrush Tuff	Tiva Canyon Member	Tiva Canyon welded unit (TCw)	1, 3
	Yucca Mountain Member	Paintbrush Tuff nonwelded unit (PTn)	
	Pah Canyon Member		
	Topopah Spring Member		Topopah Spring welded unit (TSw ₁)
			(TSw ₂)
Tuffaceous beds of Calico Hills		Vitric (CHrv)	
Crater Flat Tuff	Prow Pass Member	Zeolitized (CHnz)	
	Bullfrog Member		Crater Flat unit (CFu)

Note: Figure not to scale

Figure 3.4-3. Stratigraphic locations of geohydrologic contact test sites.

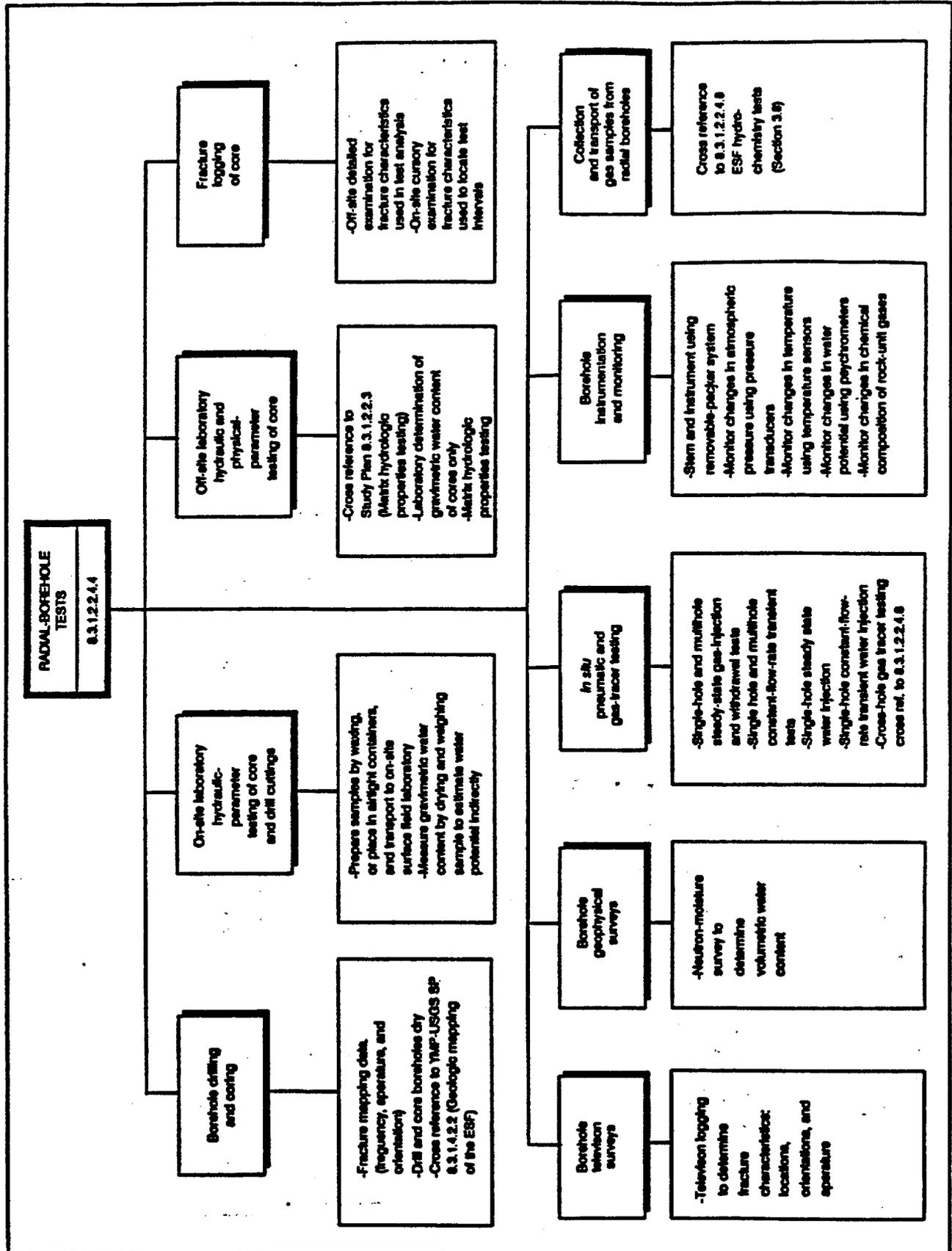


Figure 3.4-4. Organization of the radial-borehole activity, showing tests, analyses, and methods.

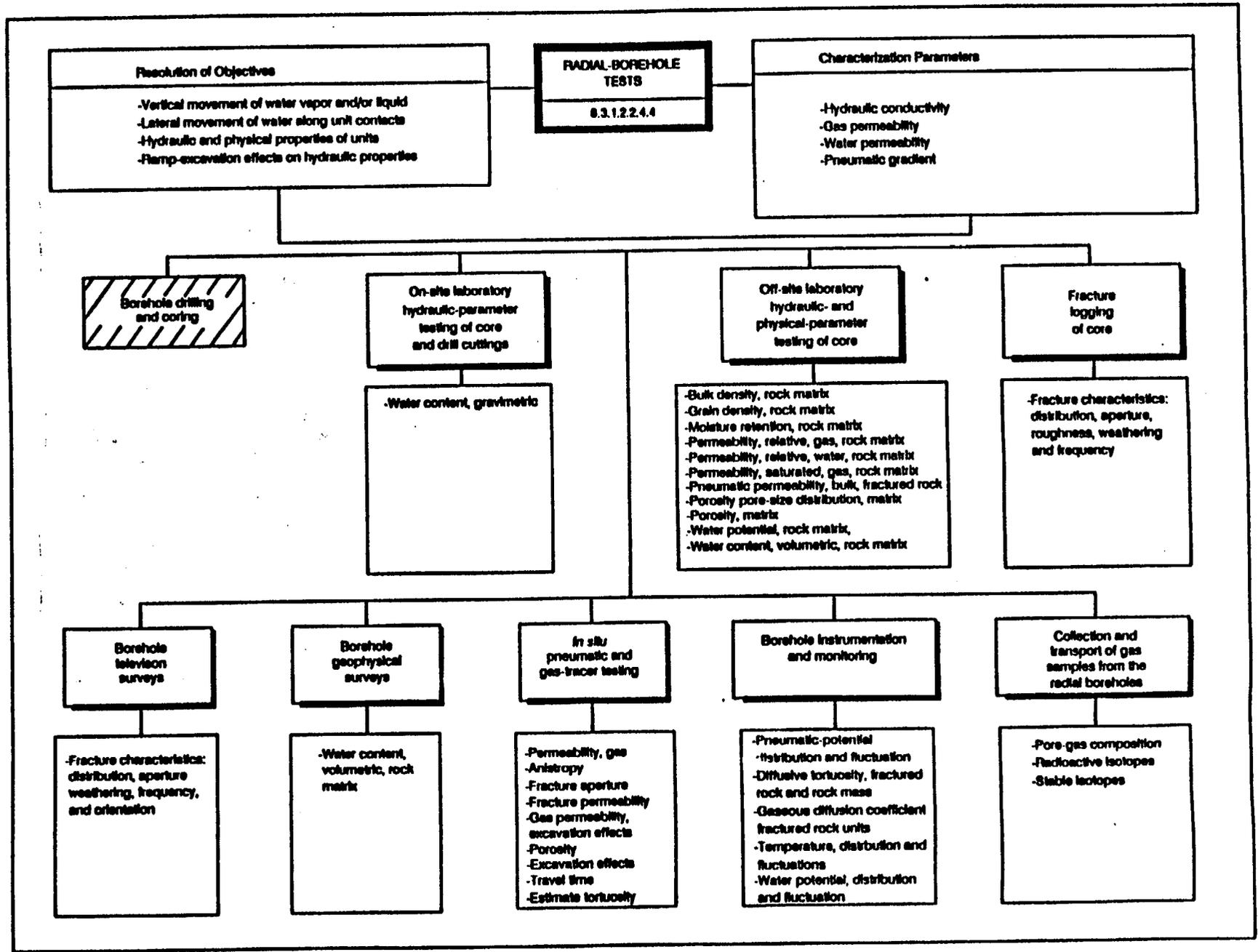


Figure 3.4-5. Organization of the radial-borehole activity, showing tests, analyses, activity parameters, and characterization parameters. (The cross-hatched box indicates that no activity parameter will be generated.)

located in alcoves off the main ramps. Each alcove will be perpendicular to the ramp and the boreholes will be drilled in the far end of the alcove. The boreholes will be drilled in a conical configuration based on an expanding triangle as shown in Figure 3.4-6. The borehole drill locations are configured in an equilateral triangle with 2-m sides. The boreholes are then drilled at an 8-degree angle off perpendicular of the triangle and away from the center of the triangle. This drilling will expand the equilateral triangle so that the equilateral sides will measure 9.3 m when the boreholes are 30 m in length. However, this configuration may be modified based on future information on fracture orientation, etc. obtained in the ramps. The boreholes will be dry drilled with tracer-tagged compressed air. The HQ core will be collected, packaged, labeled, and transported to an off-site laboratory for hydrologic analysis. The alcove must be large enough to allow the drilling operations and sample handling operations to proceed concurrently. Following drilling the boreholes will be logged. Nine preliminary test sites for permeability-anisotropy testing have been selected (see Figure 3.4-2). The final test site locations will be selected during ramp construction.

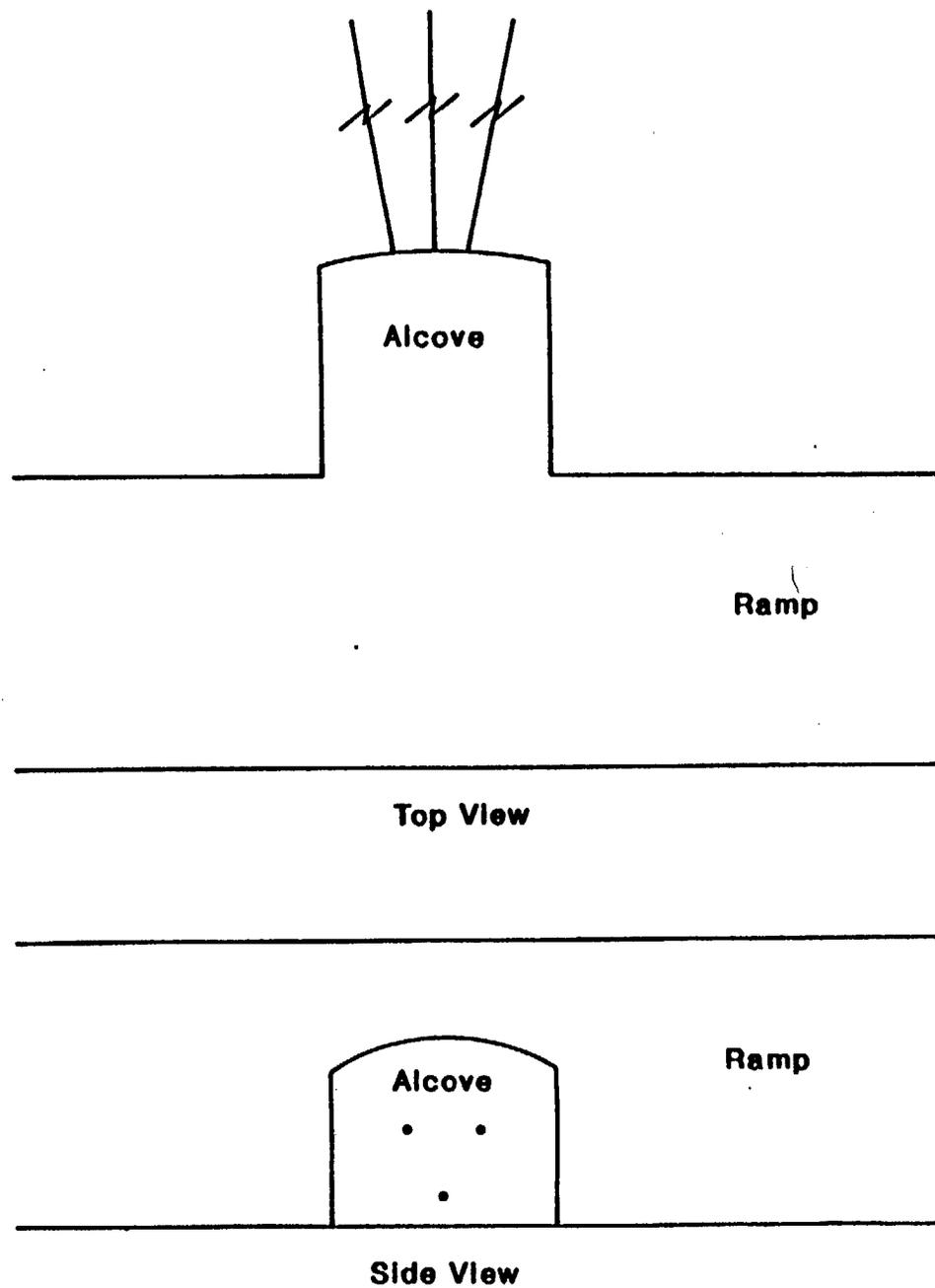
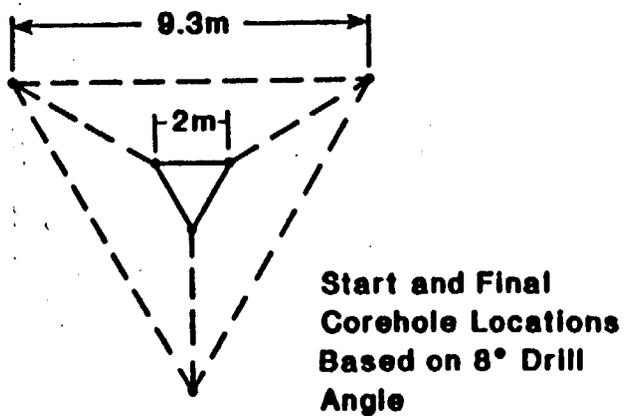
The length of the radial boreholes was chosen to insure that the testing is conducted in both the zone of stress redistribution associated with the ramps and in the undisturbed zone outside the stress redistribution zone. The stress redistribution zone is predicted to extend for two ramp diameters from the ramp wall into the surrounding rock. This prediction is based on the solution derived from the theory of elasticity for a circular opening. The borehole length of 30 m extends well beyond the predicted disturbed zone of 16 m and will allow testing of both disturbed and undisturbed rock.

3.4.3.1.2 Geohydrologic unit contact boreholes

The geohydrologic unit contact testing borehole test sites will consist of four 30-m HQ boreholes arranged in a rectangle straddling the contact (see Figure 3.4-7). The boreholes will be drilled in alcoves off the main ramps. The alcoves will intersect the geohydrologic contacts and be perpendicular to the ramps. The alcove size will depend on the angle at which the ramp intersects the contact. The boreholes will be drilled perpendicular to the ramps, parallel to the contact, and parallel to each other (see Figure 3.4-7). Two of the boreholes will be located approximately 1.5 m above the contact and separated by 2 m, and two boreholes will be located approximately 1.5 m below the contact and separated by 2 m. These dimensions will probably be altered based on geologic and hydrologic information obtained at the contact test sites. Four preliminary test sites for contact testing have been selected

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Figure 3.4-6. Schematic of permeability - anisotropy borehole configuration.

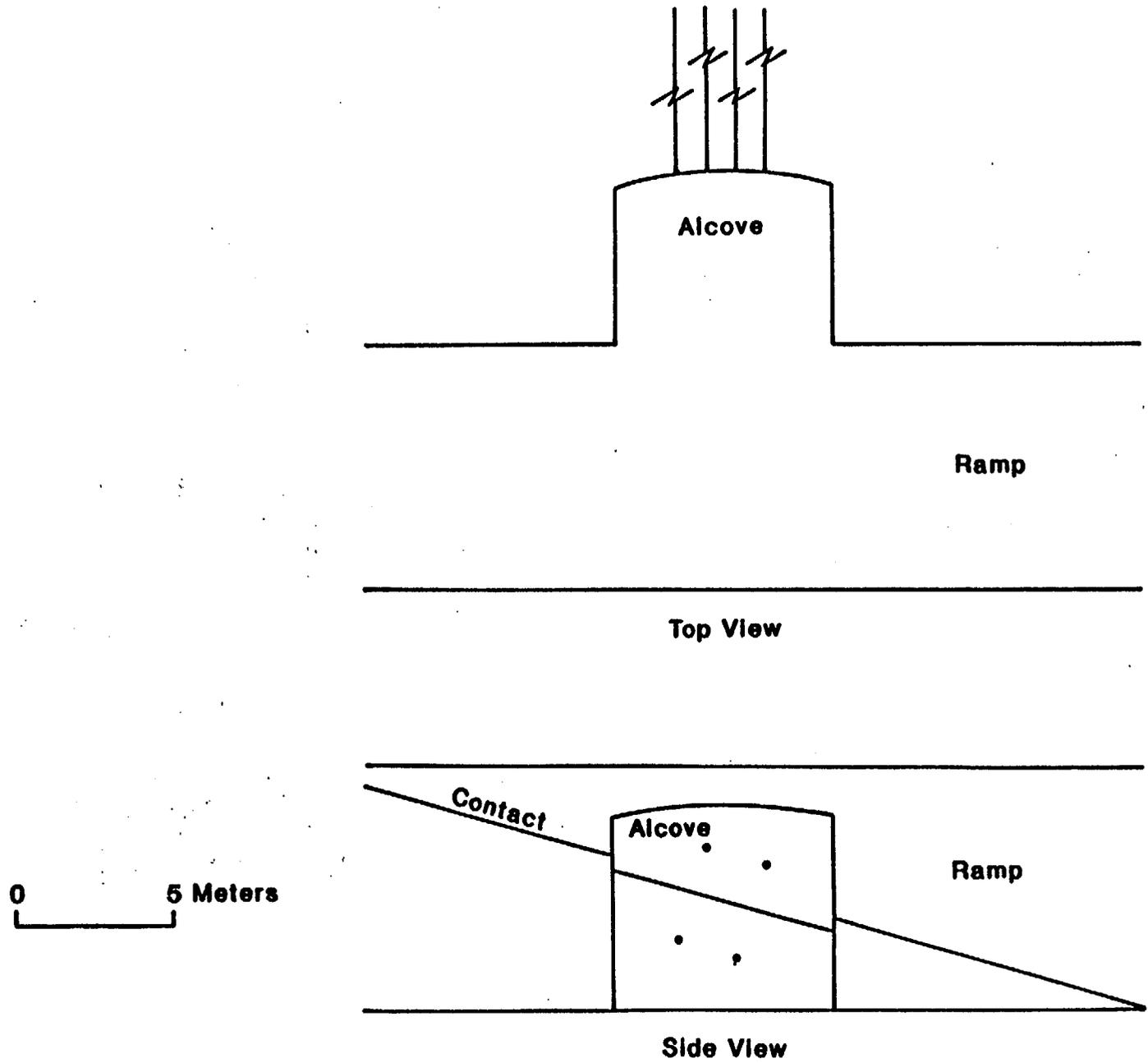


Figure 3.4-7. Schematic of geohydrologic contact borehole configuration.

(see Figure 3.4-3). However, information obtained during ramp construction, such as identification of zones with large changes in permeability and/or porosity within geohydrologic units, may require addition of test sites. Following drilling the boreholes will be logged.

Like the permeability-anisotropy boreholes, the contact boreholes also will be dry drilled using tracer-tagged compressed air as the drilling medium to provide bit cooling and removal of cuttings. The length selection for these holes is also based on the same stress redistribution rationale as in the permeability-anisotropy boreholes. The HQ core will be collected, packaged, labeled, and transported for off-site hydrologic analysis.

3.4.3.2 On-site laboratory hydraulic-parameter testing of core and drill cuttings.

Core and drill-cutting samples obtained during the drilling process will immediately be sealed in wax, or placed in air-tight canisters and transported to a field laboratory, where gravimetric-water content of selected core and cuttings will be determined. Information obtained by this method will be used in the interpretation of gas-injection tests and will serve as baseline data for the newly drilled boreholes.

Table 3.4-1 indicates that an alternative to waxing or sealing the samples in containers is to transport the samples to the laboratory without preparing or preserving them first. Drilling and sampling downtime could be reduced if this practice were adopted, but the samples also could begin to dry out if they were not quickly processed and analyzed.

3.4.3.3 Off-site laboratory hydraulic- and physical-parameter testing of core

Core and cutting samples not utilized during on-site hydrologic testing will be sent off site to laboratories for testing the following properties: volumetric water content, grain density, porosity, bulk density, water potential, water retention, saturated-water permeability, and relative water and gas permeability. The information obtained from these tests will be used in the interpretation of gas injection tests and will serve as baseline data for the newly drilled boreholes. Methods used to measure these important hydrologic parameters are described in the matrix hydrologic properties testing activity (Activity 8.3.1.2.2.3.1) in YMP-USGS SP 8.3.1.2.2.3, (Unsaturated-zone percolation - surface-based studies), along with possible alternatives. Table 3.4-1 gives the activity parameters addressed by these tests.

Table 3.4-1. Summary of tests and methods for the radial-boreholes activity (SCP 8.3.1.2.2.4.4) (continued)

Methods (selected and alternate)	Activity parameter
<u>Fracture logging of core</u>	
Off-site detailed examination for fracture characteristics used in test analysis (selected)	Fracture characteristics: distribution, aperture, weathering, roughness, and frequency
On-site cursory examination for fracture characteristics used to locate test intervals (selected)	
<u>Borehole television surveys</u>	
Television logging to determine fracture characteristics (selected)	Fracture characteristics: distribution, aperture, weathering, frequency, and orientation
<u>Borehole geophysical surveys</u>	
Neutron-moisture survey to determine volumetric water content (selected)	Water content, volumetric, rock matrix
<u>In-situ pneumatic and gas-tracer testing</u>	
Single-hole and multihole, steady-state, gas-injection and -withdrawal tests (selected)	Permeability, Gas
▪	Anistropy
▪	Fracture aperture
▪	Fracture permeability
▪	Excavation effects
Single-hole and multihole, gas-injection, constant-flow-rate, transient tests (selected)	Permeability, Gas
▪	Anistropy
▪	Porosity
▪	Gas permeability, excavation effects
Single-hole and multihole, gas-injection, constant-pressure, transient tests (alternate)	Permeability, Gas

Table 3.4-1. Summary of tests and methods for the radial-boreholes activity (SCP 8.3.1.2.2.4.4)

Methods (selected and alternate)	Activity parameter
<u>Borehole drilling and coring</u>	
Drill and core boreholes dry (selected)	(No activity parameters)
Cross-reference to YMP-USGS SP 8.3.1.4.2.2 (Geologic mapping in the ESF)	(See YMP-USGS SP 8.3.1.4.2.2)
<u>On-site laboratory hydraulic-parameter testing of core and drill cuttings</u>	
Prepare samples by waxing, or place in airtight containers, and transport to on-site surface field laboratory (selected)	(No activity parameters)
Measure gravimetric water content by drying and weighing preserved sample to estimate water potential indirectly (selected)	Water content, gravimetric, rock matrix
Measure gravimetric water content by drying and weighing non-preserved sample (alternate)	
<u>Off-site laboratory hydraulic- and physical-parameter testing of core</u>	
Matrix hydrologic properties testing (selected)	Bulk density, rock matrix
"	Grain density, rock matrix
"	Moisture retention, rock matrix
"	Permeability, relative, gas, rock matrix
"	Permeability, relative, water, rock matrix
"	Permeability, saturated, water, rock matrix
"	Permeability, saturated, gas, rock matrix
"	Pneumatic permeability, bulk, fractured rock
"	Porosity pore-size distribution, matrix
"	Porosity, matrix
"	Water potential, rock matrix
Laboratory determination of gravimetric water content of cores only (selected)	Water content, volumetric, rock matrix

Table 3.4-1. Summary of tests and methods for the radial-boreholes activity (SCP 8.3.1.2.2.4.4) (continued)

Methods (selected and alternate)	Activity parameter
<u>In-situ pneumatic and gas-tracer testing (continued)</u>	
Single-hole and multihole, gas injection, constant-pressure, transient tests (alternate)	Anistropy
"	Porosity
"	Gas permeability, excavation effects
Cross-hole gas tracer testing, cross reference to 8.3.1.2.2.4.8 (selected)	Travel time
"	Estimate tortuosity
<u>Borehole instrumentation and monitoring</u>	
Stem and instrument using removable-packer system (selected)	(No activity parameters)
Monitor atmospheric pressure changes within test intervals using pressure transducers (selected)	Pneumatic-potential distribution and fluctuation
Monitor changes in chemical composition of rock-unit gases (selected)	Diffusive tortuosity, fractured rock and rock mass
"	Gaseous diffusion coefficient, fractured rock units
Monitor changes in temperature within borehole using temperature sensors (selected)	Temperature, distribution and fluctuations
Monitor changes in water potential within boreholes using psychrometer (selected)	Water potential, distribution and fluctuation
<u>Collection and transport of gas samples from the radial boreholes</u>	
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Pore-gas composition
"	Radioactive isotopes
"	Stable isotopes

3.4.3.4 Fracture logs of core

If continuous coring is possible, a cursory examination of the core for fracture characteristics (i.e., type of fracture, frequency, depth to fracture, etc.) will be made on-site during drilling. In the laboratory, a more detailed examination of the core will be made to develop detailed fracture-characteristic logs. Fracture data from boreholes will be used in conducting the permeability-anisotropy and geohydrologic contact testing along with selection of the long-term monitoring zones. No alternative methods for this activity were identified, although borehole-television cameras will also be used to view fractures *in situ*.

3.4.3.5 Borehole television surveys

Following completion of drilling, all boreholes will be logged with an oriented television camera for fracture characteristics and lithology. The survey will be used for fracture orientation and to determine whether the fractures intersecting the borehole are open or closed. The fracture data will be used to supplement geologic mapping in the ESF and to determine the location of test intervals and long-term monitoring zones. An alternative to borehole-television surveys is to maintain orientation of the core during drilling. This would require a special oriented-core barrel. The oriented core could be used to determine fracture orientation; however, it is often difficult to determine from core whether fractures are open or closed, and if they are drilling-induced or natural, especially at greater depths where weathering is not as prominent.

3.4.3.6 Borehole geophysical surveys

Following television logging all boreholes will be neutron-logged. Neutron surveys also will be conducted in the permeability-anisotropy boreholes on a periodic basis. These data will be used to look at long-term drying trends in the far-field environment.

3.4.3.7 *In-situ* pneumatic and gas-tracer tests

Single and cross-hole gas injection tests will be conducted at the permeability-anisotropy and geohydrologic unit contact sites. Testing will use a downhole liner to isolate numerous sections of each borehole. These isolated sections can then be used as monitoring or injection zones. The fracture-log data obtained from the drill core and video-camera surveys will be used to select the test zones. The early test site boreholes will probably have their full lengths tested. After some experience and initial analysis, the testing density can probably be reduced.

Fluid-injection or -withdrawal (production) field tests are used to evaluate the *in-situ* permeability and storativity of rock subjected to natural overburdening and confining stresses. Laboratory testing of core is another method commonly used to evaluate rock permeability and porosity. Unfortunately, laboratory permeability tests require subjecting the drill core to stress conditions expected in the field in order to accurately determine *in-situ* permeabilities; this requires prior knowledge of the stress conditions, including stress directions and magnitudes. In addition, the *in-situ* permeability of fractured rocks with large fracture permeability would be grossly underestimated if laboratory-test results on core, which usually represent matrix permeabilities, were used exclusively.

Another alternative to measuring permeability directly from cores or *in-situ* field tests is to use a fracture model to estimate permeability indirectly (Dershowitz, 1991; Van Golf-Racht, 1982; Rissler, 1978; Snow, 1965). Fracture data, including fracture orientations, surface roughness, densities, and apertures, are collected from drill-hole video, core, and geophysical logs and then used directly in a fracture model to compute rock permeability. This method is somewhat restrictive because a large fracture data base is required to characterize the rock and determine permeability; there is a great deal of uncertainty associated with measuring *in-situ* fracture apertures accurately because borehole unloading can result in near-borehole fracture deformation, and fracture lengths are very difficult to determine if only one drill hole is present or the distance between multiple holes is large. Due to the inherent problems associated with using fracture models and laboratory permeabilities to determine *in-situ* rock permeability, fluid-injection or -production field tests provide the most effective method of determining this important parameter.

Prototype testing has determined that several gas-injection and -withdrawal methods will be utilized during the testing program. They include: (1) single-hole, constant-flow-rate, transient tests; (2) single-hole steady-state, gas-injection and -withdrawal tests; (3) cross-hole constant-flow-rate transient tests; and (4) cross-hole steady-state gas injection and withdrawal tests.

Single-hole fluid injection or withdrawal (production) field tests are commonly used to evaluate reservoir or aquifer permeability. These tests utilize only one active well and no observation wells. Rock parameters are evaluated from data (flow rates, pressure, and temperatures) collected from a single borehole (Earlougher, 1977). The two single-hole methods listed above and in Table 3.4-1 are briefly described below. A thorough treatise on each method can be found in the references accompanying each description.

Steady-state, gas-injection and -withdrawal tests will be used to determine the permeability of individual fractures.

Steady-state tests consist of injecting gas into or withdrawing gas from the rock until the downhole pressure and uphole measured injection (withdrawal) flow rates remain constant. Trautz (1984) used this method to characterize fractures in unsaturated fractured tuffs. Schrauf and Evans (1984) also used this method to evaluate the relation between the gas conductivity and geometry of natural fractures in the laboratory.

The single-hole constant-rate transient test consists of injecting gas into the rock at a constant rate and at the same time monitoring the transient pressure response (i.e., change in pressure with time). Constant-production-rate, transient tests are commonly used in the oil industry to evaluate gas-reservoir parameters (Earlougher, 1977). An alternative to this method, which is listed in Table 3.4-1, is a constant-pressure, transient test. As the name implies, gas is injected or produced from the rock at a constant pressure while the change in gas-flow rate is monitored with time. Such a test is seldom made because it is much easier to measure pressure accurately than it is to accurately measure flow rate (Earlougher, 1977). Constant-rate tests, however, may inadvertently become constant-pressure tests, and so it is desirable to be able to analyze both types of tests.

Cross-hole pneumatic and hydraulic field tests, commonly referred to as "interference tests" in the petroleum industry, are used to evaluate reservoir properties such as permeability and storativity, determine the location of structural features such as faults, no-flow and recharge boundaries, and evaluate isotropic versus anisotropic conditions in reservoirs (Earlougher, 1977) and fractured aquifers (Hsieh and Neuman, 1985; and Hsieh and others, 1985). Cross-hole testing is a descriptive phrase used to describe a multiple-well test. Multiple-well tests require at least one active (producing or injecting) well and at least one observation well; however, only one active well will be utilized at any given location and time during this study. Gas will be injected or produced from an isolated test interval in one of the boreholes and the response of the formation to the change in fluid pressure will be monitored in numerous nearby observation intervals located in the other boreholes. The test results, namely active- and observation-well fluid pressures, and injection or production-flow rates, are used to calculate reservoir aquifer parameters. Analysis of the test results is dependent upon flow-domain boundary conditions, the type of fluid injected into the formation, the saturation state of the formation, and the type of test conducted (e.g., steady-state or transient).

The methods described with regard to single-hole tests apply equally to cross-hole testing. The greatest difference between the two test configurations is the quality of results that can be determined from the test data. Single-hole test results can be heavily influenced by wellbore conditions (i.e., skin effects caused by wellbore damage or improvement), making it difficult or impossible to calculate reservoir parameters. In addition, it is

impossible to characterize the anisotropic nature of a reservoir using a single-hole test. The cross-hole tests provide a convenient test configuration for gaining important hydraulic information about the geohydrologic units penetrated by the ramps, information that could not be obtained from single-hole testing methods alone. Types of cross-hole tests to be conducted include: (1) constant-rate transient gas-injection tests; and (2) steady-state, gas injection and withdrawal. A possible alternative to these methods could be constant-pressure, gas-injection tests.

3.4.3.7.1 Permeability-anisotropy pneumatic testing

Single and cross-hole gas injection tests will be conducted at the permeability-anisotropy test sites. During single-hole testing, intervals will be tested and analyzed for spatial correlations (Winberg, 1991). During cross-hole testing, two boreholes will be used as monitoring boreholes. They will be fitted with downhole liners isolating up to 30 intervals in each borehole. These intervals will be connected to the alcove by small-diameter tubes. The tubes can be attached to pressure transducers and used to monitor the pressure in the downhole interval or attached to pumps to obtain gas samples. The third borehole will be fitted with a liner with a single large-capacity injection zone. The injection zone is adjustable and can be moved throughout the borehole. The single large-capacity injection zone will be connected to the surface with a large-diameter tube through which gas can be injected or pumped. The tube will be connected to a surface gas source and used to conduct pneumatic tests. Each of the three boreholes will be used as the injection borehole while the remaining two boreholes are monitored.

Cross-hole pneumatic tests between the permeability-anisotropy boreholes will be used to define the three-dimensional permeability tensor in the same manner that Hsieh and Neuman (1985) used cross-hole hydraulic tests to determine the hydraulic-conductivity tensor of saturated, fractured rock. Hsieh and Neuman's (1985) method will be modified to account for gas flow. An important feature of Hsieh and others' (1985) method is that it allows the investigator to determine the anisotropic nature of the medium without prior knowledge of principal-permeability directions or magnitudes. Virtually all of the previously proposed methods required that one or more principal directions be known prior to the test (Papadopoulos, 1965; Hantush, 1966; Snow, 1965).

3.4.3.7.2 Geohydrologic unit contact pneumatic testing

Single and cross-hole gas injection tests will be conducted at the geohydrologic contact test sites. During single-hole testing, intervals will be tested and analyzed

for spatial correlations (Winberg, 1991). During cross-hole testing, three of the boreholes will be fitted with downhole liners isolating up to 30 intervals in each borehole. These intervals will be connected to the alcove by small-diameter tubes. The tubes can be attached to pressure transducers and used to monitor the pressure in the downhole interval or attached to pumps to obtain gas samples. The fourth borehole will be fitted with a downhole liner with one large-capacity injection interval. The large-capacity injection interval is adjustable and can be moved throughout the boreholes. A single larger-diameter tube will connect the large-capacity injection interval to an alcove gas source and will be used to inject or pump gas. Each of the four boreholes will be used as injection boreholes while the remaining three are used as monitoring boreholes.

Cross-hole pneumatic tests between the geohydrologic unit contact boreholes will be used to quantify the hydrologic characteristics of the geohydrologic contacts. Compressed air will be injected into an isolated interval in one borehole and the pressure response monitored in numerous intervals in monitoring boreholes on both sides of the contact. The boreholes will be placed so the influence of the contact on the injection zone and monitoring zones in boreholes on the same side of the contact will yield information as to what type of boundary the contact represents. Numerous isolated intervals in all four boreholes will be used as the injection zone. Use of numerous injection intervals over the full lengths of all the boreholes will evaluate contact characteristics over a large area and evaluate the geohydrologic units' near-contact permeability and effective porosity over a large area.

3.4.3.7.3 Gas tracer testing

Following pneumatic testing, cross-hole tracer testing will be conducted at both the permeability-anisotropy and geohydrologic unit contact test sites. Tracer travel times between selected intervals can be compared to velocities calculated from pneumatic testing and used to estimate tortuosity. Tracer testing will be conducted in cooperation and under guidelines of the geochemistry staff using methods referenced in Section 3.8.

3.4.3.8 In-situ hydraulic testing

Following pneumatic and tracer testing, one or more of the permeability-anisotropy and geohydrologic unit contact test sites may be selected for hydraulic testing. Pneumatic and hydraulic test results will differ due to gravity, air entrapment, Klinkenberg effect, and other possible influences. However, an opportunity to compare pneumatic and hydraulic test results is an

important need in the site characterization program. If reliable techniques can be derived for estimating permeability (and hydraulic conductivity) from air- and water-injection test data at the field-scale (that scale which corresponds to the zone which is evaluated in the air- or water-phase testing), then pneumatic testing results may be more efficient and provide a more comprehensive assessment of the permeability of the formations. It will be necessary to perform single and cross-hole hydraulic tests at select locations in order to determine the usefulness of effective air permeability in calculating hydraulic conductivity, and may provide some insight into questions on water flow across geohydrologic unit contacts.

Obviously, sites chosen for a comparative analysis of hydraulic and pneumatic testing should be representative of other locations in both welded and nonwelded units. However, they should also be situated away from areas where water might interfere with other test activities. The selected hydraulic test sites should provide the confidence needed for correlating pneumatic and hydraulic parameters. All water will be tagged to facilitate identification.

Hydraulic testing will also allow for long-term monitoring following water injection. Because the two ramps provide matching test sites, this will allow long-term monitoring of the same formation following air versus water injection.

Those sites not tested before long-term monitoring will be tested following the long-term monitoring program.

Figure 3.4-4 lists the types of cross-hole pneumatic and hydraulic tests that will be conducted during cross-contact testing. Constant flow-rate transient tests and steady-state tests will be utilized.

3.4.3.9 Borehole instrumentation and monitoring

The second phase of the tests consists of instrumenting and monitoring selected intervals in one or more boreholes at all radial borehole sites and periodically withdrawing rock-gas samples. Permanent instrumentation will be installed in selected boreholes and continuously monitored for *in-situ* water potential, pneumatic pressure, and temperature changes for a period up to 5 years.

Long-term monitoring of the radial boreholes will enable detection of changes in the water potential, pneumatic pressure, and temperature associated with possible water pulses, barometric influences, or ramp influences that are occurring in the unsaturated zone. During infiltration events, percolation of water will disturb the *in-situ* water potential and temperature. Water potential will be monitored with thermocouple psychrometers that measure relative humidity in the unsaturated zone. This is related to water potential in the voids by Kelvin's equation

(Hillel, 1971). Prototype testing by the USGS has shown that thermocouple psychrometers can be calibrated with salt solutions to a sensitivity of 0.05 bars and accuracy of 0.7 bars over a range of -1 to -75 bars. Prototype thermistor testing has developed thermistors with sensitivity of 0.001 deg C, and accuracies of 0.005 deg C over a range of 10 to 50 deg C. Prototype pressure transducer testing and development has resulted in units with sensitivities of 10.0 Pascals, and accuracies of 20.0 Pascals over a range of 0.5 to 1.5 atms.

A preliminary data analysis of the pneumatic tests and borehole television logs will be used to determine optimal emplacement of the long-term monitoring stations. At least three stations will be installed in each selected borehole. Each station will be instrumented with a thermocouple psychrometer, pressure transducer, thermistor, and access tube for gas sampling. Sensor leads will be connected to a local data-acquisition system (DAS) located near the collar of the borehole in the ramps or drifts. The DAS will convert analog to digital signals which will be sent to the integrated data system (IDS). The design and operation of the system is based on the prototype systems developed in G-tunnel and during the Hydrologic Research Facility prototype boreholes work.

After the sensors and data-acquisition system are installed, data monitoring will continue throughout the *in-situ* phase tests being conducted throughout the ramps and Main Test Level. No alternatives were identified for the methods presented in Table 3.4-1.

3.4.3.10 Collection and transport of gas samples from radial boreholes

Gas sampling (collecting, transporting, and analyzing gas samples) will be conducted as part of the plans described in Section 3.8 (Hydrochemistry tests). A brief description of activities is presented here so that the reader has a better understanding of the interface between the radial-borehole tests and the hydrochemistry tests.

Two sets of gas samples will be taken from the radial boreholes. The first will be for analysis of the general composition of air in the unsaturated zone, including nitrogen, oxygen, argon, and carbon dioxide. Drilling and injected gas will be identified by the tracers. This sampling will be conducted approximately every three months and will continue throughout the *in-situ* phase tests. The second set will be for analysis of gaseous radioactive and stable isotopes: carbon-14, carbon-13, tritium, oxygen-18, and deuterium. Sampling for the second set is complicated and may last about five weeks. For this reason, this sampling will be repeated only annually but will continue throughout the duration of the *in-situ* phase testing.

3.4.3.11 Methods summary

The activity parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.4-1. Also listed are the selected and alternate methods for determining the parameters. 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 3.4-1 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 that they believe are suitable to provide accurate data within the expected range of the activity characterization parameter. Models and analytical techniques have been or will be developed to be consistent with test results.

3.4.4 Quality assurance requirements

The USGS Quality Assurance Program Plan for the YMP (USGS, 1989) requires technical procedures for all technical activities that require quality assurance.

Table 3.4-2 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a hydrologic procedure number. Procedures identified as "TBD" will be approved prior to being needed for use in site characterization.

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 3.4-2. Technical procedures for the radial-borehole activity (SCP 8.3.1.2.2.4.4)

Technical procedure number (YMP-USGS-)	Technical Procedure
<u>Borehole drilling and coring</u>	
HP-12	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS
HP-38	Method for measuring humidity, pressure, and temperature of intake and exhaust air during vacuum drilling
TBD	Borehole cleaning and verification techniques
TBD	Borehole drilling and coring horizontal holes dry
<u>On-site laboratory hydraulic-parameter testing of core and drill cuttings</u>	
HP-32	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone
HP-73	Calibration and use of the Sartorius Electronic Toploader (balance) Model 1507 MP8
<u>Off-site laboratory hydraulic- and physical-parameter testing of core</u>	
HP-28	Laboratory procedures for the determination of moisture-retention curves on rock core
TBD	Procedures for the measurement of (1) volumetric water content, (2) bulk density, (3) porosity, (4) saturated water and gas permeability, (5) relative permeability
TBD	Cross-reference to 8.3.1.2.2.3.1 for a complete listing of matrix hydrologic-properties technical procedures
<u>Fracture logging of core</u>	
GP-11	Logging fractures in core
TBD	On-site fracture logging of core

Table 3.4-2. Technical procedures for the radial-borehole activity (SCP 8.3.1.2.2.4.4)
(continued)

Technical procedure number (YMP-USGS-)	Technical Procedure
<u>Borehole television surveys</u>	
GP-10	Borehole video fracture logging
TBD	Borehole video logging in horizontal boreholes
TBD	Operation of borehole television
TBD	Method for cleaning borehole walls prior to television camera survey
<u>Borehole geophysical surveys</u>	
HP-62	Method for measuring subsurface moisture content, using a neutron moisture meter
<u>In situ pneumatic and gas-tracer testing</u>	
TBD	Air permeability testing in the ESF
TBD	Operation of borehole liner system in ESF
TBD	Calibration of pressure transducers for air permeability testing
TBD	Calibration of thermistors for air permeability testing
TBD	Calibration of TCPs for air permeability testing
<u>Borehole instrumentation and monitoring</u>	
HP-14	Method for calibrating Peltier-type thermocouple psychrometer for measuring water potential of partially saturated media
HP-17	Method of calibration and testing for operation of pressure transducers for air-permeability studies in the unsaturated zone

Table 3.4-2. Technical procedures for the radial-borehole activity (SCP 8.3.1.2.2.4.4)
(continued)

Technical procedure number (YMP-USGS-)	Technical Procedure
<u>Borehole instrumentation and monitoring (continued)</u>	
TBD	Data-acquisition system operations check
TBD	Field procedure for connection of sensor leads and initializing data-acquisition system
TBD	Field procedure for in situ calibration of pressure transducers
TBD	Field procedure for in situ evaluation of thermocouple psychrometer sensor performance
TBD	Field procedure for stemming and instrumentation boreholes
TBD	Flow-test data identification, shipping, handling, and archiving
TBD	Laboratory procedures for calibration of thermal sensors
TBD	Final checkout and acceptance of instrumentation packages and emplacement into radial test holes, exploratory studies facility NTS (preliminary plan)
<u>Collection and transport of gas samples from the radial boreholes</u>	
HP-56	Gas and water-vapor sampling from unsaturated-zone test holes
HP-131	Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis
TBD	Procedure for shipping and handling gas samples

3.5 Excavation-effects test

3.5.1 Objective of activity

The objective of this activity is to estimate the magnitude and extent of modification to the Topopah Spring welded unit (TSw) hydrologic properties caused by excavation and the mechanical supports of the ESF openings.

3.5.2 Rationale for activity selection

Permeability before and after excavation is a parameter required in SCP Table 8.3.1.2-1. This parameter is required to estimate errors that may be introduced in evaluating hydrologic properties in other tests in the ESF. Data from the percolation (Section 3.2), bulk-permeability (Section 3.3), and radial-borehole (Section 3.4) tests may be influenced by hydrologic properties of the rock around openings constructed to conduct the tests. Therefore an evaluation is needed to determine the significance of excavation effects and to develop methods to correct for changes in physical properties that may be introduced by modification of the rock hydrologic properties near these openings.

3.5.2.1 Theoretical background

Excavation in fractured rocks can significantly alter the physical properties of the rock near an underground opening (Montazer, 1982). Olsson (1992) reported a factor of eight in the reduction of water flow rate through a fractured zone into one drift after excavation using blasting. The location was at the Swedish Stripa project site, which is in the saturated zone.

These changes are a concern because modification of the hydrologic properties, such as permeability, may alter existing pathways or introduce new pathways for gas and liquid flow. The travel time of liquids 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 fracture permeability, effective porosity, and saturation depends on the excavation method, in-situ stress tensors, and fracture orientation around the opening. Fracture permeability may increase or decrease, depending on the orientation of the excavation with respect to fractures and to in-situ stress. Fractures that are parallel to the long axis of the opening (but not radial from this axis) and in close proximity to the walls are expected to open due to the stress relaxation in the radial direction. However, radial fractures are expected to close due to stress increase in the tangential direction. In addition, deformation of fracture apertures may significantly change saturation within the fractures, so that some fractures attain larger water saturation. These complex relative permeability relations may be evaluated by monitoring

fracture deformation, saturation, stress changes, and permeability during construction.

3.5.2.2 Parameters required for evaluation

To evaluate the excavation effects, some or all of the following parameters will be required. The choice will depend on the approach that will be followed as described in Section 3.5.3. The parameters are:

- (a) pre-mining fracture permeability around the excavation,
- (b) pre-mining state of rock stress,
- (c) pre-mining water saturation,
- (d) mechanical properties of the *in-situ* rock,
- (e) stress changes after the opening is made,
- (f) fracture deformation, and
- (g) permeability changes due to excavation.

3.5.3 General approach

In order for the excavation effects to be considered significant, the changes in fracture permeability around underground openings need to be measurable and the final permeability values statistically different from the initial values, as well as, those of the surrounding vicinity.

There are two approaches that may be utilized to evaluate the excavation effects. The first approach is a deterministic one where the physics of the process is investigated. It is achieved by measuring all the parameters mentioned above in Section 3.5.2.2 and using them to support a geomechanical model. The model may allow prediction of excavation effects at other locations within the ESF where rock stress and properties are different. This approach will need to be evaluated at least twice at two locations where the stress and rock properties are different. It will be desirable to measure parameters (e) through (g) in Section 3.5.2.2 during and after excavation. This will give more case studies to verify the geomechanical model to predict changes in the study vicinity. An advantage to this approach is that a physical model may be applied to predict changes in permeabilities where conditions are different.

The second approach is a statistical one. The changes in fracture permeability before and after an excavation is made are measured. The same set of measurements is repeated at several other locations to gather enough data to minimize uncertainty levels in predicting permeability changes at different locations. An important restriction to this approach is that predictions will be valid only to areas where the physical properties and stresses of the *in-situ* rock are similar to those where the measurements were made, provided that the same excavation method is used. The number of repetitions required to achieve a given uncertainty level can be estimated after making a few initial *in-situ* measurements at two or more locations. This approach will have little interference with construction and will not require an extensive instrumentation scheme.

3.5.4 Test approaches

Figure 3.5-1 summarizes the objectives and organization of the excavation-effects tests. Cross-references to other study plans which provide input to the excavation-effects tests also appear in Figure 3.5-1. Figure 3.5-2 lists the test procedures. A brief description of each method appears in the boxes below each procedure.

Figures 3.5-1 and -2 summarize the overall structure of the planned activity in terms of approaches and procedures to be employed and measurements to be made. The descriptions of the following sections are organized on the basis of these figures. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) the activity 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.

3.5.4.1 Initial evaluation

Since a prototype to this test has not been made, at least one statistical test is required to verify that (a) changes in permeability are measurable, and (b) that the final permeabilities are statistically different from the initial values as well as those of the surrounding vicinity. If either condition is shown not to be true, then the tests will not be continued. However, if both conditions are shown to be true, then either approach, as listed above in Section 3.5.3, or a combination of the two approaches, can be employed. The choice will depend on the cost and interference with construction involved with each approach.

This stage will be accomplished by conducting a comparison of air-permeability profiles around a planned opening before and after its excavation. The measurements will be made in the ESF from boreholes drilled parallel to a proposed opening.

The test will be conducted from two alcoves excavated along both sides of a planned excavation as shown in Figure 3.5-3. The location of the site will be determined based on drift-wall mapping such that the opening will intersect many fractures. Although this selection will result in a biased sample, it will be a sample that may indicate worst-case scenarios.

Following the completion of each alcove, up to twelve boreholes, six on each side, will be drilled for permeability measurements. These boreholes will have a maximum length of 30 m (100 ft) and be parallel to the planned excavation with a minimum length of 25 m (80 ft). The boreholes will be within one excavation diameter (or width) from the wall of the planned excavation. This interval is chosen because the stress redistribution, and hence, expected permeability changes around circular openings is mostly effective within two radii. If

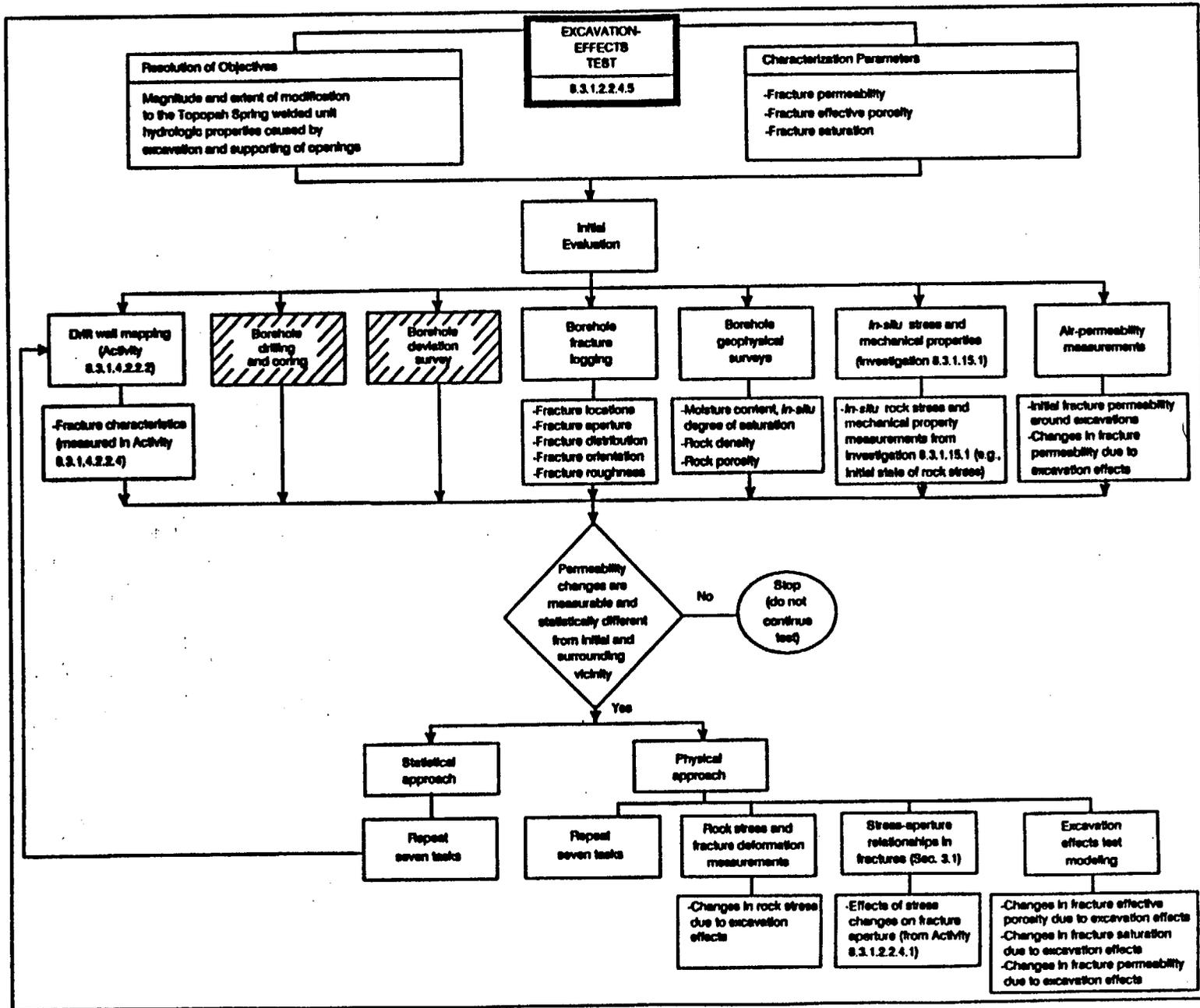


Figure 3.5-1. Organization of the excavation effects activity showing objectives, methods, activity parameters, and characterization parameters. (The cross-hatched box indicates that no activity parameters will be generated)

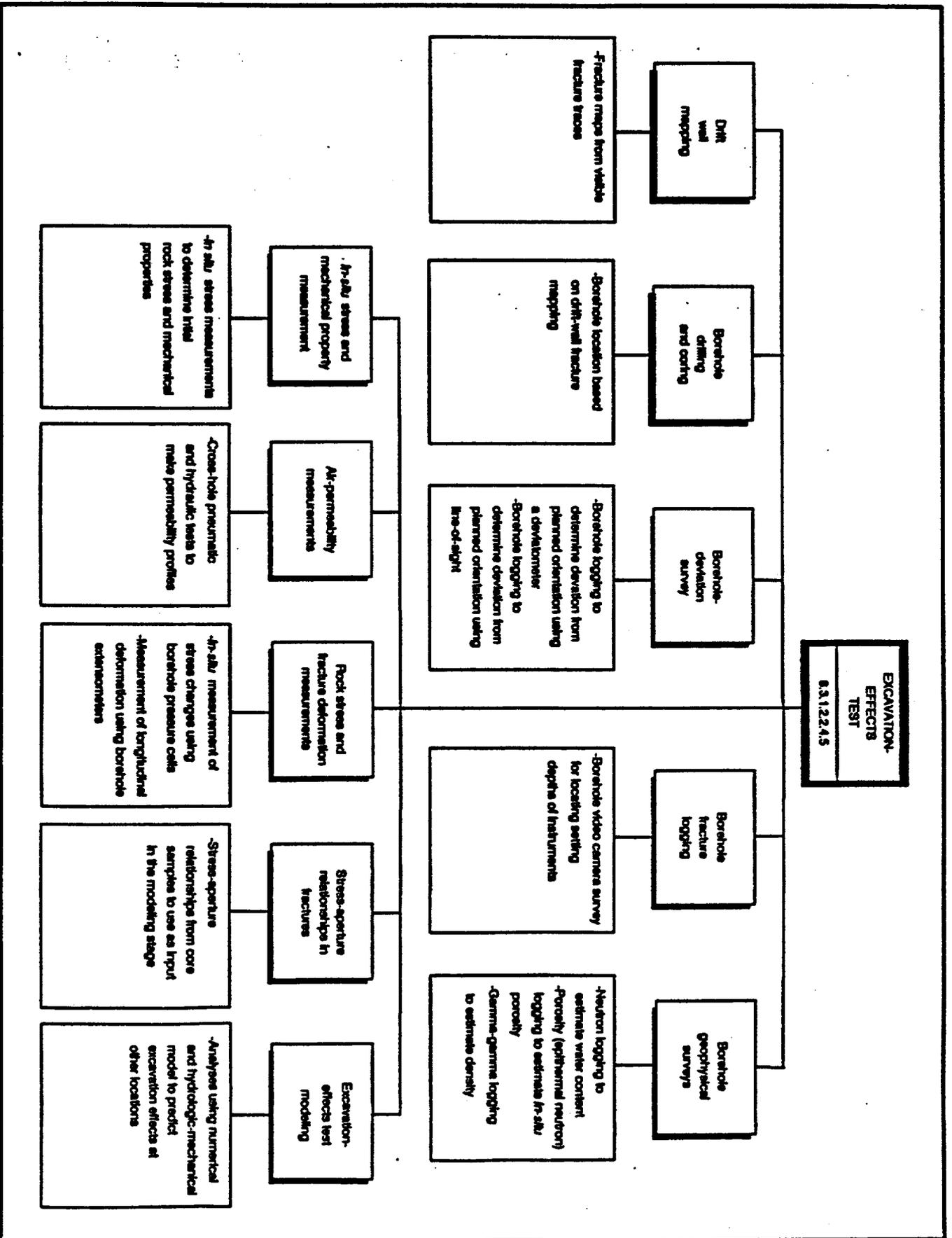


Figure 3.5-2. Organization of the excavation-effects activity showing tests and methods.

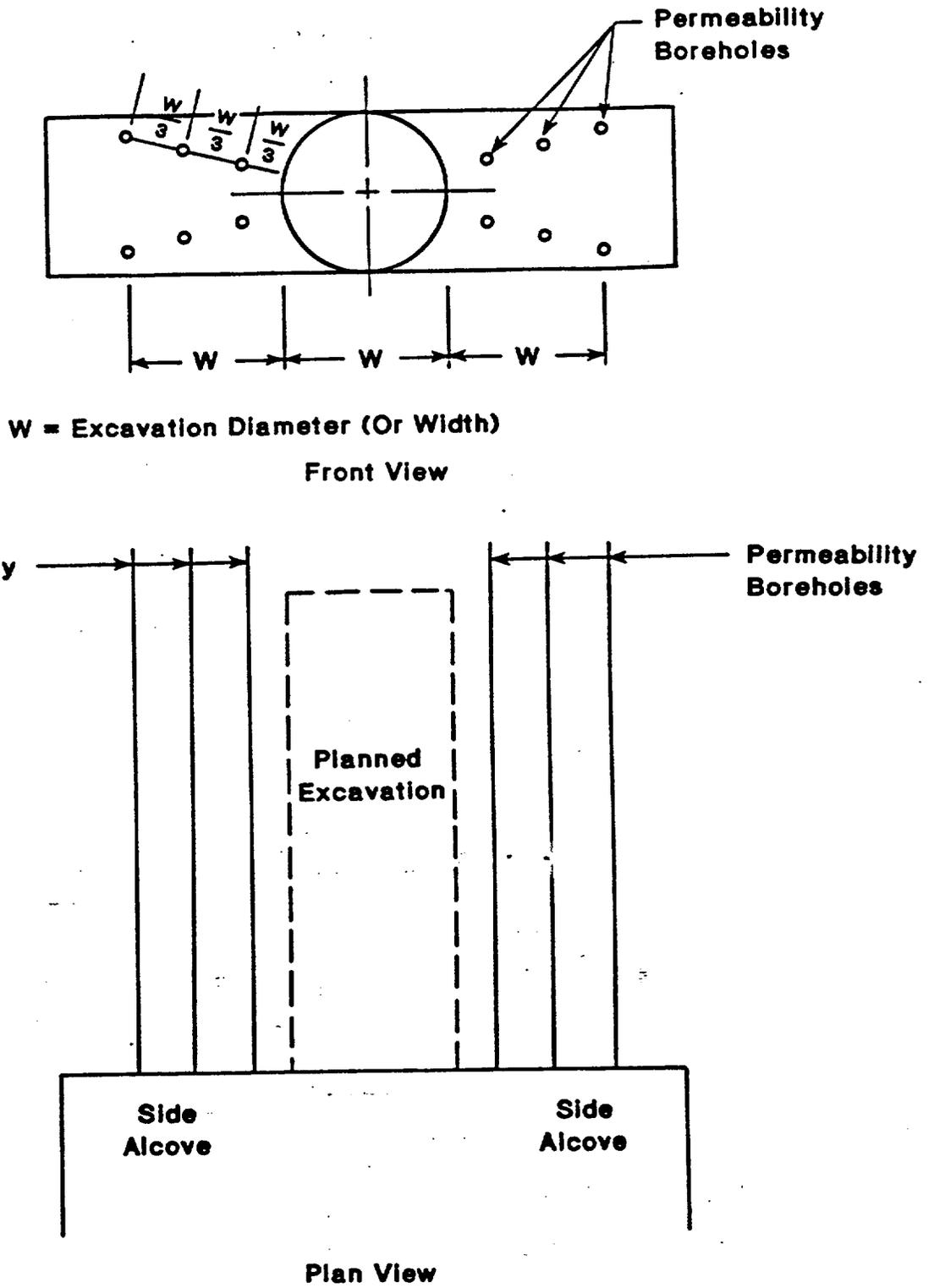


Figure 3.5-3. Excavation effects test plan for the initial evaluation and statistical approach.

required, additional undisturbed zone permeability estimates beyond the two-radii zone will be estimated in the radial-boreholes tests (Section 3.4).

After the boreholes are drilled, they will be logged with geophysical surveying devices to estimate the water saturation, density, and porosity in the vicinity of the proposed excavation. Then an initial permeability profile along the boreholes will be measured. Rock excavation will proceed until it is past the depth of the boreholes. A second geophysical log, using the neutron moisture and epithermal neutron tools, will be run in the boreholes prior to additional permeability tests. Finally, a second permeability profile will be made in the same boreholes.

If it can be demonstrated that permeability changes are measurable and that the final values can be differentiated from the initial values as well as those of the surrounding vicinity, then either of the following approaches can be followed to complete this test.

3.5.4.2 Physical approach

After verifying that the effects are significant, and if this approach is chosen, calibrated instruments will be installed around another planned excavation to measure all the parameters listed above in Section 3.5.2.2. Initial fracture permeability, state of stress, water saturation, and mechanical properties of the *in-situ* rock will be measured. Rock stress and permeability changes, and fracture deformation during and after the excavation, also will be measured. These measurements will be conducted from up to 30 boreholes drilled around a proposed opening in the ESF as shown in Figure 3.5-4. However, since this approach requires extra instrumentation, the decision to implement it needs to be made at least six months in advance so that enough time is allowed for stress and deformation instrument procurement and calibration.

A coupled hydrologic-mechanical model will be used to analyze the results and predict excavation effects at other locations within the ESF where rock stress and properties are different. Uncertainty will be associated with the *in-situ* measurements. This uncertainty will propagate to the predicted results. It is yet to be determined whether the level of uncertainty from physical models is different from that resulting from statistical models to justify one approach over the other.

Although the borehole density in this approach seems high, the stress disturbance caused by the drill holes is expected to be very small compared to the disturbance that will be caused by the excavation. This is based on the assumption that if the rock behaves as a linear elastic material then most of the stress redistribution will take place within two radii (one diameter) of a circular opening. Since the biggest borehole is not expected to be larger than 150 mm (6 in) in diameter, the disturbed zone

W = Excavation Diameter (or width)

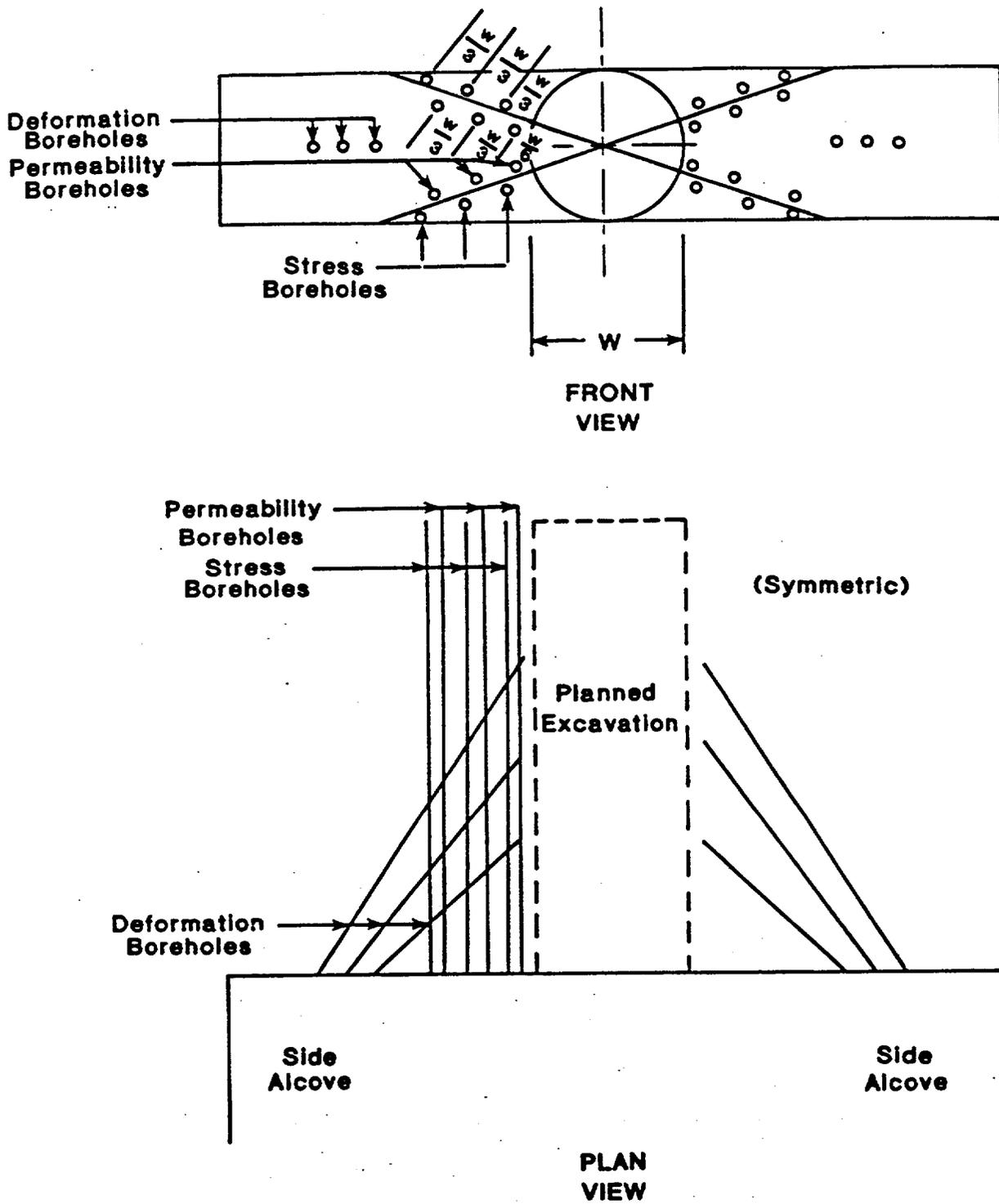


Figure 3.5-4. Excavation effects test plan for the physical approach

around these boreholes is not expected to extend beyond one diameter from the borehole wall.

3.5.4.3 Statistical approach

If the statistical approach is chosen to complete the test, then the experimental procedure will be similar to that described earlier in the section on initial evaluation (Section 3.5.4.1 and Figure 3.5-3). No extra instrumentation will be needed. The number of repetitions will depend on the required level of uncertainty which has not yet been defined.

3.5.5 Test procedures

All boreholes will be instrumented after they are logged for fractures with a video camera. This will allow instrument installation to be more precise such that the measurements will reflect values in fractured zones. The following procedures will be utilized during this test. The first seven procedures will be required for both approaches. The latter three will be required only if the physical approach is implemented.

3.5.5.1 Drift-wall mapping

Locations of the proposed testing sites will be based on fracture maps which are a part of Activity 8.3.1.4.2.2.4, (Geologic mapping of the ESF) in Study 8.3.1.4.2.2 (Structural features in the site area).

3.5.5.2 Borehole drilling and coring

Boreholes will be drilled following the completion of side alcoves, if needed. The tentative borehole locations are shown in Figures 3.5-3 and 3.5-4. A predetermined drilling scheme, rather than a random one, will be used for this study. A random drilling scheme will not be used since a limited and small number of boreholes will be drilled. A few boreholes will not have a uniform distribution to cover the area surrounding the opening.

3.5.5.3 Borehole-deviation survey

All boreholes will be logged using a deviatometer. This is essential for the analysis stage of this test where the locations of the instruments, which will be installed later, relative to the opening are required. The line-of-sight method will be used for boreholes that appear to be straight.

3.5.5.4 Borehole fracture logging

All boreholes will be logged with a video camera to locate the fractures and possibly fractured or damaged zones. USGS personnel will log the cores of the same boreholes for sections that cannot be viewed clearly with the video camera. This is required in order to determine the depth settings of the different instruments needed for this test and for updating the

fracture map which is required for the analysis 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.

3.5.5.5 Borehole geophysical surveys

All boreholes will be logged using neutron-moisture, epithermal neutron (porosity), and gamma-gamma tools before and after excavation. These parameters will be needed for the analysis stage of this test. Laboratory methods will be used to determine more accurate estimates for porosity and density. Laboratory determination of water content is another alternative to geophysical surveying, although not as accurate.

3.5.5.6 *In-situ* stress and mechanical property measurements

The *in-situ* stress and mechanical property measurements will be required in the vicinity of the proposed testing locations. This information will be performed under Investigation 8.3.1.15.1 (Spatial distribution of thermal and mechanical rock properties).

3.5.5.7 Air-permeability measurements

Permeability boreholes will be drilled after completing the side alcoves as shown in Figures 3.5-3 and 3.5-4. Based on borehole fracture logging, the depth settings of the packers will be determined. This is done in order to monitor fracture permeability in the permeability boreholes. Permeability will be measured before excavation is started to gather baseline values. Another set of measurements will be taken after the opening is complete, i.e., past the permeability boreholes. If the physical approach is chosen, then measurements during excavation will be desirable. The testing methods are described in Section 3.4 (Radial borehole tests).

3.5.5.8 Rock stress and fracture deformation measurements

Boreholes for monitoring stress changes and fracture deformations will be instrumented after the completion of the side alcoves. Stress changes and axial borehole deformation are required for the modeling stage of this test. The borehole pressure cell (Haramy and Kneisley, 1991) will be considered for measuring changes in rock stress. The U.S. Bureau of Mines three-component borehole deformation gage (Bickel, 1978) is another alternative provided that one gage is used in a borehole located in an area where vibrations will not affect gage sensitivity. Borehole extensometers will be utilized to monitor axial deformation (strain) in the angled boreholes (Figure 3.5-4). All instruments will be connected to a data-acquisition system for continuous monitoring.

3.5.5.9 Stress-aperture relationship of fractures

Since fracture aperture is stress-dependent (Olsson, 1992), a relationship between fracture aperture, which is related to permeability, and stress will be required to model fractured rock behavior. This information will be collected under the Intact-fracture test in the exploratory studies facility (SCP Volume IV, Part B, Section 8.3.1.2.2.4.1).

3.5.5.10 Excavation-effects test modeling

Fracture data (statistical and mechanical parameters), permeability profiles, fracture deformation, stress-aperture relationships, and rock mechanical properties will be utilized to validate coupled hydrologic-mechanical models to predict permeability changes around different underground openings in the potential repository. There are several models that may be used to simulate such a behavior. Examples of such models are reported by Olsson (1992).

3.5.5.11 Methods summary

The activity parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.5-1. Tests that are part of other studies are not included in this table.

The table lists selected as well as alternate methods for determining the parameters. 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, resolution, duration of methods, expected range, and interference with other tests.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the activity parameter. Models and analytical techniques have been or will be developed to be consistent with test results.

3.5.6 Quality assurance requirements

The USGS Quality Assurance Program Plan for the YMP (USGS, 1989) requires technical procedures for all technical activities that require quality assurance.

Table 3.5-2 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a hydrologic procedure number. Procedures identified as "TBD" will be approved prior to being needed for use in site characterization. Technical procedures that belong to tests that are part of other studies are not included in this table.

Table 3.5-1. Summary of tests and methods for the excavation-effects activity
(SCP 8.3.1.2.2.4.5)

Methods (selected and alternate)	Activity parameter
<u>Drift-wall mapping (Activity 8.3.1.4.2.2.2)</u>	
Drift-wall mapping	Fracture characteristics
<u>Borehole fracture logging</u>	
Borehole deviation survey using a deviatometer (selected)	--
Using the line-of-sight method (alternate)	--
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
<u>Borehole geophysical surveys</u>	
Neutron logging to estimate water content (selected)	Moisture content, in situ degree of saturation
Laboratory determination of water content from cores (alternate)	"
Porosity (epithermal neutron) logging to estimate in situ porosity (selected)	Rock porosity
Laboratory determination of porosity (alternate)	"

Table 3.5.1. Summary of tests and methods for the excavation-effects activity
(SCP 8.3.1.2.2.4.5) (continued)

Methods (selected and alternate)	Activity parameter
<u>Borehole geophysical surveys (continued)</u>	
Gamma-gamma (density) logging (selected)	Rock density
Density determination from laboratory measurements (alternate)	"
<u>In-situ stress and mechanical properties (Investigation 8.3.1.15.1)</u>	
In-situ stress and mechanical properties measurements	In-situ stress and mechanical properties
<u>Air permeability measurements</u>	
Cross-hole pneumatic and hydrologic tests (selected)	Initial fracture permeability around excavations
"	Changes in fracture permeability due to excavation effects
<u>Rock stress and fracture deformation measurements</u>	
In situ measurements of stress, using borehole pressure cells (selected)	In situ stress changes, magnitude and orientation
"	Changes in rock stress due to excavation effects
In situ measurements of stress, using U.S. Bureau of Mines 3-component borehole deformation gage (alternate)	In-situ stress changes, magnitude and direction
"	Changes in rock stress due to excavation effects

Table 3.5.1. Summary of tests and methods for the excavation-effects activity (SCP 8.3.1.2.2.4.5) (continued)

Methods (selected and alternate)	Activity parameter
<u>Rock stress and fracture deformation measurements (continued)</u>	
Measurement of longitudinal deformation using borehole extensometers (selected)	Fracture deformation
•	Changes in rock stress due to excavation effects
<u>Stress-aperture relationships in fractures (Sec. 3.1)</u>	
Stress-aperture relationships from core samples	Effects of stress changes on fracture aperture
<u>Excavation-effects test modeling</u>	
Test using numerical hydrologic-mechanical model (selected)	Changes in fracture effective porosity due to excavation effects
•	Changes in fracture saturation due to excavation effects
•	Changes in fracture permeability due to excavation effects

Table 3.5-2. Technical procedures for the excavation-effects activity
(SCP 8.3.1.2.2.4.5)

Technical procedure number (YMP-USGS-)	Technical procedure
<u>Borehole drilling and coring</u>	
HP-12	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes
TBD	Method for measuring humidity, pressure, and temperature of intake and exhaust air during vacuum drilling
<u>Borehole-deviation surveys</u>	
TBD	Borehole deviation surveys
TBD	Oriented core logging
<u>Borehole fracture logging</u>	
GP-10	Borehole video fracture logging
TBD	Borehole fracture logging from oriented cores
<u>Borehole geophysical surveys</u>	
TBD	Method for measuring in situ porosity, using porosity (epithermal neutron) logs
TBD	Method for measuring in situ density, using gamma-gamma logs
HP-62	Method for measuring subsurface moisture content, using a neutron moisture meter
<u>Rock stress and fracture deformation measurements</u>	
TBD	Method for assembling, calibrating, installing, and using rock stress gages in boreholes
TBD	Method of assembling, calibrating, installing, and using extensometers
<u>Excavation-effects test modeling</u>	
TBD	Method for evaluating the correctness of a coupled-hydraulic-mechanical finite-element model (bench-mark problems)

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, 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.

3.6 Calico Hills test

The Calico Hills test has been deleted from this current ESF unsaturated-zone study. If the YMPO decides to expand ESF testing to include the Calico Hills geologic unit, the following tests will include tests in this unit: Radial boreholes, Perched water, Hydrochemistry, Excavation effects, Hydrologic properties of major faults, Intact fracture, Percolation, and Bulk permeability. Preliminary test locations have been selected in the Calico Hills for *in-situ* hydrologic characterization tests for these eight tests.

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 perched-water 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 hydrogeologic 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 the ESF. This evaluation is needed to understand the hydrogeologic 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.

Surface boreholes, drilled in advance of construction of the North and the South Ramps, may encounter perched water. If perched water is detected in any of the North or South Ramp geology boreholes, it will allow full preparation for sample collection and testing in the ramps. If perched water has not been detected in the North or South Ramp geology boreholes, it will be necessary to visually inspect ramp walls for indications of perched water, and to sample and test, if any is encountered. All ramp and drift walls will be visually inspected for the occurrence of perched water during ESF construction.

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 and others, 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 or part 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 obstructing flow, which could increase travel time, or from barriers creating shorter preferential pathways, which would decrease travel time.

Because the ESF has not been constructed at Yucca Mountain, geologic and hydrologic prototype testing has been conducted at G-tunnel in Rainier Mesa, which is located at the Nevada Test Site about 60 km (40 mi) from Mercury, Nevada. This prototype testing has helped to develop and test hydraulic methods for determining the rate of flow, hydraulic head, and procedures for collecting representative water samples from a mined ramp or drift wall. In addition, instrumentation needed to provide long-term hydrogeologic data in perched-water zones has been identified.

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 the ESF. As the tunnel boring machine (TBM) advances, prior to the walls being prepared for geologic mapping, seeps or saturated zones will be looked for in conjunction with mapping activities. If the inflow of appreciable quantities of perched water is reported, hydraulic tests will be initiated as soon as the ramp or drift becomes accessible. If perched water or fracture flow is observed, boreholes will be drilled laterally into the ESF walls to test and sample the zone. A flow-rate measurement will precede the borehole drilling if the flow rate into the ESF 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 or fracture networks that are poorly connected or are truncated against some network overlying relatively impermeable material. Depending on the hydrogeologic characteristics of each zone, the rate of discharge into the ESF 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 ESF may affect the interpretation of the hydrogeology of the perched-water test. The disturbed zone around the ESF and the stress changes caused by excavation and drilling 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 *in-situ* borehole tests. In addition to excavation effects, the possibility of lining portions of the ESF with concrete may modify the hydrogeologic properties of the rocks surrounding the ESF. Water from the wet concrete may enter fractures in the ESF walls 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 ESF before access can be gained to the perched-water zone. The limited access afforded by the TBM could enhance these uncertainties and limitations. 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, directing water away from the repository, would be evaluated. The perched-water data would also be important in formulating mathematical models of the flow in the unsaturated zone.

Any perched water encountered by the ESF 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, site-characterization parameters, and activity parameters. 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 activity 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.

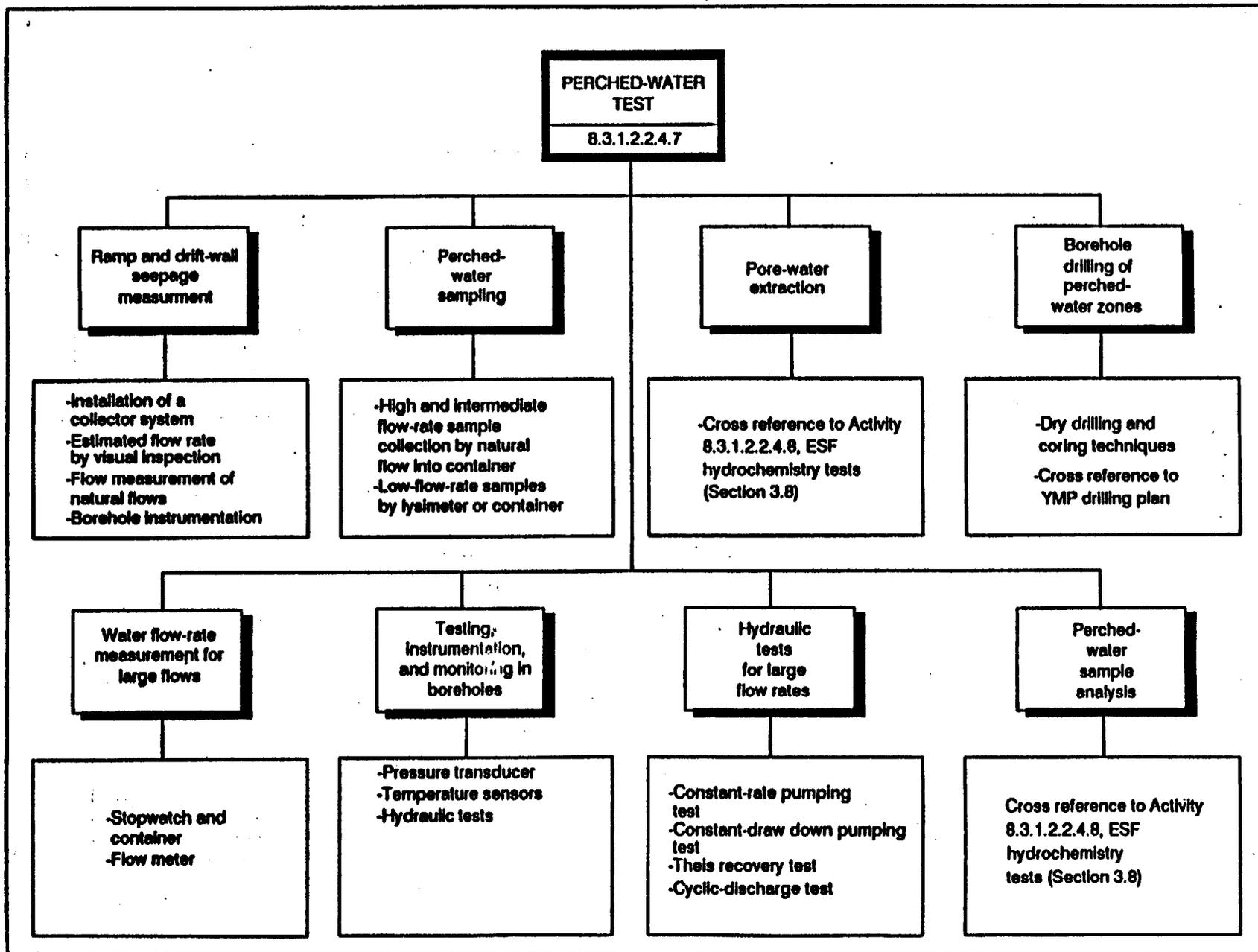
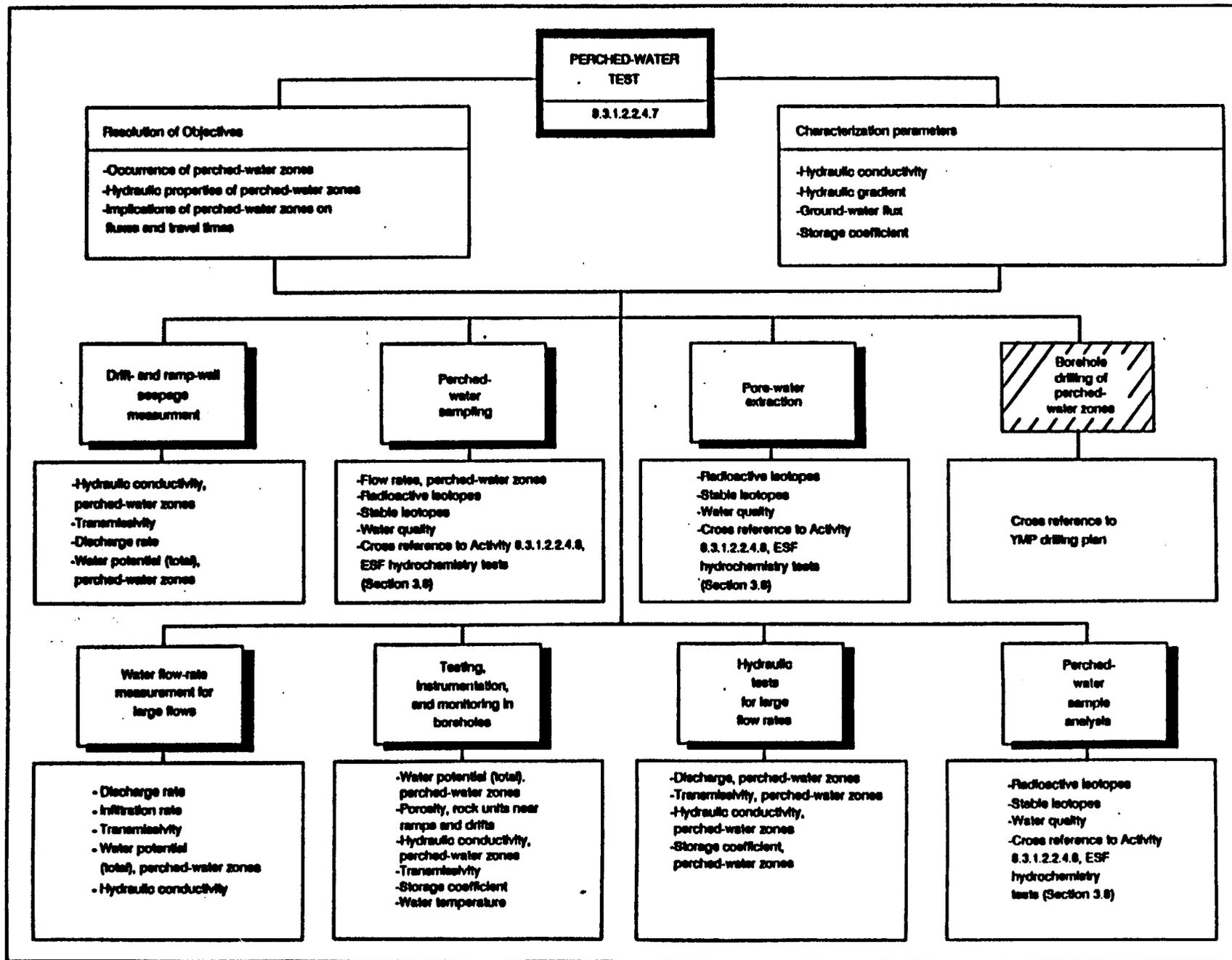


Figure 3.7-1. Organization of the perched-water activity, showing tests, analyses, and methods.



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

The perched-water tests will be conducted in the ESF, which will penetrate the same hydrogeologic units as 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 hydrogeologic 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 Ramp- and drift-wall seepage measurement

In the event that perched water is encountered during construction, the rate of seepage from ramp- and drift-walls 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. Boreholes drilled into perched-water zones will allow access for instrumentation and seepage or flow measurements. In lined portions of the ESF, block-outs and subsequent boreholes will allow easy access for later instrumentation and seepage or flow 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 ESF 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. The selected methods are presented in 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 be accomplished using dry-drilling methods. These dry-drilling and coring methods have been 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.

3.7.3.5 Measurement of large flows

The selected methods of measuring the rate of perched water flowing from either the drift or ramp 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 ESF construction and will be cased to the outer edge of the disturbed 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 borehole instrumentation packages to further test and sample the perched-water zone. If the amount of water is inadequate to justify a pumping test, short boreholes will be drilled into the walls of the ESF for testing of the water-bearing zone.

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 may be drilled and completed with borehole instrumentation packages for long-term monitoring. The diameter of the borehole will be small, but will still allow installation of a borehole instrumentation package, such as piezometers. The borehole instrumentation will be designed to enable monitoring of the *in-situ* pressure, sampling of the water, and testing of the perched-water 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 any concrete lining for later sampling. In the event that the borehole is in a lined portion of the ESF, 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 ensure the detection of transient boundaries. These may include (1) pressure transducers to measure hydraulic head; (2) lysimeters for collecting water samples; (3) 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; (5) geophysical logging; and (6) temperature sensors. There are two alternate methods. The first alternate method involves using thermocouple psychrometers, but this was not selected because it is used to measure matric potential in rocks that contain less water than would be present in a perched-water zone. 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 perched-water zones. Monitoring of the boreholes may also be useful in measuring temporal changes in a perched-water 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 in portions of the ESF where a liner is installed. All boreholes will be subjected to long-term hydraulic monitoring to estimate the extent and hydrologic properties of the perched-water zone.

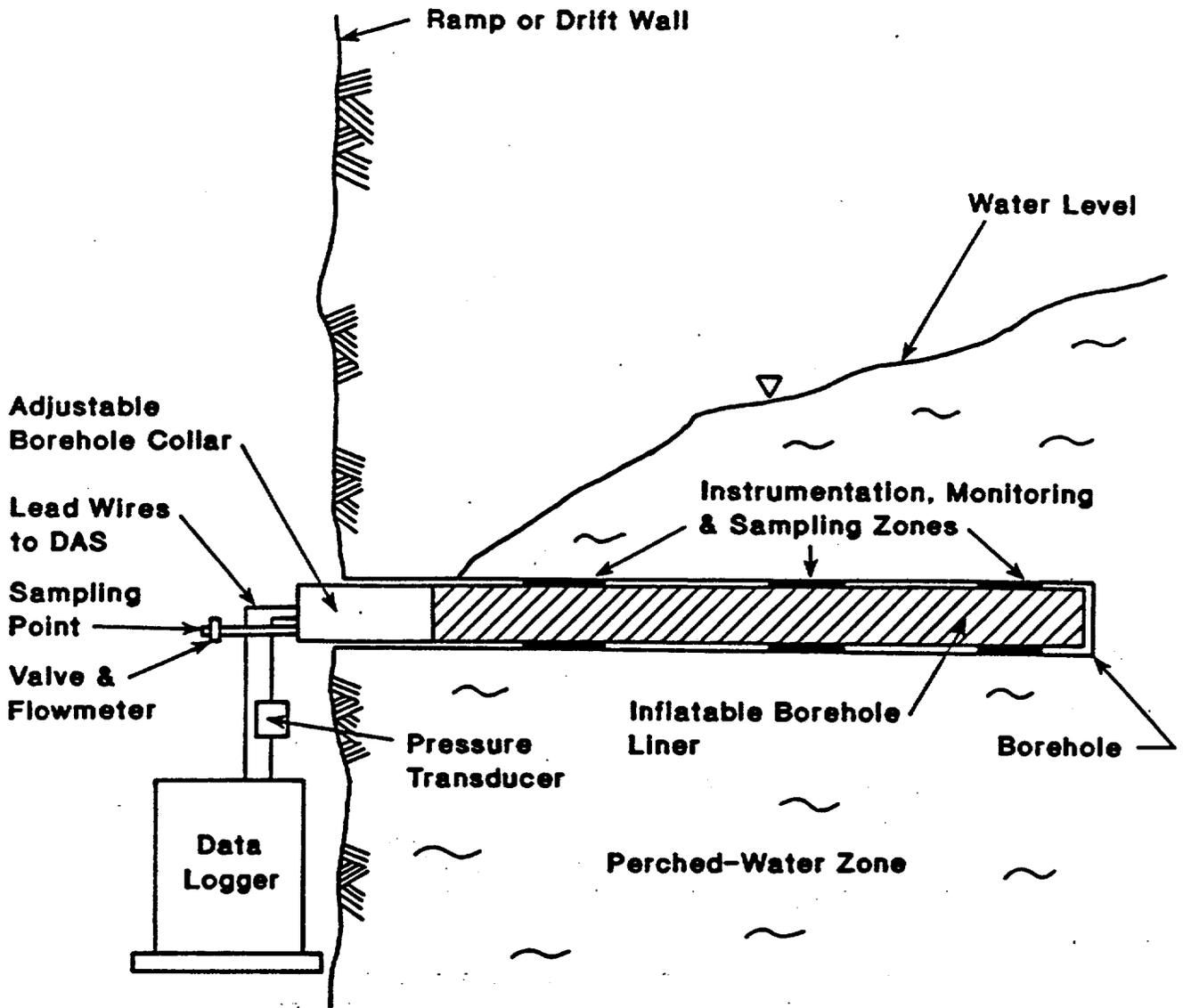
3.7.3.7 Hydraulic tests for large flow rates

Pumping tests will be conducted in the ESF if water flows at a sufficient rate into the underground openings. 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 ESF 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.

Inflows to the ESF may not be analyzable by standard hydraulic-test methods. Hydrologic assessment will need to be planned and formed on a case-by-case basis.

3.7.3.8 Perched-water sample analysis

Any perched water encountered in the ESF will be sampled. These samples will be analyzed for major anions and cations, and for stable and radioactive isotopes. The water quality 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).



Note: Figure Not to Scale

Figure 3.7-3. Schematic diagram of instrumentation of a perched-water zone within the ESF.

There are no viable alternate methods to use in place of the selected methods which are presented in Table 3.7-1 in Section 3.7.3.9.

3.7.3.9 Methods summary

The activity 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. 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 that they believe are suitable to provide accurate data within the expected range of the activity parameter. Models and analytical techniques have been or will be developed to be consistent with test results.

3.7.4 Quality assurance requirements

The USGS Quality Assurance Program Plan for the YMP (USGS, 1989) requires procedures for all technical activities that require quality assurance.

Table 3.7-2 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a hydrologic procedure number. Procedures identified as "TBD" will be approved prior to being needed for use in site characterization. Many of the needed technical procedures depend on the selection and procurement of borehole instrumentation and cannot be completed until that is accomplished.

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, 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 3.7-1. Summary of tests and methods for the perched-water activity (SCP 8.3.1.2.2.4.7)

Methods (selected and alternate)	Activity parameter
<u>Ramp- and drift-wall seepage measurement</u>	
Installation of collector system (selected)	Hydraulic conductivity, perched-water zones
▪	Transmissivity
▪	Discharge rate
▪	Water potential (total), perched-water zones
Estimate flow rate by visual inspection (selected)	Hydraulic conductivity, perched-water zones
▪	Transmissivity
▪	Discharge rate
▪	Water potential (total), perched-water zones
Measurement of natural flows by borehole instrumentation (selected)	Hydraulic conductivity, perched-water zones
▪	Transmissivity
▪	Discharge rate
▪	Water potential (total), perched-water zones
<u>Perched-water sampling</u>	
Large-flow- and intermediate-flow-rate sample collection by natural flow into container (selected)	Flow rates, perched-water zones
Small-flow-rate samples by lysimeter or container (selected)	▪
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Radioactive isotopes
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Stable isotopes
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Water quality

Table 3.7-1. Summary of tests and methods for the perched-water activity (SCP 8.3.1.2.2.4.7) (continued)

Methods (selected and alternate)	Activity parameter
<u>Pore-water extraction</u>	
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Radioactive isotopes
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Stable isotopes
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Water quality
<u>Borehole drilling of perched-water zones</u>	
Dry drilling and coring (selected)	--
Wet drilling and coring (alternate)	--
<u>Measurement of large flows</u>	
Stopwatch and a container (selected)	Discharge, perched-water zones
"	Infiltration rate
"	Transmissivity
"	Water potential (total), perched-water zones
"	Hydraulic conductivity
Flow meter (selected)	"
"	Infiltration rate
"	Transmissivity
"	Water potential (total), perched-water zones
"	Hydraulic conductivity

Table 3.7-1. Summary of tests and methods for the perched-water activity (SCP 8.3.1.2.2.4.7) (continued)

Methods (selected and alternate)	Activity parameter
<u>Testing, instrumentation, and monitoring of boreholes</u>	
Pressure transducer (selected)	Water potential, total, perched-water zones
Hydraulic tests (selected)	Hydraulic conductivity, perched-water zones
"	Storage coefficient, perched-water zones
"	Transmissivity, perched-water zones
Periodic visual inspection (alternate)	Water potential, total, perched-water zones
<u>Hydraulic tests for large flow rates</u>	
Theis recovery test (selected)	Discharge, perched-water zones
"	Hydraulic conductivity, perched-water zones
"	Storage coefficient, perched-water zones
"	Transmissivity, perched-water zones
Cyclic-discharge test (selected)	Discharge, perched-water zones
Cyclic-discharge test (selected)	Hydraulic conductivity, perched-water zones
"	Storage coefficient, perched-water zones
"	Transmissivity, perched-water zones
Constant-drawdown pumping test (selected)	Discharge, perched-water zones
"	Hydraulic conductivity, perched-water zones
"	Storage coefficient, perched-water zones
"	Transmissivity, perched-water zones
Constant-rate pumping test (selected)	Discharge, perched-water zones
"	Hydraulic conductivity, perched-water zones
Constant-rate pumping test	Transmissivity, perched-water zones

Table 3.7-1. Summary of tests and methods for the perched-water activity (SCP 8.3.1.2.2.4.7) (continued)

Methods (selected and alternate)	Activity parameter
<u>Perched-water sample analysis</u>	
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Radioactive isotopes
Cross reference to 8.3.1.2.2.4.8 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. Technical procedures for the perched-water activity
(SCP 8.3.1.2.2.4.7)**

Technical Procedure Number	Technical Procedure
TBD	Sampling, testing, and monitoring perched-water seepage in the exploratory studies facility
TBD	Sampling, testing, and monitoring perched-water zones in boreholes in the exploratory studies facility
HP-06	Hydrologic pumping test
HP-53	Method for calibrating digital and analog watches
HP-17	Method of calibration and testing for operation of pressure transducers for air-permeability studies in the unsaturated zone
HP-108	Long-term monitoring of boreholes in perched-water zones in the exploratory studies facility
HP-103	Pumping tests of perched water in the exploratory studies facility

3.8 Hydrochemistry tests

3.8.1 Objectives of activity

The objectives of this activity are:

1. to extract unaltered pore water and gas samples from core samples, and gas and water vapor samples from boreholes;
2. to obtain hydrochemical and isotopic data that will help in understanding the transport mechanism, flow direction, and travel time of gas and water in the unsaturated zone; and
3. to determine the geochemical evolution of unsaturated-zone water by hydrochemical and isotopic techniques.

3.8.2 Rationale for activity selection

Understanding the unsaturated-zone flow system at Yucca Mountain is essential to the site-characterization program because it is within this interval of rocks that the proposed repository is to be constructed. It is important to evaluate the flow and storage of gas, vapor, and water within the repository block because moisture (vapor and liquid) is the expected major medium for any transport of radionuclides to the accessible environment. Furthermore, a chemical evaluation of gaseous and liquid constituents is important in understanding hydrologic processes, water/rock interactions, geochemical evolution of ground water, and transport mechanisms in the unsaturated zone.

In the unsaturated zone, water is presumed to be present both in liquid and vapor phases. Water flow and storage is envisioned to be complexly three dimensional, controlled by structural, textural, stratigraphic, and climatological factors. In general, liquid-water flow is expected to occur within interconnected pores and fractures, together with advective and diffusive vapor-phase flow within interconnected air-filled fractures. In the geohydrologic units beneath Yucca Mountain, flow paths and fluxes are not clearly understood, and the movement of moisture (gas and liquid) between surficial units and the repository block has not been directly quantified. Because liquid water and water vapor are expected to be in local thermodynamic phase equilibrium, liquid-water saturation, water-vapor, and solute concentrations are coupled through the prevailing geothermal regime. Consequently, hydrologic evaluation of the site constitutes a problem of two-phase, multi-component, coupled heat (geothermal) and moisture flow within alluvium and a layered sequence of variably-saturated, tuffaceous, geohydrologic units which have been tilted, faulted, and fractured. Thus, a hydrochemical evaluation of the unsaturated zone constitutes a study in which the liquid and gaseous chemical interactions must be considered within an already complicated hydrologic scenario.

A study of unsaturated-zone chemistry and distribution of gases will help evaluate chemical transport and flow processes within the

repository block. ^{14}C and tritium concentration measurements will determine the residence time of gases in the unsaturated zone. $^{13}\text{C}/^{12}\text{C}$ isotopic data will also be used in support of ^{14}C age estimates. Stable-isotope ratios ($^{18}\text{O}/^{16}\text{O}$ and D/H), which might indicate the climatic and evaporative history of moisture, will provide information on flow paths of gases through the unsaturated zone as well as interactions with other minerals or transport properties.

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.

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 could be relatively dilute compared with water from poorly interconnected fractures. A dilute chemical concentration in water at great depths combined with a young ^{14}C age of water would imply a relatively fast travel time in the unsaturated zone, and possibly periods of intense recharge at the land surface. Conversely, nondilute 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. Hydrochemical data and interpretations will be used as a cross-check on travel times computed from hydraulic parameters.

Pore-water chemistry data and mineralogic data for the matrix and fractures in the unsaturated zone will be input to geochemical models 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 implies an approach to equilibrium, and possibly a long contact time (long residence time), whereas a poor match indicates the relative importance of reaction kinetics in controlling vadose-zone water composition.

Rock-water interaction affects 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. Rock-water interaction parameters, such as ionic strength and ranges of Eh/pH, will also 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.

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 and higher in the mountains, and also lighter 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. Isotopic variations resulting from these effects can provide input to interpretations of a variety of hydrologic processes at Yucca Mountain, as discussed below.

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 may have relatively small isotopic compositional variation with time due to an averaging effect. Thus, long-term climatic changes might be inferred from significant differences in isotopic composition of unsaturated-zone water. Precipitation at the Nevada Test Site during a cooler climate should be 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 might be possible to identify the climate at the time of recharge (that is, recharged during the warm- or cold-climatic regime). Hydrologic processes on a shorter time scale might also be inferred from stable isotopes of hydrogen and oxygen. 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 inferred. Furthermore, from the age of water determined by ^{14}C and 3H methods, it is possible to identify the time of recharge, travel, and residence time (Yang and others, 1985).

Tritium ^3H analyses will be used to determine the residence time of pore and fracture water up to about 100 yr; ^{14}C analyses will extend the determination range from 100 to 40,000 yr, and ^{36}Cl yields dates from 50,000 to about 900,000 yr. Obtaining age estimates from each of these isotopic analyses requires, at a minimum, evaluation of all sources and sinks of the elements, and the isotopic signature of each. To the degree that this is possible, four relative-age scenarios will be tested:

- (a) Very young (<200 yr) fracture water and near-fracture water, and relatively old (>5,000 yr) 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 yr) pore water and relatively old (>5,000 yr) fracture and near-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-water, fracture-water, and near-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.
- (d) General absence of fracture and near-fracture water, and the occurrence of relatively old (>5,000 yr) 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 $^{36}\text{Cl}/\text{Cl}$ ratio analysis (YMP-LANL-SP 8.3.1.2.2.2, water-movement test).

When water percolates primarily downward, travel time can be estimated from the ages of pore, fracture, near-fracture, and perched water at known depths. In more complicated scenarios, when water moves tortuously, assessment of flow paths will require input from mineralogy, stable isotopes, and reaction modeling. After this flow path information is combined with estimates of 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 were undertaken prior to the ESF hydrochemistry tests to design and validate methods of pore-water and gas collection. The optimal rubble size test and the dry coring of rubble tests are not described here because mining rubble will not be available from the ramp and drift construction. The pore-water extraction by compression testing is described in more detail in Section 3.8.3.5. The pore water extraction prototype test has indicated the potential of one-dimensional compression to obtain water from nonwelded core samples, with a degree of saturation greater than 16 percent and from welded core samples with a degree of saturation greater than 37 percent. Additional research is being attempted to determine if water can be obtained from welded core having smaller degrees of saturation using fragmented core samples.

3.8.3 General approach and summary of tests and analyses

The activity is designed to collect gas and unaltered pore, near-fracture, fracture, and perched water from long (45.7 m; 150 ft) boreholes and borehole cores located in all geologic units, and near significant geologic features throughout the ESF (Figure 3.8-1). These long boreholes will be constructed from alcoves off of the main drift. The alcoves will be perpendicular to the ramp/drift, and the boreholes will be drilled in the far end of the alcove. The alcove approximate dimensions are: width, 6 m; height, 5 m; and depth, 6 m. The boreholes should be drilled as soon as the alcoves are completed. Short (1-2 m) small diameter (2.5-5 cm) boreholes will be hammer-drilled as close as practicable behind the tunnel boring machine (TBM) using a jackleg. These short boreholes will be situated along the wall of the 61-m (200-ft) starter tunnel and at the locations of the long boreholes, prior to construction of the alcoves, to provide a sample as nearly representative of pre-mining conditions as possible. If it can be shown during initial testing that short borehole analytical results are similar to long borehole results the short borehole construction and testing will be discontinued. If initial testing indicates the borehole length is too short to escape effects of mining, then these short boreholes will be drilled deeper.

Core samples will be collected continuously during borehole coring, and gas samples will be collected twice a year for three years from the radial boreholes (Section 3.4), from most of the bulk-permeability holes (Section 3.3), from most of the major fault holes (Section 3.10), and from boreholes cored specifically for the hydrochemistry tests. The possibility of construction of the Calico Hills north and south ramps and exploratory drifts could provide access for drilling hydrochemistry-test boreholes that would provide critical information on water residence time in the Calico Hills nonwelded unit and direction of water flow in this unit. Collection of gas and core samples to determine these parameters is of paramount importance to the site characterization for waste isolation. These boreholes will be generally located as described in Table 3.8-1, and

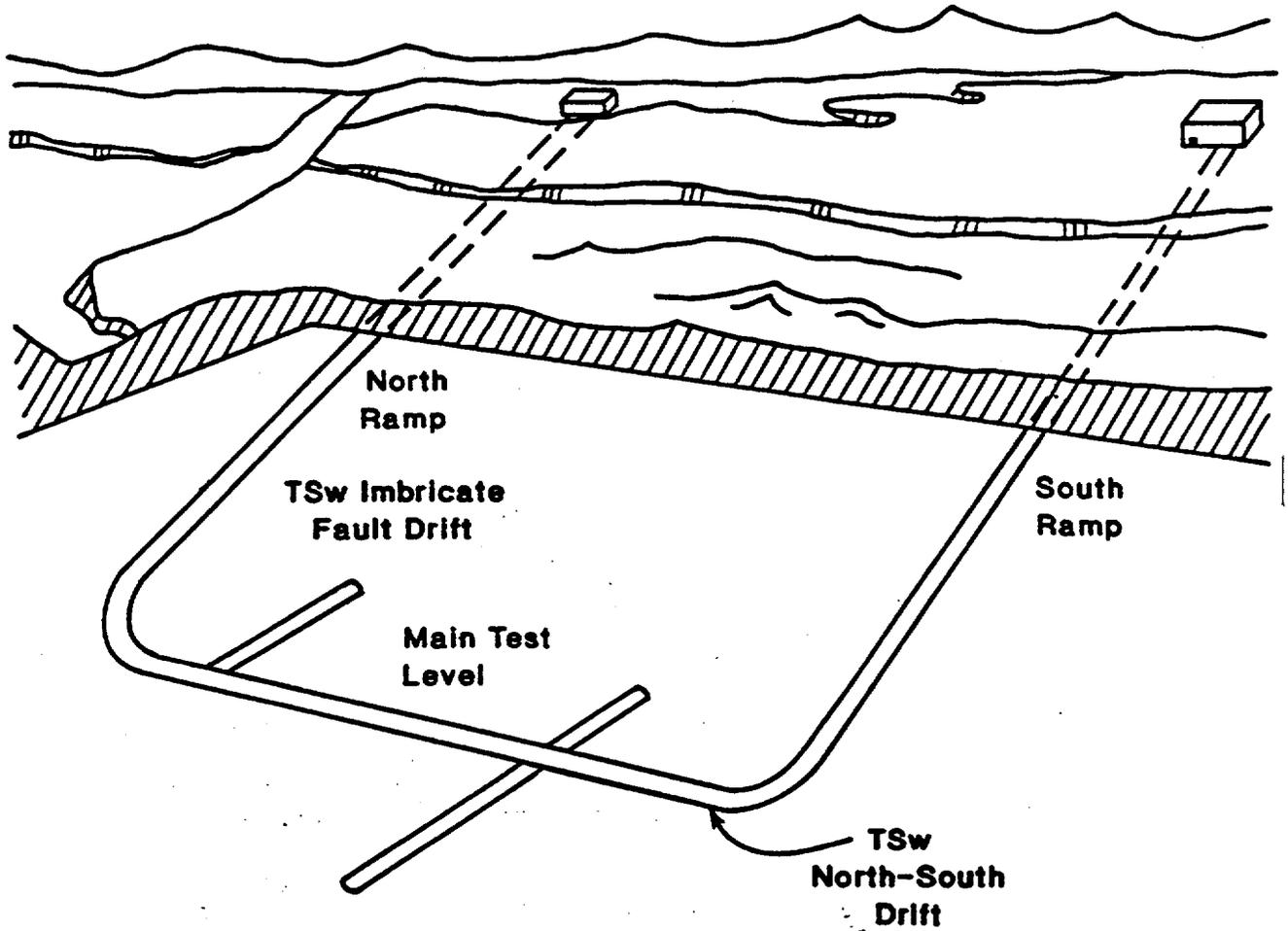


Figure 3.8-1. ESF Option 30 configuration.

Table 3.8-1. Generalized locations of boreholes for use in ESF UZ Hydrochemistry testing

<u>North Ramp</u>		
ESF-NR-1	Alcove upper TCw	(Radial Boreholes Anisotropy Test)
ESF-NR-2	Alcove Bow Ridge Fault	(Major Faults Test)
ESF-NR-3	Alcove lower TCw	(Radial Boreholes Anisotropy Test)
ESF-NR-4	Alcove TCw-PTn Contact	(Radial Boreholes Contact Test)
ESF-NR-5	Alcove middle PTn	(Radial Boreholes Anisotropy Test)
ESF-NR-6	Alcove Imbricate Fault	(Major Faults Test)
ESF-NR-7	Alcove PTn-TSw ₁	(Radial Boreholes Contact Test)
ESF-NR-8	Alcove TSw ₁	(Radial Boreholes Anisotropy Test)
ESF-NR-9	Alcove Drill Hole Wash Fault	(Major Faults Test)
ESF-NR-10	Alcove TSw ₁	(Hydrochemistry Test)
<u>South Ramp</u>		
ESF-SR-1	Alcove Upper TCw	(Radial Boreholes Anisotropy Test)
ESF-SR-2	Alcove Dune Wash Fault	(Major Faults Test)
ESF-SR-3	Alcove Lower TCw	(Radial Boreholes Anisotropy Test)
ESF-SR-4	Alcove TCw-PTn	(Radial Boreholes Contact Test)
ESF-SR-5	Alcove middle PTn	(Radial Boreholes Anisotropy Test)
ESF-SR-6	Alcove Imbricate Fault	(Major Faults Test)
ESF-SR-7	Alcove PTn-TSw ₁ Contact	(Major Faults Test)
ESF-SR-8	Alcove TSw ₁	(Radial Boreholes Anisotropy Test)
ESF-SR-9	Alcove Abandon Wash Fault	(Major Faults Test)
ESF-SR-10	Alcove TSw ₂	(Radial Boreholes Anisotropy Test)
ESF-SR-11	Alcove Yucca Ridge Fault	(Major Faults Test)
<u>Topopah Spring Drifts</u>		
<u>TSw North-South Drift</u>		
ESF-TSD-1	Alcove TSw ₁ Horizontal	(Hydrochemistry Test)
ESF-TSD-2	Alcove TSw ₁ Vertical	(Hydrochemistry Test)
ESF-TSD-3	Alcove TSw ₂ Horizontal	(Hydrochemistry Test)

Table 3.8-1. Generalized locations of boreholes for use in ESF UZ Hydrochemistry testing
(continued)

Tsw East-West Drift

ESF-TSD-4	Alcove TSw, Horizontal	(Hydrochemistry Test)
ESF-TSD-5	Alcove Ghost Dance Fault	(Major Faults Test)
ESF-TSD-6	Alcove Solitario Canyon Fault	(Major Faults Test)

Tsw Imbricate Fault Drift

ESF-TSD-7	Alcove Imbricate Fault	(Major Faults Test)
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as shown in Figures 3.8-1, 3.8-2, 3.8-3, and 3.8-4. A stratigraphic column indicating the location of anticipated geologic units in the exploratory studies facility is shown in Figure 3.8-5.

Due to limited hydrologic and geologic data available at the present, the geological locations of the boreholes may need to be changed, or additional holes may be required as more information becomes available.

A location for short-term core storage, measuring 3 m deep, 3 m high and 3 m wide must be provided underground, out of traffic areas.

During gas sampling no other hydrologic testing should be done within 25 m of the intervals being sampled.

Matrix pore water will be removed from borehole cores (collected from the long boreholes) by one-dimensional compression. Near-fracture matrix water samples will be extracted by compression of fracture intersections from long borehole cores. Fracture water will be collected in the short and long boreholes using absorbent pads. Perched water will be pumped out of the short and long boreholes or collected in the borehole using a borehole liner system.

These gas and water samples will be analyzed for their major ions, and stable and radioactive isotope compositions. Table 3.8-2 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 have been described in detail in Section 3.8.2 (Rationale for activity selection) or 3.8.3 (General approach and summary of tests and analyses).

The activity will be performed throughout the construction phase of the North and South ramps, the Topopah Spring north-south drift, the Topopah Spring east drift, the Topopah Spring west drift, and the Imbricate Fault drift (see Figures 3.8-1, 3.8-2, 3.8-3, and 3.8-4). Testing will continue for a period of as long as three years after completion of the drifting. When wet zones (water content of >50 percent) are encountered as the drifts are being mined, additional samples will be collected. Core samples collected from the long boreholes will be immediately sealed (according to technical procedure HP-237T) for shipment (according to technical procedure HP-131) to the USGS UZ Hydrochemistry Laboratory in Denver, Colorado, or to the Raytheon Services Nevada (RSN) Materials Testing Laboratory (MTL) in Mercury, Nevada.

A tracer gas (SF_6) will be added to the compressed air during borehole drilling to determine if contamination from ramp and drift ventilation or compressed drilling air has occurred. The residual SF_6 background will be checked before the data from core samples will be used for site characterization. Any water used at the ESF site will be tagged with a tracer. The universal water tracer will be lithium bromide. Samples of any water, and samples of other

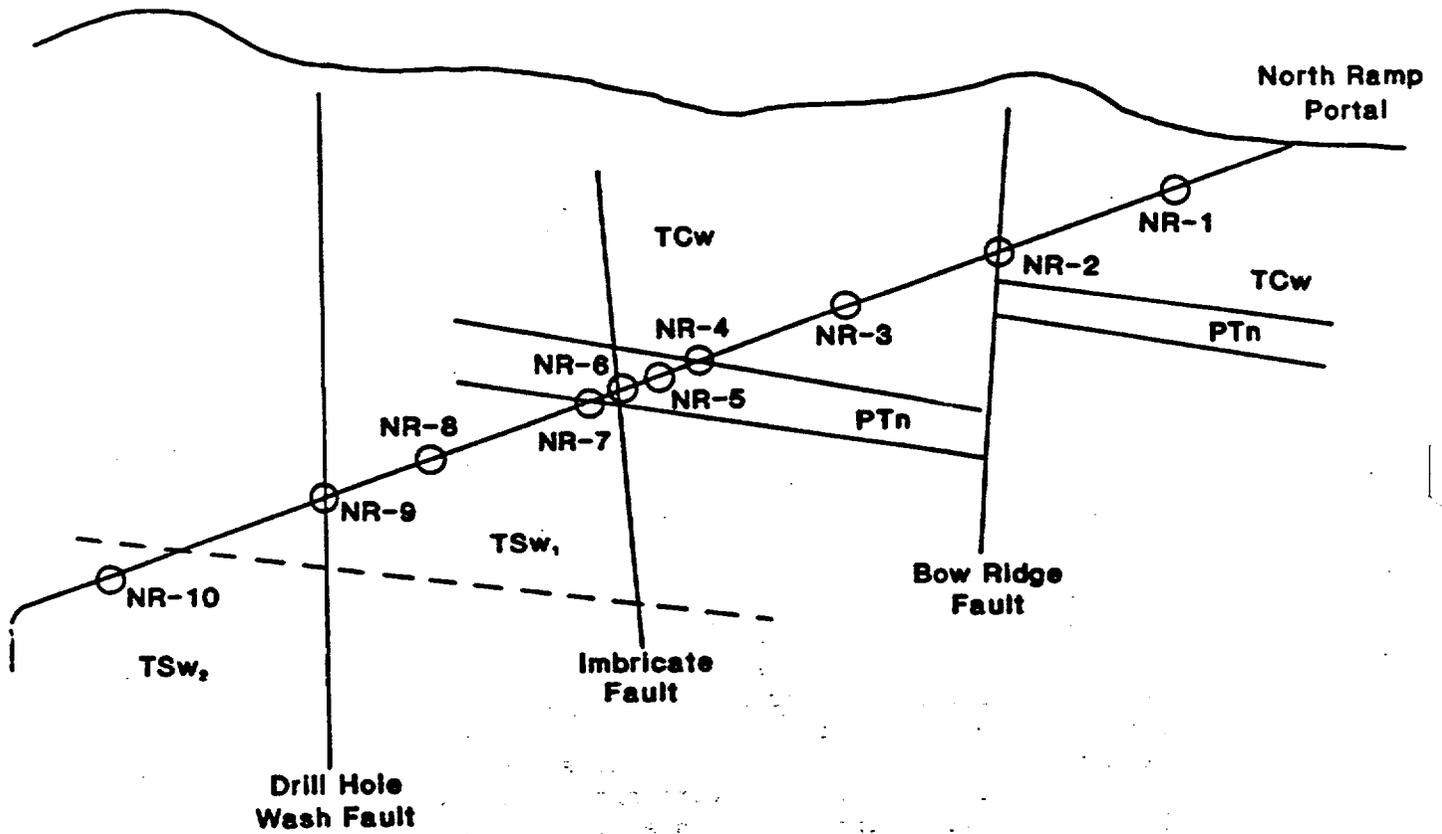


Figure 3.8-2 Generalized location of boreholes in the North Ramp for use in the ESF hydrochemistry test

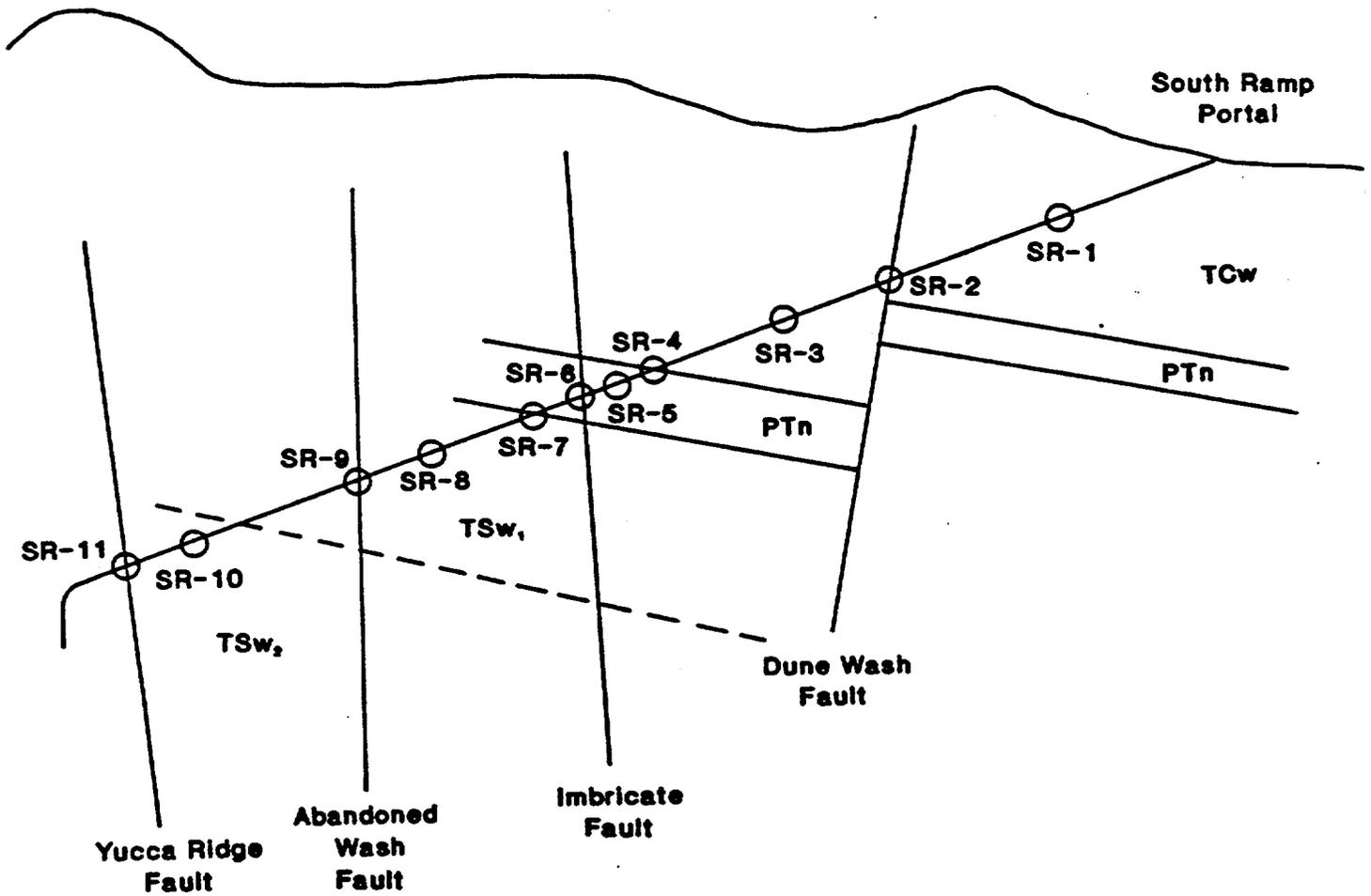


Figure 3.8-3 Generalized location of boreholes in the South Ramp for use in the ESF hydrochemistry test

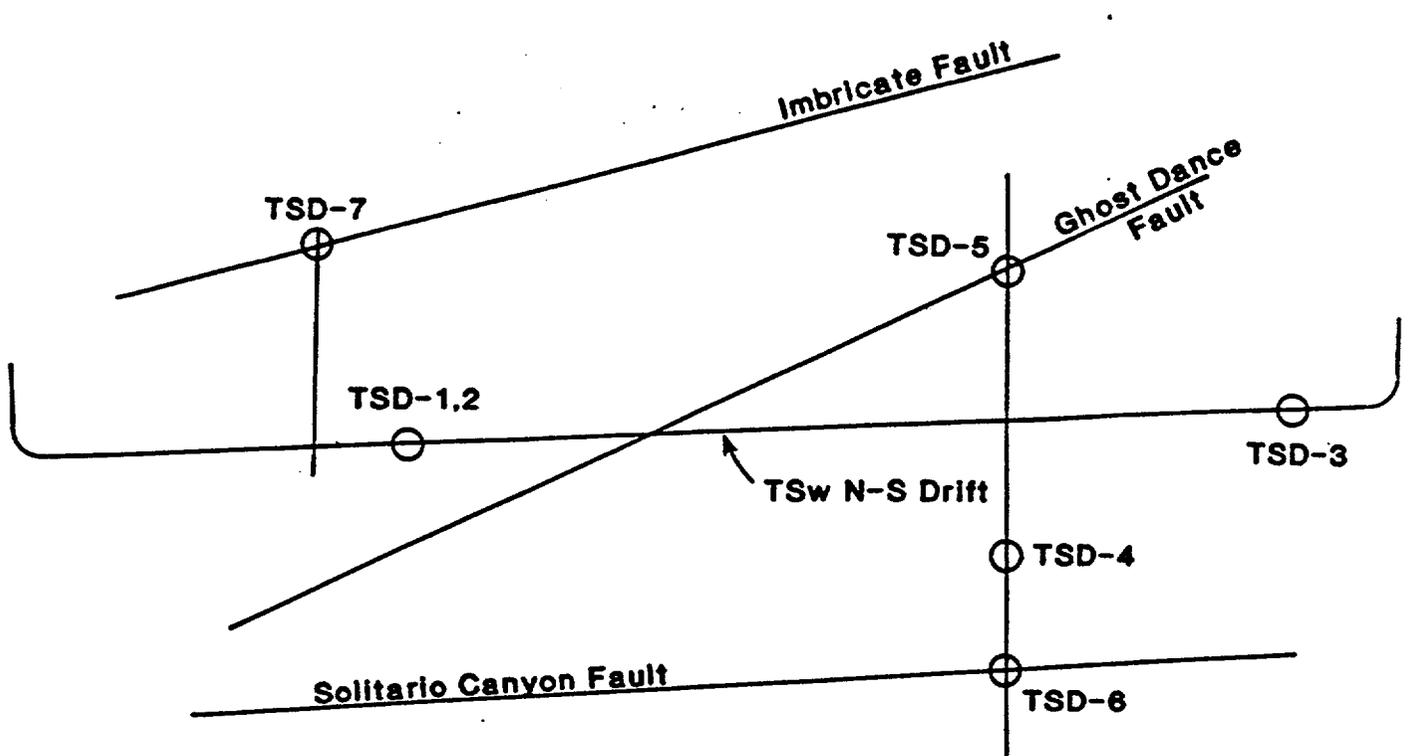


Figure 3.8-4. Generalized location of boreholes in the Topopah Spring drifts for use in the ESF hydrochemistry test.

Stratigraphic unit		Geohydrologic unit (where unsaturated)
Alluvium		Alluvium (QAL)
Paintbrush Tuff	Tiva Canyon Member	Tiva Canyon welded unit (TCw)
	Yucca Mountain Member	Paintbrush Tuff nonwelded unit (PTn)
	Pah Canyon Member	
	Topopah Spring Member	Topopah Spring welded unit (TSw ₁)
		(TSw ₂)
Tuffaceous beds of Calico Hills		Calico Hills non-welded unit (CHn)
Crater Flat Tuff	Prow Pass Member	Vitric (CHnv)
	Bullfrog Member	Zeolitized (CHnz)
		Crater Flat unit (CFu)

Note: Figure not to scale

Figure 3.8-5 Stratigraphic column of anticipated geologic units in the ESF

Table 3.8-2. Chemical and isotopic analyses

Parameter	Chemical Species	Information
Inorganic cations and anions	Na, Ca, Mg, K, HCO ₃ , SO ₄ , Cl, SiO ₂ , Mn, Fe, Al, pH, SC	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	¹⁸ O/ ¹⁶ O and D/H ratios	Timing of major recharge events.
Age dating	¹⁴ C, ³ H, ¹³ C/ ¹² C ratio, ³⁶ Cl	Age and travel time of unsaturated zone waters. Style and pattern of fluid flow in the unsaturated zone.
Gas diffusion	CO ₂ , CH ₄ , Ar, O ₂ , N ₂ , SF ₆ , fluorocarbons	Diffusion of gases (¹⁴ C, ³ H) into the unsaturated zone.
Contamination check	Li, Br, I, NO ₃ , BO ₃	Washdown of tracers.

Note: Temperature and redox parameters will be determined for perched water occurrences but are not applicable to extracted pore water.

materials (grout, concrete, etc.) used in the ESF should be provided to the UZ hydrochemistry test Principal Investigator (PI) for analysis.

Figure 3.8-6 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. Figure 3.8-7 summarizes the objectives of the activity, site-characterization parameters which are addressed by the activity, and the activity 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 3.8-7.

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 activity 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 hydrochemistry tests will be conducted in the ESF, which will penetrate the same geohydrologic units as will 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 from boreholes throughout the lateral extent of the drifting, to provide information on horizontal variability of the host-rock hydrochemistry around the ESF. The methods utilized in this activity will provide information that is approximately representative of the repository area. The spatial variability of existing conditions within the repository block, and the correlations to present and potential future repository conditions are represented by the activity. Data from the hydrochemistry tests will be used to model (1) the geochemical evolution of ground water, (2) the gas-transport mechanisms and water (liquid and vapor) movement within the repository host rock, and (3) residence time of water and directions of water flow.

3.8.3.1 Collection and transport of gas samples from boreholes

Collection of gas samples from short boreholes will be collected according to a technical procedure to be prepared at a future date. Four types of gas samples will be collected from long boreholes cored as part of the hydrochemistry, bulk-permeability, radial-borehole, and major-fault tests: (1) gas-composition samples, (2) $^{13}\text{C}/^{12}\text{C}$ ratio samples, (3) ^{14}C samples, and (4) water-vapor samples. The dimensions, orientations, and instrumentation configurations are discussed in Sections 3.3, 3.4, and 3.10 and illustrated in Figures 3.4-6, 3.4-7, 3.8-2, 3.8-3, and 3.8-4. All boreholes will be cored (HQ3 size) and

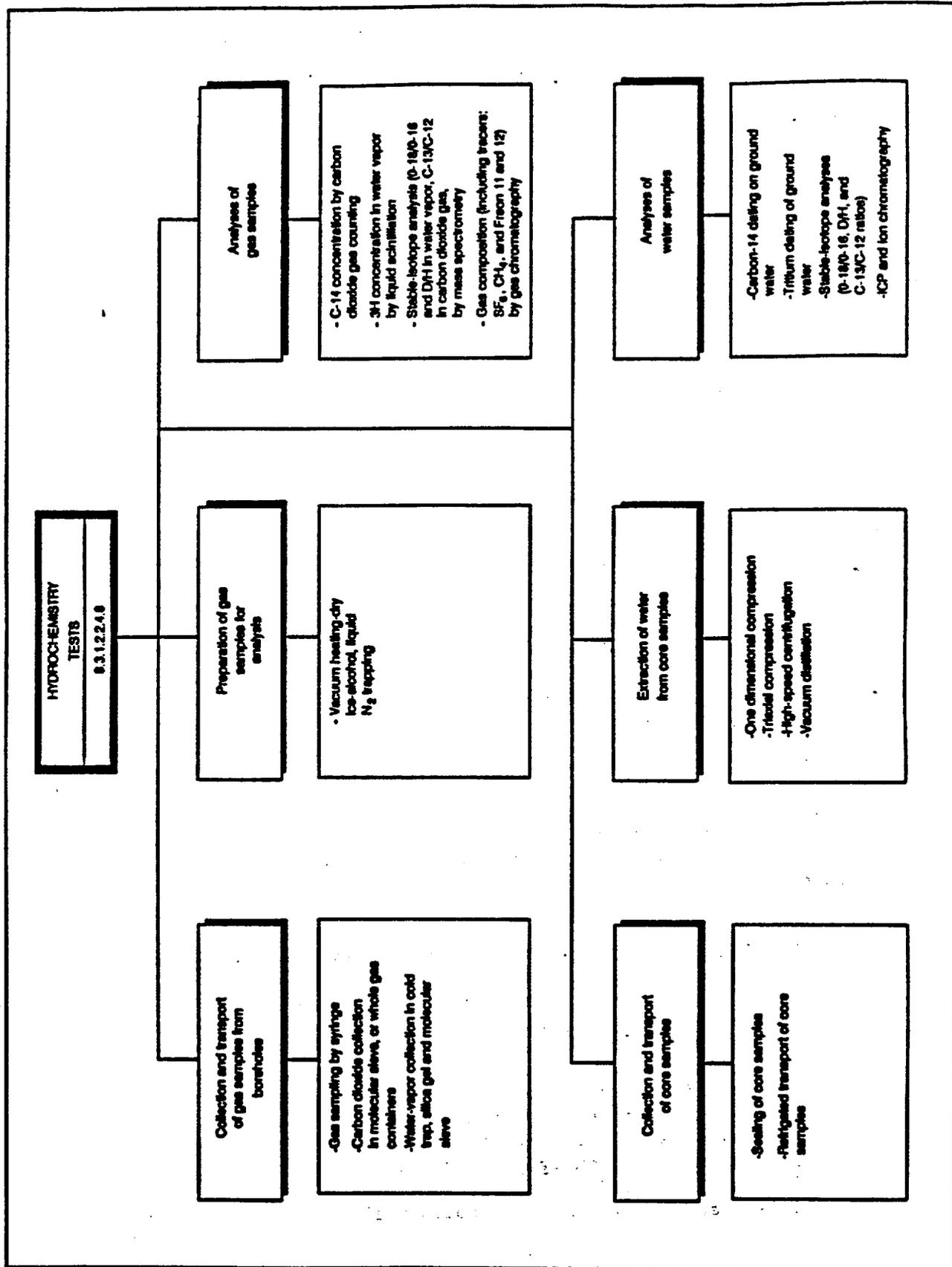


Figure 3.8-6. Organization of the hydrochemistry activity, showing tests, analyses, and methods.

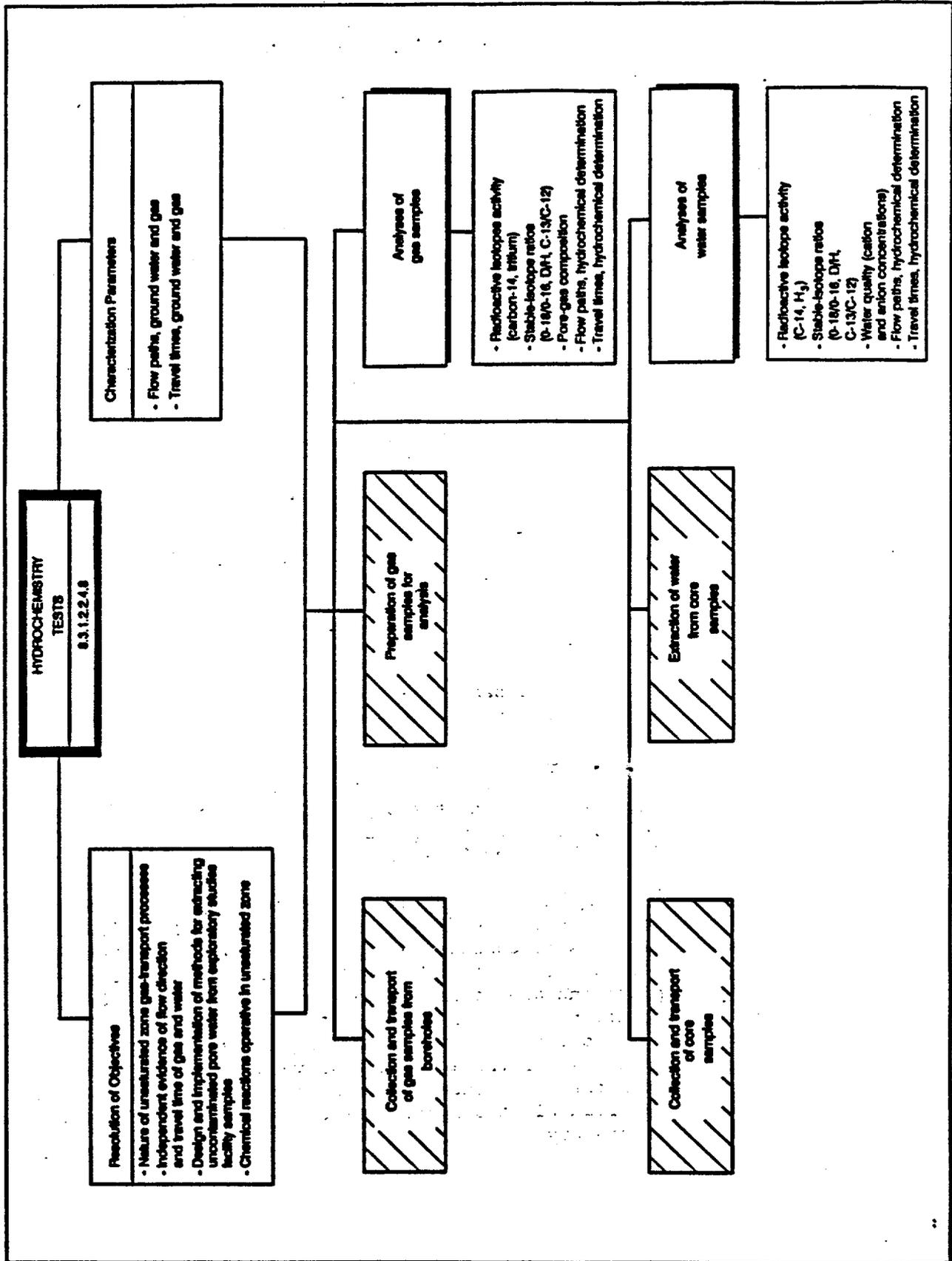


Figure 3.8-7. Organization of the hydrochemistry activity, showing tests, analyses, activity parameters, and characterization parameters. (The cross-hatched boxes indicate that no activity parameter will be generated).

sulfur hexafluoride (SF_6) will be used as a trace gas for drilling air.

Gas samples will be collected from boreholes using a full borehole liner that inverts down and up hole, horizontally or vertically, and is capable of transporting gas sampling tubes from the collar to ported sampling locations downhole. 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. Sample collection will not begin until drilling air tracer levels have been significantly reduced. During sample collection, the sample gas will be pumped at a flow rate of 500 mL/minute. (See Figure 3.8-8 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 (according to technical procedure HP-160). Gas-composition samples require no tracking because they are immediately analyzed in the field.
- (2) $^{13}\text{C}/^{12}\text{C}$ ratio samples -- Two methods will be used. The first method uses 5Å 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 5Å molecular-sieve pellets which trap the CO_2 . The second method involves allowing the CO_2 gas to flow into a 250-ml or 500-ml flow-through glass container, 3- or 10-liter Tedlar bags, or 2.1-liter aluminum cylinders.
- (3) ^{14}C samples -- Two methods will be used for ^{14}C sample collection. The first method employs a 5Å 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 ^{14}C sampling over the KOH method is its simple design and insured, nonbreakable transport between the sampling site and the laboratory.

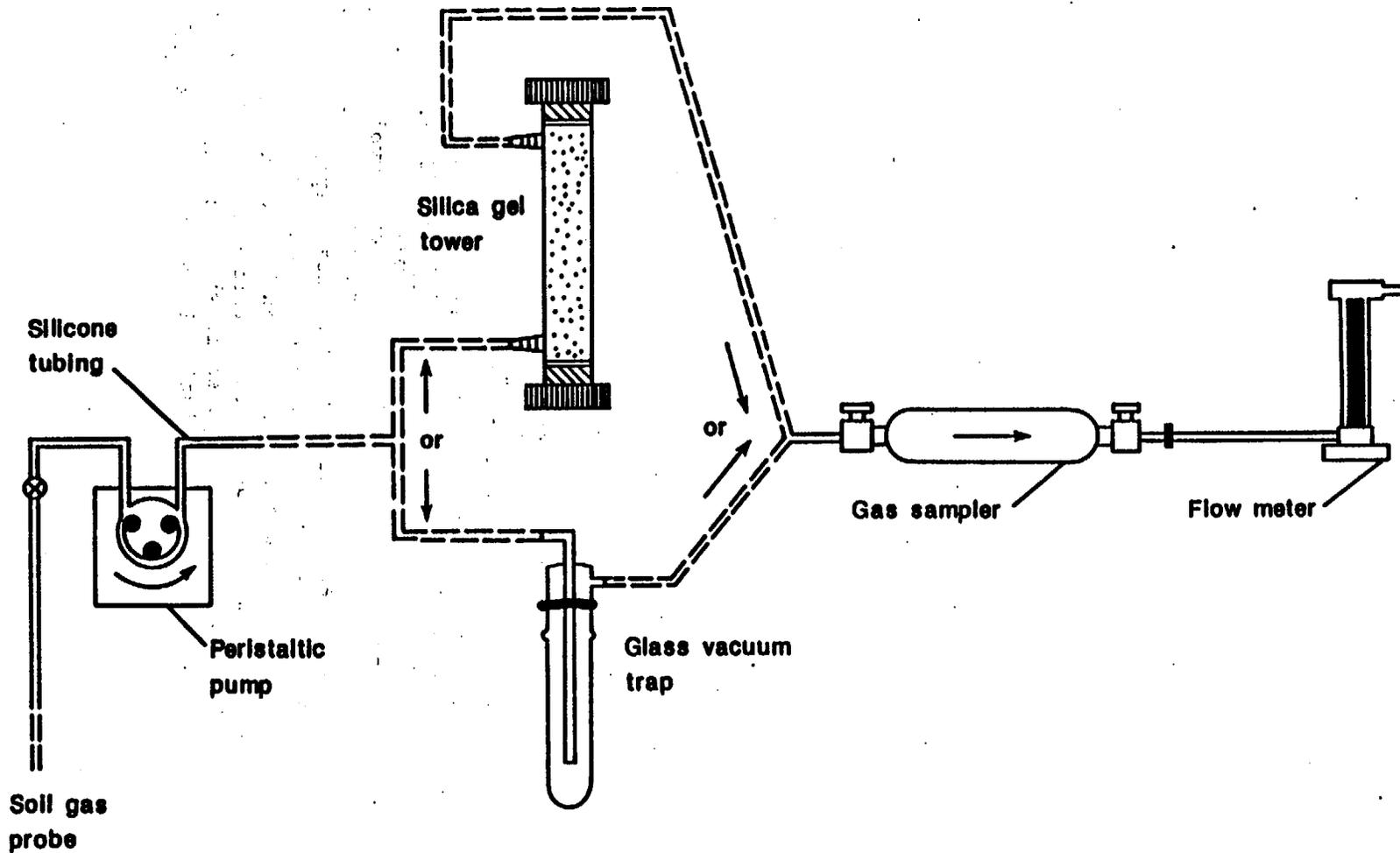


Figure 3.8-8. Diagram showing apparatus for on-site soil-gas collection for hydrochemistry tests.

^{14}C and $^{13}\text{C}/^{12}\text{C}$ ratio samples will be packed in cardboard boxes and mailed directly from the field to the USGS UZ Hydrochemistry Laboratory at the Denver Federal Center in Colorado or hand-carried to the Hydrologic Research Facility (HRF) laboratory for processing.

- (4) Water-vapor samples -- Three methods will be used: cold trap, silica gel, and 5Å molecular sieve. The first method involves pumping the gas sample through a glass 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 5Å molecular sieve similar to (2) above to collect the water vapor. All three methods provide water volume measurements, however, water-vapor sampling using a cold trap is preferred over collection by silica gel tower or molecular sieve because the water can be used for isotopic determinations. The degas heating of the water vapor from the silica gel or molecular sieve causes exchange of oxygen atoms in the water vapor 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 the USGS Hydrochemistry Laboratory.

All data obtained by each group of methods (selected or alternate) should be compared to insure the validity of the selected method. Gas sample collection methods are detailed in technical procedure HP-56.

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 sieve 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 is detailed in technical procedure HP-86, and 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 warm-up CO_2 gas in a storage cylinder. A simplified diagram of the degassing system is shown in Figure 3.8-9. The CO_2 collected in the KOH solution is released by acidification

3.8-21

December 28, 1992

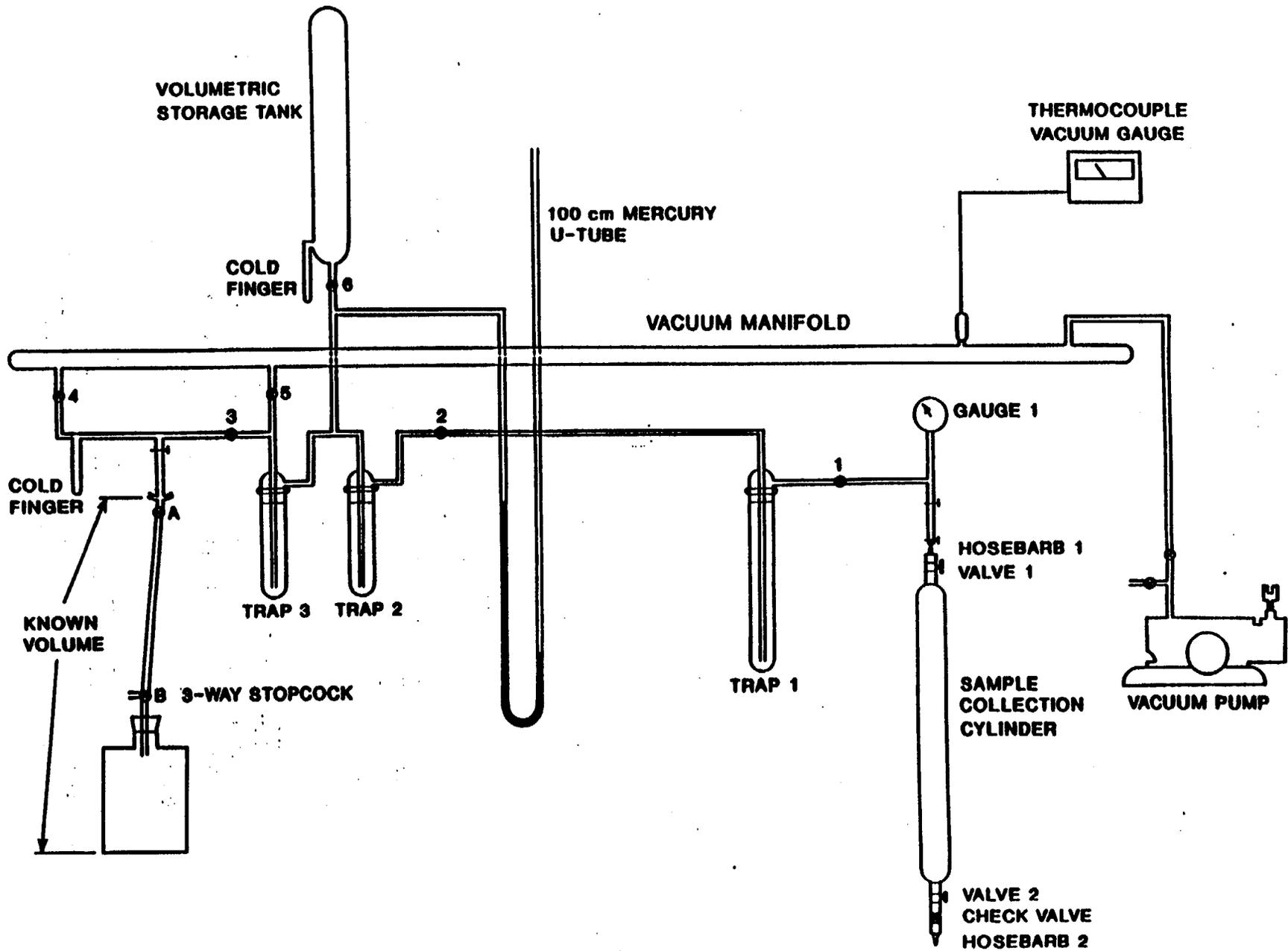


Figure 3.8-9. Diagram showing degassing system for hydrochemistry tests.

and converted into benzene for ^{14}C analysis by scintillation counting. Water vapor collected using a glass cold trap requires no further preparation. Water vapor collected on molecular sieve or silica gel is removed by heating, then collected in a cold trap immersed in a dry-ice/alcohol slurry.

Internal checks assure release of all of the CO_2 gas. For example, near the end of the degassing procedure, the liquid-nitrogen level is raised around the CO_2 cold trap. This exposes a clean section of the collection tube in the trap to liquid nitrogen; any CO_2 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 CO_2 solid ensures that all of the CO_2 has been trapped.

3.8.3.3 Analyses of gas samples

Stable-isotope ratios ($^{18}\text{O}/^{16}\text{O}$, $^{13}\text{C}/^{12}\text{C}$, and D/H) will be analyzed using mass spectrometry by the USGS Research Laboratory, Reston, Virginia, or by the USGS, Geologic Division, Branch of Petroleum Geology, Organic Geochemistry Lab, Denver, Colorado. Low-level gas counters will be used to determine ^3H activity in water vapor at the University of Miami, Miami, Florida and at the USGS UZ Hydrochemistry Laboratory. Large ^{14}C samples ($^{14}\text{CO}_2$ gas) will be analyzed using conventional gas-counting methods by Geochron, Inc. in Boston, Massachusetts. Small ^{14}C samples will be analyzed by tandem accelerator mass spectrometry (TAMS) at the University of Arizona, Tucson, Arizona. Gas composition samples will occasionally be analyzed for the presence of construction-phase tracers (SF_6 and fluorocarbons), using gas chromatography.

3.8.3.4 Collection and transport of core samples

Core samples will be collected by dry coring into the face of the alcoves constructed adjacent to the ramps and drifts. These samples should be collected at least 6.1 m (20 ft) from the line of the ramp or drift to ensure that they are unaffected by the drift and ramp mining. The samples for this activity will be obtained by a dry-coring technique using traced (SF_6) drilling air, and will be HQ3 core with diameter of 6.1 cm (2.4 in). Borehole core samples will be collected and sealed according to technical procedure HP-237T.

The core will be transported to the Sample Management Facility (SMF) to be stored in a refrigerated room as soon as possible after collection. Portions of the core will be released to the PI or his designate to be transferred to the RSN Materials Testing Laboratory (MTL), Mercury, Nevada, or to the UZ Hydrochemistry Laboratory.

The sealed core samples will be transported to the laboratory in Denver 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 technical procedure HP-131. Coordination with the sample overview committee is required in order to preclude sample-handling and sample-custody conflicts in the ESF and SMF.

3.8.3.5 Extraction of water from core samples

Five methods are available to extract water from unsaturated tuffs: (1) one-dimensional compression (technical procedures HP-223, HP-248T, and HP-249), (2) triaxial compression (technical procedure HP-125), (3) high-speed centrifugation, (4) vacuum distillation, and (5) immiscible displacement. One-dimensional and triaxial compression involve placing a core sample in a compression chamber and applying axial pressure in step increases to force water and air from the pore space (see Figure 3.8-10). 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-water composition. The centrifugation method (technical procedure HP-110) 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 3.8-11). The removal process can be simple drainage, or an immiscible fluid can be introduced to displace the pore water during centrifugation. The distillation method (technical procedure HP-126) 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 by 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 one-dimensional compression to vacuum distillation for a single sample ensures optimum water removal. One-dimensional compression is favored over centrifugation for two major reasons.

- (1) The forces acting on the core are much better understood for one-dimensional compression than centrifugation; therefore, more information about the actual pore-volume reduction process that occurs within the core will be gained from one-dimensional compression.
- (2) The one-dimensional compression method recovers gas from the sample pore space, which is not possible using centrifugation. The chemical and isotopic composition of the gas in the sample may also be useful in pore-fluid characterization.

Centrifugation and one-dimensional compression can be used on crushed or broken cores which are unsuitable for triaxial compression. One-dimensional compression, triaxial compression,

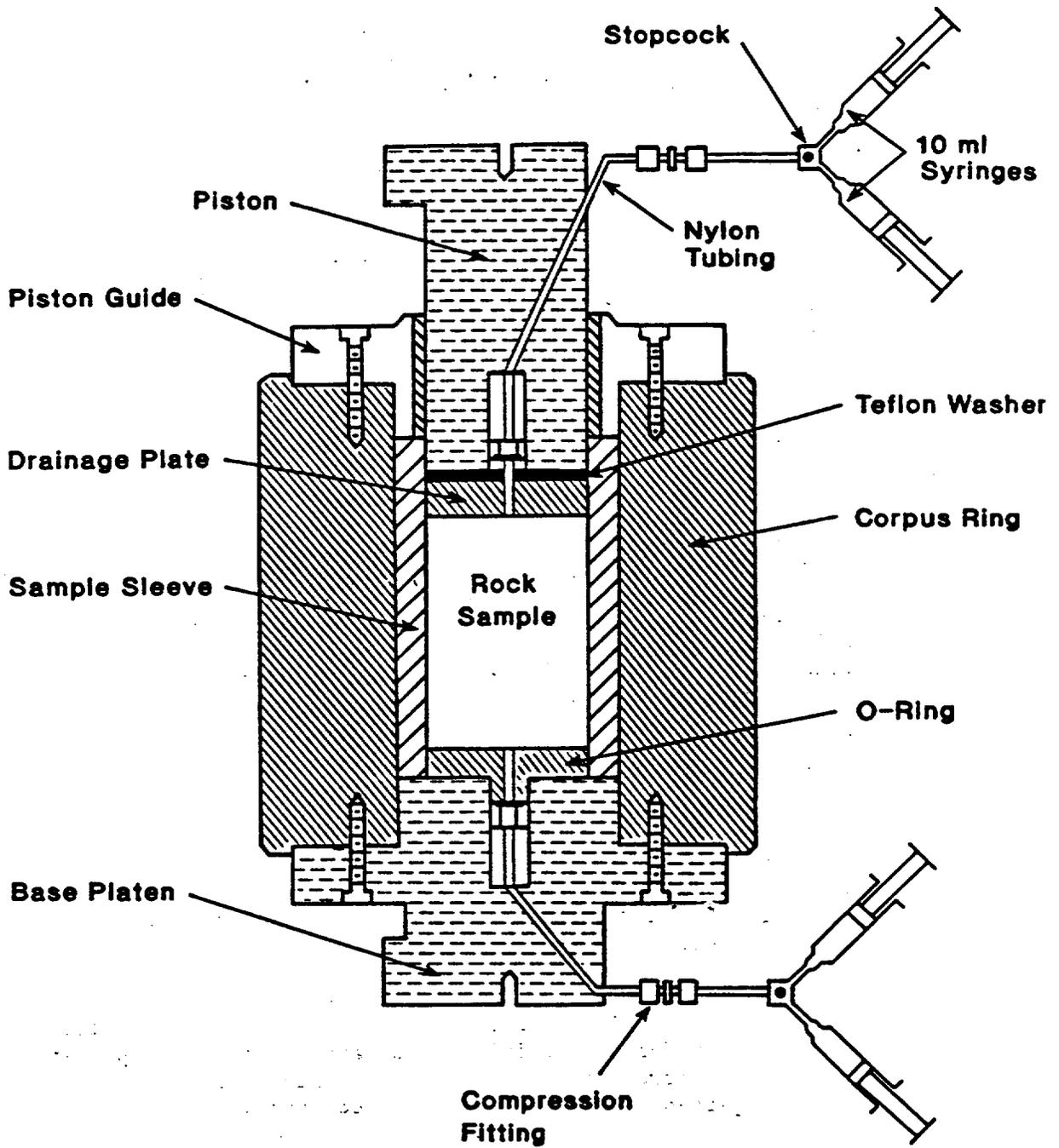
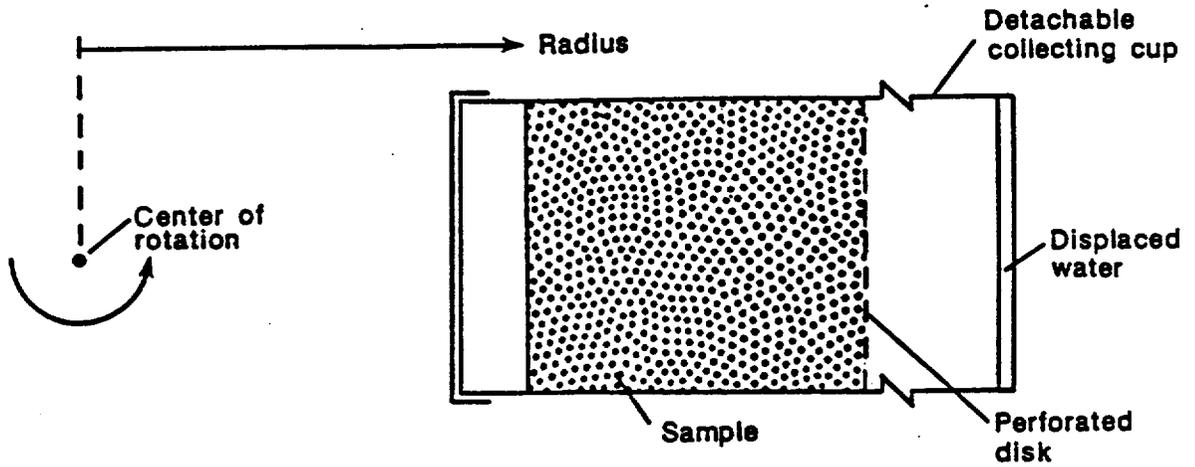


Figure 3.8-10. Diagram showing apparatus for pore-water extraction by one-dimensional compression.

Drainage method



Immiscible displacement

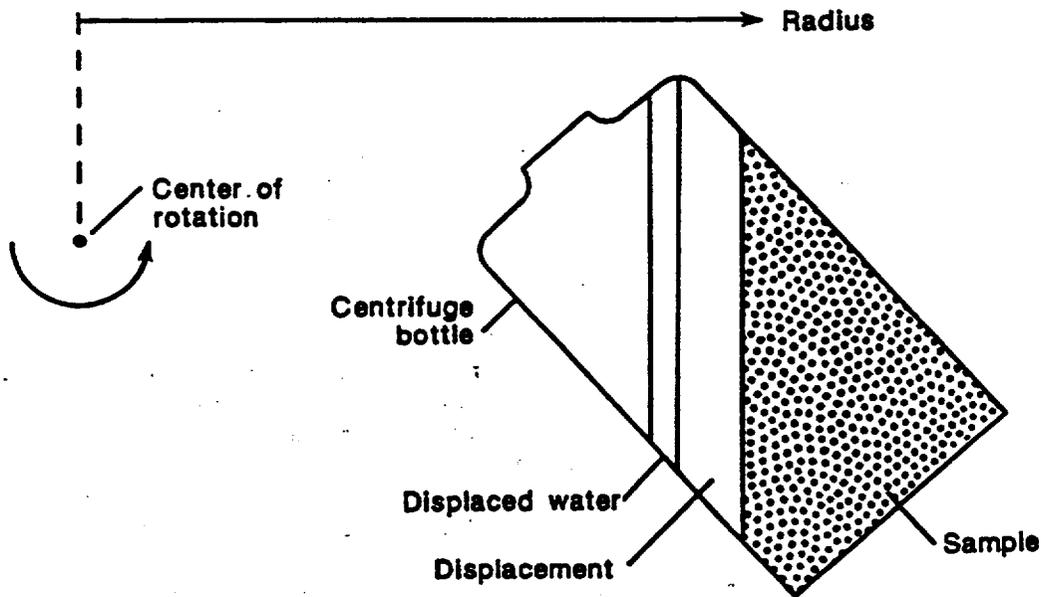


Figure 3.8-11. Diagram showing methods of centrifugation for hydrochemistry tests.

and centrifugation are preferred over vacuum distillation because cation and anion concentrations are not preserved through the distillation process. 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.)

Whether a representative water sample is extracted from a core sample can be verified in two ways. First, by taking water samples at each pressure level during the compression procedure, corresponding chemical-concentration data relating cation and anion concentrations to each axial pressure will be obtained. If the ion concentrations do not change with increasing pressure, then the compression process is not affecting the original pore-water composition. (Also, if a sharp change in concentration is noted at a higher pressure level, future testing can secure representative samples by holding pressures below that level.) Preliminary results from the pore-water extraction prototype testing indicate that the mean concentration of dissolved ions generally decreases slightly (≈ 15 percent) during compression. The relative abundance of major cations does not vary with increasing pressure, and the relative abundance of major anions varies moderately with increasing pressure. However, these changes are minor relative to differences in pore-, fracture-, and saturated-zone-water chemistry from natural waters from different geologic units (Peters and others, 1992). Second, water-sample analyses from cores which were extracted by centrifugation were compared to analyses from nearby cores extracted by triaxial compression. Although not an unequivocal demonstration, similar chemical concentrations obtained by both methods support the validity of compression for producing representative pore water samples (Yang and others, 1990).

The pore-water extraction by triaxial- and one-dimensional compression prototype testing has determined proper extraction procedures to produce representative water samples and has determined that no particular rock-core orientation is more favorable than another for water extraction (Yang and others, 1988). The methods developed during the prototype test will be implemented during ESF hydrochemistry testing.

Core samples containing fractures will be used to determine the chemical and isotopic composition of near-fracture pore-water. The section of core near the fracture will be chipped off of the core sample and the water extracted by one-dimensional compression. These chemical results will be compared to chemical results from the remaining intact core sample.

An absorbent rope segmented into one foot sections will be inserted into the boreholes and pressed against the borehole wall

using a borehole liner system. Upon retrieval any water will be removed from each section of the absorbent rope for chemical analysis. Borehole televiewer logs and core logs will be used to correlate water collected in the absorbent rope segments to occurrent fractures.

If a perched-water zone is encountered, it will be sampled according to technical procedure HP-231T or by using a specially designed borehole liner system. The perched water study is further described in Section 3.7.

3.8.3.6 Analyses of water samples

Cation concentrations will be determined by using inductively coupled plasma (ICP) by subcontractor laboratories, and anion concentrations will be determined using ion chromatography at the USGS Central Laboratory, Denver, Colorado or at the UZ Hydrochemistry Lab, Denver, Colorado according to technical procedure HP-202. Stable-isotope ratios will be analyzed using mass spectrometry performed by the USGS Research Laboratory, Reston, Virginia. Low-level-concentration gas counters or liquid scintillation counters will be used to determine ^3H activity at the University of Miami, Miami, Florida, or in Reston, Virginia, or at the UZ Hydrochemistry Lab, Denver, Colorado according to technical procedure HP-204. Large ^{14}C samples will be analyzed using conventional gas-counting methods by Geochron, Inc. in Boston, Massachusetts. Small ^{14}C samples will be analyzed by tandem-accelerator mass spectrometry (TAMS) at the University of Arizona, Tucson, Arizona. ^{36}Cl will be analyzed using TAMS at the Lawrence Livermore National Laboratory, Livermore, California. All water samples will be analyzed for the presence of tracers (bromide, nitrate, iodide, borate, lithium, etc.), using ion chromatography (IC) and high-pressure liquid chromatography (HPLC) either in-house according to technical procedure HP-202 or by a subcontractor laboratory.

^{36}Cl for age dating is dependent on the extent of in-situ production in the subsurface. If this interference is minimal, ^{36}Cl will be used for water-age dating. $^{18}\text{O}/^{16}\text{O}$, $^{13}\text{C}/^{12}\text{C}$, and D/H 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, IC, GCMS, HPLC, and TAMS is 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.

^{14}C dating will determine the age of the water in the unsaturated zone, and ^3H 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 ESF construction and drilling on water in the unsaturated zone. Refer also to the beginning of Section 3.8.2 for more detail concerning the uses of the chemical and isotopic analyses of pore water.

3.8.3.7 Methods summary

The activity parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.8-3. Also listed are the selected and alternate methods for determining the parameters. 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 3.8-3 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 that they believe are suitable to provide accurate data within the expected range of the activity parameter. Models and analytical techniques have been or will be developed to be consistent with test results.

3.8.4 Quality assurance requirements

The USGS Quality Assurance Program Plan for the YMP (USGS, 1989) requires technical procedures for all technical activities that require quality assurance.

Table 3.8-4 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a hydrologic procedure number. Procedures identified as "TBD" will be approved prior to being needed for use in site characterization.

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, calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and record requirements are included in these documents.

Table 3.8-3. Summary of tests and methods for the hydrochemistry activity
(SCP 8.3.1.2.2.4.8)

Methods (selected and alternate)	Activity parameter
<u>Analysis of gas samples</u>	
Age dating of carbon dioxide gas samples using conventional gas counter (selected)	Radioactive-isotope activity
Age dating by scintillation counting of tritium in water vapor (selected)	"
Stable-isotopes analyses ($^{18}\text{O}/^{16}\text{O}$ and D/H in water vapor, $^{13}\text{C}/^{12}\text{C}$ in carbon dioxide gas) (selected)	Stable isotope ratios
Gas composition (including tracers) by gas chromatography (selected)	Pore-gas composition
Argon-39 dating of gas (alternate)	Radioactive-isotope activity
Hydrochemical determination by sample analysis and modeling (selected)	Flow paths, hydrochemical determination
Hydrological determination, other activities (alternate)	"
Mass spectrometry (alternate)	Stable isotope ratios
Hydrochemical determination by sample analysis and modeling (selected)	Travel times, hydrochemical determination
Hydrologic determination, other activities (alternate)	"
<u>Analysis of water samples</u>	
Carbon-14 dating on ground water (selected)	Radioactive-isotope activity
Age-dating of carbon dioxide in water samples using tandem-accelerator mass spectrometry (selected)	"
Tritium dating of ground water (selected)	"

**Table 3.8-3. Summary of tests and methods for the hydrochemistry activity
(SCP 8.3.1.2.2.4.8) (continued)**

Methods (selected and alternate)	Activity parameter
<u>Analysis of water samples (continued)</u>	
Stable-isotope analyses ($^{18}\text{O}/^{16}\text{O}$, D/H, and $^{13}\text{C}/^{12}\text{C}$ ratios) (selected)	Stable-isotope ratios
ICP and ion chromatography (selected)	Water quality, cations and anions
Chlorine-36 dating of ground water (alternate)	Radioactive-isotope activity
Argon-39 dating of ground water (alternate)	"
Mass spectrometry for other stable isotopes (alternate)	Stable isotope ratios
Atomic absorption (alternate)	Water quality, cations and anions

Table 3.8-4. Technical procedures for the hydrochemistry activity (SCP 8.3.1.2.2.4.8)

Technical Procedure Number (YMP-USGS-)	Technical Procedure
<u>Collection and transport of gas samples from boreholes</u>	
HP-56	Gas and water-vapor sampling from unsaturated-zone test holes
HP-160	Methods for collection and analysis of samples for gas composition by gas chromatography
HP-176	Procedure to collect gas composition at selected depth intervals
HP-239T	Method for removing traced drilling air from unsaturated zone boreholes
TBD	Method for installing a full borehole liner system for collection of gas, water vapor and fracture water
TBD	Method for collecting carbon dioxide in KOH solution using a fritted glass plate bubbler
<u>Preparation of gas samples for analysis</u>	
HP-86	Method for degassing carbon dioxide and water (vapor) samples from unsaturated-zone test holes
HP-190T	Silica gel dewatering
HP-194	Calculation of relative humidity at depth within unsaturated zone test holes using a silica gel tower
<u>Analyses of gas samples</u>	
HP-160	Methods for collection and analysis of samples for gas composition by gas chromatography
HP-240	Method for analysis of CO ₂ and CH ₄ gas sample concentrations using Summit Interest SIP 1000
HP-242	Method for analyzing the concentration of halocarbon gases with an ITI Leakmeter 120
<u>Collection and transport of core samples</u>	
HP-07	Use of a trace gas for determining atmospheric contamination in a dry-drilled borehole
HP-12	Method for collection, processing, and handling of drill cuttings and core from unsaturated-zone boreholes at the well site, NTS

Table 3.8-4. Technical procedures for the hydrochemistry activity (SCP 8.3.1.2.2.4.8)
(continued)

Technical Procedure Number (YMP-USGS-)	Technical Procedure
<u>Collection and transport of core samples (continued)</u>	
HP-131	Methods for handling and transporting unsaturated-zone core and rubble samples for hydrochemical analysis
HP-237T	Methods for sealing unsaturated-zone borehole core samples to preserve moisture content
HP-238T	Injection of a trace gas for determining atmospheric contamination in a dry-drilled borehole
TBD	Method for boring short (1-2 meter) small diameter (2.5-5 cm) boreholes
TBD	Gas sampling from short boreholes
TBD	Method for injecting a trace gas into drilling air using an automated injection system
<u>Extraction of water from core samples</u>	
HP-110	Extraction of pore waters by centrifuge methods
HP-125	Method for extraction of pore water from tuff cores by triaxial compression
HP-126	Extraction of residual water from tuff samples by vacuum distillation
HP-223	Method for pore water extraction using one-dimensional compression
HP-231T	Identification, monitoring, and sampling of perched or ground water encountered while drilling surface-based boreholes
HP-249	Method for pore water extraction using high pressure one-dimensional compression
TBD	Method for extraction of pore water using immiscible displacement
TBD	Method for preparing core for pore water extraction
TBD	Method for collection of near-fracture pore water

**Table 3.8-4. Technical procedures for the hydrochemistry activity (SCP 8.3.1.2.2.4.8)
(continued)**

Technical Procedure Number (YMP-USGS-)	Technical Procedure
<u>Analyses of water samples</u>	
HP-202	Analysis of water samples for anion and cation concentrations by Ion Chromatography
HP-204	Liquid Scintillation spectrometry method for tritium measurement of H ₂ O samples
HP-209	Method for preparing tracers for addition to a water supply system
HP-229	Determination of water content and physical properties for laboratory rock samples

3.9 Multipurpose-boreholes testing near the exploratory shafts

The multipurpose-boreholes testing has been deleted because the original concept of the construction of exploratory shafts has been changed to an exploratory-studies facility with ramps and drifts. The original purpose for the multipurpose-boreholes was to provide hydrologic and engineering properties data in the immediate areas of the shafts prior to their construction and to provide for the monitoring of changes in ambient conditions that may have resulted from shaft construction. These needs are no longer valid.

3.10 Hydrologic properties of major faults encountered the ESF

Although the hydrologic properties of major faults activity is a part of the ESF construction-phase testing, it is not included in this revision of the study plan due to scheduling constraints. 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 YMP 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 1.2. Logic diagram (Figure 2.1-1) and Table 2.1-1 are used to summarize specific relations between performance- and design-parameter needs and activity parameters determined from this study.

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;
- 8.3.1.15.2 - 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 Activity 8.3.1.2.2.4.4 (Radial-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 Activity 8.3.1.2.2.4.8 (Hydrochemistry tests in the ESF). 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 (Activity 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 four 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 Activity 8.3.1.2.2.4.8 (Hydrochemistry tests in the ESF) 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 Activity 8.3.1.2.2.4.8 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 tests), 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 ESF 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) and 8.3.1.2.2.4.5 (Excavation-effects test).

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 (Excavation-effects test) 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 schedules presented in Figures 5.1-1, 5.1-2, 5.1-3, and 5.1-4 summarize the logic network and reports for the four activities of the ESF construction-phase hydrologic testing included in this study plan. These figures represent a summary of the schedule information which includes the sequencing, interrelations, and relative durations of these activities. Specific durations and start and finish dates for these 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.

Accurate characterization of unsaturated-zone percolation will require several years of hydrologic testing and monitoring.

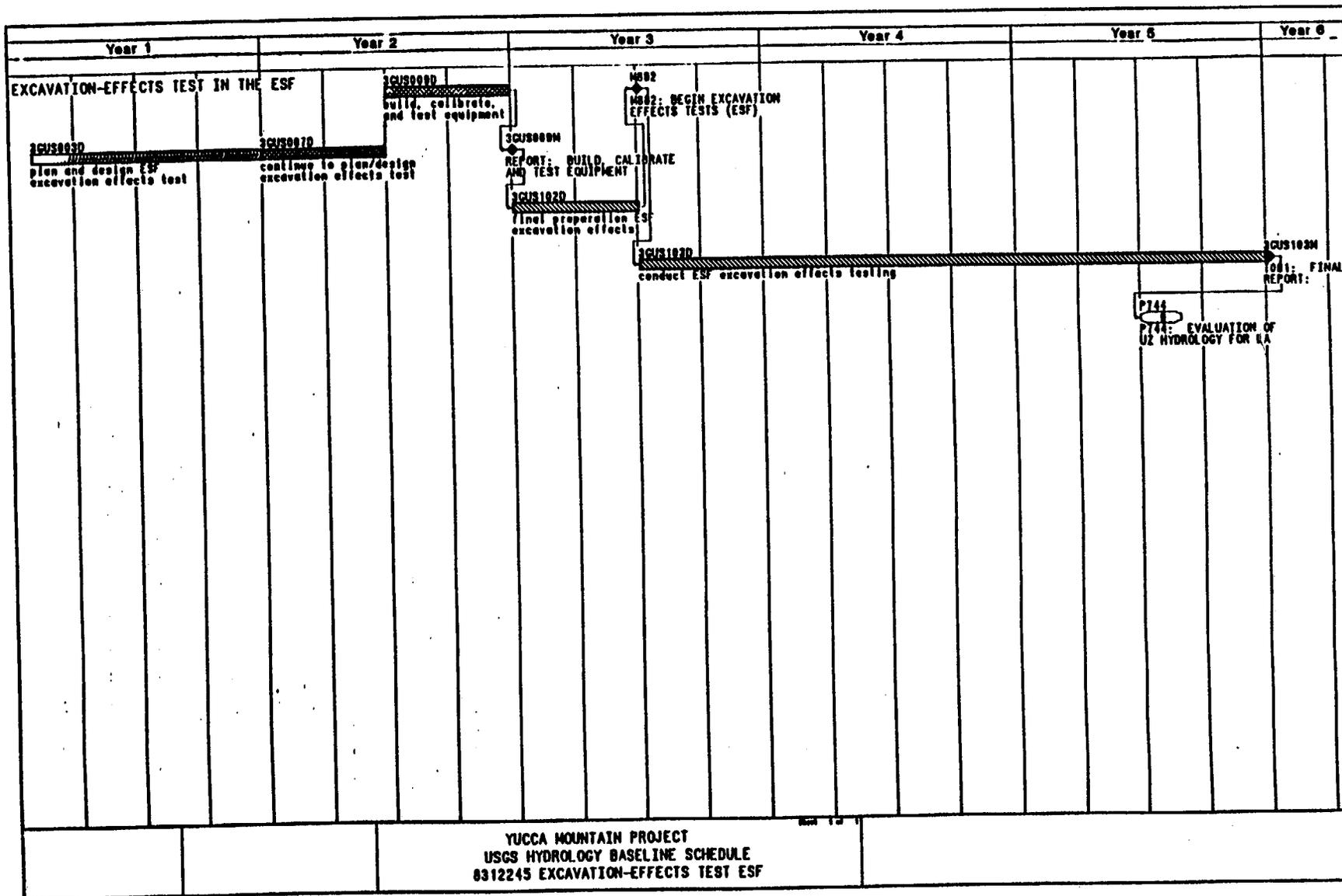


Figure 5.1-2. Summary network for the excavation-effects activity.

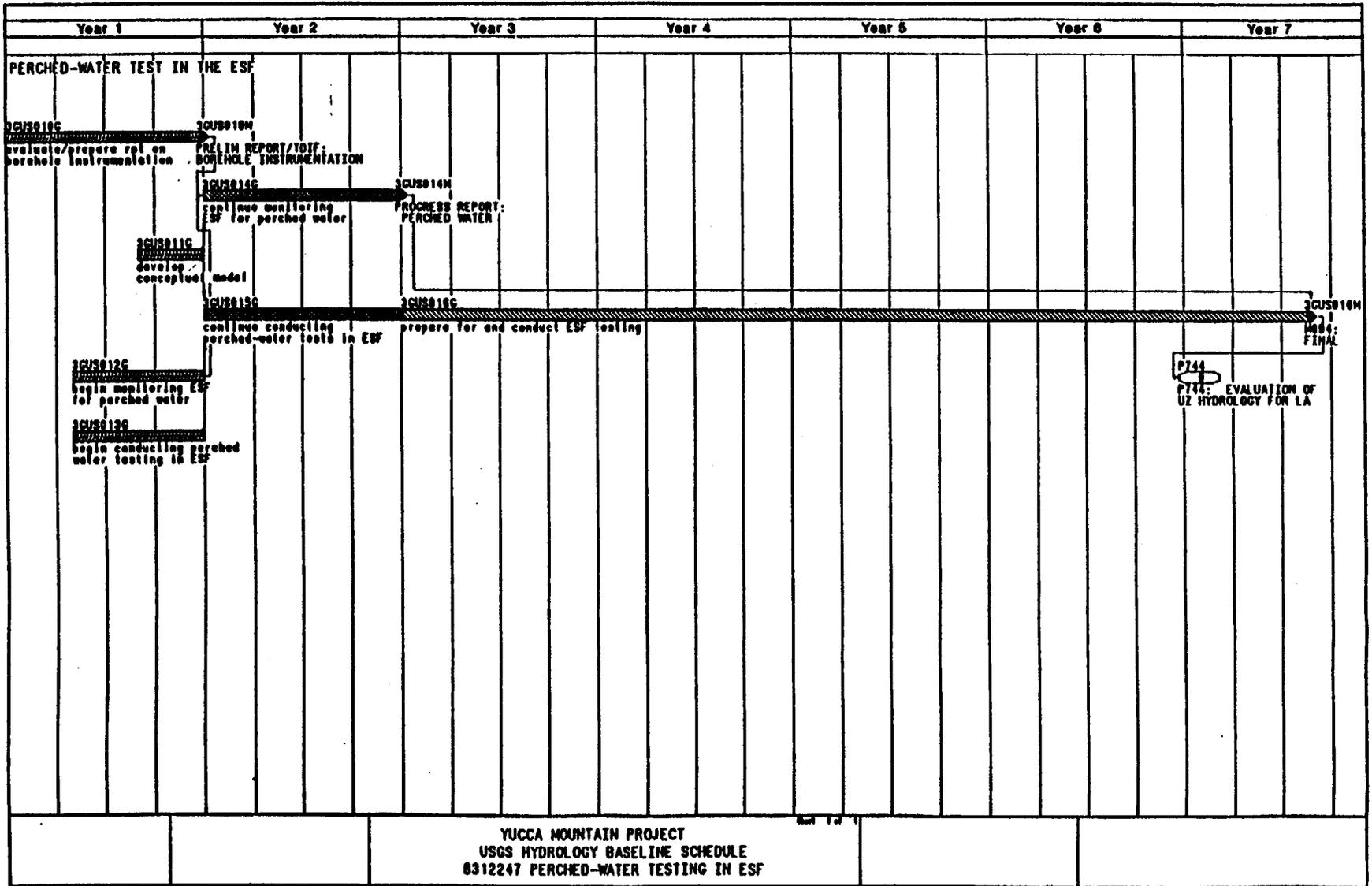


Figure 5.1.-3. Summary network for the perched-water activity.

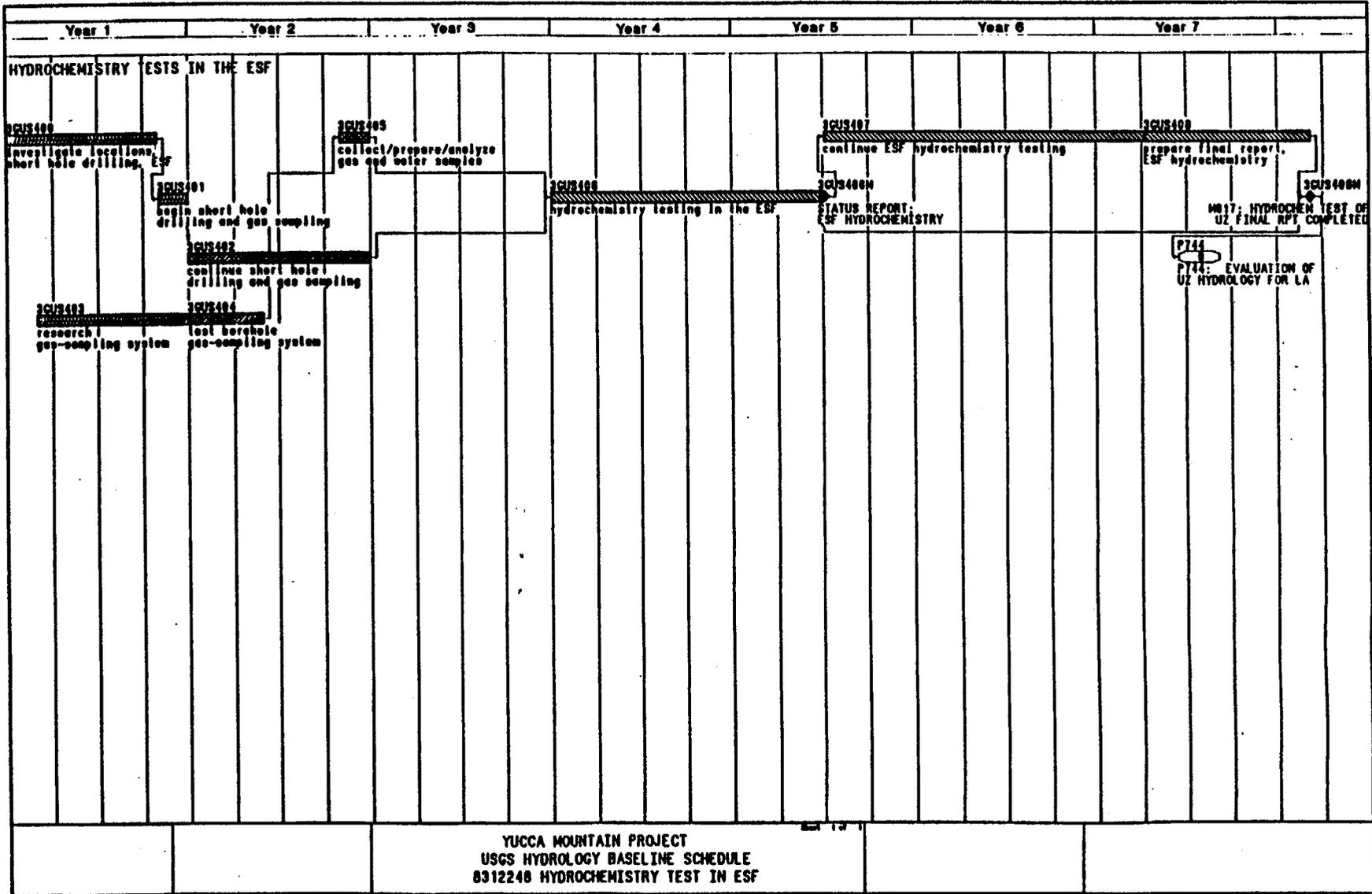


Figure 5.1-4. Summary network for the hydrochemistry activity.

5.2 Milestones

The milestone numbers, titles, levels, and corresponding work-breakdown-structure (WBS) number associated with the four 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 Figures 5.1-1, 5.1-2, 5.1-3, and 5.1-4. Specific dates for the milestones 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 8.3.1.2.2.4
(WBS number 1.2.3.3.1.2.4)

Milestone Number	Milestone	Milestone Level
<u>Radial-borehole tests in the ESF: 8.3.1.2.2.4.4</u>		
M640	OFR: radial borehole testing data	3
M654	Ramp construction complete	3
<u>Excavation-effects testing: 8.3.1.2.2.4.5</u>		
M882	Begin excavation effects tests (ESF)	3
3GUS009M	Report: build, calibrate and test equipment	3
3GUS103M	T081: Final report: excavation effects testing	3
<u>Perched-water testing: 8.3.1.2.2.4.7</u>		
3GU5016M	M694: Final report: perched-water results	3
3GUS014M	Progress report: perched-water	3
3GUS01M	Preliminary report/TDIF: borehole instrumentation	3
<u>Hydrochemistry tests in the ESF: 8.3.1.2.2.4.8</u>		
3GUS406M	Status report: ESF hydrochemistry	3
3GUS408M	M617: Hydrochemistry test of UZ final report completed	3

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Accession number: NNA.930104.0088