received with letter dtd 9/13/91

CONTROLLED
NO. 2
THIS IS A
RED STAMP
COPY

Study Plan for
Study 8.3.1.2.2.7

Hydrochemical Characterization of the Unsaturated Zone

Revision 0

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

Prepared by
U.S. Geological Survey

102.8

9109190196 910913
PDR WASTE
WM-11 PDR

YUCCA MOUNTAIN PROJECT

T-AD-088
12/89

Study Plan Number 8.3.1.2.2.7

Study Plan Title Hydrochemical Characterization of the Unsaturated Zone

Revision Number R 0, July 1990

Prepared by:

U. S. Geological Survey

Date:

July 1990

Maxwell P. Lambert 9/13/90
Director, Regulatory and Site Evaluation Division / Date

James Blaylock for 9/18/90
Director, Quality Assurance Division / Date

ABSTRACT

This study plan describes the plans for gaseous- and aqueous-phase chemical investigations at Yucca Mountain, Nevada. These activities will contribute to our understanding of the unsaturated-zone hydrochemical environment at the site, providing hydrochemical-parameter input for the resolution of design and performance issues. The two activities described in this study plan involve collection of water and gas samples from surface-based boreholes, preparation of the samples for analysis, and methods of hydrochemical analyses to be employed. The chemical and isotopic tests will include analysis for inorganic cations and anions, organic compounds, and stable isotopes. In addition, age dating, gas diffusion, and contamination testing will be conducted.

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

Table of Contents

	Page	Revision	IRN
1 PURPOSE AND OBJECTIVES OF STUDY	1.1-1		
1.1 Purpose of the Study Plan	1.1-1		
1.1.1 Prototype testing	1.1-3		
1.2 Objectives of the study	1.2-1		
1.3 Regulatory rationale and justification	1.3-1		
2 RATIONALE FOR STUDY	2.1-1		
2.1 Technical rationale and justification	2.1-1		
2.1.1 Statement of problem	2.1-1		
2.1.2 Interpretation of results	2.1-1		
2.1.3 Parameters and testing strategies	2.1-7		
2.1.3.1 Gaseous-phase sampling	2.1-12		
2.1.3.2 Aqueous-phase sampling	2.1-13		
2.1.4 Hydrologic hypothesis	2.1-15		
2.1.5 Geohydrologic model	2.1-15		
2.2 Constraints on the study	2.2-1		
2.2.1 Representativeness of repository scale and correlation to repository conditions	2.2-1		
2.2.2 Accuracy and precision of methods	2.2-1		
2.2.3 Potential impacts of activities on the site	2.2-1		
2.2.4 Time required versus time available	2.2-1		
2.2.5 Interference	2.2-11		
3 DESCRIPTION OF ACTIVITIES	3-1		
3.1 Gaseous-phase chemical investigations	3.1-1		
3.1.1 Objectives of activity	3.1-1		
3.1.2 Rationale for activity selection	3.1-1		
3.1.3 General approach and summary of tests and analyses	3.1-1		
3.1.3.1 Collection and transportation of samples	3.1-4		
3.1.3.2 Preparation of samples for analysis	3.1-6		
3.1.3.3 Analyses	3.1-7		
3.1.3.4 Methods summary	3.1-9		
3.1.4 Technical procedures	3.1-9		
3.2 Aqueous-phase chemical investigations	3.2-1		
3.2.1 Objectives of activity	3.2-1		
3.2.2 Rationale for activity selection	3.2-1		
3.2.3 General approach and summary of tests and analyses	3.2-3		
3.2.3.1 Collection and transportation of samples	3.2-4		
3.2.3.2 Extraction of water from core samples	3.2-7		
3.2.3.3 Analyses	3.2-11		
3.2.3.4 Methods summary	3.2-12		
3.2.4 Technical procedures	3.2-15		

4 APPLICATION OF STUDY RESULTS 4.1-1
4.1 Application of results to resolution of design and performance issues 4.1-1
4.2 Application of results to support other site-characterization investigations and studies 4.2-1

5 SCHEDULES AND MILESTONES 5.1-1
5.1 Schedules 5.1-1
5.2 Milestones 5.2-1

6 REFERENCES 6-1

7 APPENDICES 7-1.1
7.1 Quality-assurance requirements 7-1.1
7.1.1 Quality-assurance requirements matrix 7-1.1
7.2 Relations between the site information to be developed in the study and the design- and performance-information needs specified in the SCP 7.2-1

List of Figures

		Page	Revision	IRN
1.1-1	Diagram showing the location of study within the unsaturated-zone investigation and organization of the Geohydrology Program ...	1.1-2		
1.2-1	Map showing location of Yucca Mountain	1.2-2		
1.2-2	Map showing locations of repository site and gaseous- and aqueous-phase sampling locations at Yucca Mountain, Nevada	1.2-3		
1.2-3	Map showing locations of repository site and gaseous- and aqueous-phase sampling locations at Yucca Mountain, Nevada (continued)	1.2-4		
1.2-4	Diagram showing the relation of geohydrologic units to stratigraphic and thermal/mechanical units	1.2-6		
1.3-1	Diagram showing interfaces of the unsaturated-zone hydrochemistry study with YMP performance and design issues and other site-characterization programs	1.3-2		
2.1-1	Map showing location of precipitation-collection stations	2.1-2		
2.1-2	Logic diagram of geohydrology program, including model components and parameter categories	2.1-10		
3.1-1	Logic diagram of the gaseous-phase chemical investigations showing tests, analyses, and methods	3.1-2		
3.1-2	Logic diagram of the gaseous-phase chemical investigations showing tests, analyses, and site parameters	3.1-3		
3.1-3	Schematic of apparatus for on-site, soil-gas collection for gaseous-phase chemical investigations	3.1-5		
3.1-4	Schematic of degassing system for gaseous-phase chemical investigations	3.1-8		
3.2-1	Logic diagram of the aqueous-phase chemical investigations showing tests, analyses, and methods	3.2-5		
3.2-2	Logic diagram of the aqueous-phase chemical investigations showing tests, analyses, and site parameters	3.2-6		
3.2-3	Schematic of apparatus for pore-water extraction by triaxial compression in aqueous-phase chemical investigations	3.2-8		

3.2-4 Schematic of apparatus for pore-water extraction by uniaxial compression in aqueous-phase chemical investigations 3.2-9
3.2-5 Methods of centrifugation for aqueous-phase chemical investigations 3.2-10
5.1-1 Schedule for gas sampling and water extraction for unsaturated-zone hydrochemistry study 5.1-2
5.2-1 Milestone flow chart showing reports, drilling and prototype test constraints 5.2-3

List of Tables

		Page	Revision	IRN
1.2-1	Chemical and isotopic analyses	1.2-5		
2.1-1	Activity parameters derived from this study	2.1-8		
2.1-2	Sampling scheme from different lithologic units for each borehole	2.1-14		
2.1-3	Relation between unsaturated-zone hydrological conceptual-model hypotheses and the objectives of the activities of this study	2.1-16		
2.2-1	Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests	2.2-2		
3.1-1	Summary of tests and methods for the gaseous-phase chemical investigations (SCP Activity 8.3.1.2.2.7.1)	3.1-10		
3.1-2	Technical procedures for gaseous-phase chemical investigations (SCP Activity 8.3.1.2.2.7.1)	3.1-11		
3.2-1	Summary of tests and methods for the aqueous-phase chemical investigations (SCP Activity 8.3.1.2.2.7.2)	3.2-13		
3.2-2	Technical procedures for aqueous-phase chemical investigations (SCP Activity 8.3.1.2.2.7.2	3.2-16		
5.2-1	Milestone list for the study (SCP 8.3.1.2.2.7)	5.2-2		
7.2-1	Design and performance issues and parameters supported by results of this study	7.2-2		

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 hydrologic, hydrochemical, and geologic information to evaluate the suitability of Yucca Mountain for development as a 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 Department of Energy (DOE) to demonstrate in its environmental-impact statement and license application that the MGDS will 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 collection, transportation, preparation, and chemical and isotopic analyses of gas and water samples collected from the unsaturated zone at Yucca Mountain. The study is organized into two activities:

- 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations; and
- 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations.

Note that the numbers (e.g., 8.3.1.2.2.7.1) used throughout this plan serve as references to specific sections of the YMP Site Characterization Plan (SCP). The SCP (U.S. Department of Energy, 1988) 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. The study is one of nine studies planned to characterize the unsaturated zone at Yucca Mountain. Seven of the studies are surface-based evaluations and two, 8.3.1.2.2.4 (Characterization of Yucca Mountain percolation in the unsaturated-zone -- exploratory-shaft-facility study) and 8.3.1.2.2.5 (Diffusion tests in the exploratory-shaft facility), will study the *in situ* hydrologic characteristics of Yucca Mountain from shafts and underground drifts including hydrochemical tests in the exploratory-shaft facility (8.3.1.2.2.4.8). The two activities in this study were selected on the basis of a number of 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. (*Parameter* is used in this plan to mean a property, characteristic, and/or value of a constant that is used to describe the unsaturated-zone hydrologic system.) These factors are described in Sections 2 and 3.

Plans for gaseous- and aqueous-phase chemical investigations are described in Sections 3.1 and 3.2, respectively. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) tests and analyses. Alternate methods of testing and analysis are summarized, and

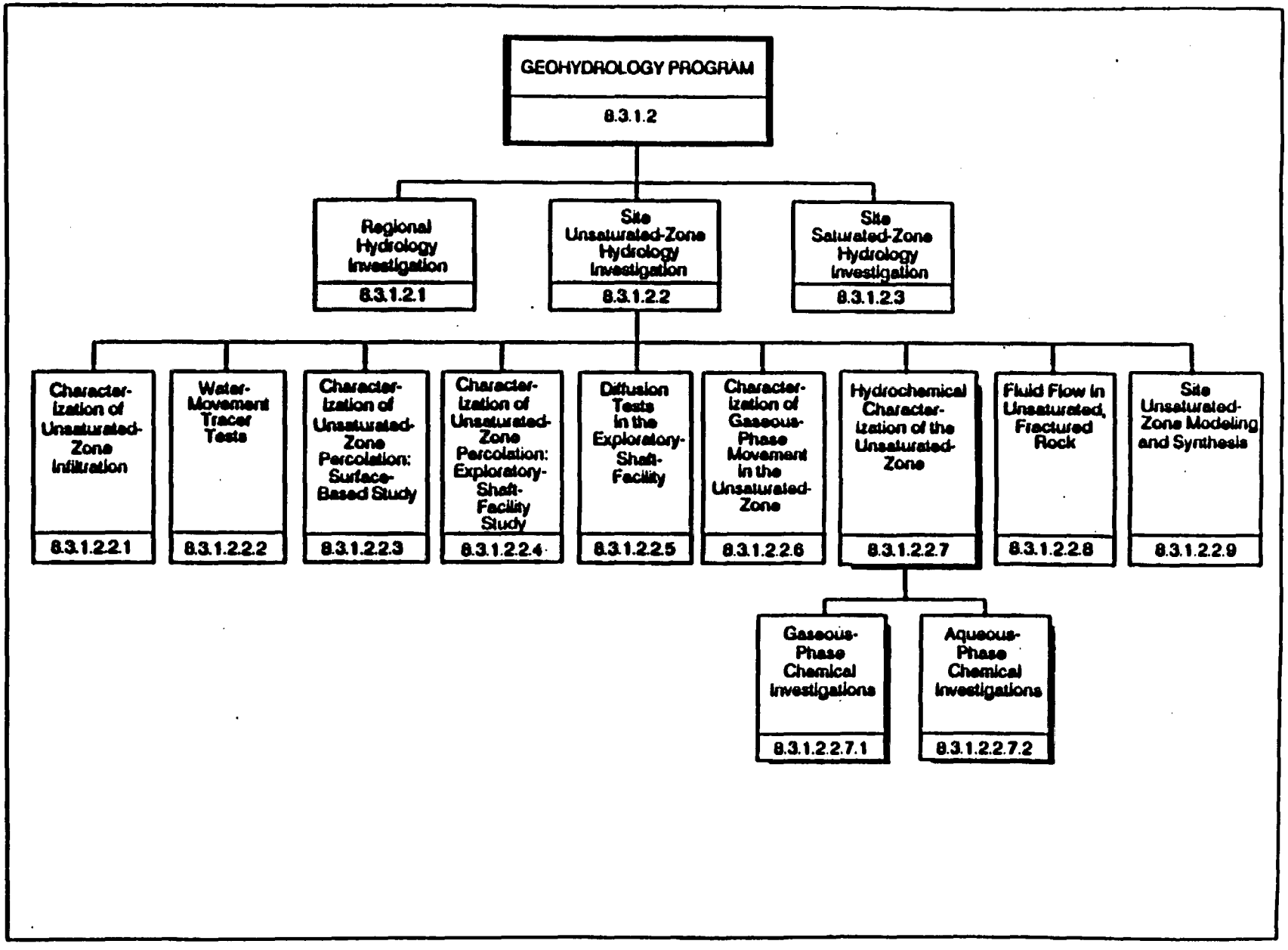


Figure 1.1-1. Diagram showing the location of study within the unsaturated-zone investigation and organization of the Geohydrology Program.

cross references are provided for quality-assurance levels and technical procedures.

Application of the study results is summarized in Sections 1.3 and 4, schedules and milestones for the study and activities are presented in Section 5, and a study-plan reference list is presented in Section 6. Quality-assurance requirements are documented in Section 7.1.

1.1.1 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. Therefore, prototype tests to evaluate the feasibility of the proposed methods have been planned.

Prototype testing will serve 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 will provide an opportunity to understand, implement, refine, and practice testing procedures prior to the actual field implementation. If the tests do not perform as the hydrologists expect them to conceptually, either due to basic design flaws or unanticipated physical properties *in situ*, potential licensing data could be lost. The only credible means to reduce this risk is to validate the test concepts and to test designs before actual testing in the field.

Prototype test plans which are critical for this study are described in Section 3 and in the draft prototype-test plans. Prototype tracer tests, triaxial compression tests, and uniaxial compression tests will develop and test techniques that are directly applicable to the gaseous- and aqueous-phase chemical activities. In addition, perched-water and wet versus dry drilling prototype testing which are pertinent to the present study are discussed in Study 8.3.1.2.2.4 (Characterization of Yucca Mountain percolation in the unsaturated-zone -- exploratory-shaft-facility study).

The critical prototype testing must be completed successfully before the site-characterization testing is started. Characterization of the site will not be conducted by methods described in this Study Plan if prototype testing demonstrates that the methods and/or equipment cannot be applied successfully to Yucca Mountain. Prototype tests critical to the continuation of this study are underway or will be started soon. Upon completion of prototype testing, all results will be fully documented in published reports.

1.2 Objectives of the study

Hydrochemical evaluation of the unsaturated zone will aid in the understanding of flow and transport of gas and water in the tuffs at Yucca Mountain. The data resulting from the hydrochemistry analyses will complement other data from hydrologic and hydrochemical studies of the unsaturated and saturated zones. The objective of this study is to characterize the hydrochemistry of the unsaturated zone by (1) determining transport mechanisms, flow directions, and travel times for gas and water, (2) determining the extent of water/rock interactions, and (3) providing conceptual hydrologic and geochemical models based on the results of hydrochemical analysis. These concepts will help evaluate the potential for migration of radioactive wastes stored at Yucca Mountain.

The specific objectives of individual activities in the unsaturated-zone hydrochemistry study are:

- o 8.3.1.2.2.7.1 - to understand the transport mechanism, flow direction, flux, and travel time of gas within the unsaturated zone; and

- o 8.3.1.2.2.7.2 - to implement methods designed in prototype testing for extracting unaltered pore water from unsaturated-zone tuff units; to obtain hydrochemical data to provide evidence of flow direction, flux and travel time of water; and to determine the geochemical evolution of ground water within the unsaturated zone by hydrochemical and isotopic techniques.

Figure 1.2-1 shows the location of Yucca Mountain at which samples for the unsaturated-zone hydrochemistry test will be collected. Specific boreholes to be sampled and overall sampling strategy are summarized in Sections 2.1.3.1 (Gaseous-phase sampling) and 2.1.3.2 (Aqueous-phase sampling). This study is confined to that area of Yucca Mountain immediately overlying and adjacent to the boundaries of the proposed repository block. Vertically, the study extends from the near surface of Yucca Mountain down to immediately above the water table. Figures 1.2-2 and 1.2-3 show the location of the proposed repository block in relation to the gaseous- and aqueous-phase sampling locations. Table 1.2-1 lists the chemical and isotopic analyses for the hydrochemical tests. Figure 1.2-4 depicts the relation between the stratigraphic, geohydrologic, and thermal/mechanical units at Yucca Mountain.

The objectives initially identified in this document, evaluation of chemical reactions and producing data that will help evaluate fluxes and transport times, should in fact be feasible although the achievement of these goals may be far from straight forward -- a point that should be kept in mind throughout the reading of the remainder of this document.

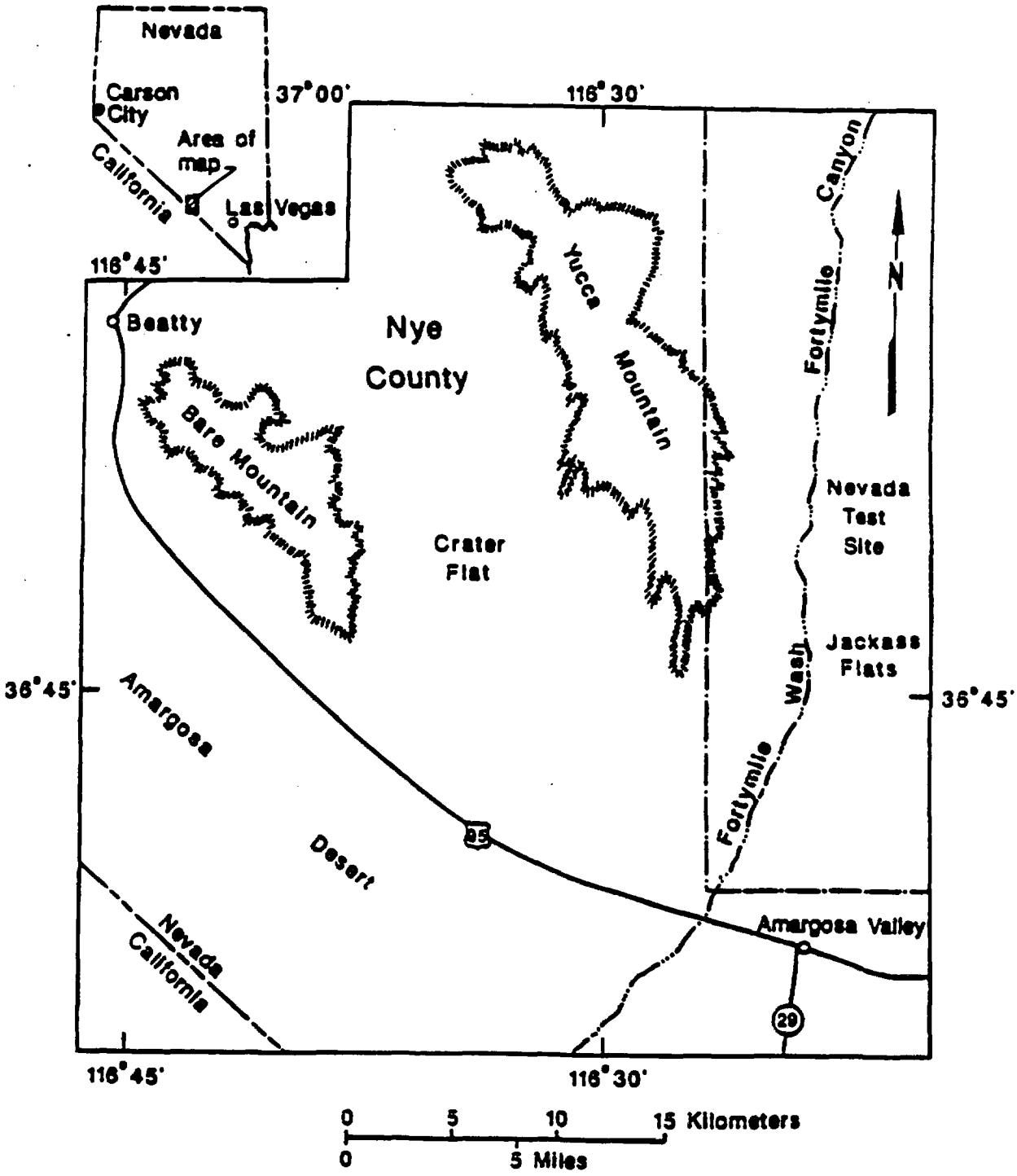


Figure 1.2-1. Map showing location of Yucca Mountain.

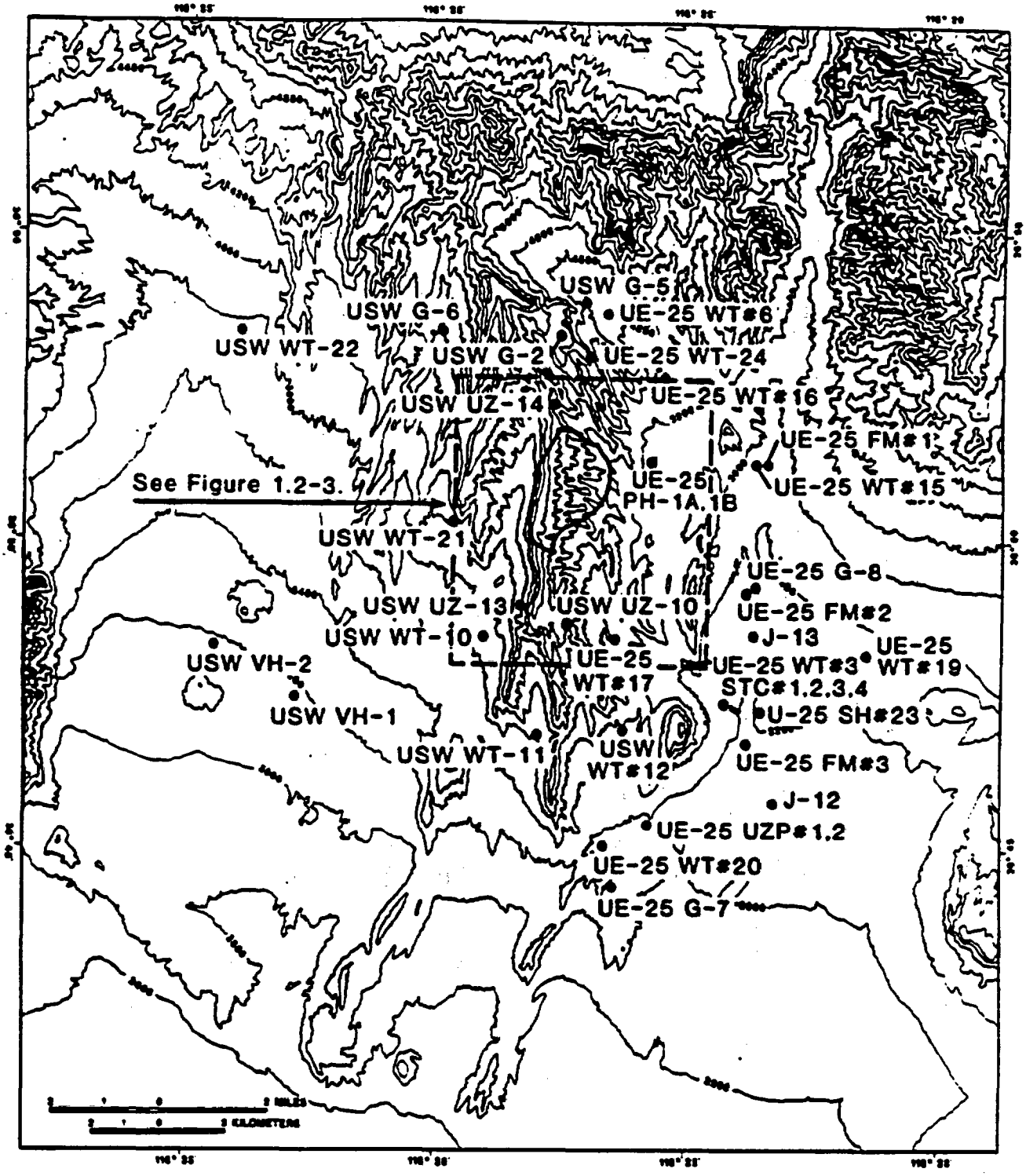


Figure 1.2-2. Map showing locations of repository site and gaseous- and aqueous-phase sampling locations at Yucca Mountain, Nevada.

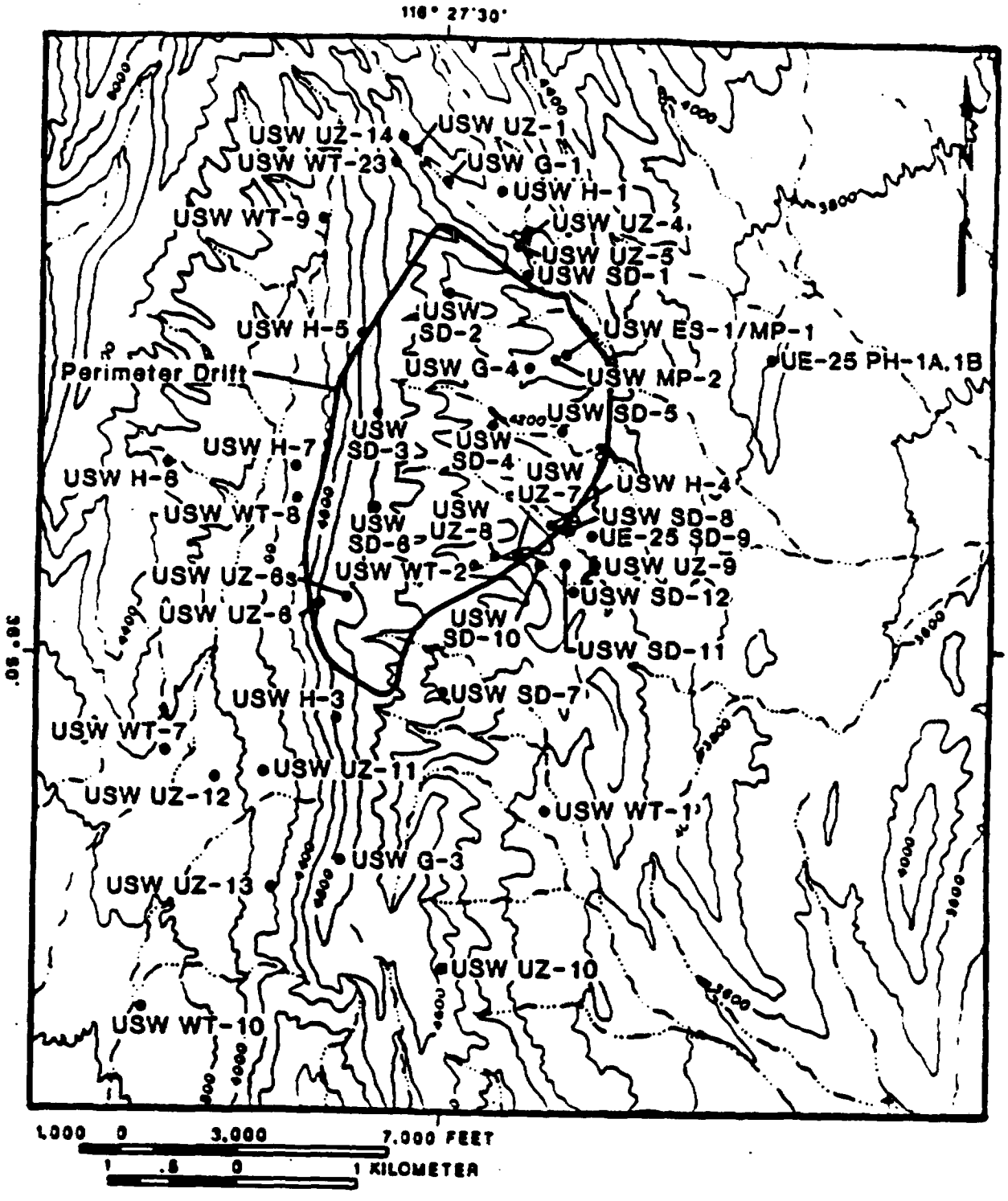


Figure 1.2-3. Map showing locations of repository site and gaseous- and aqueous-phase sampling locations at Yucca Mountain, Nevada (continued).

Table 1.2-1. Chemical and isotopic analyses

Parameter	Chemical species	Remarks
Inorganic cations and anions	Na, Ca, Mg, K, HCO_3, SO_4, Cl, pH, SiO_2, Mn, Fe, Al	Types of ongoing chemical reactions. Residence times of fracture fluids.
	Rare-earth elements and other trace elements.	Fluid inclusions in secondary minerals to identify the sources of water.
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. Fluid inclusion in secondary minerals to identify the sources of water.
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	Freon-11, Freon-12, CO_2, H_2, SF_6, CH_4, Ar, O_2, N_2	Diffusion of gases (^{14}C, ^{3}H, and ^{39}Ar) into the unsaturated zone.
Contamination check	Li, Br, I, NO_3, BO_3	Washdown of tracers.

* ^{36}Cl work to be performed by Los Alamos National Laboratory in Study 8.3.1.2.2.2.1 (Chloride and Chlorine-36 measurement of percolation at Yucca Mountain).

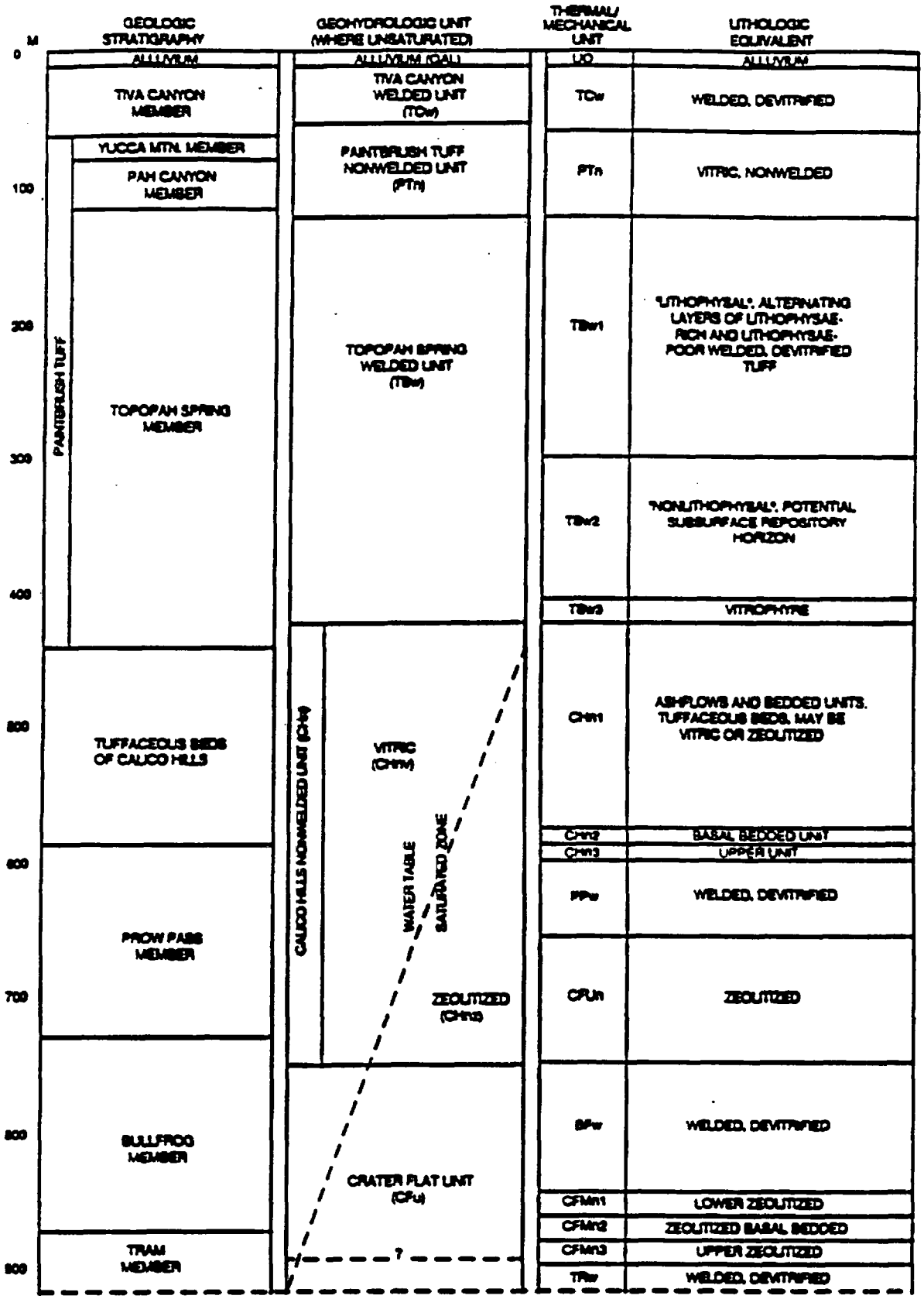


Figure 1.2-4. Diagram showing the relation of geohydrologic units to stratigraphic and thermal/mechanical units.

1.3 Regulatory rationale and justification

The results of unsaturated-zone testing will provide hydrologic data for performance-assessment 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 described in the geohydrology testing strategy (SCP Section 8.3.1.2) and the issue-resolution strategies (repository, seals, waste package, and performance assessment; SCP Sections 8.3.2 - 8.3.5). The description presented below provides a more specific identification of these relations as they apply to this study. A detailed tabulation of parameter relations is presented in Appendix 7.2.

Project-organization interfaces between the Hydrochemical characterization of the unsaturated-zone study (8.3.1.2.2.7) and the YMP performance and design issues are illustrated in Figure 1.3-1. 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 performance determinations of pre-waste-emplacement, ground-water travel time (Issue 1.6) and the predictions of radionuclide releases to the accessible environment (Issue 1.1). Study results will also be used in the analyses for repository underground-facility design (Issue 4.4). Unsaturated-zone information on fracture characteristics and hydrologic/hydrochemical conditions will be used in developing the design requirements for the waste package (Issue 1.10) and shaft and borehole seals (Issue 1.12).

Performance Issue 1.1
(Total-system performance for limiting radionuclide release to the accessible environment)

This issue requires that the geologic setting, engineered barrier system, shafts, boreholes, and seals be selected and designed so as to limit the cumulative releases of radionuclides for 10,000 years following permanent closure of the repository. Site information resulting from the hydrochemical characterization of the unsaturated-zone 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. Descriptions of the scenarios are given in SCP Section 8.3.5.13. The supporting parameters are used in calculations of the performance parameters for the different scenarios.

The performance parameters for each of the scenario classes apply to expected partial performance measures (EPPMs). For example, Scenario Class E has three EPPMs: one for the unsaturated-zone liquid pathway, one for the

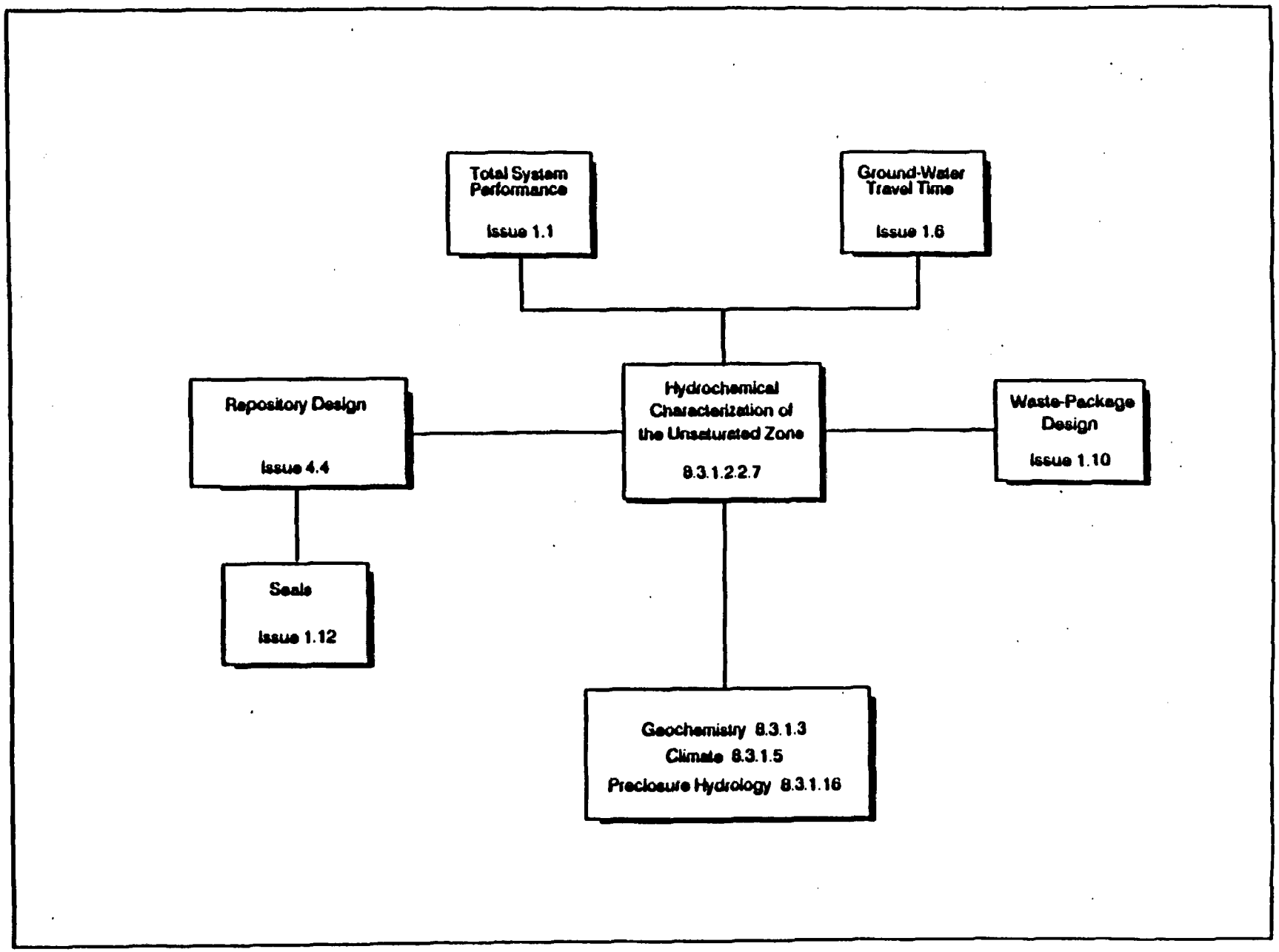


Figure 1.3-1. Diagram showing interfaces of unsaturated-zone hydrochemistry study with YMP performance and other site-characterization programs.

saturated-zone liquid pathway, and one for the gas pathway. Determination of each of these EPPMs depends upon data from performance parameters, which in turn depend on calculations from supporting parameters. The calculations are based on site information collected in the study. These relations are described in the SCP and are further documented in Appendix 7.2.

Unsaturated-zone hydrochemical properties determined in this study (e.g., pore-gas composition, isotopic ratios, and pore-water hydrochemical compositions) contribute to Issue 1.1 supporting parameters employed in the following calculations:

- Calculation of coupling factors and radionuclide retardation factors in the unsaturated zone;
- Calculation of gas-phase ^{14}C transport in the overburden units;
- Model calibration and validation of gas-phase ^{14}C transport; and
- Calculation of model validation coupling factors in the unsaturated zone.

Performance Issue 1.6
(Pre-waste-emplacement, ground-water travel time)

The general strategy for resolving this issue is to define, characterize, and assess multiple barriers to ground-water flow by dividing flow paths and flow processes into categories. In the unsaturated zone, multiple natural barriers have been identified as seven distinct geohydrologic units for which different types of general flow processes may be distinguished. These flow processes include dispersive and advective flow in rock pores, similar flow in fractures, and diffusion between and within the matrix and fractures. The frequency distribution of calculated ground-water travel times is the performance measure for each geohydrologic unit. The overall performance goal for ground-water travel-time for the combination of all geohydrologic units between the disturbed zone and the accessible environment is 1,000 years or more at a very high confidence level.

The data generated by the site-hydrochemistry study are directly applicable to the resolution of this issue. Ground-water residence times (from isotopic ratios), water, vapor, and gas fluxes, and travel times along flow paths will satisfy numerous supporting performance parameters needed to assess ground-water travel time in individual and combinations of unsaturated-zone units. These supporting parameters are used to define various aspects of the unsaturated-zone model, including initial and boundary conditions and material properties.

Performance Issues 1.8 and 1.9
(Favorable and potentially adverse conditions) (Qualifying and disqualifying conditions)

The results of this study have indirect applications to the NRC siting criteria - Favorable Condition 7 (pre-waste-emplacement, 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)

Unsaturated-zone water chemistry data obtained from this study will be used to characterize the near-field (pre-waste emplacement) environment of the waste packages. Information on radioactive isotope activities, stable isotope ratios, and water quality (cation and anion concentrations) will be used in assessing the mineral/water equilibrium and water quality of vadose-zone water. The applicable performance measure is the quality of liquid water that can contact the container.

The results of 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 1.12
(Characteristics and configurations of shaft and borehole seals)

Unsaturated-zone information derived from this study will be used in the design of repository seals. Seal design and construction will be influenced by the chemistry and sediment content of waters located in faults. Shaft and borehole seals will act to deter against fluid migration into the repository and to control gas transport from the repository. Site information on unsaturated-zone hydrochemistry will be applied to the design and placement of the following sealing-system components: single and double bulkheads in emplacement and perimeter drifts, backfilled sumps and channels, and drift backfill. These components relate to the functions of retaining, diverting, and draining water from the drifts and to reducing the potential for subsidence. The applicable design parameter is the chemistry of waters in faults, including sediment contents; the pertinent performance measure is the quantity of water entering the different underground systems.

Design Issue 4.4
(Repository design and technical feasibility)

For Issue 4.4, only the preclosure elements are considered pertinent. Unsaturated-zone water-chemistry data from this study will be applied to the repository waste-handling retrieval system element. The tentative goal is that a quantitative and qualitative analysis of formation and water chemistry will aid in the understanding of waste-package liner corrosion. The liner corrosion in 100 years, as related to the performance measure, should be less than half the original liner thickness. Site hydrochemistry data from this study will also be used to evaluate natural water inflow. This evaluation will be applicable to the water removal-system element, the performance measure being that the rate of removal equals the rate of inflow.

2 RATIONALE FOR STUDY

2.1 Technical rationale and justification

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

2.1.1 Statement of problem

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.

2.1.2 Interpretation of results

Isotopic data of precipitation (rain and snow) are important to the study of unsaturated-zone hydrochemistry beneath Yucca Mountain because they provide input information concerning the unsaturated zone. Milne and others (1987) collected and analyzed precipitation in southern Nevada from August, 1983 to August, 1986. Twelve precipitation-collection cylinders were installed throughout southern Nevada, as shown in Figure 2.1-1. Samples were collected and transferred to bottles within 24 hours of the cessation of precipitation. Temperature near the sites and the amount of precipitate were also recorded. The stable-isotope data indicates substantial variations. For example, $\delta^{18}O$ values

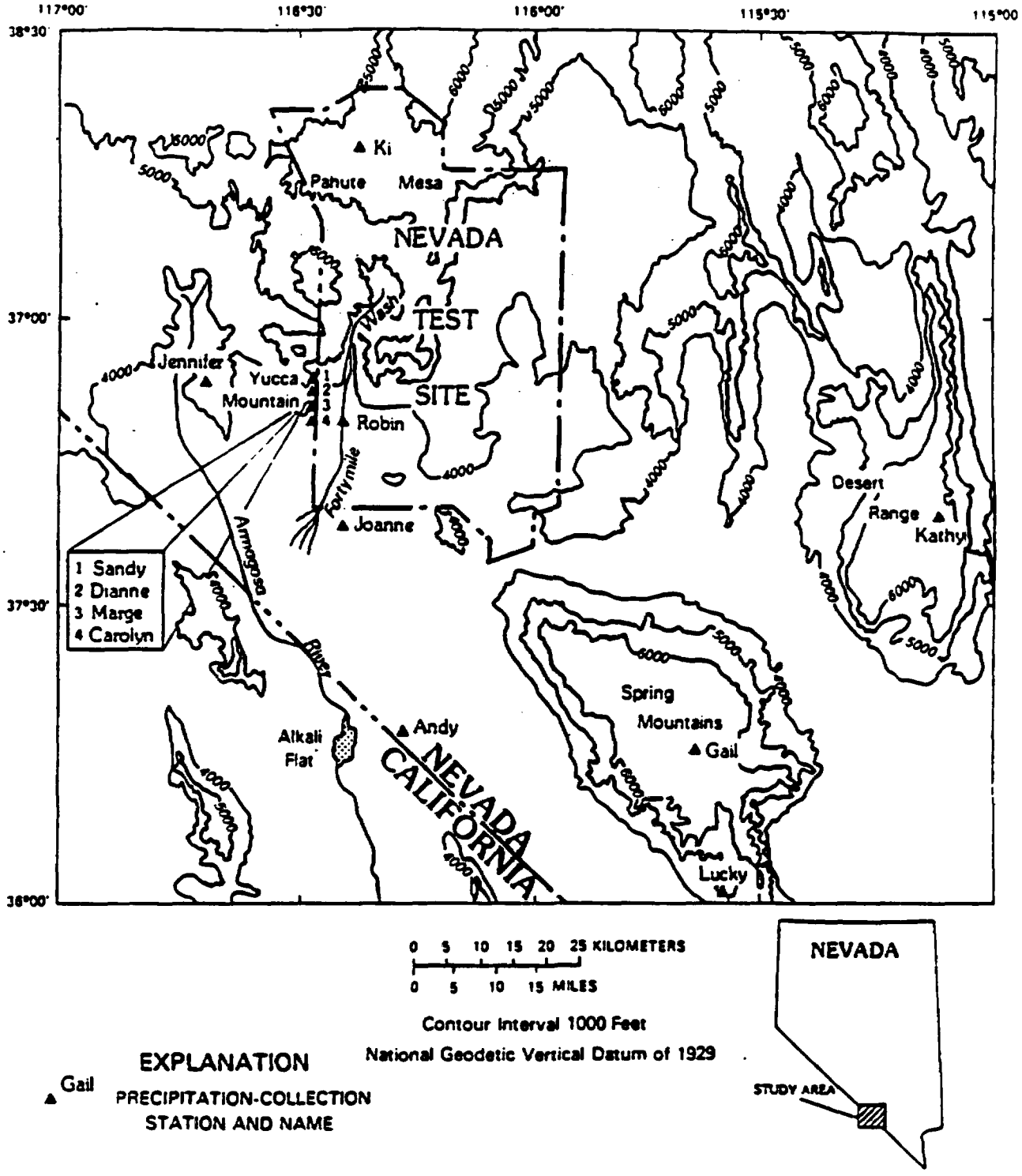


Figure 2.1-1. Map showing location of precipitation-collection stations.

range from -22.5 to +7.5°/oo and δD values range from -158.5 to -8.0°/oo. This large variability is attributable to small amounts of summer rainfall that partially evaporated as it fell. If data for precipitation in the form of snows only are considered, the $\delta^{18}O$ values range from -22.2 to -7.5°/oo and δD values range from -158.5 to -53.0°/oo. In general, winter snows are isotopically lighter than summer rains resulting in lower $\delta^{18}O$ and δD values. Pahute Mesa, at an altitude of 2,145 m (7,037 ft) above sea level, contributes the lightest isotopes because it receives a greater proportion of its precipitation in the form of snow ($\delta^{18}O$ values range from -19.4 to -10.2°/oo; δD values range from -149.5 to -75.0°/oo; with a mean value of $\delta^{18}O$ = -14°/oo and δD = -103°/oo). Isotopic data for precipitation collected at Yucca Mountain indicates $\delta^{18}O$ values range from -16.0 to -1.0°/oo, and δD values range from -125.0 to -5.0°/oo. When data for precipitation that fell in quantities of less than 1 cm (0.4 in.) are excluded, the $\delta^{18}O$ values range from -16.0 to -10.0°/oo, and δD values range from -125.0 to -65.0°/oo.

If significant amounts of unsaturated-zone water were recharging the saturated-zone ground water beneath Yucca Mountain, the isotopic and chemical compositions of both zones should be similar. The saturated-zone ground-water isotopic and chemical compositions were published by Benson and McKinley (1985). They analyzed water from 15 wells at Yucca Mountain from 1971 through 1984. Analysis of stable-isotope compositions indicate: (1) $\delta^{18}O$ values of ground water beneath Yucca Mountain range from -14.2 to -13.4°/oo, and δD values range from -108 to -99.5°/oo; (2) upper Fortymile Wash (UE-29a#2) has a $\delta^{18}O$ value of -12.8°/oo and δD value of -93.5°/oo; and (3) lower Fortymile Wash (J-2, J-3) has a $\delta^{18}O$ value of -12.9°/oo and δD value of -97.5°/oo. All tritium concentrations were less than 10 tritium units (T.U.). The distribution of uncorrected radiocarbon ages of water from volcanic tuffs sampled within 1 kilometer of the exploratory block on Yucca Mountain ranged from 12,000 to 18,500 years before present.

Hydrochemical characterization of Yucca Mountain described in this study plan will obtain isotopic and chemical data of various cores from unsaturated-zone boreholes, and attempt to interrelate these data with the above mentioned precipitation and saturated-zone ground-water data. Some questions that the study will attempt to address are: (1) Is there any significant recharge of precipitation occurring through the unsaturated-zone of Yucca Mountain?; (2) What is the flow path of the infiltration?; and (3) How long does it take for the unsaturated-zone ground water to travel to the water table, if it does recharge the ground water?

Currently, there are few data available on the hydrochemistry of the unsaturated zone beneath Yucca Mountain. These data have been collected and analyzed by methods described in Section 3 and in Yang and others (1985). The data will be used only for site-characterization work with appropriate quality-assurance qualifications. Cores from neutron access holes and UE-25 UZ#4 and UZ#5 boreholes have been analyzed for chemical and isotopic compositions of pore water. Results of ongoing neutron-hole (15-m- [49-ft-] deep) monitoring of moisture transport in the Yucca Mountain area indicate that moisture pulses only penetrate to a depth of about 10 m (33 ft) (Alan Flint, personal communication, 1989). This

depth was confirmed by tritium analysis of core moisture from neutron holes. Furthermore, our analysis of core water from UE-25 UZ#4 borehole (total depth of 111 m [364 ft]) indicated a tritium concentration of 22 T.U. at a depth of 2 to 5 m (6.5 to 16.4 ft) decreasing to 5 T.U. at 6 m (20 ft) and then to 2 T.U. between 10 to 12 m (33 to 39 ft). The fracture was observed at a depth of 23.16 m (75.96 ft); cores collected from 24.78 m (81.28 ft) had a tritium content of 28 T.U. indicating modern water. A decrease to near zero T.U. was observed at 25.60 m (83.97 ft). The lithologic unit that contains the modern water is the lower Tiva Canyon member of partially welded to nonwelded tuff. Another high tritium concentration of 45 T.U. was observed between 46.33 to 49.68 m (151.96 to 162.95 ft). The lithologic unit that contains this wet zone of modern water is the upper bedded tuff which is overlain by the Yucca Mountain member. The tritium concentration decreased to 0 T.U. at around 106 m (348 ft). There was no alluvium in the borehole. High tritium concentrations were also observed in UE-25 UZ#5 borehole with values of 60 T.U. at a depth of 28.35 m (93.0 ft), 40 T.U. at 33.53 m (110.0 ft) and 4 T.U. at 37.18 m (121.95 ft). This high tritium-concentration zone occurred in the lower Tiva Canyon member of partially to nonwelded vitric tuff, similar to that observed in UE-25 UZ#4. All these evidences of profile inversions of tritium concentration with depth point to the fact that vertical percolation was not occurring at Yucca Mountain, while either fractures or bedded units were transporting moisture laterally.

Stable-isotope ratios of oxygen and deuterium in pore water collected from UE-25 UZ#4 and UZ#5 boreholes at depths between 24 to 100 m (78 to 328 ft) indicated $\delta^{18}O$ and δD values ranging from -12.5 to -9.5‰ and -94 to -86‰, respectively. Yucca Mountain precipitation that fell between April and October for 1983 to 1986, the $\delta^{18}O$ values range from -13.0 to -1.0‰, and δD values range from -96.0 to -10.0‰. Precipitation that fell between November and March for 1983 to 1986, the $\delta^{18}O$ values range from -11.0 to -17.0‰, and δD values range from -63.0 to -125.0‰. All Yucca Mountain precipitation data fell on the Yucca Mountain precipitation line [$\delta D = 6.9(\delta^{18}O)-2.1$]. However, the unsaturated-zone ground-water isotopic ratios deviate to the right of the precipitation line. This may be due to partial evaporation of surface water before recharging into the unsaturated zone. If the regression line is drawn through the points and extended back to intercept the Yucca Mountain precipitation line, the intercept occurs at a $\delta^{18}O$ value of about -15.0‰ and a δD value of about -105.0‰, which are within the range of winter precipitation. This suggests that summer rain storms are not recharging the unsaturated zone beneath Yucca Mountain, while snow melt or winter storms are probably providing most of the recharge to the unsaturated zone.

Comparison of the regional ground-water isotopic data with unsaturated-zone water beneath Yucca Mountain indicates that the former is more depleted in ^{18}O and D isotopes than the latter. The $\delta^{18}O$ and δD values of ground water (UE-29a#2) in upper Fortymile Wash are similar to the unsaturated-zone water. Benson and McKinley (1985) reported that ground water in UE-29a#2 borehole (total depth of 422 m [1,384 ft]) contains 11.5 T.U., significantly above background levels. This may mean that modern water from the unsaturated zone of Yucca Mountain was transported laterally and reached Fortymile Wash to mix with older water

in the wash (^{14}C age of UE-29a#2 ground water was about 4,000 years old). Apparently, not much of the unsaturated-zone water was recharging the ground water beneath Yucca Mountain as determined by dissimilar $\delta^{18}O$ and δD values of the two water bodies, at least for the past 4,000 years. This dissimilarity is based on the assumption that the climate of the region has not changed dramatically during the last 4,000 years (Yang, 1989). Furthermore, ground waters from J-12 and J-13 boreholes located in Fortymile Wash have $\delta^{18}O$ and δD values of -12.9 and -97‰, respectively, which are heavier than the ground water beneath Yucca Mountain. Therefore, Fortymile Wash is an unlikely source of ground water beneath Yucca Mountain.

The $\delta^{18}O$ and δD values of precipitation at Yucca Mountain prior to 4,000 years ago are not known at this time. Future analysis of deeper pore waters, with different apparent ^{14}C ages, could be correlated with recharge which occurred under different climatic conditions. The relative change in the two isotopic ratios should follow an established pattern (i.e., meteoric water line), and any water which involved extensive evaporation before recharge should show enrichment in $\delta^{18}O$ and δD values. The assumption here is that the isotopic composition of precipitation will not have been changed by liquid-solid exchange in the unsaturated zone (e.g., interaction with aquifer carbonate or silicate rocks at a high temperature has not occurred). The δD values would not have been affected even if there were high-temperature events (200 to 300 °C) in the past because the tuff contains no hydrogen atoms. However, oxygen-isotope ratios would increase due to oxygen exchange with silicate rocks. At a low temperature (say less than 50 °C) no isotopic exchange will occur between the liquid-solid phases; this condition is the likely case from core samples already obtained. In the case of water vapor-liquid and liquid-liquid exchange, because water vapor and liquid water are both present and intimately intermingled throughout this unsaturated zone, they are likely to be in an equilibrium state. Dispersive mixing, obscuring any original paleoclimatic signal, is another possibility. If so, $\delta^{18}O$ and δD values of 500 or even 1,000 years are likely to be obtained, rather than every 100 years. Here we are looking at long-term trends of tens of hundreds of years, therefore fine resolutions are not required.

The above conceptual model of hydrologic flow in the unsaturated zone is based on geochemical isotopic analysis and can be further confirmed by analyses of matrix versus fracture flow. As mentioned in the sampling strategy (Sections 2.1.3.1 and 2.1.3.2), pore water in matrix and fracture tuff samples from the same horizon will be analyzed for their ^{14}C ages. If fracture flow dominates, ^{14}C ages of pore water in the fractures will be significantly younger than water in the matrix. Also $\delta^{18}O$ and δD values in the fractures are likely to be heavier than the matrix due to the lighter isotopic compositions for old precipitation which occurred during the last glacial time.

Measurements of ^{14}C activities in the liquid phase are possible in order to estimate residence times and flow rates. However, measurements may encounter some difficulties and uncertainties due to incorporation of other sources of carbon (e.g., caliche dissolution, or gaseous- and liquid-phase exchange of carbon). Monitoring of gas compositions ($^{12}CO_2$, $^{13}CO_2$, and $^{14}CO_2$) in USW UZ#1 borehole during the past four years

indicates that CO_2 gas in the borehole had near constancy of $\delta^{13}C$ values (-22 to -20°/oo) from 12- to 366-m- (39- to 1,200-ft-) depth, signifying no exchange of CO_2 gas with caliche or calcite in the unsaturated zone. If exchange did occur, $\delta^{13}C$ values of the CO_2 gas would have shifted toward heavier $\delta^{13}C$ values because caliche and calcite $\delta^{13}C$ values are between 0 to -5 °/oo. Furthermore, carbon content in the liquid phase in a unit volume of rock as bicarbonate is significantly (15 times) higher than the carbon in the gaseous phase in the same volume of rock. Therefore, the effect of exchange, if any, would also be small. In addition, pore water obtained from UE-25 UZ#5 cores from a depth of 91.5 m (300 ft) had a bicarbonate $\delta^{13}C$ value of -21°/oo, inferring silicate instead of caliche ($\delta^{13}C$ = -5.0 to 0 °/oo) dissolution. If a significant amount of caliche dissolved into pore water, the $\delta^{13}C$ of bicarbonate water would be close to -5.0°/oo, instead of the observed -21.0°/oo. Since silicate rocks contain no carbon atoms, ^{14}C activity corrections due to old caliche incorporation are not likely to be required.

In view of the available data from the unsaturated zone and the above discussion, the following provisional conclusions can be drawn: (1) there is no significant recharge from the unsaturated zone to the saturated zone beneath Yucca Mountain; (2) the likely flow paths of infiltrating water is through fractures, bedded units, contacts between units, or the Calico Hill unit, with lateral or inclined flow (vertical flow through a large fracture such as Ghost Dance fault is possible) recharging Fortymile-Wash ground water; and (3) ground-water flow beneath Yucca Mountain originates from the north of Yucca Mountain (i.e., Timber Mountain and Pahute Mesa) and flows south under Yucca Mountain. The confirmation of the conceptual model will be further verified through sampling and analyses of pore water in core samples as described in Sections 2.1.3.1 and 2.1.3.2.

Due to the dynamic nature of unsaturated-zone transport processes as evidenced by observations at open boreholes such as USW UZ-6 which gave the magnitude of gas flow (see 8.3.1.2.2.6 [Characterization of gaseous-phase movement in the unsaturated zone] and Weeks, 1987), the question of obtaining or inferring baseline, or *in situ*, data may provide one of the biggest challenges facing the hydrochemical characterization of the unsaturated zone beneath Yucca Mountain.

Although in the following sections of this study plan the gaseous- and aqueous-phase investigations are discussed separately, they must be discussed simultaneously in outlining the rationale and scope of the study. The combined characterization of the isotopes obtained from the gaseous- and aqueous-phase investigations will permit the first attempt at modeling the reactions responsible for the chemistry of the phases as they presently exist. A knowledge of these reactions is necessary to accomplish the objectives of this study (Section 1.2).

In order that the study produces valid conclusions, it is essential that (1) there be a sufficient number of moisture samples obtained as a function of both depth and spatial distance to represent a statistical sampling of tuff moisture, (2) the chemical composition of the moisture be accurately known, and (3) the effects of air introduced to the system (natural or man-made) can be evaluated. Pore-water samples will be obtained from rock cores from drilling of UZ-holes and neutron holes,

from bulk-rock samples taken in various zones during construction of the exploratory shaft (ES-1), and from the rock cores of radial and vertical boreholes in the ESF. Fracture-water samples taken directly from the ES-1 where inflow is observed will be available for analysis. Gas samples will be taken from isolated sampling stations installed in unsaturated-zone drillholes and in radial and vertical boreholes in the ESF. Study 8.3.1.2.2.4.8 (Hydrochemistry tests in the exploratory-shaft facility) discussed the collection and analysis of samples from the exploratory-shaft facility.

2.1.3 Parameters and testing strategies

Relations of site parameters determined by this study to design and performance parameters are used as a basis for developing the technical rationale of the planned work. Throughout the following sections of this plan, references are made to parameter categories and site parameters. These terms are used as a means of tracing information from site-characterization activities (SCP 8.3.1) to design- and performance-assessment issues resolutions (SCP 8.3.2 - 8.3.5). The parameters associated with each activity in Table 2.1-1 are described further in Section 3 under the description of the particular activity. For each activity, the parameters are grouped by the parameter categories shown in Figure 2.1-2. The parameters included in Table 2.1-1 serve three principal purposes. They are needed (1) as direct input to design and performance analyses, (2) as input to hydrologic numerical models, and (3) to test hypotheses that support conceptual models.

In order to conduct 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 chemistry, flow paths, velocity, flux, gradient, conductivity, anisotropy, boundary condition, and structural and geohydrologic-unit control 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. A common requirement of the parameters is that sufficient confidence can be placed in their numerical values to permit the construction of hydrologic modeling and hypotheses testing. That is, confidence in the calibration and validation of a model to a given level is dependent on the extent to which the input data and observations are characterized and credible.

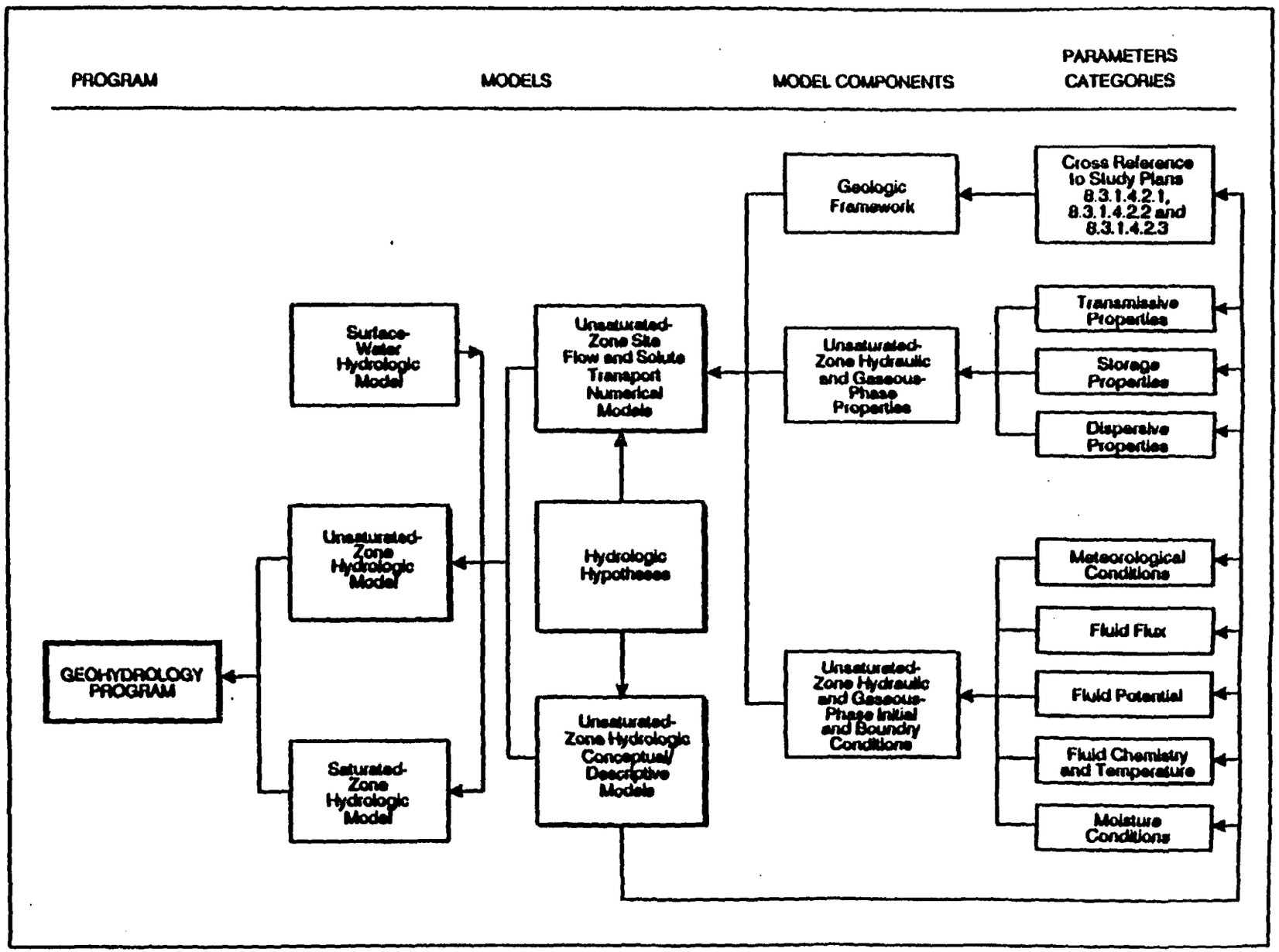
Some of the specific parameters listed in Table 2.1-1, although not required directly for resolving performance and design issues, are needed to model parameters that are directly required for performance and design purposes. Even though a single model is currently assumed, this study is designed to satisfy the requirements of alternative conceptual models (SCP Table 8.3.1.2-2a) in case the initial assumptions are invalidated. Similarly, while there are conventional theories for moisture movement in unsaturated porous soils and flow in saturated fractured rock, there is no conventional theory for describing gas and water movement in unsaturated fractured media. Development of appropriate models for unsaturated fracture flow will be part of

Table 2.1-1. Activity parameters derived from this Study

Site parameter	Spatial/geographic location	Geohydrologic-unit/structural location
Gaseous-phase chemical investigations; 8.3.1.2.2.7.1		
Unsaturated-zone fluid chemistry and temperature, and age		
Pore-gas composition	Yucca Mountain vertical boreholes	Unsaturated zone (all units penetrated by site-vertical boreholes)
Radioactive-isotope activity in gas phase (^{3}H and ^{14}C)	"	"
Stable-isotope ratio in gas phase ($^{18}O/^{16}O$, $^{13}C/^{12}C$, and D/H)	"	"
Unsaturated-zone fluid flux		
Gas flow paths, hydrochemical determination	Yucca Mountain vertical boreholes	Unsaturated zone (all units penetrated by site-vertical boreholes)
Gas travel times, hydrochemical determination	"	"
Aqueous-phase chemical investigations; 8.3.1.2.2.7.2		
Unsaturated-zone fluid chemistry and temperature, and age		
Pore water hydrochemical compositions	Yucca Mountain vertical boreholes	Unsaturated zone (all units penetrated by site-vertical boreholes)
Radioactive-isotope activity in liquid phase (^{3}H and ^{14}C)	"	"
Stable-isotope ratio in liquid phase	"	"
Water quality, cations and anions	"	"

Table 2.1-1. Activity parameters derived from this Study--Continued

Site parameter	Spatial/geographic location	Geohydrologic-unit/structural location
Aqueous-phase chemical investigations; 8.3.1.2.2.7.2		
Unsaturated-zone fluid flux		
Water flow paths ($^{18}O/^{16}O$, D/H), pore waters	Yucca Mountain vertical boreholes	Unsaturated zone (all units penetrated by site-vertical boreholes)
Water travel times (^{14}C and ^{3}H)	"	"



e 2.1-2. Logic diagram of geohydrology program ...uding model components and parameter catego...

Activity 8.3.1.2.2.8.1 (Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock).

Because input parameters for modeling cannot be known explicitly everywhere throughout the modeled area, the parameters must be expressed as statistical distribution functions. Initially the data collected in this study will be used in a conceptual model of flow and transport at Yucca Mountain. A satisfactory conceptual model will then become a numerical model which, based on statistical distributions of parameters, will be used as a principal approach to assess whether the data collected to describe the present and expected geohydrologic and hydrochemical characteristics provide the information required by the performance and design issues. Calibration of the model to observed conditions increases confidence that the modeled distribution of parameters is an acceptable representation of actual conditions. The modeling process is iterative. If the numerical models do not prove adequate to provide the information required by the performance and design issues, then the original conceptual model will be revised or expanded.

A principal strategy of the study, therefore, is to utilize approaches that minimize uncertainty in the values of the 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 and chemical properties are difficult to measure. As described below, however, the strategy of the study is to increase confidence by utilizing various methods for determining parameters not readily amenable to measurement or analysis, by testing hypotheses, and by developing acceptable models.

A major advantage to using various methods for determining parameters is that, in general, reliance is not placed on only one test to determine a value for a parameter. Some tests will provide only partial information, whereas others will provide extensive information necessary for determination of a hydrochemical parameter. By combining the analytical results and studying their relations, a greater understanding and confidence of any particular parameter can be achieved. For example, computation of travel times and residence times of pore and fracture water in the unsaturated zone will be assessed in many different ways by the hydrochemical tests. Tritium (^{3}H) analyses will be used to determine the residence time of pore and fracture water up to about 100 years; ^{14}C analyses will extend the determination range from 100 to 40,000 years; and ^{36}Cl analyses will yield dates from 40,000 to about 900,000 years.

Four relative-age scenarios will be tested:

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

(b) Relatively young (<1,000 years) pore water and relatively old (>5,000 years) fracture water, with most fractures air filled.

This unlikely situation implies that most of the flow is through the matrix network and that the fractures are poorly connected.

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

(d) General absence of fracture water, and the occurrence of relatively old (>5,000 years) pore water. This scenario implies that fractures are always dry, or the residence time of water entering the fracture system is extremely short, or that all water transported by fractures is drawn into the matrix by capillary action. Throughout the Geohydrology Program (8.3.1.2.2), work is ongoing to identify and differentiate among different flow scenarios.

In addition, if enough pore water can be extracted from unsaturated-rock samples (in excess of the amount required for hydrochemical testing, as described herein), pore-water samples will be sent to Los Alamos National Laboratory (LANL) where arrangements for $^{36}Cl/Cl$ ratio analyses will be made (8.3.1.2.2.2.1 [Chloride and Chlorine-36 measurement of percolation at Yucca Mountain]). The use of ^{36}Cl in this study is contingent upon successful results from the LANL work.

Because of the nonstandard nature of some of the tests, the possibility that one of these tests may fail in achieving the desired objectives is recognized. The use of various methods for determining parameters increases confidence that the failure or partial failure of one or more tests will not severely inhibit the ability of the characterization activities to provide the information required. In addition, prototype testing for site characterization, especially those related to characterization of the unsaturated zone, will be performed to increase confidence that test objectives will be achieved.

Several prototype tests will be undertaken prior to the hydrochemical analyses to design and validate methods of pore-water collection (the optimal rubble-size test, the dry coring of rubble test, and the pore-water extraction by triaxial and uniaxial compression tests). These tests are described in detail in Section 3.8 of Study 8.3.1.2.2.4 (Hydrochemistry tests in the exploratory-shaft facility). Triaxial and uniaxial compression tests are described in detail in Section 3 of this Study Plan.

The following sections (2.1.3.1 and 2.1.3.2) summarize the gaseous- and aqueous-phase sampling strategies.

2.1.3.1 Gaseous-phase sampling

Gas samples will be collected twice a year from ten to fifteen isolated intervals of each USW UZ borehole (UZ-1 through UZ-14) which were drilled under Study 8.3.1.2.2.3 (Characterization of percolation in the unsaturated-zone -- surface-based study), and from three isolated intervals of the seven radial boreholes in ES-1

as described in Study 8.3.1.2.2.4 (Characterization of Yucca Mountain percolation in the unsaturated-zone -- exploratory-shaft-facility study). In addition, a movable, inflatable multi-packer system will be used to collect gas samples from open boreholes. These include two multipurpose boreholes (USW MP-1 and MP-2), twelve Sandia boreholes (USW SD-1 through SD-8, UE-25 SD-9, USW SD-1 through SD-12), twelve Fortymile-Wash boreholes (UE-25 FM#1 through FM#3, FMN#1 through FMN#9), two unsaturated-zone prototype boreholes (UE-25 UZP#1 and UZP#2), and eight water-table boreholes (USW WT- and UE-25 WT-holes). All open boreholes will be checked for air contamination (test for gas tracer SF_6) before sample collection and capped and sealed after completion of sampling to prevent air from penetrating into the hole.

Also during the ES-1 construction, a small one meter-deep horizontal hole will be drilled or jack hammered into the shaft wall immediately after mining and gas samples collected for compositional analysis (see Activity 8.3.1.2.2.4.8 [Hydrochemistry tests in the exploratory-shaft-facility]). These results will be compared with the radial borehole gas samples collected at a later date. The purpose is to check the effects of atmospheric-air contamination in the radial boreholes resulting from exposure of open boreholes for 4 to 6 months before stemming of the holes.

As the gas samples are analyzed for their compositions from borehole to borehole, spatial variations will become clearer, and a decision will be made as to the needs for sampling all holes mentioned above or a select number of holes.

2.1.3.2 Aqueous-phase sampling

Core samples for pore water extractions will be collected from all air-drilled boreholes: unsaturated-zone prototype boreholes (UE-25 UZP#1 and UZP#2); unsaturated-zone boreholes (USW UZ-1 through UZ-14); Sandia boreholes (USW SD-1 through SD-8, UE-25 SD-9, USW SD-10 through SD-12); multipurpose boreholes (USW MP-1 and MP-2); paleohydrologic holes (UE-25 PH-1A and PH-1B); Solitario Canyon horizontal hole (SCH#1, 305-m- [1,000-ft-] deep); water-table boreholes (USW WT-8 and WT-9, UE-25 WT-19 and WT-20, USW WT-21 through WT-24); geologic holes (USW G-5 and G-6, UE-25 G-7); and Fortymile-Wash boreholes (UE-25 FM#1 through FM#3; FMN#1 through FMN#9). Most of the borehole depths are more than 305 m (1,000 ft), except for PH, FM, FMN, and some UZ holes.

In general, core samples will be collected from each borehole according to Table 2.1-2. Borehole locations are depicted in Figures 1.2-2 and 1.2-3. Approximately fifty boreholes are planned to be sampled at Yucca Mountain, areally distributed from north to south, and east to west. In addition, Fortymile-Wash boreholes will be sampled and analyzed to determined the source of recharge to ground water beneath Yucca Mountain. Stratigraphically, all lithologic units are to be sampled, with more frequent core samples for non-welded tuff than for welded tuff. Also, contacts between different lithologic units are likely candidates to transport moisture laterally according to the conceptual hydrologic model

Table 2.1-2. Sampling scheme from different lithologic units for each borehole.

Lithologic Unit	Sample Frequency	Sample Number
Upper lithologic units (approximately 91 m [300 ft]), Tiva, bedded, Yucca Mountain, Pah Canyon	.30 m (1 ft) core sample/every 1.5 m (5 ft)	≈60 samples
Topopah Spring units (approximately 274 m [900 ft])	.30 m (1 ft) core sample/every 15.2 m (50 ft)	≈20
Tuffaceous beds of Calico Hills (approximately 46 m [150 ft]) upper portion of Calico Hills	.30 m (1 ft) core sample/every 3 m (10 ft)	≈25
Contact between the units, sampling .30 m (1 ft) above and below the contacts and including contact (3 ft/sample)	.30 m (1 ft) core sample/contact	≈10
Perched water zone wherever encountered	1 water sample/zone	≈5
	Total	≈120 samples/borehole

(Montazer and Wilson, 1984). Therefore, sampling of cores from these units are planned.

As the isotopic and chemical compositions of the pore water from each borehole are analyzed, spatial variations will become apparent, and a decision will be made as to the needs for sampling all holes mentioned above or a select number of holes.

Collection of matrix pore water can be accomplished by squeezing non-fractured drill cores. However, for the collection of fracture waters, depending on the size of a particular fracture aperture, different methods of sampling will be attempted. For small fractures (i.e., a hair-line crack to .2-cm- [.08-in.-] aperture) samples will be collected by chiseling tuff materials away from both sides of the fracture (about 2-cm- [.8-in.-] deep into the matrix), and water collected by high-speed centrifugation. The isotopic and chemical data of these waters can be compared with the matrix water obtained from nearby cores. For large fractures (i.e., greater than .2-cm- [.08-in.-] aperture), only field sampling is possible. The fracture locations inside the boreholes can be located by TV camera log and either lysimeter or other collection apparatus placed immediately beneath the fracture inside the hole for water collection. This fracture-water collection can only be done at open boreholes which include the Sandia, Fortymile-Wash and water-table boreholes.

Furthermore, hydrochemical testing at the exploratory-shaft-facility (underground) will provide more accessible areas for sampling fracture versus matrix water. These areas include the horizontal radial boreholes, underground breakout room, and main test level (large room) (see Activity 8.3.1.2.2.4.8 [Hydrochemistry tests in the exploratory-shaft-facility]).

2.1.4 Hydrologic hypotheses

The unsaturated-zone hydrologic hypotheses describe in general terms the manner in which water and gases move through the unsaturated zone, including the directions and paths of gas and liquid flow. Data concerning of the inorganic and isotopic chemistry of the water will provide a logical and systematic approach to improving our understanding of how the gas-hydrologic system functions, the result being an improved conceptual model which, in turn, leads to increased confidence in the geohydrologic program (Figure 2.1-2). The hypothesis component shown in Figure 2.1-2 is tied to Table 2.1-3, which lists pertinent hypotheses for the unsaturated zone. The table also shows objectives and approaches of the activities that are directly involved in testing these hypotheses.

2.1.5 Geohydrologic model

Development of appropriate models for unsaturated flow will be part of this study (8.3.1.2.2.7) and can be incorporated with Activity 8.3.1.2.2.8.1 (Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock). The successful development of calibrated and validated numerical models of the gas-hydrologic system

Table 2.1-3. Relations between Quaternary regional hydrology hypotheses and the objectives of the activities of this Study (SCP Study 8.3.1.2.2.7)

Hypothesis	SCP number	Activity objectives
Temperature-driven or barometrically-driven moisture flow can occur as water vapor, especially within the interconnected fractures of the Topopah Spring welded (TSw) unit	8.3.1.2.2.7.1	To understand the nature of the gas-transport processes within the unsaturated zone and to provide independent evidence of flow directions and flux of gas. The approach will be to analyze gas samples taken from surface-based boreholes.
Flow in the TSw is vertical and occurs under steady-state conditions. Flow is primarily in the matrix when the flux is less than some value related to the saturated matrix hydraulic conductivity, and flow is primarily in the fractures at flux higher than that value.	8.3.1.2.2.7.2	To determine the flow direction, flux, and travel time of liquid water using isotope-geochemistry techniques. The approach will be to analyze water samples from fractures and matrix in cores taken during drilling of surface-based boreholes.

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.

The geohydrologic model will consist of two hydrologic models that will describe two distinct zones of the hydrologic system; the unsaturated zone and the saturated zone (Figure 2.1-2). In turn, the unsaturated zone and the upper portion of the saturated zone of Yucca Mountain have been divided into three major depth intervals to facilitate site-characterization studies. The very thick unsaturated interval of percolation is bounded above by the interval of infiltration, or upper flux boundary, and below by a saturated or nearly saturated interval of recharge at the water table. Data from each of these intervals will be used in formulating the unsaturated- and saturated-zone models. Study 8.3.1.2.2.7 (Hydrochemical characterization of the unsaturated zone) will use similar data as Study 8.3.1.2.3.2 (Characterization of saturated-zone hydrochemistry). The hydrochemistry study, and corresponding models, concentrate on the entire unsaturated zone (infiltration boundary and interval of percolation) above the saturated zone. A surface-water hydrologic model will, in addition, be developed to provide input to the other two hydrologic models as they are also impacted by surface water.

The hydrologic models will be used at many stages to perform preliminary analyses, to design and analyze tests and experiments, and to analyze and interpret data. 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 guide data collection further.

Gas-phase modeling, as described in Study 8.3.1.2.2.8 (Fluid flow in unsaturated, fractured rock), will be used to interpret the results of observations made during this study, and to extrapolate those results to interpret gas circulation beneath Yucca Mountain under natural conditions. Gaseous-phase chemical data resulting from the activities described in this study will be directly incorporated into the gas-phase modeling. Similarly, aqueous-hydrochemistry data will be used to model the hydrologic conceptual flow of the unsaturated-zone ground water at Yucca Mountain, as well as modeling the geochemical evolution of unsaturated-zone ground water. In addition, it will provide data for other studies such as Study 8.3.1.3.1.1 (Ground-water chemistry model).

Preliminary conceptual models of the present unsaturated-zone hydrologic system have been developed by Montazer and Wilson (1984), Klavetter and Peters (1985), and Wang and Narasimhan (1985). These models are fundamentally similar and are based on general unsaturated-flow principles, some preliminary data, and a basic knowledge of the geologic framework at Yucca Mountain. More recently, Yang and Thorstenson (1989) developed a hydrologic conceptual model based on isotopic and hydrochemical data from the unsaturated zone. Additional

data are necessary to test these models as well as the alternative conceptual models.

In summary, hydrologic modeling produces the velocity field essential for defining flow paths and computing radionuclide-migration time. Such modeling requires sufficiently detailed knowledge of the geohydrologic framework and is dependent on hydrochemical parameters determined by the hydrochemistry analyses. The importance of the hydrochemistry analyses for determining the magnitude and distribution of hydrochemical parameters is emphasized. Hydrologic and hydrochemical testing of surface-based and ESF boreholes, and analysis of their spatial distributions with regard to these parameters will produce the data base necessary to characterize the hydrology of the unsaturated zone. Ultimately, this will lead to the development of an unsaturated-zone model and to the geohydrologic modeling of the repository block under Yucca Mountain.

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

The unsaturated-zone hydrochemistry analysis is located within the repository area. The surface-based boreholes and the ESF, from which gas and liquid samples will be collected, penetrate some of the same geohydrologic units as does the repository. Thus, the environment from which samples for hydrochemical analyses will be collected is an approximate representation of the repository block. How well each analysis will represent past, present, or future conditions of the repository block at the scale of the repository depends on a number of factors relating to the particulars of the analysis.

2.2.2 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 estimated precision and accuracy, duration, and interference with other tests and other analyses. Methods designated as alternate will be employed only if selected methods for obtaining similar information are inadequate. The accuracy and precision of the analyses are shown in Table 2.2-1. The estimated degree of accuracy and/or precision of each analytical method is based on information from analytical laboratories.

2.2.3 Potential impacts of activities on site

The analytical activities described in this study plan will have little or no impact on the natural-state site conditions, and no adverse effect on the ability of Yucca Mountain to isolate waste. The proposed work should not affect the site in terms of either exploratory shaft or repository design, nor will the study require any permitting or environmental analysis at Yucca Mountain. The planned work for Activities 8.3.1.2.2.7.1 and 8.3.1.2.2.7.2 does include extensive sampling from unsaturated-zone boreholes. The impacts of drilling into the repository block, however, are not within the scope of this study and are addressed in detail in 8.3.1.2.2.3 (Characterization of percolation in the unsaturated zone -- surface-based study), and Section 8.4 of the SCP. Basically, analysis of impacts on site performance from drilling, testing, stemming, and monitoring of boreholes can be reduced to two significant concerns which include (1) limiting the number and location of boreholes needed for site characterization, and (2) preserving the capability to seal the holes effectively, as necessary, at the time of repository closure.

2.2.4 Time required versus time available

The hydrochemical analyses described in this study plan are constrained by the schedule of the start and completion of ES-1 and the drilling and stemming of surface-based boreholes. Section 5.1 describes a proposed schedule for the gaseous- and aqueous-phase investigations described in Section 3.

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests

Parameter	Analytical Procedure	Performed By	Selected or Alternate	Standard or Non-Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
ISOTOPES								
^{14}C	LSC	Geochron	S	S	> 0.5 L	1 to 40 K yrs	500 yrs, 3%	T, JJ
	TAMS	U of A	A	NS	< 0.5 L	1 to 40 K yrs	2 K yrs, 5%	U, JJ
$^{13}C/^{12}C$	NS	USGS, GD (Threikeld)	S	NS	> 0.2 L	-7 to -28 ‰	±0.2 ‰, ±0.2 ‰	
^{3}H	LSC	USGS, WRD (Michaels)	S	NS	10 ml	0 to 150 yrs	8 TU, 10%	T
^{36}Cl					200 mg Cl	40 to 900 K yrs	10 K yrs, 10%	
^{39}Ar						150 to 1000 yrs	100 yrs, 15%	X
^{85}Kr		USGS, WRD (Michaels)			> 120 kG	0 to 40 yrs		X
$^{18}O/^{16}O$	NS	USGS, WRD (Michaels)	S	S	2 ml	0 to -20 ‰	±0.2 ‰, ±0.2 ‰	V
D/H	NS	USGS, WRD (Michaels)	S	S	2 ml	0 to -200 ‰	±1 ‰, ±1 ‰	V
$^{3}He/^{4}He$	NS		A	S				W

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests (continued)

Parameter	Analytical Procedure	Performed By	Selected or Alternate	Standard or Non-Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
GAS								
Freon 11/12	GC- ECD	Project	S	S	5 cc	0 to 600 ppb	20 ppb, 3%	FF, R, S
CO_2	GC- FID	Project	S	S	5 cc	0 to 2%	.01%, 3%	FF, R, S
SF_6	GC- ECD	Project	S	S	5 cc	0 to 3 ppm	.01 ppm, 3%	FF, R, S
CH_4	GC- FID	Project	S	S	5 cc	0 to 5 ppm	.03 ppm, 3%	FF, R, S
Argon	GC- TCD	Project	S	S	5 cc	.5 to 1.5%	.01%, 3%	FF, R, S
Oxygen	GC- TCD	Project	S	S	5 cc	15 to 25%	.1%, 3%	FF, R, S
Nitrogen	GC- TCD	Project	S	S	5 cc	75 to 85%	.1%, 3%	FF, R, S
Hydrogen	GC- HD	Project	S	S	5 cc	0 to 5 ppm	.03 ppm, 3%	FF, R, S
Ethane	GC- FID	Project	S	S	5 cc	0 to 1 ppm	.01 ppm, 3%	FF, R, S
Ethylene	GC- FID	Project	S	S	5 cc	0 to 1 ppm	.01 ppm, 3%	FF, R, S

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests (continued)

Parameter	Analytical Procedure	Performed By	Selected or Alternate	Standard or Non-Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
WATER								
Calcium	ICP	RMAL	S	S	1 ml	0 to 120 mg/L	98%, 0.5	D
	AA	USGS, WRD	A	S	10 ml	"	, 8%	A,B,C,D ,G
Magnesium	ICP	RMAL	S	S	1 ml	0 to 20 mg/L	94%, 0.4	D
	AA	USGS, WRD	A	S	10 ml	"	, 7%	A,B,C,D ,G
Sodium	ICP	RMAL	S	S	1 ml	0 to 130 mg/L	98%, 0.2	D
	AA	USGS, WRD	A	S	10 ml	"	, 9%	A,B,C,D ,G
Potasium	ICP	RMAL	S	S	1 ml	5 to 30 mg/L	97%, 0.1	D
	AA	USGS, WRD	A	S	10 ml	"	, 10%	A,B,C,D ,G
Sulfate	IC	RMAL	S	S	.5 ml	10 to 160 mg/L	103%, 0.5	A,D
	C	USGS, WRD	A	S	10 ml	"	, 7%	F,G
Chloride	IC	RMAL	S	S	.5 ml	10 to 120 mg/L	99%, 1.0	A,D
	C	USGS, WRD	A	S	10 ml	"	, 4%	H,G
	T	USGS, WRD	A	S	10 ml	"	, 5%	I,G
	ISE	Project	A	S	10 ml	"	, 2 mv	HH
						"		
Silica	ICP	RMAL	S	S	1 ml	60 to 100 mg/L	, 12%	D
	C	USGS, WRD	A	S	10 ml	"	, 5%	B,G
	DCP	USGS, WRD	S	S	10 ml	"		KK
Manganese	ICP	RMAL	S	S	1 ml	0 to 100 ug/L	101%, 2.0	D
	AA	USGS, WRD	A	S	10 ml	"	, 8%	A,B,C,D ,G

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests (continued)

Parameter	Analytical Procedure	Performed By	Selected or Alternate	Standard or Non-Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
WATER (CONT.)								
Iron	ICP	RMAL	S	S	1 ml	0 to 10 mg/L	107%, 0.9	D
	AA	USGS, WRD	A	S	10 ml	"	, 10%	A,B,C,D ,G
Aluminum	ICP	RMAL	S	S	1 ml	1 to 10 mg/L	95%, 0.8	D
	AA	USGS, WRD	A	S	10 ml	"	, 17%	A,B,C,D
	DCP	USGS, WRD	S	S	10 ml	"	, 5%	,G KK
Rare earth	ICP/MS	RMAL	A	MS	2 ml	?	?	II
Lithium	AA	USGS, WRD	A	S	10 ml	0 to 20 ug/L	, 15%	C,G
Bromide	IC-D	RMAL	S	S	1 ml	.1 to .5 mg/L	93%, 0.8	D
	IECE	USGS, WRD	A	S	1 ml	"	, 2%	G,K
	ISE	Project	S	S	10 ml	"	, 4 mv	HH
Iodide	C	USGS, WRD	A	S	3 ml	0 to 20 ug/L	, 70%	G,L
	ISE	Project	S	S	10 ml	"	, 4 mv	
Nitrate	IC	RMAL	S	S	1 ml	1 to 10 mg/L	102%, 0.0	D
Boron	DCP	USGS, WRD	S	S	10 ml	0 to 20 ug/L	, 5%	KK
	C	USGS, WRD	A	S	10 ml	"	, 18%	G,N
	IC	Project	A	S	2 ml	"	?	D
	ISE	Project	A	S	10 ml	"	, 3 mv	HH
Organo-metallics	GC/MS	RMAL	A	S	3 ml	?	?	J

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests (continued)

Parameter	Analytical Procedure	Performed By	Selected or Alternate	Standard or Non-Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
WATER (CONT.)								
pH	E	Project	S	S	.2 ml	5 to 9 pH	0.1, 0.1	O,G
SC	E	Project	S	S	.5 ml	200 to 900 uS	, 4%	P,G
Alkalinity as $CaCO_3$	ET	RMAL	S	S	.5 ml	40 to 200 mg/L	96%, 1.2	D
	ET	USGS	A	S	5 ml	"	, 12%	O,G
Alkalinity as HCO_3	DIC-D	USGS, WRD	A	NS	2 ml	40 to 200 mg/L	, 7%	
Temperature	GT	Project	A	S	5 ml	10 to 40 C	3 C, 3%	
	DT	Project	S	S	.5 ml	"	3 C, 3%	

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests (continued)

Parameter	Analytical Procedure	Performed By	Selected or Alternate	Standard or Non-Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
ROCK								
Moisture Contents	Oven Dry	Project	S	S	100g	0 to 40%	, 0.5%	AA
	Distillation	Project	A	S	100 g	0 to 40%	, 0.5%	AA
Mineralogy	Microscopy Thin Sections	Crystal	S	S	2mm X 2mm	NA	95%, 5%	BB
	Grains	N & N	A	S	2mm X 2mm	NA	95%, 5%	BB
	Electron Microprobe	USGS, GD	A	S	1 cubic um	NA	95%, 5%	CC
	X-ray diffraction	USGS, GD	A	S	150 mg	NA	90%, 5%	DD
CEC	Ammonium Displacement	USGS, GD	A	S	100 g	?	90%, 5%	GG
Porosity	Calculated	Project	S	S	NA	10 to 60%	96%, 5%	EE
	Gas Pycnometer	N & N Core Labs	A	S	100 cubic cm	10 to 60%	97%, 3%	EE
Pore Size	Mercury Injection	Surtek	S	S	2 cubic cm	.05 u to 2 mm	, .1 u	EE
	Water Desorption	USGS, GD	A	S	100 g	.05 u to 2 mm	95%, 3%	EE

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests (continued)

ABBREVIATIONS USED IN TABLE

A - ALTERNATE
AA - ATOMIC ABSORPTION
C - COLORIMETRIC
CED - CATION EXCHANGE CAPACITY
DCP - DIRECT CURRENT PLASMA SPECTROMETRY
DIC-D - DISSOLVED INORGANIC CARBON - DOWRMAN
DT - DIGITAL THERMOCOUPLE
ECD - ELECTRON CAPTURE DETECTOR
ET - ELECTROMETRIC TITRATION
FID - FLAME IONIZATION DETECTOR
GC - GAS CHROMATOGRAPHY
GD - GEOLOGIC DIVISION
GT - GLASS THERMOMETER
IC-D - ION CHROMATOGRAPH - DIONEX
ICP - INDUCTIVELY COUPLED PLASMA
IECE - ION EXCHANGE CHROMATOGRAPHIC ELECTROCHEMICAL
ISE - ION SELECTIVE ELECTRODE
LSC - LIQUID SCINTILLATION COUNTER
mg - MILLIGRAM
MS - MASS SPECTROMETRY
NA - NOT APPLICABLE
NS - NON STANDARD
RMAL - ROCKY MOUNTAIN ANALYTICAL LABS
S - STANDARD OR SELECTED
SC - SPECIFIC CONDUCTANCE
T - TITRIMETRIC
TAMS - TANDEM ACCELERATOR MASS SPECTROMETRY
TCD - THERMAL CONDUCTIVITY DETECTOR
TU - TRITIUM UNITS
USGS - UNITED STATES GEOLOGICAL SURVEY
WRD - WATER RESOURCES DIVISION
u - MICRON
ug - MICROGRAM

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests (continued)

REFERENCES

A - American Public Health Association and others, 1980
B - American Society for Testing and Materials, 1978
C - Fishman and Bradford, 1982
D - U.S. Environmental Protection Agency, 1979
E - Faires and Boswell, 1981
F - Colovos and others, 1976
G - Fishman and Friedman, 1985
H - O'Brien, 1962
I - Clark, 1950
J - U.S. Environmental Protection Agency, 1983
K - Fishman and Pyen, 1979
L - Mitchell, 1966
M - Johnson and others, 1979
N - Spencer and Erdmann, 1979
O - Durst, 1969
P - Hughes, 1966
Q - Barnes, 1964
R - Fritz and Schenk, 1976
S - Pecsok and others, 1976
T - International Atomic Energy Agency, 1967
U - Donahue and others, 1984
V - Hoefs, 1987
W - Damon and Green, 1963
X - Lippolt and Gentner, 1963
AA - Gardner, 1986
BB - Cady and others, 1986
CC - Sawhney, 1986
DD - Whittig and Allardice, 1986
EE - Danielson and Sutherland, 1986
FF - Peters, 1988
GG - Chapman, 1965
HH - Sekeykra and Lechner, 1973
II - U.S. Environmental Protection Agency, 1986
JJ - Yang, 1988
KK - Keirs and Vickers, 1977

* Complete references appear in Section 6.

Table 2.2-1. Summary of procedures for analysis of parameters for the unsaturated-zone hydrochemistry tests (continued)

LABORATORIES - QA

The accuracy number is shown first in the table followed by a comma and then the precision number. When there is no information available from a laboratory for either number, a space is left either before or after the comma.

GEOCHRON - Precision is reported for each ^{14}C analysis performed and is reported as +/-% of modern carbon. The number shown on the table is the highest reported in the last year of analysis. The accuracy is also determined for each analysis performed and is reported as +/- years. The number in the table is the highest reported in the last year of analysis.

USGS, GD (Threlkeld) - TBD

USGS, WRD (Michaels) - TBD

ROCKY MOUNTAIN ANALYTICAL LABS - Control limits for accuracy are based on the average, historical percent recovery +/- 3 standard deviation units. Control limits for precision range from 0 to the average, historical relative percent difference + 3 standard deviation units. These control limits are fairly narrow based on the consistency of the matrix being monitored and are updated on a quarterly basis.

Accuracy for LCS is measured by Percent Recovery.

$$\%\ \text{Recovery} = \frac{\text{Measured Concentration}}{\text{Actual Concentration}} \times 100$$

Precision for LCS is measured by Relative Percent Difference (RPD).

$$\text{RPD} = \frac{\text{Measured Concentration LCS1} - \text{Measured Concentration LCS2}}{(\text{Measured Concentration LCS1} + \text{Measured Concentration LCS2})/2}$$

USGS, WRD (CENTRAL LAB) - No accuracy numbers are reported by the central laboratory. Precisions are expressed in terms of the percent relative standard deviation, the ratio of the standard deviation to the means times 100 percent.

2.2.5 Interference

There are no known interferences between this study and other studies within the site characterization plan. However, this study is dependent on the drilling and stemming of drillholes at Yucca Mountain (see Figure 5.2-1) which will provide core samples for aqueous-phase chemical investigations and access for unsaturated-zone gaseous sampling.

Interferences between boreholes is discussed in detail in Study 8.3.1.2.2.3 (Characterization of percolation in the unsaturated zone -- surface-based study), and Section 8.4 of the SCP. For clustered boreholes, drilling and testing during construction are likely to have some effect on the region of the rock mass which either contains or will contain another borehole, thereby affecting measurements of *in situ* moisture potential. Interference between widely spaced boreholes might involve some combination of separated unsaturated-zone boreholes, the boreholes of the systematic drilling program, the exploratory shaft, or any of the existing boreholes at Yucca Mountain. The concern is that boreholes left uncased, and especially those open to the atmosphere, will perturb the pneumatic potential field and pore-gas composition over a large region. As discussed in Section 8.4.2.2.3 of the SCP, however, all boreholes at the site will be shut in most of the time after drilling to control interference with borehole monitoring activities. The pre-waste emplacement gaseous flow field, identification of structural controls, and evaluation of air circulation in the repository block from open boreholes will be discussed in Study 8.3.1.2.2.6 (Characterization of gaseous-phase movement in the unsaturated zone).

Aqueous samples extracted during the hydrochemistry study will be provided to LANL for ^{36}Cl analyses as described in Study 8.3.1.2.2.2 (Water-movement tracer tests using chloride and chlorine-36 measurements of percolation at Yucca Mountain). There are no anticipated interferences between the sampling needs of these two studies for hydrochemical analyses. Similarly, sampling needs of other studies for unsaturated-zone core is being coordinated by a sampling overview committee to ensure that there is no interference between sampling requirements.

3 DESCRIPTION OF ACTIVITIES

The study is organized into two activities:

- o 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations; and
- o 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations.

The plans for these activities are described in Sections 3.1 and 3.2.

3.1 Gaseous-phase chemical investigations

3.1.1 Objectives of activity

The objectives of this activity are:

1. to understand the gas-transport mechanism; and

2. to provide evidence of gas-flow direction, flux, and travel time within the unsaturated zone.

3.1.2 Rationale for activity selection

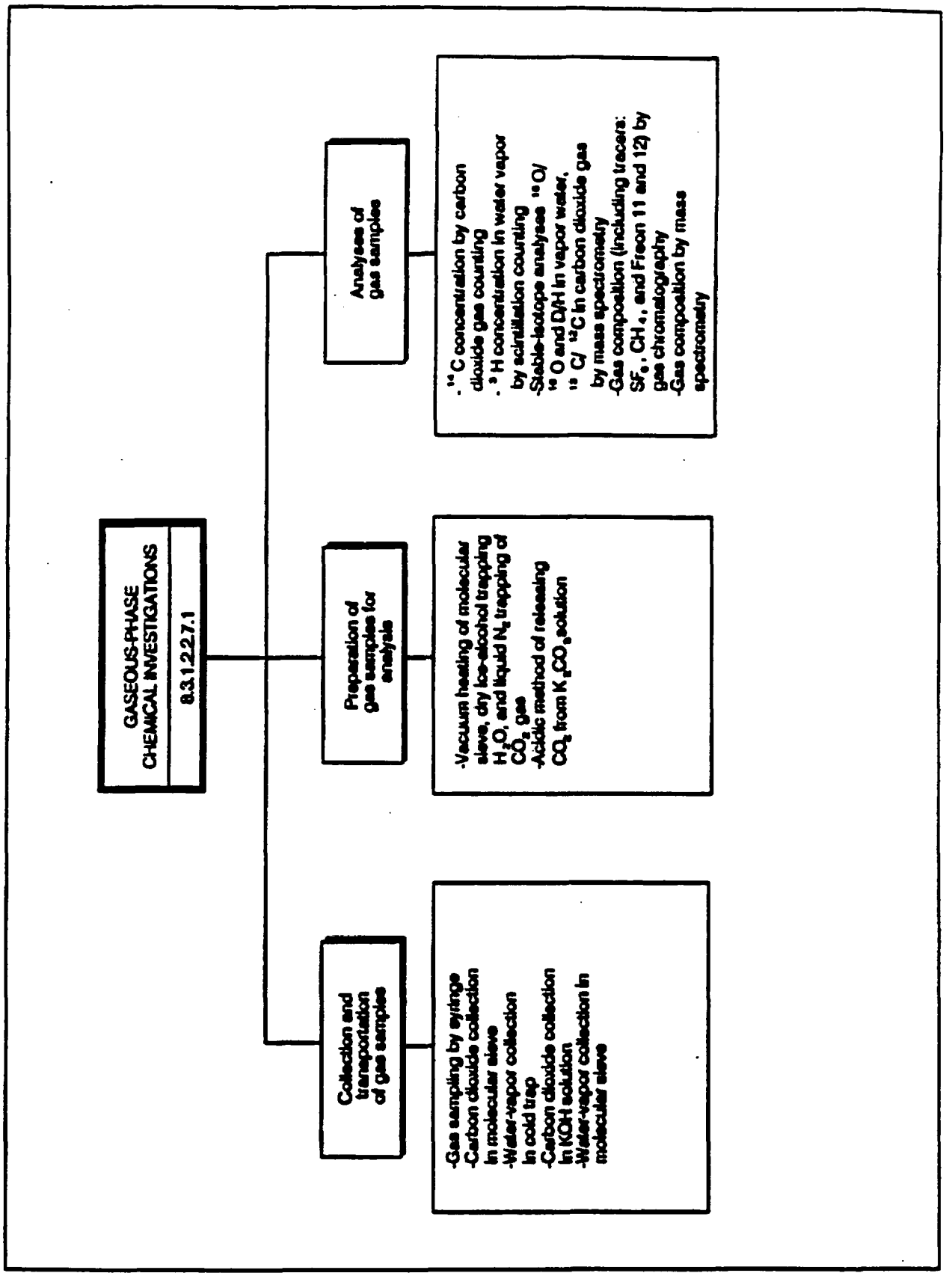
A study of unsaturated-zone chemistry and distribution of gases will help evaluate chemical transport and flow processes within the repository block. ^{14}C and tritium concentration measurements will determine the residence time of gases in the unsaturated zone. $^{13}C/^{12}C$ isotopic data will also be used in support of ^{14}C age estimates. Stable-isotope ratios ($^{18}O/^{16}O$ 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.

3.1.3 General approach and summary of tests and analyses

The gaseous-phase chemical investigations are designed to collect gas samples from isolated sampling stations installed in unsaturated-zone, surface-based boreholes, and from vertical and radial boreholes in the ESF. Collection of gas samples from the unsaturated-zone holes will be performed in open boreholes after drilling and in instrumented boreholes after stemming. Open-borehole gas will be sampled using a downhole packer system. In the ESF, gas samples will be collected during the construction phase from small (1- to 2-m- [3- to 6-ft-] long) horizontal boreholes located at the same horizon as radial boreholes. Post-construction-phase sampling will be from drilled and stemmed radial boreholes. A detailed discussion of hydrochemical sampling in the ES-1 is provided in Section 3.8 of Study Plan 8.3.1.2.2.4 (Characterization of Yucca Mountain percolation in the unsaturated-zone -- exploratory-shaft-facility study).

Four different types of gas samples will be collected including gas-composition, $^{13}C/^{12}C$ ratio, ^{14}C, and water-vapor samples. To guarantee the integrity of the samples, they will be collected and transported by techniques appropriate to ensure accurate collection and transportation (see Section 3.1.3.1).

Figure 3.1-1 summarizes the organization of the gaseous-phase chemical investigations. A descriptive heading for each analysis appears in the shadowed boxes of the second row. Below each analysis are the individual methods that will be utilized. Figure 3.1-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed analysis boxes, respectively.



F(ı 3.1-1. Logic diagram of the gaseous-phase ch(ıl investigations showing tests, analyses, and met

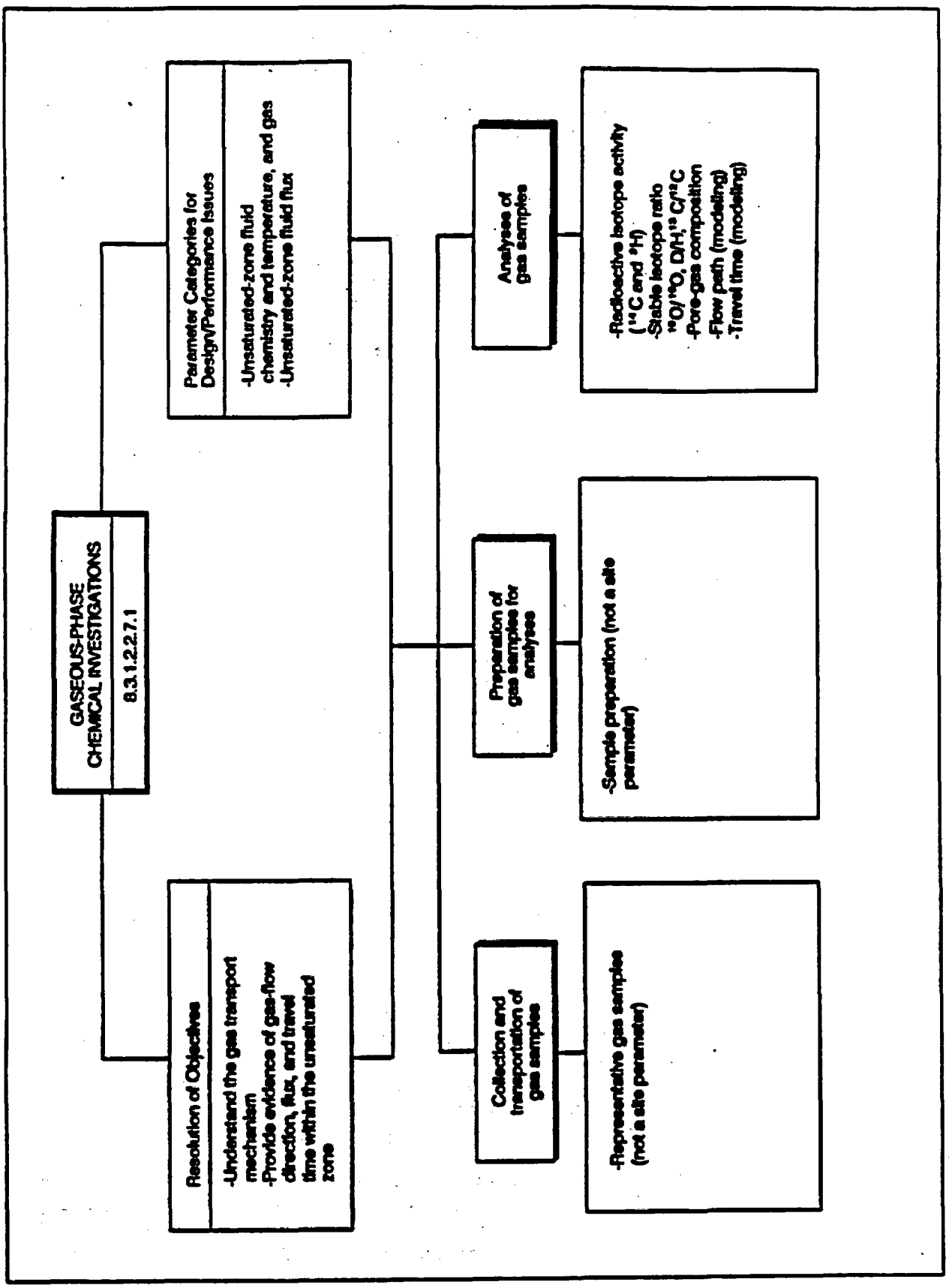


Figure 3.1-2. Logic diagram of the gaseous-phase chemical investigations showing tests, analyses, and site parameters.

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

The following sections describe tests to be conducted as a part of the gaseous-phase chemical investigations. Each test and analysis has one or more procedures associated with it (Table 3.1-1 in Section 3.1.3.4). The table includes procedures selected for site characterization as well as alternate procedures that were considered but are not currently planned to be implemented. In some cases, many approaches are available for conducting the analyses. In these cases, only the most common procedures are included in the table.

3.1.3.1 Collection and transportation of samples

Gas samples will be extracted from packer intervals of surface-based boreholes that are drilled under Study 8.3.1.2.2.3 (Characterization of Yucca Mountain percolation in the unsaturated-zone -- surface-based study), and from packer intervals of the radial boreholes in ES-1 as described in Study 8.3.1.2.2.4 (Characterization of Yucca Mountain percolation in the unsaturated-zone -- exploratory-shaft-facility study). Four types of gas samples will be collected from surface-based and radial boreholes including (1) gas composition, (2) $^{13}C/^{12}C$ ratio, (3) ^{14}C, and (4) water vapor samples. Sampling tubes will be pumped overnight before sample collection to purge the tubes of any atmospheric air that might have been introduced while connecting the pumps to the system. Extended pumping and collection times decrease knowledge of the precise location of sample recovery. Then data will be used to evaluate the drilling effect and equilibration time. Available information suggests that this does not cause a problem with interpretation, however, there are plans to test the validity of this assumption using tracer gases applied to surrounding intervals. During sample collection, the sample gas will be pumped at a flow rate of 500 milliliters per minute (see Figure 3.1-3 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 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. Analysis will be made for CO_2, CH_4, Ar, N_2, H_2, O_2, SF_6, Fr, and BFC.

2. $^{13}C/^{12}C$ 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. Isotope fractionation is not a concern with the large sample sizes available. This has been

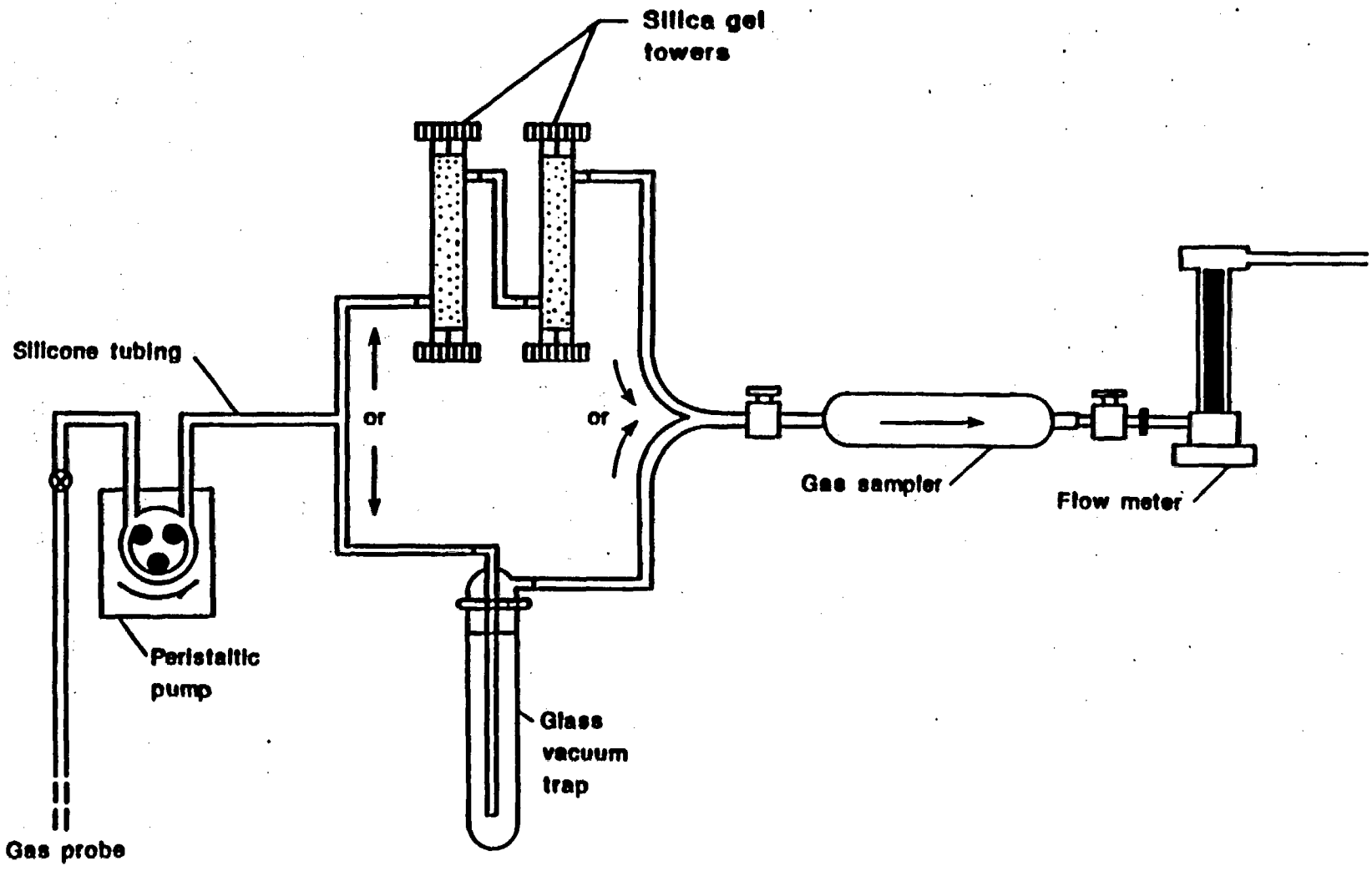


Figure 3.1-3. Schematic of apparatus for on-site, soil-gas collection for gaseous-phase chemical investigations.

verified by prototype testing. The second method involves allowing the gas to flow into a 250- ml flow-through glass container.

3. ^{14}C samples -- two methods will be used for ^{14}C sample collection. The first method employs a 5Å molecular sieve as discussed 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) (Haas and others, 1983).

4. Water-vapor samples -- two methods will be used. The first method, cold trap, involves pumping the gas through a gas trap cooled by a dry-ice-alcohol slurry to remove the water vapor. The efficiency of the trap will be evaluated during prototype testing. If the cold trap method does not prove satisfactory, it will be revised or rejected as necessary. The second method uses a 5Å molecular sieve similar to the method discussed above. Samples will be analyzed for tritium, D/H, and $^{18}O/^{16}O$.

To transport the samples, ^{14}C- and ^{13}C-/^{12}C-ratio samples will be packed in a cardboard box and mailed from the field to the Denver Federal Center laboratory for processing. Gas-composition syringe samples require no transportation because they are analyzed in the field. Condensed water-vapor samples (in vials) will be hand-carried to Denver.

Gas-composition sampling by syringe is preferred over collection in a flow-through cylinder; the syringe method is easier and allows the sample to be injected directly from the syringe into a gas chromatograph for analysis. $^{13}C/^{12}C$ sampling uses both molecular-sieve and collection in a flow-through cylinder method because it is important to check by both methods. The principal advantage of the molecular-sieve method of ^{14}C sampling over the potassium hydroxide (KOH) method is its simple design and ensured, nonbreakable transport between the sampling site and the laboratory. Water-vapor sampling using a cold trap is preferred over collection by silica-gel tower or molecular sieve. During degas heating of the water vapor from the silica gel or molecular sieve, oxygen atoms in the vapor exchange with oxygen atoms in the silicate minerals of the silica gel and molecular sieve, causing errors in oxygen-isotope measurements; the cold-trap method does not have this problem.

3.1.3.2 Preparation of samples for analyses

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

cooled to -78 °C by a dry ice-alcohol slurry, collecting the CO_2 as a solid in a cold trap cooled by liquid nitrogen, and storing the CO_2 in a storage cylinder. A simplified diagram of the degassing system is shown in Figure 3.1-4. The KOH method of releasing the collected CO_2 is performed by acidifying the solution; the CO_2 evolved is then reacted with hydrogen gas, using ruthenium pellets as a catalyst in a pressurized converter to form methane (CH_4) gas for gas counting. Water vapor collected as described in Section 3.1.3.1 requires no further preparation. Also, sample sizes will be large enough to use nonstandard procedures during degassing.

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

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 carbon-dioxide solid ensures that all of the carbon dioxide has been trapped. This also can be checked by the installation of a thermocouple vacuum gage.

3.1.3.3 Analyses

All analyses will be conducted by existing qualified laboratories that have been approved by the USGS Quality Assurance Program. All gas and water-vapor samples will be checked for contamination from drilling fluids by using sulfur hexafluoride, SF_6, or a similar conservative-gas tracer which may have been introduced during air-coring of rubble cores or boreholes. Stable-isotope ratios ($^{18}O/^{16}O$, $^{13}C/^{12}C$, and D/H) will be analyzed using mass spectrometry. Gas counters will be used to determine tritium activity in water vapor. Large ^{14}C samples ($^{14}CO_2$ gas) will be analyzed using conventional gas-counting methods. Small ^{14}C samples will be analyzed by tandem accelerator mass spectrometry (TAMS). ^{39}Ar and ^{85}Kr will be separated out from other gases in the samples, processed, and measured by proportional counter. In addition, gas samples will be analyzed for the presence of tracers (SF_6, CH_4, freon, etc.), using gas chromatography (GC).

^{14}C and tritium concentration measurements are preferred over ^{39}Ar and ^{85}Kr. Because argon is a rare gas, whose natural concentration is very small, a very large volume of sample gas would be necessary for conventional gas counting which requires some type of gas-separation system. Such a system would be difficult to handle. Measurement of ^{14}C allows for a much smaller sample volume, because it can be measured by the TAMS. Furthermore, ^{39}Ar has an additional drawback in that it can also be produced by *in situ* neutron activation in the subsurface which may interfere with the

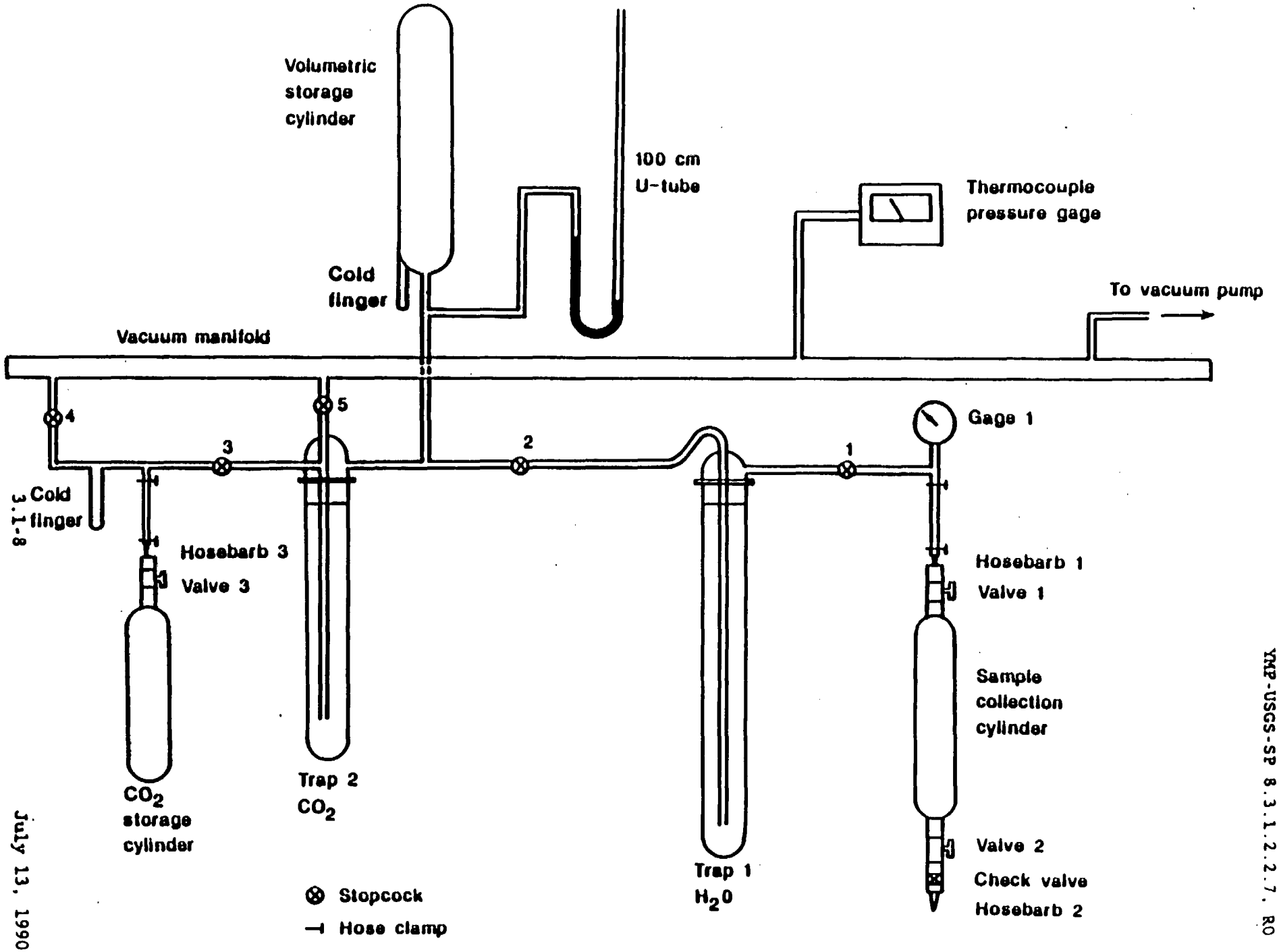


Figure 3.1-4. Schematic of degassing sy[illegible] for gaseous-phase chemical investigations.

measurement of cosmogenic ^{39}Ar. The feasibility of dating samples with ^{39}Ar and ^{85}Kr needs to be evaluated. Similarly, ^{222}Rn will be evaluated with other noble gases, and if appropriate will be studied at Yucca Mountain. ^{36}Cl, which is also likely to be formed *in situ* will be evaluated as well for the gas-phase studies. $^{18}O/^{16}O$, $^{13}C/^{12}C$, and D/H stable-isotope ratios are preferred over other stable-isotope ratios because more conventional methods are available, and standard analysis techniques already exist for these isotopes.

3.1.3.4 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.1-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be utilized only if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, there are many approaches to conducting the test. In those cases, only the most common methods are included in the tables. The selected methods in Table 3.1-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they feel are suitable to provide accurate data within the expected range of the site parameter. Models and analytical techniques have been or will be developed to be consistent with test results. The expected ranges of the site parameters have been bracketed by previous data collection and computer modeling and are shown in Table 3.1-1.

3.1.4 Technical procedures

The USGS quality-assurance program plan for the YMP (U.S. Geological Survey, 1986) requires documentation of technical procedures for all technical activities that require quality assurance. Applicable quality-assurance procedures are presented in Appendix 7.1.

Table 3.1-2 provides a complete tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS number (NWM-USGS-) and a procedure effective date. Procedures that require preparation do not have procedures numbers.

Procedures that are not identified with an effective date in the table will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Many of the needed technical procedures depend on the results of ongoing prototype testing and cannot be completed until work is done.

Table 3.1-1. Summary of tests and methods for the gaseous-phase chemical investigations (SCP Activity 8.3.1.2.2.7.1)
[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site parameter	Expected range
Analyses of gas samples		
Age dating of carbon dioxide gas samples using conventional gas counter (selected)	Radioactive-isotope activity	1,000 yr to 40,000 yr
Age dating by scintillation counting of ^{3}H in water vapor (selected)	"	Up to 150 yr
^{39}Ar dating of gas, ^{85}Kr dating of gas (alternate)	"	^{39}Ar - 150 to 1,000 yr ^{85}Kr - 0 to 40 yr
Stable-isotope analyses ($^{18}O/^{16}O$ and D/H in water vapor, $^{13}C/^{12}C$ in carbon dioxide gas) (selected)	Stable isotope ratio	$^{18}O/^{16}O$: 0 to -20 per mil D/H: 0 to -200 per mil $^{13}C/^{12}C$: -7 to -28 per mil
Gas composition (including tracers) by gas chromatography (selected)	Pore-gas composition	CO_2 - 0 to 2% CH_4 - 0 to 5 ppm H_2 - 0 to 5 ppm
Mass spectrometry (alternate)	"	"
Hydrochemical determination by sample analysis and modeling (selected)	Gas flow paths, gas travel times, hydrochemical determination	--
Hydrologic determination, other activities (alternate)	"	--

Table 3.1-2. Technical procedures for the gaseous-phase chemical investigation (SCP Activity 8.3.1.2.2.7.1)*

Technical procedure number (NWM-USGS-)	Technical procedure	Effective date
	Collection and transportation of gas samples	
HP-56,R1	Gas and vapor sampling from unsaturated-zone test holes	04/15/88
TBD	Field procedure for gas and water vapor sampling using a removable collection instrument	--
	Preparation of gas samples for analysis	
HP-86,R0	Method for degassing carbon dioxide and water (vapor) samples from unsaturated-zone test holes	05/16/88
	Analyses of gas samples	
HP-160,R0	Methods for analysis of samples for gas composition by gas chromatography	06/16/88

*Procedures not listed are in place and will be performed by certified external laboratories which have been approved by the USGS Quality Assurance Program.

Equipment requirements and instrument calibration are described in USGS 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.

3.2 Aqueous-phase chemical investigations

3.2.1 Objectives of the activity

The objectives of this activity are:

1. to design and implement methods for extracting pore water from unsaturated-zone tuff;

2. to obtain data that will be used to evaluate flow direction, flux, and travel time of water in the unsaturated zone;

3. to determine the extent of water/rock interaction; and

4. to model the geochemical evolution of water in the unsaturated zone.

3.2.2 Rationale for activity selection

Processes and conditions that may affect the precipitation, sorption, and mobility of radionuclides can be inferred from the inorganic composition of unsaturated-zone water. The chemistry of pore water reflects the results of water/rock interactions within the matrix of the rock, and the chemistry of fracture water reflects the results of chemical processes along the water/rock interface. Chemical parameters such as ionic strength and ranges of pH will provide information on solubility and reactivity of the natural geochemical environment beneath Yucca Mountain. Processes affecting the artificial environment of the engineered-barrier systems and the transport behavior of radionuclides leached from the waste package will be better understood and interpreted by studying the composition of unsaturated-zone water.

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 that the pore water may have come in contact with and the duration of this contact. The composition of fracture water may be useful in determining the degree of interconnectivity of the fractures. Some fractures may not extend over long distances and hence may not intersect major water pathways. The water composition in these fractures may be similar to adjacent pore water, which have had long periods of water/rock interaction. Water within interconnected fractures, however, probably has had relatively short residence times and should be relatively dilute compared with water from poorly interconnected fractures or surrounding matrix pore water. This 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, or periods of intense recharge at the land surface. Conversely, large solute concentrations at great depth and a large ^{14}C age of water would imply a slow travel time or overall minor recharge at the site.

Isotopic compositional 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 $HD^{16}O$; therefore, atmospheric water vapor is depleted in heavy isotopes relative to sea water. 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 precipitated water to be progressively lighter. As a result, precipitation is lighter farther inland, higher in the mountains, and toward both poles. There is also an "amount effect" on isotopic composition of precipitation in that a heavy rainfall tends to be isotopically lighter than a light rainfall. Thus, large storms which are particularly noticeable in arid regions are likely to produce recharge events through thick unsaturated zones, and are likely to be significantly depleted in heavy isotopes relative to long-term mean-values which are based mostly on smaller, more frequent storms. Thus, precipitation at various locations at the Nevada test site (and also different altitudes) and different storm events should be collected and analyzed for their stable hydrogen- and oxygen-isotope compositions.

From August 1983 through August 1986, the stable-isotope compositions of precipitation in southern Nevada were collected and published by Milne and others (1987). Twelve stations were set up: four at the top of Yucca Mountain, one each at Pahute Mesa, Desert Range, Bare Mountain, Spring Mountain (at the top), Spring Mountain (at the bottom), City of Pahrump, J-13 well site, and the southern end of Fortymile Wash. Samples usually were obtained within 24 hours of the cessation of precipitation. In June of 1985, Microloggers in addition to temperature probes and tipping-bucket rain gages were installed at seven stations to record date, time, temperature, and number of rain-gage tips. The rain gage tips each time the bucket is filled with 0.025 cm (0.01 in.) of rain. Also sequential rain samplers were placed at two sampling sites to determine the changes in $\delta^{18}O$ and δD due to the "amount effect" during a storm.

The long-time average of the isotopic compositions in rain and snow collected at different stations can be compared with the unsaturated- and saturated-zone ground waters to identify the sources of recharge to the ground water beneath Yucca Mountain. Evaporation of snowmelt before recharge will cause the $\delta^{18}O$ and δD values of infiltrated ground water to be heavier. By comparing the isotopic compositions of ground water and precipitation, evaporation history of the recharge water can be determined. On the other hand, if the ground water is found to possess slightly negative $\delta^{18}O$ and δD values as compared with the average composition of the precipitation falling on the recharge areas, it means that only heavy rain showers contribute to the local rain discharge (amount effect) and these are of a lighter than average isotopic composition. Preliminary results indicate that only very depleted $\delta^{18}O$ and δD values in precipitation (snowmelt from high altitude or precipitation from cold climate or last glaciation) can match the isotopic signals of the saturated-zone ground water beneath Yucca Mountain.

Furthermore, collections of large-storm-event precipitation in the fractures of the unsaturated zone at depths (such as in the exploratory-shaft radial boreholes) will aid in identifying source and amount of

ground-water recharge. From the age of water determined by ^{14}C and tritium methods, the likely time of recharge will be identified.

Although individual precipitation at the same location varies greatly in composition with time due to local weather fluctuations (e.g., temperature, humidity, and wind), water infiltrating the ground has relatively small isotopic compositional variation with time due to an averaging effect. Thus, only long-term climatic changes can be recognized by significant differences in isotopic composition of unsaturated-zone water. Precipitation at Yucca Mountain during a cooler climate is comparatively more depleted in heavy isotopes than that from a warmer climate. Therefore, by analyzing the compositions of ^{18}O and D in the unsaturated-zone water, it is possible to identify the climate at the time of recharge (i.e., recharged during warm- or cold-climatic regime). The isotope ratios of oxygen and hydrogen recharged during the last ice age (about 10,000 years ago) were significantly depleted compared to isotopic ratios of different sources. Therefore, when stable-isotope compositions of oxygen and hydrogen are compared with the climates of the past, flow paths of the water can likely be identified.

The sources of recharge can be identified from the differences in stable-isotope ratios due to an altitude effect (the higher the altitude, the cooler the condensation temperature, hence the lower the isotopic ratios). The possible sources of Yucca Mountain's precipitation are the Pacific Northwest, California coast, Gulf of California, and the Gulf of Mexico. Each is probably tagged with different stable oxygen- and hydrogen-isotope ratios (see Study 8.3.1.5.1.1, Characterization of modern regional climate). 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 (Yang and Thorstenson, 1989). Furthermore, the age of water determined by ^{14}C and tritium methods will likely identify recharge, travel, and residence times (Yang and others, 1985). In unsaturated-zone conditions, conventional theories may not be directly applicable. Therefore, data obtained from this study will be compared to other Alternative Conceptual Models (see Study 8.3.1.2.2.1).

Two critical prototype tests will be undertaken prior to hydrochemistry testing in order to design and validate methods of pore-water collection. The two prototype tests are triaxial and uniaxial compression tests. These tests are described in detail in Section 3.2.3.2.

3.2.3 General approach and summary of tests and analyses

Pore water from the rock matrix and near fractures will be extracted from unsaturated-zone drill cores for chemical and isotopic analyses. The drill core will be provided from the coring of neutron-access holes (Activity 8.3.1.2.2.1.2, Evaluation of natural infiltration), surface-based boreholes (Study 8.3.1.2.2.3, Characterization of percolation in the unsaturated-zone -- surface-based study), and radial and vertical boreholes in the ESF, (Study 8.3.1.2.2.4, Characterization of Yucca Mountain percolation in the unsaturated-zone -- exploratory-shaft facility study). Samples will also be checked for the presence of artificial tracers that would indicate contamination during the drilling

of the wells and the ESF construction. The water will be extracted by applying pressure (triaxial or uniaxial compression), high-speed centrifugation, vacuum distillation, or immiscible displacement. These different water-extraction techniques will be evaluated during prototype testing. Water has been expressed from 4-inch core pieces with moisture contents as low as 6%. Tests are continuing to try to collect water from drier cores.

Figure 3.2-1 summarizes the organization of the aqueous-phase chemical investigations. A descriptive heading for each test and analysis appears in the shadowed boxes of the second row. Below each test/analysis are the individual methods that will be utilized. Figure 3.2-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed analysis boxes, respectively.

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 the site parameters to be determined, the informational needs of the performance and design issues, the mechanical objectives of the activity, and the methods to be used.

3.2.3.1 Collection and transportation of samples

The procedures for collecting, sealing, and transporting samples from the ESF are listed in Study 8.3.1.2.2.4.8 (Hydrochemistry tests in the exploratory-shaft facility). Dry-coring procedures will be used for collecting samples for aqueous-phase chemical investigations from surface-based boreholes and neutron holes. The dry-coring techniques are described in studies 8.3.1.2.2.1 (Characterization of unsaturated-zone infiltration) and 8.3.1.2.2.3 (Characterization of percolation in the unsaturated-zone -- surface-based study).

When samples are available after coring, procedures for handling those samples are as follows: (1) the samples will be preserved by sealing in Lexan liners, beeswaxed, and Protecore®, and marked with an indelible marker on tape and placed in storage containers; (2) the sealed and containerized core and rubble samples will be transported from Yucca Mountain to the Sample Management Facility (SMF) cold storage room, and then to the cold storage facility at the Denver Federal Center in an air-conditioned vehicle to ensure core-moisture preservation; (3) the samples are prepared for triaxial compression in a nitrogen-atmosphere glove box to prevent atmospheric contamination; and (4) the effects of extended holding times under controlled cold room conditions on cores sealed by various methods are being investigated.

The effects of dry coring (i.e., evaporative enrichment of the core-sample water) are being investigated in two prototype tests:

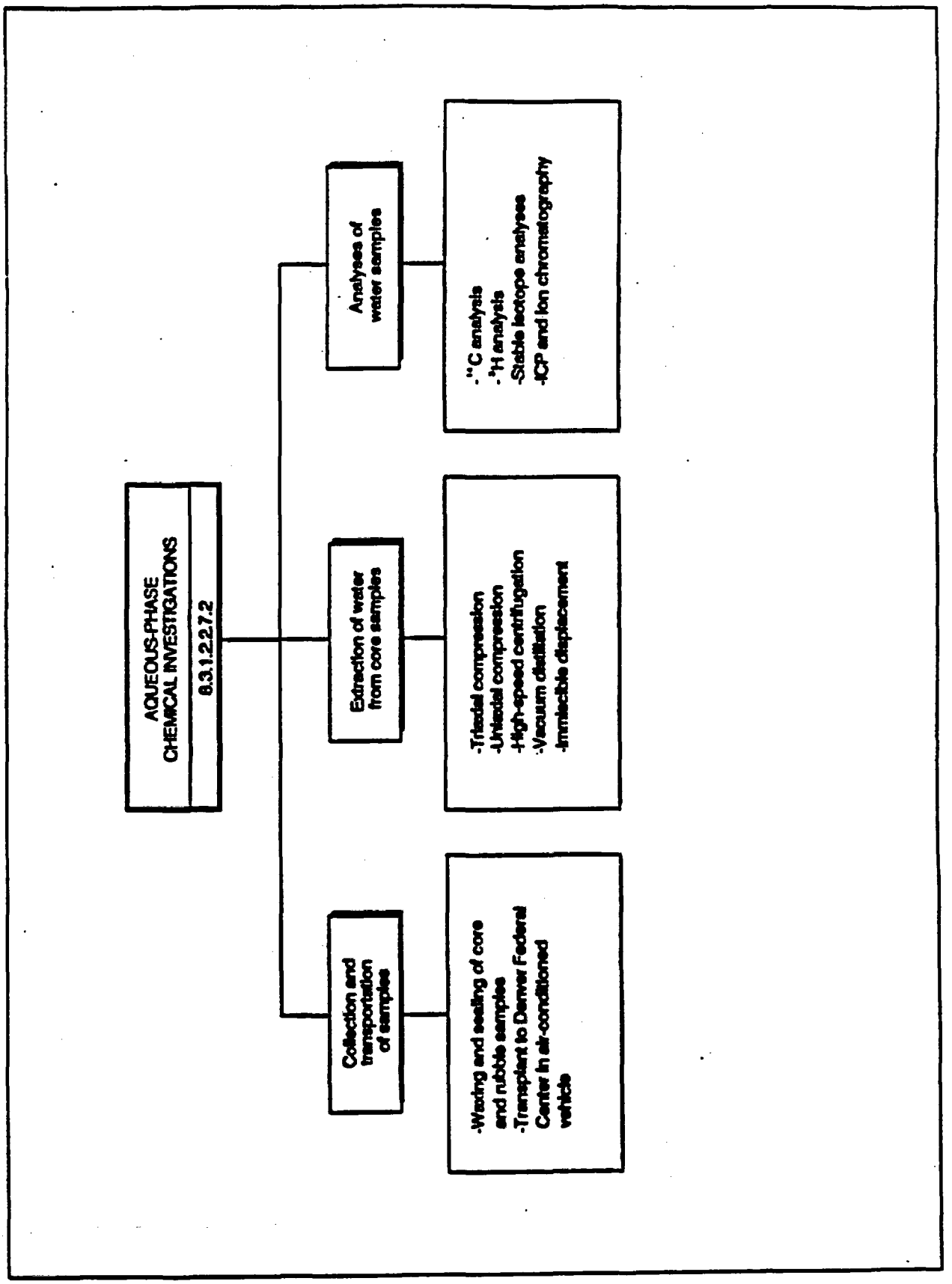


Figure 3.2-1. Logic diagram of the aqueous-phase chemical investigations showing tests, analyses, and methods.

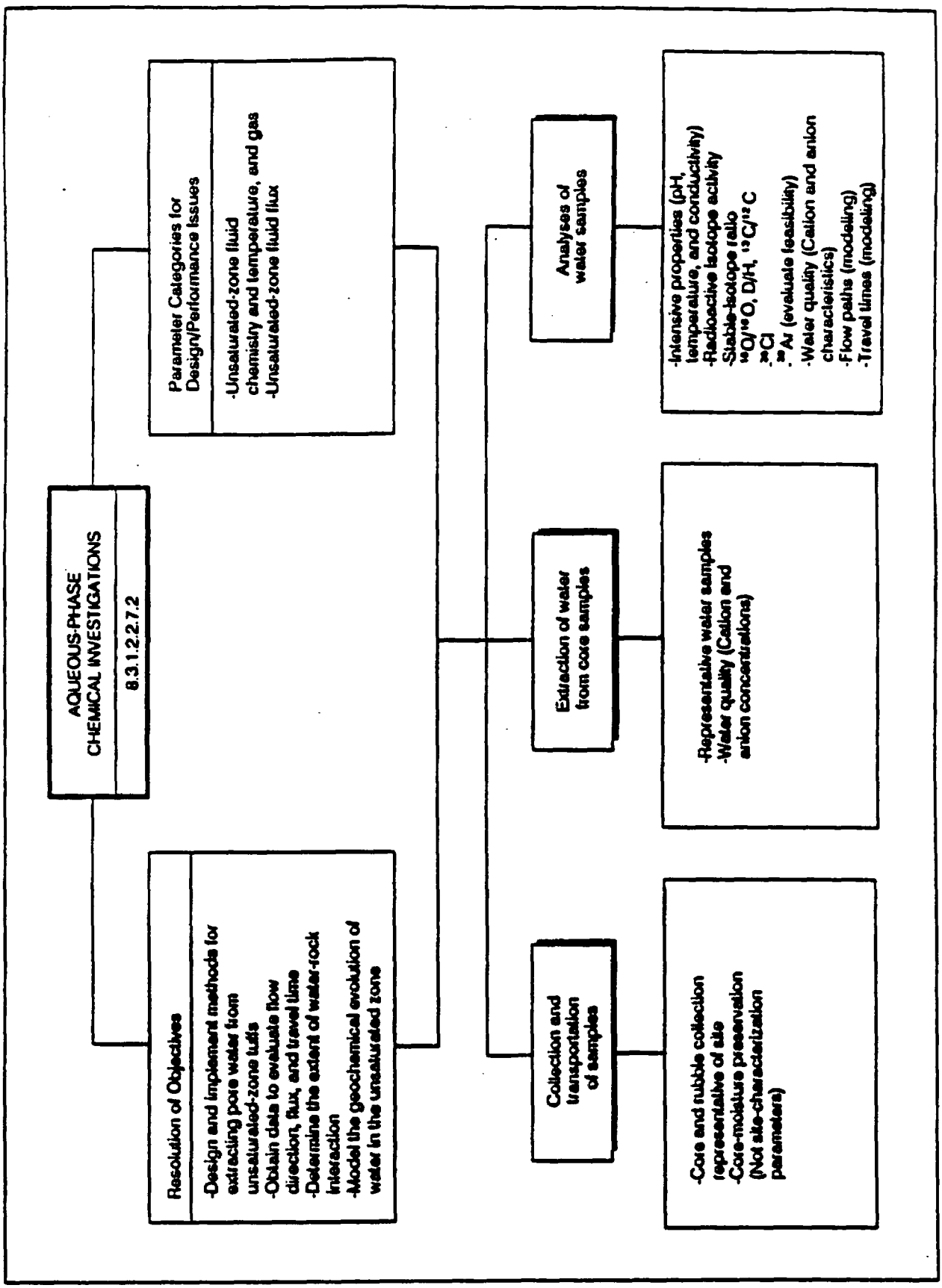


Figure 3.2-2. Logic diagram of the aqueous-phase chemical investigations showing tests, analyses, and e parameters.

(1) wet versus dry drilling and (2) dry coring of rubble samples. These tests have been described in detail in Section 3.8.3.4, 3.8.3.5, and 3.8.3.6 in Study 8.3.1.2.2.4 (Characterization of Yucca Mountain percolation in the unsaturated-zone -- exploratory-shaft-facility study).

Core from previously completed boreholes has been sealed in aluminum foil and beeswax, and kept in a refrigerated environment. Data obtained from water removed from this core will not be used for site characterization without being QA qualified.

3.2.3.2 Extraction of water from core samples

The four methods to extract water from unsaturated tuffs include triaxial compression, high-speed centrifugation, vacuum distillation, and immiscible displacement. Triaxial compression involves placing a core sample in a compression chamber and applying axial and confining pressures incrementally to force water and air from the pore space (see Figure 3.2-3). Using a sequence of incremental pressures allows a maximum amount of water to be recovered with a minimum potential for water/rock interactions which might alter the original pore-water composition. (Axial pressure is increased in three steps: 76, 117, and 152 MPa; at the same time, confining pressure is increased from 55 to 62 MPa.) A unaxial compression chamber (Figure 3.2-4) was used to successfully extract pore water from the welded tuff. Different core orientations (in relation to the tuff fabric) can also be tested to optimize water recovery. The centrifugation method uses the large centrifugal force developed in a high-speed (8,000 to 18,000 rpm) centrifuge to drive pore water out of a core (Figure 3.2-5) (Davis and others, 1985). The removal process can be simple drainage, or an immiscible fluid can be introduced to displace the pore water during centrifugation.

Centrifugation can be used on broken samples as well as on intact core pieces. The distillation method involves heating the core under a vacuum and capturing the vaporized pore water in a low-temperature (-78 °C) cold trap (see Table 3.2-2, technical procedure HP-126). The immiscible-displacement method uses an immiscible fluid (usually a halogenated hydrocarbon) to displace pore water from the core in a leaching process (Kinniburgh and Miles, 1983).

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

1. the forces acting on the core are better understood for triaxial compression than centrifugation; therefore, more information about the actual pore-volume reduction process

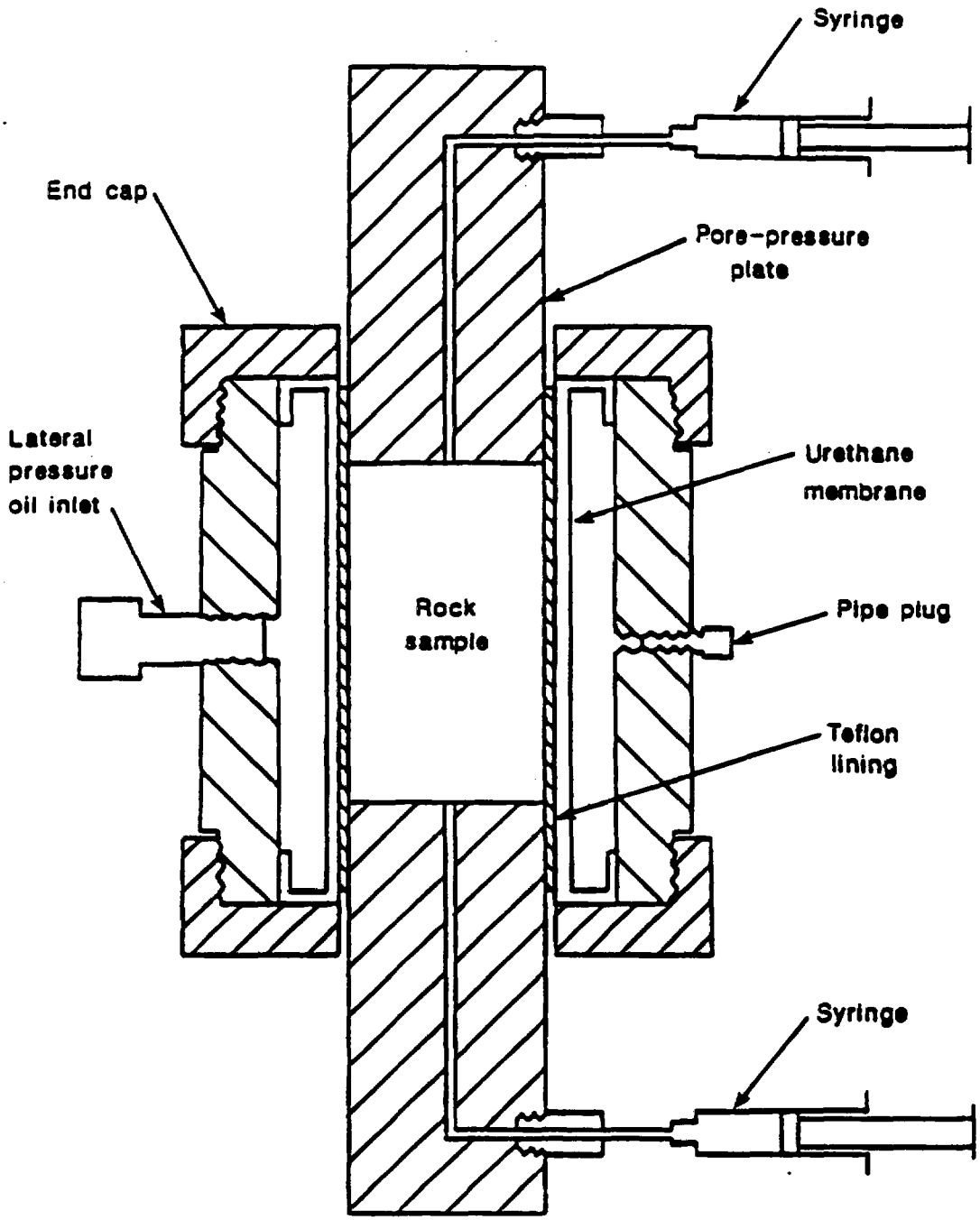


Figure 3.2-3. Schematic of apparatus for pore-water extraction by triaxial compression in aqueous-phase chemical investigations.

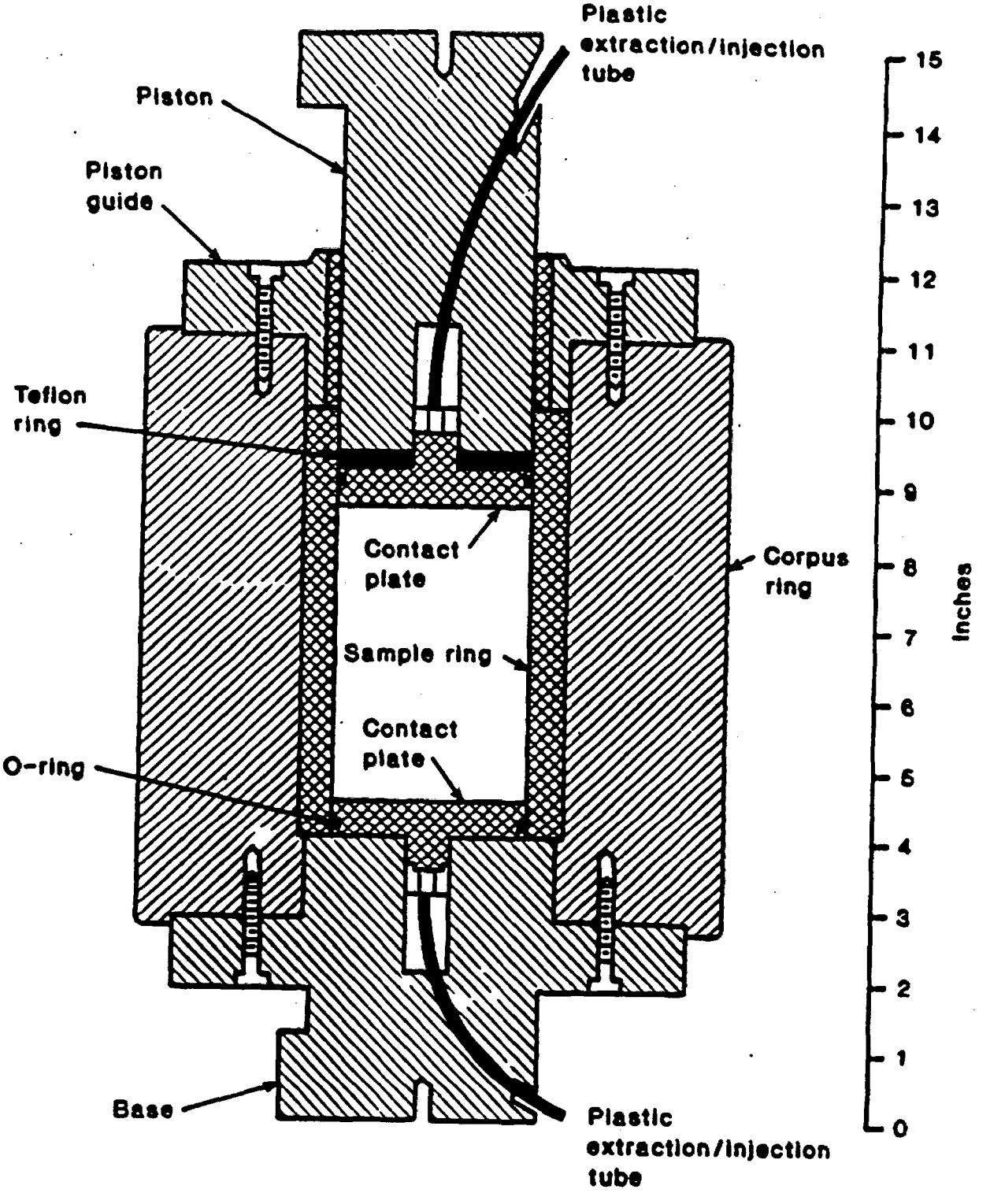


Figure 3.2-4. Schematic of apparatus for pore-water extraction by uniaxial compression in aqueous-phase chemical investigations.

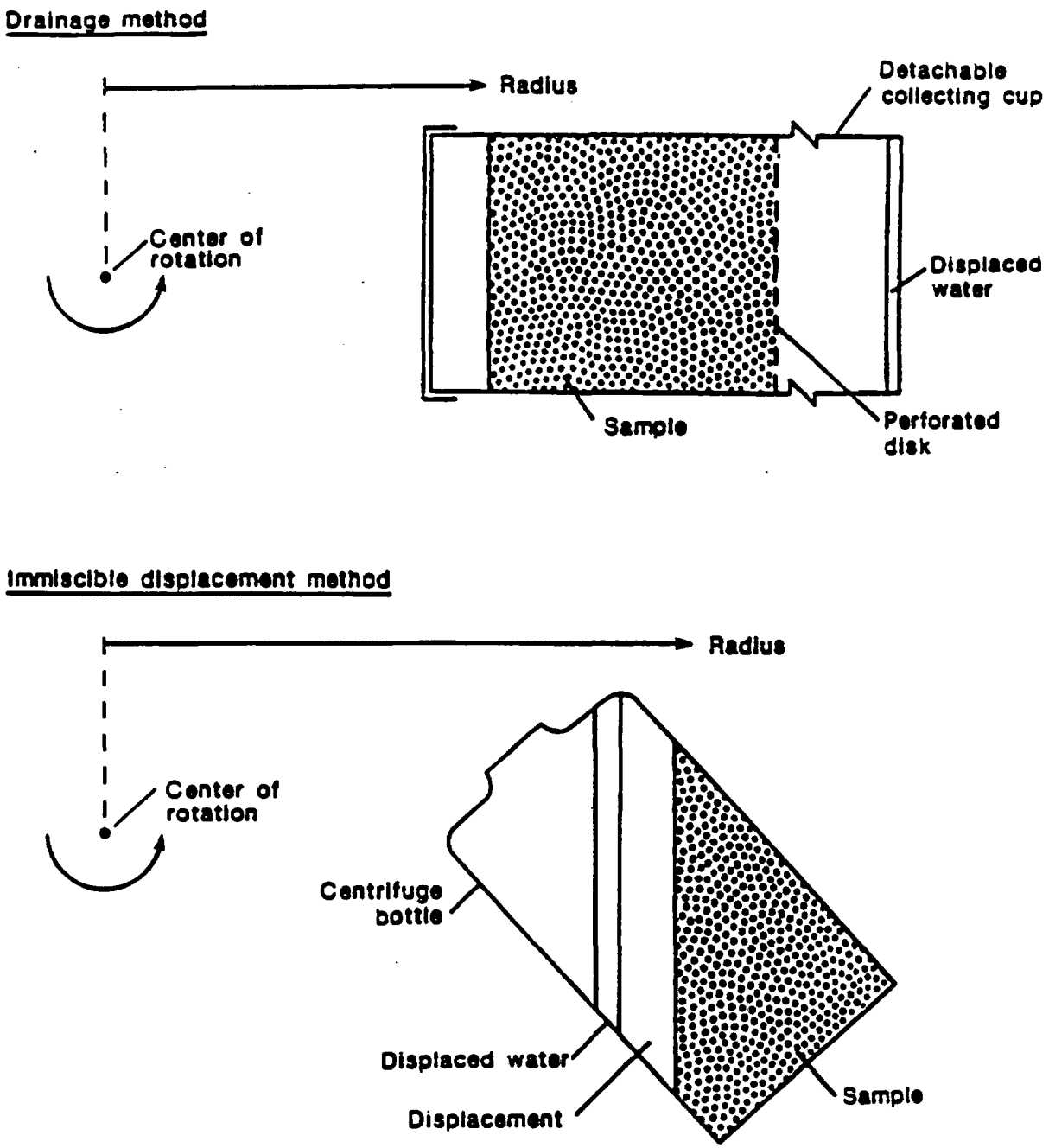


Figure 3.2-5. Methods of centrifugation for aqueous-phase chemical investigations.

that occurs within the core will be gained from triaxial compression; and

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

Centrifugation, however, can be used on broken cores which are unsuitable for triaxial compression. Immiscible displacement is the least favored method, because by forcing a new fluid into 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 using simple drainage only and not incorporating an immiscible fluid for this same reason.)

A representative water sample extracted from the core can be verified in two ways. First, by taking water samples at each pressure during the triaxial compression procedure, a set of chemical-concentration data relating cation and anion concentrations to axial pressure will be available. If the ion concentrations do not increase with increasing pressure, then the triaxial compression process is probably not affecting the original pore-water composition. (Also, if a sharp increase in concentration is noted at a larger pressure, future work can secure representative samples by holding pressures to smaller than that amount.) Second, water-sample analyses from a core which was extracted by centrifugation can be compared to analyses from a nearby core used for triaxial compression. Similar chemical concentrations obtained by both methods would, again, support the validity of triaxial compression in producing representative samples (Yang and others, 1988).

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

3.2.3.3 Analyses

All analyses will be conducted by existing qualified laboratories that have been approved by the USGS Quality Assurance Program. Cation concentrations will be measured by using inductively coupled plasma (ICP), and anion concentrations will be measured using ion chromatography. Stable-isotope ratios will be analyzed using mass spectrometry. Small-concentration gas counters or liquid scintillation counters will be used to determine tritium activity. Large ^{14}C samples will be analyzed using conventional gas-counting methods. Small ^{14}C samples will be analyzed by tandem accelerator mass spectrometry (TAMS). ^{36}Cl will be analyzed using TAMS. ^{39}Ar and ^{85}Kr will be purged from the water samples, processed, and measured by proportional counter. Selected water and

gas samples will be analyzed for the presence of tracers (Cl, Br, NO_3, SF_6, Freon-11, -12, etc.) and rare-earth elements, using gas chromatography-mass spectrometry (GCMS), high-pressure liquid chromatography (HPLC), and ICP-MS.

For water-sample dating, ^{14}C and tritium are preferred over ^{39}Ar and ^{85}Kr. Because argon and krypton are so insoluble in water, a very large volume of water would be necessary to use these isotopes for sample-age dating. It is doubtful that such a large amount of water could be obtained. In addition, ^{39}Ar and ^{85}Kr are counted in a conventional gas counter; small sample volumes cannot be measured. Carbon-14 requires much smaller sample volumes because it can be measured by the TAMS method. Furthermore, ^{39}Ar has an additional drawback in that it can also be produced by *in situ* neutron activation in the subsurface which may interfere with the measurement of cosmogenic ^{39}Ar. Nevertheless, the feasibility of dating samples with ^{39}Ar and ^{85}Kr needs to be evaluated.

The use of ^{36}Cl for age dating is also dependent on the extent of *in situ* production in the subsurface. If this interference is minimal, ^{36}Cl will be used for age dating of water. Samples for ^{36}Cl age dating will be sent to LANL and the work will be conducted under Activity 8.3.1.2.2.2.1 (Chloride and ^{36}Cl measurement of percolation at Yucca Mountain). $^{18}O/^{16}O$, $^{13}C/^{12}C$, 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. The use of ICP, ion chromatography, GCMS, and HPLC are preferred to atomic absorption because these techniques can analyze more than one element at a time, whereas atomic absorption must determine each element individually and so would require much more time and sample volume to complete an analysis.

^{14}C and tritium dating will determine the age of water in the unsaturated zone. Stable-isotope ratios will provide information on the flow path of the water through the unsaturated zone and any large-temperature water/rock interactions. Age and flow-path length together will be used to estimate travel times of water in the unsaturated zone. Ion concentrations will provide information about chemical processes involving the rock matrix and pore water. Tracer concentrations will help determine the effects of excavation/operations on water in the unsaturated zone.

3.2.3.4 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.2-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be utilized only if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, there are many approaches to conducting the test. In those cases, only the most common methods are included in the tables. The selected methods in Table 3.2-1 were chosen wholly or in part on the basis of accuracy, precision, duration of

Table 3.2-1. Summary of tests and methods for the aqueous-phase chemical investigations (SCP Activity 8.3.1.2.2.7.2)
[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site parameter	Expected range
	Analyses of water samples	
^{14}C dating on ground water (selected)	Radioactive-isotope activity	1,000 to 40,000 yr
Age-dating of carbon dioxide in water samples using tandem-accelerator mass spectometry (selected)	"	"
^{3}H dating of ground water (selected)	"	Up to 150 yr
^{36}Cl dating of ground water (alternate)	"	Up to 900,000 yr
^{39}Ar dating of ground water, ^{85}Kr dating of ground water (alternate)	"	^{39}Ar - 150 to 1,000 yr ^{85}Kr - 0 to 40 yr
Stable-isotope analyses ($^{18}O/^{16}O$, D/H, and $^{13}C/^{12}C$ ratios) (selected)	Stable-isotope ratio	$^{18}O/^{16}O$: 0 to -20 per mil D/H: 0 to -200 per mil
Mass spectrometry for other stable isotopes (alternate)	"	--
ICP and ion chromatography (selected)	Water quality, cations and anions	0 to 300 mg/l
Atomic adsorption (alternate)	"	"
Hydrochemical determination by sample analysis and modeling (selected)	Water flow paths ($^{18}O/^{16}O$ and D/H), pore waters	--
Hydrochemical determination, other activities (alternate)	"	--

Table 3.2-1. Summary of tests and methods for the aqueous-phase chemical investigations (SCP Activity 8.3.1.2.2.7.2)--Continued

Methods (selected and alternate)	Site parameter	Expected range
	Analyses of water samples--Continued	
Hydrochemical determination by sample analysis and modeling (selected)	Water travel times (^{14}C and ^{3}H)	--
Hydrochemical determination, other activities (alternate)	"	--

methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they feel are suitable to provide accurate data within the expected range of the site parameter. Models and analytical techniques have been or will be developed to be consistent with test results. The expected ranges of the site parameters have been bracketed by previous data collection and computer modeling and are shown in Table 3.2-1.

3.2.4 Technical procedures

The USGS quality-assurance program plan for the YMP (U.S. Geological Survey, 1986) requires documentation of technical procedures for all technical activities that require quality assurance. Applicable quality-assurance procedures are presented in Appendix 7.1.

Table 3.2-2 provides a complete tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS number (NWM-USGS-) and a procedure effective date. Procedures that require preparation do not have procedures numbers.

Procedures that are not identified with an effective date in the table will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Many of the needed technical procedures depend on the results of ongoing prototype testing and cannot be completed until work is done.

Equipment requirements and instrument calibration are described in USGS 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 3.2-2. Technical procedures for the aqueous-phase chemical investigation (SCP Activity 8.3.1.2.2.7.2)*

Technical procedure number (NWM-USGS-)	Technical procedure	Effective date
	Collection and transportation of water samples	
HP-131,R0	Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis	06/13/88
	Extraction of water from core and rubble-core samples	
HP-110,R0	Extraction of pore waters by centrifuge methods	06/08/88
HP-125,R0	Method for extraction of pore water from tuff cores by triaxial compression	05/20/88
HP-126,R0	Extraction of residual water from tuff samples by vacuum distillation	06/15/88
TBD	Collection of near fracture pore water	--
	Analyses of water samples	
HP-08,R0	Methods for determination of inorganic substances in water	08/06/82
TBD	Methods for determination of radioactive substances in water	--

*Procedures not listed are in place and will be performed by certified external laboratories which have been approved by the USGS Quality Assurance Program.

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 waste package (Issue 1.10) and underground-repository facilities (Issue 4.4). Issues concerned with repository seals (Issue 1.12) will also use the hydrochemical information resulting from this study.

The application of site information from this study to design- and performance-parameter needs required for the resolution of design and performance issues is addressed in Section 1.3. Logic diagrams and tables are used to summarize specific relations between performance- and design-parameter needs and site parameters determined from this study. Section 7.2 provides additional detailed parameter relations (see Table 7.2-1).

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 (Studies to provide a description of the unsaturated-zone hydrologic system at the site) as well as studies in the following investigations.

8.3.1.2.1 - Studies to provide a description of the regional hydrologic system;

8.3.1.2.3 - Studies to provide a description of the saturated-zone hydrologic system at the site;

8.3.1.3.1 - Studies to provide the information on water chemistry within the potential emplacement horizon and along potential flow paths;

8.3.1.3.4 - Studies to provide the information required on radionuclide retardation by sorption processes along flow paths to the accessible environment;

8.3.1.3.5 - Studies to provide the information required on radionuclide retardation by precipitation processes along flow paths to the accessible environment;

8.3.1.3.6 - Studies to provide the information required on radionuclide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment;

8.3.1.3.7 - Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment;

8.3.1.3.8 - Studies to provide the required information on retardation of gaseous radionuclides along flow paths to the accessible environment;

8.3.1.5.1 - Studies to provide the information required on nature and rates of change in climatic conditions to predict future climates;

8.3.1.5.2 - Studies to provide the information required on potential effects of future climatic conditions on hydrologic characteristics;

8.3.1.16.3 - Ground-water conditions within and above the potential host rock; and

8.3.4.2.4 - Postemplacement near-field environment.

Investigation 8.3.1.2.2, of which Study 8.3.1.2.2.7 is a component, is directed at understanding the fundamentals of unsaturated flow and transport at Yucca Mountain. Of the nine studies in this investigation, only Study 8.3.1.2.2.4 and Activity 8.3.1.2.2.4.8 (Hydrochemistry tests in the exploratory-shaft facility) address the issues of both aqueous and gaseous

chemistry and transport in the unsaturated zone. Study 8.3.1.2.2.6 (Characterization of gaseous-phase movement in the unsaturated zone) addresses gas-flow phenomena but focuses very little on transport and hydrochemistry. Studies 8.3.1.2.2.2 (Water-movement tracer tests using chloride and chlorine-36 measurements of percolation at Yucca Mountain) and 8.3.1.2.2.5 (Diffusion tests in the exploratory-shaft facility) address aqueous transport.

The characterization of unsaturated-zone hydrochemistry at the site interfaces with several other studies and investigations to provide an understanding of the hydrology and chemistry beneath Yucca Mountain. In Investigation 8.3.1.2.1 (Studies to provide a description of the regional hydrologic system), results from the unsaturated-zone hydrochemistry study will be applicable to Activity 8.3.1.2.1.3.3 (Fortymile Wash recharge study) and Study 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling).

The data acquired in this study will complement data from Investigation 8.3.1.2.3. (Studies to provide a description of the saturated-zone hydrologic system at the site). Chemical and isotopic analyses of unsaturated-zone interstitial waters will be used specifically in Study 8.3.1.2.3.2 (Characterization of the site saturated-zone hydrochemistry). Also, in order to calculate flow path, flux, and velocity within the saturated zone which is required for Study 8.3.1.2.3.3 (Saturated-zone hydrologic system synthesis and modeling), input from unsaturated-zone hydrochemical models (Study 8.3.1.2.2.9) are needed.

Investigation 8.3.1.3.1 (Studies to provide the information on water chemistry within the potential emplacement horizon and along potential flow paths) will receive direct input from the activities in this study. Study 8.3.1.3.1.1 (Ground-water chemistry model) will employ the water-sample and analyses data generated by Activity 8.3.1.2.2.7.2.

In Investigations 8.3.1.3.4 (Studies to provide the information required on radionuclide retardation by sorption processes along flow paths to the accessible environment), 8.3.1.3.5 (Studies to provide information required on radionuclide retardation by precipitation processes along flow paths to the accessible environment), and 8.3.1.3.6 (Studies to provide the information required on radionulcide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment), the hydrochemical characteristics researched in this study will contribute to sorption, precipitation, and dispersive/diffusive/advective transport studies. Knowledge of hydrochemistry provides information relevant to water/rock interactions and, consequently, to radionuclide migration and retardation by all processes along flow paths to the accessible environment (Investigation 8.3.1.3.7). Data from the unsaturated-zone hydrochemistry study will be used in Study 8.3.1.3.7.1 (Retardation sensitivity analysis). In particular, data will support Activities 8.3.1.3.7.1.2 (Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations) and 8.3.1.3.7.1.3 (Transport models and related support). Similarly, the gaseous-phase chemical data generated in this study will be used in Investigation 8.3.1.3.8 (Studies to provide the required information on retardation of gaseous radionuclides along flow paths to the accessible environment) to provide information on the retardation of gaseous radionuclides along flow paths to the accessible environment.

In Investigation 8.3.1.5.1 (Studies to provide the information required on nature and rates of change in climatic conditions to predict future climates), unsaturated-zone hydrochemistry data will be used in comparison with the isotopic content of regional storms (Activity 8.3.1.5.1.1.1), paleoclimate geochemistry (Activity 8.3.1.5.1.2.3), and in the modeling of future climates (Study 8.3.1.5.1.6). Interpretation of data from this study will provide estimates of pore-water ages and insight as to recharge to, and flow within, the unsaturated zone. Hydrochemical information will also support Study 8.3.1.5.2.1 (Characterization of Quaternary regional hydrology) of Investigation 8.3.1.5.2 (Studies to provide the information required on potential effects of future climatic conditions on hydrologic characteristics) by providing isotopic and water-composition data to determine pore-water residence times and travel paths.

In Investigation 8.3.1.16.3 (Ground-water conditions within and above the potential host rock), 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 this study pertinent to unsaturated-zone characterization. These data will be used in addressing repository-design requirements, design analyses, and underground-facilities technology.

In Investigation 8.3.4.2.4 (Postemplacement near-field environment) to be conducted by Lawrence Livermore National Laboratory (LLNL), Activity 8.3.4.2.4.1.3 (Composition of vadose water from the waste-package environment) will integrate data collected in this study to establish the variability of vadose-water composition within the repository horizon. This information will define the bounds to be expected on vadose-water composition in the pre-emplacement waste package environment.

5 SCHEDULES AND MILESTONES

5.1 Schedules

A tentative schedule for the work covered in this study plan is presented in Figure 5.1-1. The proposed schedule summarizes the logic network and reports for the two activities described in this study. The schedule information includes the sequencing, interrelations, and relative durations of the described activities. Specific durations, and start and finish dates for the activities are being developed as part of ongoing planning efforts. The development of the schedule for the present study has taken into account how the study will be affected by contributions of data or interferences from other studies, and also how the present study will contribute or may interfere with other studies.

The sampling of the unsaturated zone for chemical analyses as described in this study plan will be dependent on the drilling schedules of the surface-based holes as described in Study 8.3.1.2.2.3 (Characterization of percolation in the unsaturated-zone -- surface-based study) and the construction schedules of the ESF. Accurate characterization of the unsaturated-zone hydrochemistry will require several years of sampling and monitoring. Because of the relatively long period of time needed, the planned activities provide little time for delay.

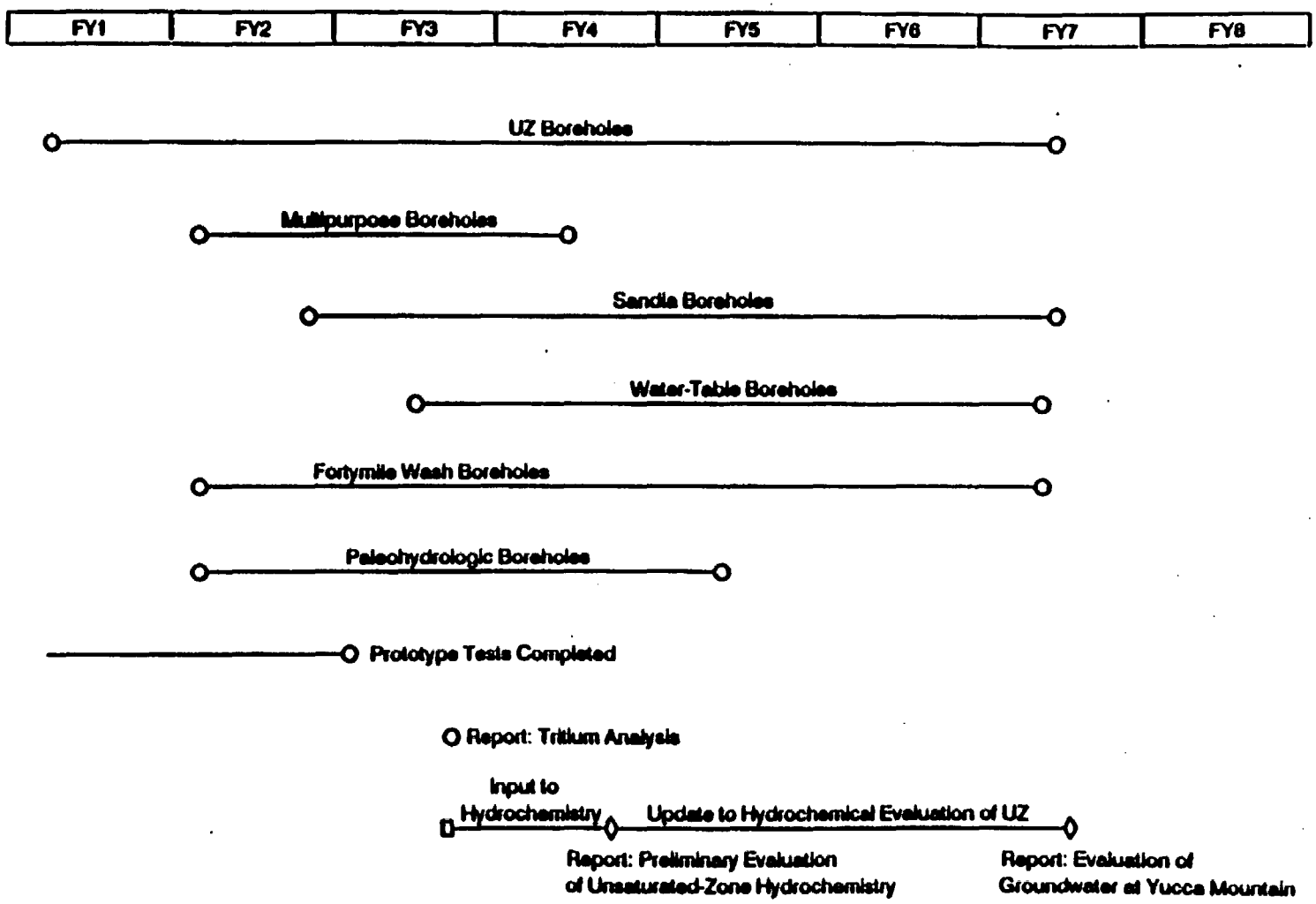


Figure 5.1-1. Schedule for gas sampling and water extraction for unsaturated-zone hydrochemistry study

5.2 Milestones

The milestone number, title, and corresponding work-breakdown-structure (WBS) number associated with the two activities of the unsaturated-zone hydrochemistry study are summarized in Table 5.2-1.

The information presented in the table represents major events or important summary milestones associated with the activities presented in this study plan as shown in Figure 5.1-1. The work breakdown structure number is included following the milestone description in order to facilitate the relation of different milestones and activities within the structure of the site-characterization program. Figure 5.2-1 presents a milestone flow chart indicating sequence of events and relative dates. In addition, drilling and prototype testing constraints are included. Specific dates for milestones are not included in the tables or figures, as these dates are subject to change due to ongoing planning efforts.

Table 5.2-1. Milestone list for the study (SCP 8.3.1.2.2.7)

Milestone number	Milestone	Work-breakdown structure number	Proposed
Gaseous-phase chemical investigations: 8.3.1.2.2.7.1			
P710	Preliminary report: Gas sampling in the unsaturated zone at Yucca Mountain	1.2.3.3.4.4.G	1.2.3.3.1.2.7
P731	Final report: Gas sampling in the unsaturated zone	1.2.3.3.4.4.G	1.2.3.3.1.2.7
Aqueous-phase chemical investigations: 8.3.1.2.2.7.2			
P715	Preliminary evaluation of unsaturated zone hydrochemistry	1.2.3.3.4.4.G	1.2.3.3.1.2.7
P736	Final report: Evaluation of hydrochemistry of groundwater at Yucca Mountain	1.2.3.3.4.4.G	1.2.3.3.1.2.7

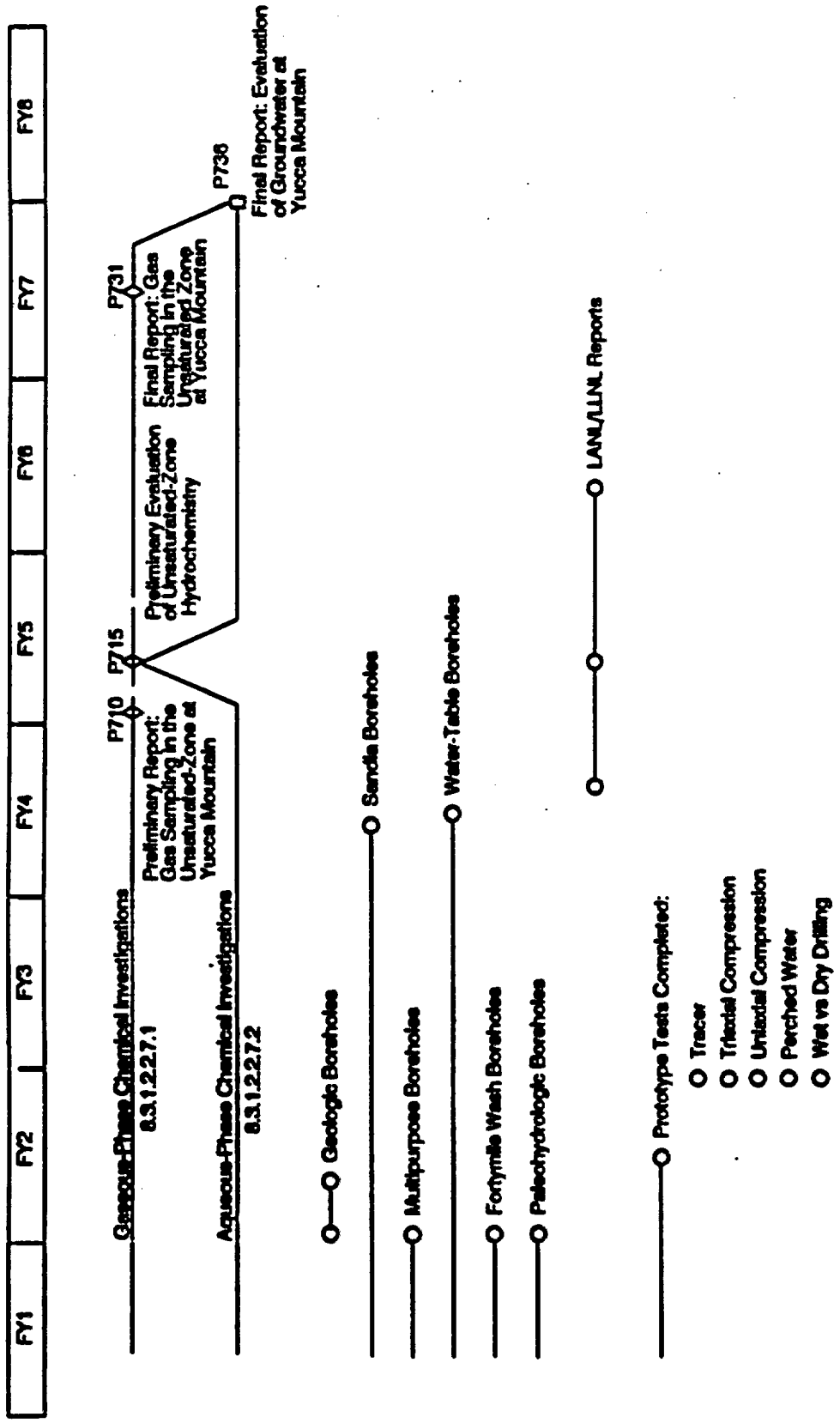


Figure 5.2-1. Milestone flow chart showing reports, drilling and prototype test constraints.

6 REFERENCES

American Public Health Association and others, 1980, Standard methods for the examination of water and wastewater: American Public Health Association, Washington, D.C., 1134 p.

American Society for Testing and Materials, 1978, Manual on water: American Society for Testing and Materials, Special Technical Publication No. 442A, 472 p.

Barnes, I., 1964, Field measurement of alkalinity and pH: U.S. Geological Survey Water-Supply Paper 1535 H, 17 p.

Benson, L. V. and McKinley, P. W., 1985, Chemical composition of ground water in the Yucca Mountain area, Nevada, 1971-84: U.S. Geological Survey Open-File Report 85-484, 10 p.

Cady, J. G., Wilding, L. P., and Drees, L. R., 1986, Petrographic Microscope Techniques, in Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (Klute, A., ed.), American Society of Agronomy, Inc., and Soil Science of America, Inc., Agronomy Monograph No. 9, p. 185-218.

Chapman, H. D., 1965, Cation exchange capacity, in Methods of Soil Analysis, American Society of Agronomy (Black, C. A., ed.), p. 896-898.

Clarke, F. E., 1950, Determination of chloride in water: Analytical Chemistry, v. 22, p. 553, 1458.

Colovos, G., Paanesar, M. R., and Parry, E. P., 1976, Linearizing the calibration curve in determination of sulfate by the methylthymol blue method: Analytical Chemistry, v. 48, p. 1693.

Damon, P. E., and Green, W. D., 1963, Investigations of the helium age dating method by stable-isotope dilution technique, in Radioactive Dating: International Atomic Energy Agency, Vienna, p. 55-71.

Danielson, R. E., and Sutherland, P. L., 1986, Porosity, in Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (Klute, A., ed.), American Society of Agronomy, Inc., and Soil Science Society of America, Inc., Agronomy Monograph No. 9, p. 443-461.

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

Donahue, D. J., Jull, A. J. T., and Zabel, T. H., 1984, Results of radioisotope measurements at the NSF-University of Arizona tandem accelerator mass spectrometer facility, in Nuclear Instruments and Methods in Physics Research B5, North-Holland, Amsterdam, p. 162-166.

Durst, R. A. (ed.), 1969, Ion-selective electrodes: National Bureau of Standards Special Publications 314, U.S. Government Printing Office, Washington, D.C., 452 p.

Faires, R. A., and Boswell, G. G., 1981, Radioisotope laboratory techniques: Bulterwook and Co., Ltd., London, 335 p.

Fishman, M. J., and Bradford, W. L., 1982, A supplement to methods for the determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Open-File Report 82-272, 136 p.

Fishman, M. J., and Friedman, L. C., 1985, Methods for determination of inorganic substances in water and fluvial sediments: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5, Chapter A1, Open-File Report 85-495, 709 p.

Fishman, M. J., and Pyen, G. S., 1979, Determination of selected anions in water by ion chromatography: U.S. Geological Survey Water-Resources Investigations, 79-101, 30 p.

Fritz, J. S., and Schenk, G. H., 1976, Quantitative Analytical Chemistry: Allyn and Bacon, Inc., Boston, 689 p.

Gardner, W. H., 1986, Water content, in Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (Klute, A., ed.): American Society of Agronomy, Inc., and Soil Science of America, Inc., Agronomy Monograph No. 9, p. 493-544.

Haas, H. H., Fisher, D. W., Thorstensen, D. C., and Weeks, E. P., 1983, $^{13}CO_2$ and $^{14}CO_2$ measurements on soil atmosphere sampled in the sub-surface unsaturated zone in the western Great Plains of the U.S.: Radiocarbon, v. 25, no. 2, p. 301-314.

Hoefs, J., 1987, Stable Isotope Geochemistry: Springer-Verlag, New York, 241 p.

Hughes, L. S., 1966, Use of thermistor-thermometer in determination of specific conductance: U.S. Geological Survey Water-Supply Paper 1822, 66 p.

International Atomic Energy Agency, 1967, Guidebook on Isotopic Techniques in Hydrology: International Atomic Energy Agency, Vienna, 175 p.

Johnson, G. W., Taylor, H. E., and Skogerboe, R. K., 1979. Determination of trace elements in natural waters by the D.C. Argon-plasma, multielement atomic emission spectrometer (DCP-MAES) technique: Spectrochimica Acta, v. 34B, p. 197-212.

Keirs, C. D., and Vickers, T. J., 1977, DC plasma arcs for elemental analysis: Applied Spectrochimica Acta, v. 15, 138 p.

Kinniburgh, D. G., and Miles, D. L., 1983, Extraction and chemical analysis of interstitial water from soils and rocks: Environmental Science and Technology, v. 17, no. 6, p. 362-368.

Klavetter, E. A., and Peters, R. R., 1985, Fluid flow in fractured rock mass: Sandia National Laboratories Report SAND85-0855c, 48 p.

Lippolt, H. J., and Gentner, W., 1963, K-Ar dating of some limestones and fluorites (examples of K-Ar ages with low Ar-concentrations), in Radioactive Dating: International Atomic Energy Agency, Vienna, p. 239-244.

Milne, W. K., Benson, L. V., and McKinley P. W., 1987, Isotope content and temperature of precipitation in southern Nevada: U.S. Geological Survey Open-File Report 87-463, 32 p.

Mitchell, C. G., 1966, Semianalytical method for the determination of iodide in water: U.S. Geological Survey Water-Supply Paper 1822, 77 p.

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

O'Brien, J. E., 1962, Automatic analysis of chlorides in sewage: Wastes Engineering, v. 33, p. 670-672.

Pecsok, R. L., Shields, L. D., Cairns, T., and McWilliam, I. G., 1976, Modern methods of Chemical Analysis: John Wiley & Sons, New York, 573 p.

Peters, C. A., 1988, Methods for collection and analysis of samples for gas composition by gas chromotography: U.S. Geological Survey, Yucca Mountain Project, NWM-USGS-HP-160, R0, 34 p.

Sawhney, B. L., 1986, Electron microprobe analysis, in Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (Klute, A., ed.), American Society of Agronomy, Inc., and Soil Science Society of America, Inc., Agronomy Monograph No. 9, p. 271-290.

Sekerka, I., and Lechner, J. F., 1973, some characteristics of ion-selective electrodes: Canada Center for Inland Waters, Technical Bulletin No. 72, Burlington, Ontario.

Spencer, R. R., and Erdmann, D. E., 1979, Azomethine H colorimetric method for determining dissolved boron in water: Environmental Science and Technology, v. 13, p. 954-956.

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

U.S. Environmental Protection Agency, 1986, Test methods for evaluating solid wastes, physical/chemical methods: Office of Solid Waste, EPA-SW-846.

U.S. Environmental Protection Agency, 1983, Methods for chemical analyses of water and wastes: Environmental Monitoring and Support Lab, EPA-600/4-79-020 (revised March 1983).

U.S. Environmental Protection Agency, 1979, Methods for chemical analyses of water and wastes: Environmental Monitoring and Support Lab, EPA-600/4-79-020.

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

Wang, J. S. Y., and Narashimhan, T. N., 1985, Hydrologic measurements governing fluid flow in a partially saturated fractured porous medium: Water Resources Research, v. 21, no. 12, p. 1861-1874.

Weeks, E. P., 1987, Effect of topography on gas flow in unsaturated-fractured rock: concepts and observations, in Flow and Transport through Unsaturated Fracture Rock (Evans, D. D., and Nicholson, T. J., eds.), American Geophysical Union, Geophysical Monograph Series #42, Washington, D.C., p. 165-170.

Whittig, L. D., and Alardice, W. R., 1986, X-ray diffraction techniques, in Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (Klute, A., ed.), American Society of Agronomy, Inc., and Soil Science Society of America, Inc., Agronomy Monograph No. 9, p. 331-362.

Yang, I. C., 1989, Climatic changes inferred from analyses of lake-sediment cores, Walker Lake, Nevada: U.S. Geological Survey Water Resources Investigations 89-4006, 15 p.

------ 1988, Methods for carbon-14 age dating of Walker Lake sediment core: U.S. Geological Survey, Yucca Mountain Project, NWM-USGS-HP-63, R0, 34 p.

Yang, I. C., and Thorstenson, D. C., 1989, Conceptual model of unsaturated-zone ground-water flows at Yucca Mountain in Nevada, based on geochemical isotopic data: Water Resources Research (submitted).

Yang, I. C., Haas, H. H., Weeks, E. P., and Thorstenson, D. C., 1985, Analysis of gaseous-phase stable and radioactive isotopes in the unsaturated zone, Yucca Mountain, Nevada: National Water Well Association, Proceedings of the Characterization and Monitoring of the Vadose (Unsaturated) Zone, November 19-21, 1985, Denver, Colorado, p. 488-506.

Yang, I. C., Sayre, T. M., Turner, A. K., and Montazer, P., 1988, Pore-water extraction by triaxial compression from unsaturated tuff, Yucca Mountain, Nevada: U.S. Geological Survey Water-Resources Investigations 88-4189, 68 p.

7 APPENDICES

7.1 Quality-assurance requirements

Determination of the quality status for the activities of this study will be made separately, according to AP-6.17Q, "Determination of the Importance of Items and Activities", which implements NUREG-1318, "Technical Position on Items and Activities in the High-Level Waste Geologic Repository Program Subject to Quality Assurance Requirements". The results of that determination will be contained in the Q-List, Quality Activities List and Non-Selection Record, which will be controlled documents.

QA grading packages for the activities of this study plan will be prepared separately, according to AP-5.28Q, "Quality Assurance Grading". The resultant Quality Assurance Grading Report will be issued as a controlled document.

7.1.1 Quality-assurance requirements matrix

Applicable NQA-1 criteria for Study 8.3.1.2.2.7 and how they will be satisfied

NQA-1 Criteria #	Documents addressing these requirements
1. Organization and interfaces	The organization of the OCRWM program is described in the Mission Plan (DOE/RW-005, June 1985) and further described in Section 8.6 of the SCP. Organization of the USGS-YMP is described in the following: QMP-1.01 (Organization Procedure)
2. Quality-assurance program	The Quality-Assurance Programs for the OCRWM are described in YMP-QA Plan-88-9, and OGR/83, for the Project Office and HQ, respectively. The USGS QA Program is described in the following: QMP-2.01 (Management Assessment of the YMP-USGS Quality-Assurance Program) QMP-2.02 (Personnel Qualification and Training Program) QMP-2.05 (Qualification of Audit and Surveillance Personnel) QMP-2.06 (Control of Readiness Review) QMP-2.07 (Development and Conduct of Training)

		Each of these QA programs contains Quality Implementing Procedures further defining the program requirements. An overall description of the QA Program for site characterization activities is described in Section 8.6 of the SCP.
3.	Scientific investigation control and design	This study is a scientific investigation. The following QA implementing procedures apply: QMP-3.02 (USGS QA Levels Assignment [QALA]) QMP-3.03 (Scientific and Engineering Software) QMP-3.04 (Technical Review of YMP-USGS Publications) QMP-3.05 (Work Request for NTS Contractor Services [Criteria Letter]) QMP-3.06 (Scientific Investigation Plan) QMP-3.07 (Technical Review Procedure) QMP-3.09 (Preparation of Draft Study Plans) QMP-3.10 (Close-out Verification for Scientific Investigations) QMP-3.11 (Peer Review)
4.	Administrative operations and procurement	QMP-4.01 (Procurement Document Control) QMP-4.02 (Acquisition of Internal Services)
5.	Instructions, procedures, plans, and drawings	The activities in this study are performed according to the technical procedures listed in Section 3 of this study plan, and the QA administrative procedures referenced in this table for criterion 3. QMP-5.01 (Preparation of Technical Procedures) QMP-5.02 (Preparation and Control of Drawings and Sketches) QMP-5.03 (Development and Maintenance of Management Procedures)

		QMP-5.04 (Preparation and Control of the USGS QA Program Plan)
6.	Document control	QMP-6.01 (Document Control);
7.	Control of purchased items and services	QMP-7.01 (Supplier Evaluation, Selection and Control)
8.	Identification and control of items, samples, and data	QMP-8.01 (Identification and Control of Samples) QMP-8.03 (Control of Data)
9.	Control of processes	Not applicable
10.	Inspection	Not applicable
11.	Test control	Not applicable
12.	Control of measuring and test equipment	QMP-12.01 (Instrument Calibration)
13.	Handling, shipping, and storage	QMP-13.01 (Handling, Storage, and Shipping of Instruments)
14.	Inspection, test, and operating status	Not applicable
15.	Control of nonconforming items	QMP-15.01 (Control of Nonconforming Items)
16.	Corrective action	QMP-16.01 (Control of Corrective Action Reports) QMP-16.02 (Control of Stop-Work Orders) QMP-16-03 (Trend Analysis)
17.	Records management	QMP-17.01 (YMP-USGS Records Management) QMP-17.02 (Acceptance of Data Not Developed Under the YMP QA Plan)
18.	Audits	QMP-18.01 (Audits) QMP-18.02 (Surveillance)

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

This section tabulates in Table 7.2-1 the specific technical information relations between SCP design- and performance-parameters needs and site parameters to be determined in this study. The relations were developed using model-based parameter categories (see Figure 2.1-2) that provide common terminology and organization for evaluation of site, design, and performance information relations.

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

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

Comparison of the information relations (site parameters with design/performance parameters) must be done as sets of parameters in a given parameter category. Line-by-line comparisons from the left side of the table (design/performance parameters) with the right side of the table (site parameters) within a parameter category should <u>not</u> be made. For a discussion of the design and performance issues that obtain data from this study see Section 1.3. Similarly, a discussion of how the site parameters determined in this study are interpreted from the data collected can be found in Section 2.1-2.

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance				(SCP 8.3.5.13)
Performance Measures: (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.) EPPM[B], nominal case, release scenario class E, gas pathway release					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
Profile of partial pressure of CO_2 (Ambient rock mass)	Repository area; Unsaturated-zone units, overburden	Goal: No goal Current: Low Needed: Medium	Pore-gas composition	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.1
Profiles of bicarbonate concentration, calcium-ion concentration, pH, in liquid phase (Ambient rock mass)	"	"	Radioactive-isotope activity in gas phase (^{3}H and ^{14}C)	"	"
Profile of carbon-14 concentration (Ambient, rock mass pore spaces)	"	Goal: To be determined Current: Low Needed: Medium	Stable-isotope ratio in gas phase ($^{18}O/^{16}O$, $^{13}C/^{12}C$, and D/H)	"	"
Major-ion water chemistry (composition, Eh, pH); ambient rock-mass pore fluids	"	"	Pore water hydrochemical compositions	"	8.3.1.2.2.7.2

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, gas pathway release					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
			Radioactive-isotope activity in liquid phase (^{3}H and ^{14}C)	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.2
			Stable-isotope ratio in liquid phase	"	"
			Water quality, cation and anions	"	"
Parameter Category: Unsaturated-zone fluid flux					
Mean residence time of released carbon-14 dioxide in unsaturated-zone units, gas pathway (scenario class E, nominal case)	Controlled area; Unsaturated zone	Goal: Show residence time >10,000 yr Current: Low Needed: High	Gas flow paths, hydrochemical determination	"	8.3.1.2.2.7.1

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance				(SCP 8.3.5.13)
Performance Measures:					
Parameter Category: Unsaturated-zone fluid flux					
			Gas travel times, hydrochemical determination	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.1
			Water flow paths ($^{18}O/^{16}O$, D/H), pore waters	"	8.3.1.2.2.7.2
			Water travel times (^{14}C and ^{3}H)	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures: (Supporting parameters used in calculating performance parameters for ground-water travel time.) Ground-water travel time*, Topopah Spring welded unit (secondary reliance) Ground-water travel time*, Calico Hills non-welded, vitric unit (primary reliance) Ground-water travel time*, Calico Hills non-welded, zeolitized unit (primary reliance)					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
Isotopic ratios, ground-water residence time (Fractures)	Repository area; Unsaturated zone, each geohydrologic unit below repository	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low	Pore-gas composition	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.1
Isotopic ratios, ground-water residence time (Rock matrix)	"	Goal: Mean, SCor, SDev Current: NA, NA, NA Needed: Medium, Low, Low	Radioactive-isotope activity in gas phase (^{3}H and ^{14}C)	"	"
			Stable-isotope ratio in gas phase ($^{18}O/^{16}O$, $^{13}C/^{12}C$, and D/H)	"	"
			Pore water hydrochemical compositions	"	8.3.1.2.2.7.2
			Radioactive-isotope activity in liquid phase (^{3}H and ^{14}C)	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures: Ground-water travel time[e], Topopah Spring welded unit (secondary reliance) Ground-water travel time[e], Calico Hills non-welded, vitric unit (primary reliance) Ground-water travel time[e], Calico Hills non-welded, zeolitized unit (primary reliance)					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
			Stable-isotope ratio in liquid phase	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.2
			Water quality, cation and anions	"	"
Parameter Category: Unsaturated-zone fluid flux					
Distance along flow paths	Controlled area; TSw	Goal: >10 m (100%) Current: Medium Needed: Low	Gas flow paths, hydrochemical determination	"	8.3.1.2.2.7.1
"	Controlled area; CHnv	Goal: >2.5 m (100%), >25 m (80%) Current: Low, Low[f] Needed: High, Medium	Gas travel times, hydrochemical determination	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures: Ground-water travel time[e], Calico Hills non-welded, zeolitized unit (primary reliance)					
Parameter Category: Unsaturated-zone fluid flux					
Distance along flow paths	Controlled area; CHnz	Goal: >2.5 m (100%), >25 m (80%) Current: Low, Low[f] Needed: High, Medium	Water flow paths ($^{18}O/^{16}O$, D/H), pore waters	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.2
			Water travel times (^{14}C and ^{3}H)	"	"
Issue 1.10	Waste package characteristics (postclosure)				(SCP 8.3.4.2)
Performance Measures: Quality of liquid water that can contact the container					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
Mineralogy and water quality: rock-water interaction at elevated temperature	Repository area; Repository block: TSw2	Current: Needed: High	Pore-gas composition	"	8.3.1.2.2.7.1

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.10	Waste package characteristics (postclosure)				(SCP 8.3.4.2)
Performance Measures: Quality of liquid water that can contact the container					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
Mineralogy and water quality: vadose water composition	Repository area; Repository block: TSw2	Current: Needed: High	Radioactive-isotope activity in gas phase (^{3}H and ^{14}C)	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.1
			Stable-isotope ratio in gas phase ($^{18}O/^{16}O$, $^{13}C/^{12}C$, and D/H)	"	"
			Pore water hydrochemical compositions	"	8.3.1.2.2.7.2
			Radioactive-isotope activity in liquid phase (^{3}H and ^{14}C)	"	"
			Stable-isotope ratio in liquid phase	"	"
			Water quality, cation and anions	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.12	Seal characteristics				(SCP 8.3.3.2)
Performance Measures: Quantity of water					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
Chemistry of waters (if any); in faults, including sediment content		Goal: Elemental concentration similar to those contained in SCP Table 4-6 Current: Low Needed: Medium	Pore-gas composition	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.1
			Radioactive-isotope activity in gas phase (^{3}H and ^{14}C)	"	"
			Stable-isotope ratio in gas phase ($^{18}O/^{16}O$, $^{13}C/^{12}C$, and D/H)	"	"
			Pore water hydrochemical compositions	"	8.3.1.2.2.7.2
			Radioactive-isotope activity in liquid phase (^{3}H and ^{14}C)	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.12	Seal characteristics				(SCP 8.3.3.2)
Performance Measures:					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
			Stable-isotope ratio in liquid phase	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.2
			Water quality, cation and anions	"	"
Issue 4.4	Repository construction, operation, closure, and decommissioning technologies				(SCP 8.3.2.5)
Performance Measures: Removal rate equal to rate of inflow					
Parameter Category: Unsaturated-zone fluid flux					
Natural-water inflow	Repository facilities;	Goal: Actual inflow rate to accuracy of +/- 10 gpm Current: Low Needed: Medium	Gas flow paths, hydrochemical determination	"	8.3.1.2.2.7.1

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 4.4	Repository construction, operation, closure, and decommissioning technologies				(SCP 8.3.2.5)
Performance Measures:					
Parameter Category: Unsaturated-zone fluid flux					
			Gas travel times, hydrochemical determination	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.1
			Water flow paths ($^{18}O/^{16}O$, D/H), pore waters	"	8.3.1.2.2.7.2
			Water travel times (^{14}C and ^{3}H)	"	"

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

Accession Number: NNA.891031.0099

1992 SEP -6 A 10:01