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HYDROCHEMICAL CHARACTERIZATION OF THE UNSATURATED ZONE

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YMP - USGS - SP 8.3.1.2.2.7, R1

STUDY PLAN

JUNE 1993

RECORD OF REVISIONS

REVISION DATE REVISION <u>NUMBER</u> Study rationale and plans for two activities 07-13-90 RO Gaseous-phase chemical investigations (Section 3.1) Aqueous-phase chemical investigations (Section 3.2) 06-30-93 Revision in response to 1) changes in the R1 ESF, 2) changes in references and citations, and need to $\overline{3}$) enhance description of method development and reference to prototype test SIPs.

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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.

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1 PURPOSE AND OBJECTIVES OF STUDY

1.1 Furpose 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. 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 proposed mined geologic disposal system can be expected to 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:

S.3.1.2.2.7.1 - Gaseous-phase chemical investigations; and

o 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 relationship 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 unsaturated-zone in the Exploratory Studies Facility) and 8.3.1.2.2.5 (Diffusion tests in the exploratory studies facility), will study the in situ hydrologic characteristics of Yucca Mountain from ramps and underground drifts including Hydrochemical tests in the exploratory studies 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



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

cross references are provided for 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. These procedures have not been previously tried. Therefore, prototype tests to evaluate the feasibility of the proposed methods were conducted.

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.

Prototype tests include: tracer tests, triaxial compression tests, and uniaxial compression tests. These tests will develop and test techniques that are directly applicable to the gaseous- and aqueousphase 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 unsaturated-zone in the exploratory studies facility).

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, and their progress and development up-to-date are described below.

Pore water extraction by compression prototype testing has been ongoing for several years. Results to date indicate that pore water can be obtained from nonwelded cores with saturations as low as 16% and from welded cores with saturations as low as 37%. Chemical results indicate that chemistry changes caused by the compression process are insignificant relative to the differences that exist in the natural pore water chemistries due to differences in physical, hydrologic and chemical properties of different lithologic units as well as within lithologic units. This indicates that the compression procedure is an adequate means of collecting pore water samples. Results of this testing have been reported in Yang, et al, 1988; Peters, et al, 1992; Peters, et al, 1993; and several reports that are currently in preparation.

Aqueous and gaseous tracer prototype testing has been ongoing for several years. The aqueous laboratory testing has been completed and recommendations for primary, secondary, and tertiary aqueous tracers have been identified (Bowman, et al, 1990; Kool, 1990; and other reports currently in preparation). Field testing of aqueous tracers will be undertaken as opportunities arise. Gas tracer lab testing will be completed in 1993, preliminary recommendations for gas tracers will be identified in a report to be completed in 1994. Field gas tracer testing of the injection and withdraw of borehole drilling air has been ongoing, both at Apache Leap, AZ and at UZ16 at the NTS, and will continue during drilling in 1993 at the NTS. Results of the field gas tracer testing will be reported in publications at the conclusion of this testing.

Wet versus dry drilling prototype testing and perched water prototype testing were undertaken in G-tunnel in 1989-1990. Results of this testing will be discussed in reports by Chornack, et al, that are currently in process.

Additional methods development prototype testing, such as core sealing, near fracture water sampling, packer and borehole liner systems, etc., have been ongoing and will continue to be undertaken as situations warrant. Results of these tests will be documented in publications as they are completed.

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:

•	8.3.1.2.2.7.1 -	to unders:	tand the	transpo	ort 1	nechanis	m,	flow	direction	ı,
0 0.0.2.0.0	flux, and	travel	time of	gas	within	tne	unsa	aturated		
		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. Figure 1.2-2 depicts the relation between the stratigraphic, geohydrologic, and thermal/mechanical units at Yucca Mountain. Figures 1.2-3 and 1.2-4 show the location of the proposed repository block in relation to the gaseousand aqueous-phase sampling locations. Table 1.2-1 lists the chemical and isotopic analyses for the hydrochemical tests.

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.



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



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Figure 1.2-2. Diagram showing the relation of geohydrologic units to stratigraphic and thermal/mechanical units.



Figure 1.2-3. Map showing locations of repository site and gaseous- and aqueousphase sampling locations at Yucca Mountain, Nevada.



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Figure 1.2-4. Map showing locations of repository site and gaseous- and aqueous- | phase sampling locations at Yucca Mountain, Nevada (continued).

Parameter	Chemical species	Remarks
Inorganic cations and anions	Na, Ca, Mg, K, HCO ₃ , SO4, Cl, pH, SiO2, Mn, Fe, Al	Types of ongoing chemical reactions. Residence times of fracture fluids.
i. A	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, D/H ratios and ⁸⁷ Sr/ ⁸⁶ Sr.	Timing of major recharge events. Fluid inclusion in secondary minerals to identify the sources of water. ⁸⁷ Sr/ ⁸⁶ Sr will delineate past fluid pathways through the volcanic rocks. Important to understanding fracture flow.
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.
Contami nation check	Li, Br, I, NO ₃ , BO ₃	Washdown of tracers.

Table 1.2-1. Chemical and isotopic analyses

* ³⁶Cl 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).

Freon concentration is currently about 0.5 to 0.8 ppm in the atmospheric air, and can be used as a natural tracer in the determination of downhole air contamination.

1.3 Regulatory rationale and justification

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

The overall regulatory-technical relations between the SCP designand 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 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 complementary cumulative distribution function (CCDFs). For example, Scenario Class E has three CCDFs: one for the unsaturated-zone liquid pathway, one for the saturated-zone liquid pathway, and one for the gas pathway. Determination of each of these CCDFs depends upon data from



jure 1.3-1. Diagram showing interfaces of unsat interfaces hydrochemistry study with YMP performince insues and other site-characterization programs.

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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 7.1.

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;
- o Calculation of gas-phase ¹⁴C transport in the overburden units;
- o Model calibration and validation of gas-phase ¹⁴C transport; and
- o 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

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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 vadosezone 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, δ^{18} O values



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

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June 30, 1993

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range from -22.5 to +7.5% and δD values range from -158.5 to -8.0% of δD . 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 δ^{18} O values range from -22.2 to -7.5% and δD values range from -158.5 to $-53.0^{\circ}/_{\circ\circ}$. In general, winter snows are isotopically lighter than summer rains resulting in lower δ^{13} O and δ D 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 (δ^{18} O values range from -19.4 to -10.2°/₀₀; δ D values range from -149.5 to -75.0°/ $_{\infty}$; with a mean value of δ^{18} O = -14°/ $_{\infty}$ and δ D = $-103^{\circ}/_{\circ\circ}$). Isotopic data for precipitation collected at Yucca Mountain indicates δ^{18} O values range from -16.0 to -1.0°/_{oo}, and δ D values range from -125.0 to -5.0°/ $_{\infty}$. When data for precipitation that fell in quantities of less than 1 cm (0.4 in.) are excluded, the δ^{18} O values range from -16.0 to -10.0°/ $_{\infty}$, and δD values range from -125.0 to -65.0°/00.

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) δ^{18} O values of ground water beneath Yucca Mountain range from -14.2 to -13.4°/₀₀, and δ D values range from -108 to -99.5°/₀₀; (2) upper Fortymile Wash (UE-29a#2) has a δ^{18} O value of -12.8°/₀₀ and δ D value of -93.5°/₀₀; and (3) lower Fortymile Wash (J-2, J-3) has a δ^{18} O value of -12.9°/₀₀ and δ D value of -97.5°/₀₀. 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

Hvdrochemical 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 neutronhole (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, oral 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). A heavily fractured zone was observed in UE-25 UZ#4 cores 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 δ^{18} O and δ D values ranging from -12.5 to $-9.5^{\circ}/_{\circ\circ}$ and -94 to $-86^{\circ}/_{\circ\circ}$, respectively. Yucca Mountain precipitation that fell between April and October for 1983 to 1986, the δ^{18} O values range from -13.0 to -1.0°/ $_{oo}$, and δD values range from -96.0 to - $10.0^{\circ}/_{\infty}$. Precipitation that fell between November and March for 1983 to 1986, the δ^{18} O values range from -11.0 to -17.0°/ $_{oo}$, and δ D values range from -63.0 to -125.0%, All Yucca Mountain precipitation data fell on the Yucca Mountain precipitation line $[\delta D = 6.9(\delta^{18}O) \cdot 2.1]$. 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 δ^{18} O value of about -15.0°/_{co} and a δ D value of about -105.0°/ $_{oo}$, 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 ¹⁸O and D isotopes than the latter. The δ^{18} O and δ D 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

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in the wash (¹⁴C 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 δ^{18} O and δ D 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 δ^{18} O and δ D values of -12.9 and -97°/₀₀, 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 δ^{18} O and δ D 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 ¹⁴C 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 δ^{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 ¹⁴C ages. If fracture flow dominates, ¹⁴C ages of pore water in the fractures will be significantly younger than water in the matrix. Also δ^{18} O and δ D 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 ¹⁴C 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

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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, gas with caliche or calcite in the unsaturated zone. If exchange did occur, δ^{13} C values of the CO, gas would have shifted toward heavier δ^{13} C values because caliche and calcite δ^{13} C values are between 0 to $-5 \, {}^{\circ}/_{oo}$. 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 δ^{13} C value of $-21^{\circ}/_{\circ\circ}$, inferring silicate instead of caliche ($\delta^{13}C = -5.0$ to 0 °/₀₀) dissolution. If a significant amount of caliche dissolved into pore water, the $\delta^{13}C$ of bicarbonate water would be close to $-5.0^{\circ}/_{\circ\circ}$, instead of the observed $-21.0^{\circ}/_{\circ\circ}$. Since silicate rocks contain no carbon atoms, ¹⁴C 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 are drawn: (1) there appears to be no significant recharge from the unsaturated zone to the saturated zone beneath Yucca Mountain; however, more supporting data are needed; and (2) the likely flow paths of infiltrating water appears to be through fractures, bedded units, contacts between units, or the Calico Hills unit, with lateral or inclined flow (vertical flow through a large fracture such as Ghost Dance fault is possible). 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 gaseousphase 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, and

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from rock cores of radial boreholes and vertical boreholes during construction of the exploratory studies facility. Fracture-water samples taken directly from the ESF 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. Section 3.8 (Hydrochemistry tests) of YMP-USGS SP 8.3.1.2.2.4 (Unsaturated-zone percolation - ESF studies) discusses the collection and analysis of samples from the exploratory studies facility.

2.1.3 Parameters and testing strategies

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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 sitecharacterization activities (SCP 8.3.1) to design- and performanceassessment 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 Activity 8.3.1.2.2.8.1 (Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock).

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Site perameter	Spatial/geographic location	Geohydrologic+unit/structurs/ location
Gaseque-phase c	hemical investigations: 8.3.1.2	.2.7.1
Inseturated-zone fluid chemistry and tempe	rature, and age	
Pore-gas composition	Yucca Hountain vertical borenoles	Unsaturated zone (all units penetrated by site-vertical boreholes)
Radioactive-isotops activity in ses phase (³ H and ¹⁴ C)	-	•
Stable-isotope ratio in gas phase (¹⁸ 0/ ¹⁶ 0, ¹³ 0/ ¹² 0, and D/H)	•	
Unsaturated-zone fluid flux		
Gas flow paths, hydrochemical oetermination	Yucca Mountain vertical boreholes	Unsaturated zone (all unit) penetrated by site-vertics boreholes)
Gas travel times, hydrochemical determination	•	•
Aqueous - phase	chemical investigations; 8.3.1	.2.2.7.2
Unsaturated-zone fluid chemistry and ten	persture, and age	
Pore water hydrochemical compositions	Yucca Mountain vertical borenoies	Unsaturated zone (all unit penetrated by site-vertic borenoles)
Radioactive-isotope activity in Liquid pnase (³ H and ¹⁴ C)	•	•
Stable-isotope ratio in liquid phase	•	• ·
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Water quality, cations and anions

Table 2.1-1. Activity parameters derived from this Study

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Table 2.1-1. Activity parameters derived from this StudyContinued				
Site parameter	Spatial/geographic location	Geonyarologic-unit/structural Location		
Aqueous - pha	se chemical investigations; 5.3.1.2	.2.7.2		
Unseturated-zone fluid flux		Unsaturated zone (all units		
$\frac{100}{100}$, 10	TUECE MOLETERINE THE CTORY			

Water flow paths (180/180, D/N), pore waters

Tucca Aduntain Vertica

Unsaturated zone (all units penetrated by site-vertical borenoles)

water travel times (^{14}C and ^{3}H)



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YMP-USGS-SP 8.3.1.2.2.7.

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ure 2.1-2. Logic diagram of geohydrology program

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 (³H) analyses will be used to determine the residence time of pore and fracture water up to about 100 years; ¹⁴C analyses will extend the determination range from 100 to 40,000 years; and ³⁶Cl 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 unsaturatedrock 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, such as stated in section 1.1.1 of Page 1.1-3. 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 porewater extraction by triaxial and uniaxial compression tests). These tests are described in detail in Section 3.8 of YMP-USGS SP 8.3.1.2.2.4. 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 gaseousand 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 isolated intervals of each radial borehole and vertical borehole in the ESF as described in YMP-USGS SP 8.3.1.2.2.4 (Unsaturated-zone - ESF studies). In addition, a movable, inflatable multi-packer system will be used to collect gas samples from all open boreholes. These include Sandia boreholes (USW SD-1 through SD-8, UE-25 SD-9, USW SD-1 through SD-12), Fortymile-Wash boreholes (UE-25 FM#1 through FM#3, FMN#1 through FMN#9), and water-table boreholes (USW WT- and UE-25 WT-holes). All open boreholes will be checked for air contamination (test for gas tracer SF₆) before sample collection and capped and sealed after completion of sampling to prevent air from penetrating into the hole.

Also during the ESF construction, a small one-meter-deep horizontal hole will be drilled or jack hammered into the tunnel wall immediately after boring and gas samples collected for compositional analysis (Activity 8.3.1.2.2.4.8, Hydrochemistry tests in the exploratory studies 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 and vertical boreholes resulting from exposure of open boreholes for a longer period 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 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); 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); 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 (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 intact (non-fractured) drill cores. However, for the collection of fracture waters, depending on the size of a particular fracture
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<u>Lithelogic Unit</u>	Sample Frequency	Sample Number
Upper lithologic units (approximately 91 m 1300 ft . Tiva. bedded. Tucca Mountain. Pah Canyon	.30 m (1 ft) core sample/everv 1.5 m (5 ft)	≈60 samples
Topopan Spring units (approximately 274 m 1900 ft	.30 m (l 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 (l 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 (l ft) core sample/contact	≈10
Perched water zone wherever encountered	l water sample/zone	≈5

Total ≈120 samples/borehole

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 squeezing chips. 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 using commercially available "SEAMIST" for fracture-water collection. This fracture-water collection can be done at any open borehole.

Furthermore, hydrochemical testing at the exploratory studies facility (underground) will provide more accessible areas for sampling fracture versus matrix water. These areas include the horizontal radial boreholes, access ramps, drifts, and fault zones (see Activity 8.3.1.2.2.4.8, Hydrochemistry tests in the exploratory studies 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 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 fluidflow in unsaturated, fractured rock). The successful development of calibrated and validated numerical models of the gas-hydrologic system will increase confidence that the geohydrologic framework, distribution of input parameters, and nature of initial and boundary conditions are appropriate for utilization in performance and design analyses.

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 sitecharacterization 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

Table 2.1-3.	Relations between hydrologic 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 weided (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.
Gas-transport mechanism within the unsaturated zone is predominantly by diffusion mechanism, and little affected by the advection.	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.
No significant recharge from unsaturated zone to the saturated zone beneath the Yucca Mountain.	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.
Flow paths of infiltrating water into the unsaturated zone is likely through fractures, bedded units, contacts between units, or Calico Hills unit, with lateral or inclined flow.	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.
Volumes containing many pores and fractures are definable such that changes in boundary fluxes equal changes in internal moisture storage.	8.3.1.2.2.7.2	To determine the extent of water-rock interaction so that geochemical modeling can be performed to deduce the flow path and to understand the geochemical evolution of the unsaturated-zone water.

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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 : each zone, to test hypotheses, and to guide data collection furtner.

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 unsaturatedzone 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. 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 cavelopment of an unsaturated-zone model and to the geohydrologic modeling of the repository block under Yucca Mountain.

2.2 Constraints on the study

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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 studies facility 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 ESF 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.

Parameter	Analytical Procedure	Performed By*	Selected of Alternate	Standard or Non Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
ISOTOPES							500 7 8	•
"C	LSC	Geochron	S	5	> 0.5 L	1 to 40 K yrs	500 yrs, 3%	•
	TAMS	U of AZ	s	s	< 0.5 L	1 to 40 K yrs	2 K yrs, 5%	Ų
''c/''c	MS	USGS, GD (Threlkeld)	S	NS	> 0.2 L	-7 to -28 */	<u>+0.2 "/, +0.2 "/</u>	
'H	LSC	USGS, WRD (Michaels)	S	NS	10 ml	0 to 150 yrs	3 TU, 10%	1
PC1	TAMS	LLNL	S	S	200 mg Ci	40 to 900 K yrs	10 K yrs, 10%	
						150 to 1000 yrs	100 yrs, 15%	x
"Kr	PGC	USGS, WRD (Michaels)	٨	NS	> 120 kG	0 to 40 yrs	•	x
"0/"0	MS	USGS, WRD (Michaels)	S	S	2 ml	0 to -20 "/	<u>+0.2 "/_, +0.2 */</u> _	v
D/H	MS	USGS, WRD (Michaels)	S	S	2 ml	0 to -200 */	<u>+1 "/</u>	V
'He/'He	MS		A	s				` H

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* The analytical laboratories listed are not the only qualified laboratories to perform the analyses. Other laboratories would likely be added as approved vendors in the future by the QA Office.

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Parameter	Analytical Procedure	Performed By	Selected or Alternate	Standard or Non Standard	Optimal Sample Size	Expected Ringe	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,	GC- FID	Project	S	S	5 cc	0 to 2%	.01%, 3%	FF, R, S
SF.	GC- ECD	Project	S	s	5 cc	0 to 3 ppm	.01 ppm, 3%	FF, R, S
CH,	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	S	5 cc	75 to 85%	.1%, 3%	FF, R, S
Hydrogen	GC- HD	Project	Ŝ	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

S cc

S

Project

GC- FID

S

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

Ethylene

YMP-USGS-SP 8.3.1.2.2.7, R1

FF, R, S

.01 ppm, 3%

0 to 1 ppm

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Parameter	Analytical Procedure	Performed By*	Selected or Alternate	Standard or Non Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Refei ence
WATER								
Calcium	1CP AA	RMAL USGS, WRD	S A	s s	1 ml 10 ml	0 to 120 mg/L "	98%, 0.5 , 8%	D A,B,C,D ,G
Magnesium	I CP AA	RMAL USGS, WRD	S A	S S	1 ml 10 mi	0 to 20 mg/L w	94%, 0.4 , 7%	D A,B,C,D ,G
Socium	1CP AA	RMAL USGS, WRD	S A	S S	1 ml 10 ml	0 to 130 mg/L w	98%, 0.2 , 9%	D A,B, C,D ,G
Potassium	I CP AA	RMAL USGS, WRD	S A	s s	1 ml 10 mi	5 to 30 mg/L ₩	97%, 0.1 , 10%	D A,B,C,D ,G
Sulfate	1C C	RMAL USGS, WRD	S A	s s	.5 ml 10 ml	10 to 160 mg/L	103%, 0.5 , 7%	A,D F,G
Chlorid e	IC C T ISE	RMAL USGS, WRD USGS, WRD Project	S A A A	S S S S	.5 ml 10 ml 10 ml 10 ml	10 to 120 mg/L " " "	99%, 1.0 , 4% , 5% , 2 mv	A,D H,G 1,G HH
Silica	1 CP C DCP	RMAL USGS, WRD USGS, WRD	S A S	S S S	1 ml 10 mi 10 mi	60 to 100 mg/L ⊮ ⊮	, 12% , 5%	D В,G КК
<u>Hanganese</u>	ICP AA	RMAL USGS, WRD	S A	S S	1 mł 10 mł	0 to 100 ug/L "	101%, 2.0 , 8%	D A,B,C,D ,G

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

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* The analytical laboratories listed are not the only qualified laboratories to perform the analyses. Other laboratories would likely be added as approved vendors in the future by the QA Office.

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Parameter	Analytical Procedure	Performed By*	Selected of Alternate	Standard or Non Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
WATER (CONT.)	2							
Iron	ICP AA	RMAL USGS, WRD	S A	S S	1 mi 10 mi	0 to 10 mg/L H	107%, 0.9 , 10%	D A,B,C,D ,G
Aluminum	ICP AA DCP	RMAL USGS, WRD USGS, WRD	S A S	S S S	1 ml 10 ml 10 ml	1 to 10 mg/L #	95%, 0.8 , 17% , 5%	D A,B,C,D ,G KK
Rare earth	ICP/MS	RMAL		NS	2 ml	?	?	11
Lithium	AA	USGS, WRD	A	S	10 ml	0 to 20 ug/L	, 15%	C,G
Bromide	IC IECE ISE	RMAL USGS, WRD Project	S A S	S S S	1 ml 1 ml 10 ml	.1 to .5 mg/L "	93%, 0.8 , 2% , 4 mv	D G,K HH
Iodidë	C I SE	USG S, WRD Project	A S	S S	3 ml 10 ml	0 to 20 ug/L "	, 70% , 4 mv	G,L
Nitrate	10	RMAL	S	S	1 ml	1 to 10 mg/L	102%, 0.0	D
Baron	DCP C IC ISE	USGS, WRD USGS, WRD Project Project	S A S	S S S	10 mi 10 mi 2 mi 10 mi	0 to 20 ug/L " "	, 5% , 18% , 5% , 3 mv	` КК G,н D НН
Organo metallics	GC/MS	TBD	A	S	3 ml	?	?	.

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* The analytical laboratories listed are not the only qualified laboratories to perform the analyses. Other laboratories would likely be added as approved vendors in the future by the QA Office.

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Parameter	Analytical Procedure	Performed By*	Selected or Atternate	Standard or Non-Standard	Optimal Sample Size	Expected Range	Accuracy and Precision	Reference
WATER (LONT.)				_	2 -1	5 to 9 of	0.1. 0.1	0,6
рH	E	Project	S	S	.2 ML	5 (0 y pii		
SC	E	Project	S	S	.5 ml	200 to 900 uS	. 4%	P,G
Athalinity	F T	PMAL	S	S	.5 ml	40 to 200 mg/L	96%, 1.2	0
as CaCO,	ET	USGS	A	S	5 ml	*	, 124	4,6
Alkalinity as HCO,	D1C-D	USGS, WRD	٨	NS	2 ml	40 to 200 mg/L	, 7%	
Temperatura	61	Project	A	S	5 ml	10 to 40 C	0.3°C, 3%	
remperature	DT	Project	S	S	.5 ml	88	U.3 C, 34	

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

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* The analytical laboratories listed are not the only qualified laboratories to perform the analyses. Other laboratories would likely be added as approved vendors in the future by the QA Office. 8 .*

Parameter	Analytical Procedure	Performed By*	Selected or Alternate	Standard or Non-Standard	Optinal Sample Size	Expected Range	Accuracy and Precision	Reference
ROCK						0 to 40%	. 0.5%	**
Moisture	Oven Dry	Project	S	S	100g		·	
Concento	Distillation	Project	A	s	100 g	0 to 40%	, 0.5%	AA .
Mineralogy	Microscopy	Countral	s	s	2mm X 2mm	NA	95%, 5%	68
	Inin Sections	LEVEL		S	2mm X 2mm	NA	95%, 5%	88
	Flectron	USGS, GD	٨	S	1 cubic um	NA	95%, 5%	CC
1	Nicroprobe	•		_	150	MA	90%, 5%	DD
	X-ray diffraction	USGS, GD	*	S	IDU mg			
CEC	Ammonium Displace-	USGS, GD	A	S	100 g	0-150 millequivalent per 100 g	90%, 5%	GG
	ment		F	c	NA	10 to 60%	96%, 5%	EE
Porosity	Calculated	Project	3	, ,	100 cubic cm	10 to 60%	97%, 3%	EE
	Gas Pycnometer	H GN Core Labs	^	5				
Pore Size	Hercury Injection	TBD	S	S	2 cubic cm	.05 u to 2 mm	, .ì u	66
	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)

* The analytical laboratories listed are not the only qualified laboratories to perform the analyses. Other laboratories would likely be added as approved vendors in the future by the QA Office. YMP-USGS-SP 8.3.1.2.2.7, R1

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

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ABBREVIATIONS USED IN TABLE

A		ALTERNATE
AA		ATOMIC ABSORPTION
C	-	COLORIMETRIC
CEC	-	CATION EXCHANGE CAPACITY
DCP	-	DIRECT CURRENT PLASMA SPECTROMETRY
DIC-D	-	DISSOLVED INORGANIC CARBON - DOHRMAN
DT	•	DIGITAL THERMOCOUPLE
F	٠	ELECTROMETRIC
FCD		ELECTRON CAPTURE DETECTOR
ET	-	ELECTRONETRIC TITRATION
E10		FLAME IONIZATION DETECTOR
00	-	GAS CHROMATOGRAPHY
60		GEOLOGIC DIVISION
13		GLASS THERMOMETER
HO		HYDROGEN DETECTOR
10		ION CHROMATOGRAPH
ICP	•	INDUCTIVELY COUPLED PLASMA
IECE		ION EXCHANGE CHROMATOGRAPHIC ELECTROCHEMICAL
ISE	-	ION SELECTIVE ELECTRODE
1 L NL	•	LAWRENCE LIVERMORE NATIONAL LABORATORY
I SC	•	LIQUID SCINTILLATION COUNTER
ma		MILLIGRAM
MS		MASS SPECTROMETRY
NA		NOT APPLICABLE
NS	-	NON STANDARD
PGS		PROPORTIONAL GAS COUNTING
RMAL	-	ROCKY MOUNTAIN ANALYTICAL LABS
S	-	STANDARD OR SELECTED
SC	-	SPECIFIC CONDUCTANCE
T	-	TITRIMETRIC
TAMS	-	TANDEM ACCELERATOR MASS SPECTROMETRY
TBD	-	TO BE DETERMINED
TCD		THERMAL CONDUCTIVITY DETECTOR
TU	•	TRITIUM UNITS
USGS	•	UNITED STATES GEOLOGICAL SURVEY
WRD	-	WATER RESOURCES DIVISION
u	-	MICRON
ug	-	MICROGRAM

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

REFERENCES*

 American Public Health Association and others, 1980 - American Society for Testing and Materials, 1978 R Fishman and Bradford, 1982 - U.S. Environmental Protection Agency, 1979 C D - Faires and Boswell, 1981 Ε · Colovos and others, 1976 · Fishman and Friedman, 1985 G - O'Brien, 1962 - Clark, 1950 - U.S. Environmental Protection Agency, 1983 t .1 - Fishman and Pyen, 1979 - Mitchell, 1966 1 Johnson and others, 1979 • M Spencer and Erdmann, 1979 -N Durst, 1969 . 0 Hughes, 1966 Ρ • - Barnes, 1964 ۵ - Fritz and Schenk, 1976 R · Pecsok and others, 1976 S - International Atomic Energy Agency, 1967 1 - Donahue and others, 1984 U - Hoefs, 1987 ۷ - Damon and Green, 1963 W. - Lippolt and Gentner, 1963 X - Gardner, 1986 AA - Cady and others, 1986 **BB** - Sawhney, 1986 CC Whittig and Allardice, 1986 DD - Danielson and Sutherland, 1986 EΕ - Peters, 1988 FF - Chapman, 1965 GG - Sekeykra and Lechner, 1973 HH - U.S. Environmental Protection Agency, 1986 11 - Keirs and Vickers, 1977 KK

* Complete references appear in Section 6.

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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 "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.
- Reported accuracy and precision are one standard deviation with respect to standard Pee Dee Belemnite (PDB) values. USGS, GD (Threlkeld)
- Reported accuracy and precision for "0/"0 and D/H are one standard deviation with respect to Standard Mean Ocean Water USGS, WRD (Michaels) -(SMOW) values.
- 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 Laboratory Control Sample (LCS) is measured by Percent Recovery.

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

Measured Concentration LCS1 - Measured Concentration LCS2

RPD = (Measured Concentration LCS1 + Measured Concentration LCS2)/2

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. USGS, WRD (CENTRAL LAB) -

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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 : borenoles, 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 studies facility, 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).

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

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The study is organized into two activities:

0 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. ¹⁴C and tritium concentration measurements will determine the residence time of gases in the unsaturated zone. ¹³C/¹²C isotopic data will also be used in support of ¹⁴C age estimates. Stable-isotope ratios $\ell^{15}O/^{16}O$ 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 and vertical boreholes. Postconstruction-phase sampling will be from drilled and stemmed radial boreholes. A detailed discussion of hydrochemical sampling in the ESF is provided in Section 3.8 of YMP-USGS SP 8.3.1.2.2.4 (Unsaturated-zone - ESF studies).

Four different types of gas samples will be collected including gascomposition, ${}^{13}C/{}^{12}C$ 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.



ure 3.1-1. Logic diagram of the gaseous-phase c'

vical investigations showing tests, analyses, and m Fods.

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

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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 surfacebased boreholes that are drilled under Study 8.3.1.2.2.3 Characterization of Yucca Mountain percolation in the unsaturatedzone - surface-based study), and from packer intervals of the radial and vertical boreholes in the ESF as described in YMP-USGS SP 8.3.1.2.2.4 (Unsaturated-zone - ESF studies). Four types of gas samples will be collected from surface-based and radial and vertical boreholes in the ESF including (1) gas composition, (2) $^{13}C/^{12}C$ ratio. (3) ¹⁴C, 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 gascomposition 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, N₂, H₂, O₂, SF₆, 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 stainlesssteel 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 verified byprototype testing. The second method involves allowing the gas to flow into a 250- ml flow-through glass container.





- 3. ¹⁴C samples -- two methods will be used for ¹⁴C 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 -- The cold-trap method involves pumping the gas through a gas trap cooled by a dry-ice-alcohol slurry to remove the water vapor. Samples will be analyzed for tritium, D/H, and ¹⁸0/¹⁶0.

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 $^{\circ}$ C by a dry ice-alcohol slurry, collecting the CO₂ 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 CO₂ 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 (CH4) gas for gas counting. Water vapor collected as described in Section 3.1.3.1 requires no



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Figure 3.1-4. Schematic of degassing system for gaseous -phase chemical investigations.

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further preparation.

Sample collection and degassing using the molecular sieve/vacuumheating 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, SF₆, or a similar conservative-gas tracer which may have been introduced during aircoring of boreholes. Stable-isotope ratios $(^{18}O/^{16}O, ^{13}C/^{12}C, \text{ and D/H})$ will be analyzed using mass spectrometry. Gas counters will be used to determine tritium activity in water vapor. Large ¹⁴C samples $(^{14}CO_2$ gas) will be analyzed using conventional gas-counting methods. Small ¹⁻⁴C samples will be analyzed by tandem accelerator mass spectrometry (TAMS). ³⁹Ar and ⁸⁵Kr 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 (SF₆, CH₆, freon, etc.), using gas chromatography (GC).

¹⁴C and tritium concentration measurements are preferred over ³⁹Ar and ⁸⁵Kr. 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 ¹⁴C allows for a much smaller sample volume, because it can be measured by the TAMS. Furthermore, ³⁹Ar 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 ³⁹Ar. The feasibility of dating samples with ³⁹Ar and ⁸⁵Kr needs to be evaluated. Similarly, ²²²Rn will be evaluated with other noble gases. and if appropriate will be studied at Yucca Mountain. ³⁶Cl, 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.

Methods for collecting, transporting, storing, preparing, and analyzing gases from the unsaturated zone are nonstandard. Methods development will be an ongoing aspect of the gaseous-phase hydrochemistry investigations. The data produced during methods development will be investigated to determine its suitability for site characterization.

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.

Methods for collecting gases from core samples are being investigated in the pore-water extraction prototype study (USGS-SIP-6942G-15,RO). Methods to introduce, sample, and analyze gas tracer samples are being investigated in the tracer prototype study (USGS-SIP-6942G-05,RO).

3.1.4 Technical procedures

The USGS quality-assurance program plan for the YMP (U.S. Geological Survey, 1989) requires documentation of technical procedures for all technical activities that require quality assurance.

Table 3.1-2 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS number. Procedures that require preparation do not have procedures numbers and are labeled "TBD". 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.

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Dashes () indicate information is not available or not applicables		
Hethods (selected and alternate)	Site parameter	Expected range-
Arei	yses of gas samples	
ge dating of carbon dioxide gas samples wing conventional gas counter	Radioactive-isotope activity	1,000 yr to 40,000 yr
selected) Noe dating by scintillation counting of ³ N	•	up to 150 yr
in water vapor (selected)		39 150 en 1 000 we
³⁹ Ar dating of gas, ⁸⁵ Kr dating of gas	•	85 _{KF} - 0 to 40 yr
(alternate) Stable-isotope analyses (¹⁸ 0/ ¹⁶ 0 and D/M in water vapor, ¹³ C/ ¹² C in carbon dioxide gas) (selected)	Stable isotope ratio	18 _{0/} 16 _{0:} 0 to -20 per mil D/N: 0 to -200 per mi 13 _{C/} 12 _{C:} -7 to -28 per mil
Gas composition (including tracers) by gas chrometography (selected)	Pore-ges composition	$CO_2 \cdot 0 \text{ to } 2X$ $CH_4 \cdot 0 \text{ to 5 ppm}$ $H_2 \cdot 2 \text{ to 5 ppm}$
Mass spectrometry (alternate)	•	
Hydrocnemical determination by sample analysis and modeling (selected)	Gas flow paths, gas travel times, hydrochemical determination	
Hydrologic determination, other ectivities	•	

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Technical procedure number	Technical procedure	
Collection and transportation of gas samples		
HP-176	Field procedure for gas and water vapor sampling from open borehole	
HP-07	Use of a trace gas for determining atmospheric contamination in a dry-drilled borehole	
HP-56	Gas and water vapor sampling from unsaturated-zone test holes (stemmed)	
HP-176	Procedure to collect gas-composition samples at selected depth intervals in open unsaturated-zone boreholes	
HP-195	Method for heat evacuating gas storage and collection cylinders	
HP-236T	Installation and operation of PVC straddle packer string in UZ boreholes for gas and water vapor sampling	
HP-239T	Method for removing traced drilling air from unsaturated-zone boreholes	
Preparation of gas samples for analysis		
HP-86	Method for degassing carbon dioxide and water (vapor) samples from unsaturated-zone test holes	
HP-190T	Scientific notebook plan: silica gel dewatering	
Analysis of gas samples		
HP-160	Methods for analysis of samples for gas composition by gas chromatography	
HP-194	Approximation of relative humidity using a silica-gel tower, cold trap, and molecular-sieve within unsaturated-zone test holes as an aid in determining pumping efficiency	
HP-204	Liquid scintillation spectrometry method for tritium measurement of water samples	
HP-240	Method for analysis of CO ₂ and/or CH ₄ gas sample concentrations by gas chromatography using Summit Interests SIP 1000	

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

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

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3.2 Aqueous-phase chemical investigations

3.2.1 Objectives of the activity

The objectives of this activity are:

- to design and implement methods for extracting pore water from unsaturated-zone tuff;
- 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 ¹⁴C 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 ¹⁴C 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 lanoward-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 meanvalues 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, U-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 δ^{19} 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 δ^{18} O and δ D 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 δ^{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 studies facility radial boreholes) will aid in identifying source and amount of ground-water recharge. From the age of water determined by ¹⁴C 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.,

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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 ¹⁸0 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. Furthermore, the age of water determined by ¹⁴C 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 porewater 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), surfacebased 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, Unsaturated-zone - ESF studies). Samples will also be checked for the presence of artificial tracers (USGS-SIP-6942G-05, Prototype tracer testing [gas and water]in support of exploratory studies hydrologic investigations) 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), 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 Section 3.8 of YMP-USGS SP 8.3.1.2.2.4.8 (Hydrochemistry tests in the exploratory studies facility). Drycoring procedures will be used for collecting samples for aqueousphase 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 -- surfacebased study).

When samples are available after coring, procedures for handling those samples are as follows: (1) the samples will be preserved and marked with an indelible marker on tape and placed in storage containers; (2) the sealed and containerized core 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 coremoisture preservation; (3) the samples are prepared for onedimensional 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 have been investigated (Striffler and others, 1993).

The effects of dry coring (i.e., evaporative enrichment of the core-sample water) are being investigated in two prototype tests: (1) wet versus dry drilling and (2) dry coring of rubble samples. These tests have been described in detail in Sections 3.8.3.4, 3.8.3.5, and 3.8.3.6 in Study 8.3.1.2.2.4 (Unsaturated-zone - ESF studies).



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

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

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Transfer of unsaturated-zone cores sealed and preserved in the containers from field site to Denver Laboratory is conducted according to the technical procedure HP-131 of U.S. Geological Survey.

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 i-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 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.



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

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

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

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 chemicalconcentration 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 one-dimensional 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 ¹⁴C samples will be analyzed using conventional gas-counting methods. Small ¹⁴C samples will be analyzed by tandem accelerator mass spectrometry (TAMS). ³⁶Cl will be analyzed using TAMS. ³⁹Ar and ³⁵Kr 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, NO₃, SF₆, 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, ¹⁴C and tritium are preferred over ³⁹Ar and ⁸⁵Kr. 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, ³⁹Ar and ⁸⁵Kr 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, ³⁹Ar 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 ³⁹Ar. Nevertheless, the feasibility of dating samples with "Ar and ⁸⁵Kr 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.

¹⁴C 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 largetemperature 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 methods, expected range, and interference with other tests and analyses.

Methods for collecting, transporting, storing, preparing, and analyzing water from the unsaturated zone are nonstandard. Methods development will be an ongoing aspect of the aqueous phase hydrochemistry investigations. The data produced during methods development will be investigated to determine its suitability for site characterization.

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. 1989) requires documentation of technical procedures for all technical activities that require quality assurance.

Table 3.2-2 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS number. Procedures that require preparation do not have procedures numbers and are labeled "TBD". 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.

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chanical investigations (SCP Activity 8.3.1.2.2.7.2)					
Dashes () indicate info	metton is not available or not a	pplicable.)			
Nethods (selected and alternate)	Site parameter				
Ana	lyses of water samples				
⁴ C dating on ground water selected)	Redicactive-isotope activity	1,000 to 40,000 yr			
Ge-dating of carbon dioxide in water samples using tandem-accelerator wass spectometry (selected)	•	•			
³ Y dating of ground water (selected)	-	Up to 150 yr			
³⁶ ct dating of ground water (alternate)	-	Up to 900,000 yr			
³⁹ Ar dating of ground water, ⁸⁵ Kr dating of ground water	-	³⁹ Ar - 150 to 1,000 yr ⁸⁵ Kr - 0 to 40 yr			
(alternate) Stable-isotope analyses (¹⁸ D/ ¹⁶ D, D/H, and ¹³ C/ ¹² C ratios) (selected)	Stable-isotope ratio	18 _{0/} 16 _{0:} 0 to -20 per mil D/H: 0 to -200 per mil			
Mass spectrometry for other stable isotopes (atternate)	-	••			
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 0/ ¹⁶ 0 and D/M), pore waters	••			
Nverochamical determination, other activities (alternate)	•	••			

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Hethods (selected and alternate)	Site parameter	Expected range
Analys	ses of water samples++Continued	
ydrochemical determination by sample nalysis and modeling selected)	Water travel times (14 C and 3 H)	
verochemical determination, other activities	•	••

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

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Technical procedure number	Technical procedure
Colle	ection and transportation of water samples
HP-131	Methods for handling and transporting unsaturated- core and rubble samples for hydrochemical analysis
HP-237T	Methods for sealing unsaturated zone borehole core samples to preserve moisture content
J	Extraction of water from core samples
HP-125	Methods for extraction of pore water from tuff cores by triaxial compression
HP-126	Extraction of residual water from tuff samples by vacuum distillation
HP-223	Method for pore-water extraction using one- dimensional compression
HP-110	Extraction of pore waters by centrifuge methods
	Analyses of water samples
HP-202	Analysis of water samples for anion and cation concentrations by ion chromatography
HP-204	Liquid scintillation spectrometry method for tritium measurement of water samples

Table 3.2-2. Technical procedures for the aqueous-phase chemical investigations (SCP Activity 8.3.1.2.2.7.2)*

* 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 7.1 provides additional detailed parameter relations (see Table 7.1-1).

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

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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 unsaturatedzone 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 studies 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 studies 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

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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 unsaturatedzone characterization. These data will be used in addressing repositorydesign 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 preemplacement 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 surfacebased 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.



Figure 5.1-1a Summary network for the unsaturated-zone hydrochemistry study.

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5.2 Milestones

The milestone numbers, titles, and levels 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. Specific dates for the milestones are not included in the table, as project schedules have been revised from those originally stated in Section 5 of the SCP, and are subject to further change due to ongoing planning efforts.

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Milestone Number	Milestone	Milestone Level
Gaseous-phase chem	ical investigations: Activity 8.3.1.2.7.7.1	
P715	Preliminary evaluation of UZ hydrochemistry	2
P736	Final evaluation of hydrochemistry	2
H20M	HP for straddle packer	3
H21M	Straddle-packer evaluation	3
H44M	WRI open file report: UZ1 data 1984-1991	3
H50M	WRIR report: Write monitoring gas tracer	3
H56M	OFR: UZ1, UZ6s, UZ16 data for FY92 & FY93	3
P710	Preliminary analysis, gas sampling of UZ	3
P731	Final analysis of gas sampling of UZ	3
H19M	HP: Portable GC, SF6 meter	. 4
H27MA	TDIF for UZ1 raw data to LRC 1984-1991	4
H46M	OFR: UZ1 gas and water vapor data 1984-1991	4
H48M	Interpretative report: Gas and water vapor data	4
Aqueous-phase che	emical investigations: Activity 8.3.1.2.7.7.2	
H14M	Report: Fracture water collection method	3
H214M	Preliminary analysis aqueous phase UZ hydrochemistry	3
H413M	Final analysis aqueous phase UZ hydrochemistry	3
HA12M	Open file report: SP, DTPS, proto & UZ hydrochemistry	3
HA14MA	HP technical procedure: Collection method for H20	3

Table 5.2-1. Milestone list for Study 8.3,1,2,2,7

Milestone Number	Milestone	Milestone Level
Aqueous-phase chem	tical investigations: Activity 8.3.1.2.7.7.2	
H013M	HP: Fracture H ₂ 0	4
H022M	Report: Effects of core sealing	4
H02M	TDIF	4
НАОМ	TDIF	4

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Table 5.2-1. Milestone list for study 8.3.1.2.2.7)--Continued

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7 APPENDICES

7.1 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 7.1-1 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 7.1-1 Design and	performance issues and param	rmance 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	
	tssue 1.1	lotal system performance			(SCP 8	.3.5.13)	
	Performance Heasures: (Su EPPI	pporting parameters needed to M [®] , nominal case, release sco	o evaluate the nominal case a enario class E, gas pathway r	nd as baseline data for the dis elease	sturbed cases.)		
		Parameter Category: 1	Insaturated zone fluid chemis	try and temperature, and age		~	
7.1-2	Profile of partial pressure of CO ₂ (Ambient rock mass)	Repository area; Unsaturated-zone units, overburden	Gual: No goal Current: Low Needed: Medium	Pore-gas composition	Yucca Hountain 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 tiquid phase (Ambient rock mass)	•	89	Radioactive-isotope activity in gas phase (³ H and ¹⁴ C)	•	4	
Jun	Profile of carbon-14 concentration (Ambient, rock mass pore spaces)	•	Goal: Io be determined Current: Low Needed: Medium	Stable-isotope ratio in gas phase (¹⁸ 0/ ¹⁶ 0, 13 <mark>C/¹²C, unkt D/H)</mark>	8	•	
e 30, 1993	Hajor-ion water chemistry (composition, Eh, pH); ambient rock-mass pore fluids		••	Pore water liydiochemicał compositions	a	8.3.1.2.2.7.2	

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	fable 7.1-1 Design a	nd performance issues and parame	ters supported by results of th	nis study	
Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
	otal system performance			(SCP I	3.3.5.13)
Performance Measures: EPPM	^e , nominal case, release	scenario class E, gas pathway re	leose		
	Parameter Category	: Unsaturated zone fluid chemist	ry and temperature, and age		
			Radioactive-isotope activity in liquid phase (³ H and ¹⁴ C)	Yucca Hountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.2
			Stáble-isotope ratio in Liquid phase	16	-
			Water quality, cation and anions	w	. •
	Par	ameter Category: Unsaturated-zor	l ne 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	a .	8.3.1.2.2.7.1

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	Table 7.1-1 Design and	d performance issues and parameters supported by results of this study				
Design and Performance Parameters	Parameter tocation	Parameter Gool and Confidence (Current and Needed)	Site Parameters	Peremeter Location	Site Activity	
ssue 1.1 To	tal system performance			(SCP	8.3.5.13)	
rformance Heasures:						
	Parame	ter Category: Unsaturated-zoni	e fluid flux			
			Gas travel times, hydrochemical	Yucća Hountain vertical boreholes; Unsaturated	8.3.1.2.2.7.1	

determination

waters

Water flow paths (¹⁸0/¹⁶0, D/H), pore

Water travel times (14 C and 3 H)

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8.3.1.2.2.7.2

zone (all units

site-vertical boreholes)

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penetrated by

		Table 7.1-1 Design and p	performance issues and paramet	ters supported by results of th	his study	······
	Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter location	Site Activity
	Issue 1.6 5	Pre-waste-emplacement, ground-	water travel time		(SCP 8.	.3.5.12) ,
	Performance Measures: (Su Grou Grou Grou	pporting parameters used in ca und-water travel time [®] , lopopa und-water travel time [®] , Calico und-water travel time [®] , Calico	alculating performance paramet sh Spring welded unit (second o Hills non-welded, vitric un o Hills non-welded, zeolitized	ters for ground-water travel t ary reliance) it (primary reliance) d unit (primary reliance)	1 mc - <i>)</i>	
7 1 5	isotopic ratios, ground-water residence time (fractures)	Parameter Category: Un Repository area; Unsaturated zone, each geohydrologic unit below repository	nsaturated-zone fluid chemist Goal: Hean, SDev Eurrent: NA, NA Needed: Hedium, Low	ry and temperature, and age Pore-gas composition	Yucca Hountain 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: Hedium, Low, Low	Radioactive-isotope activity in gas phase $({}^{3}H$ and ${}^{14}C)$ Stable-isotope ratio in one phase $({}^{18}O/{}^{16}O)$	68 18 1	54
June				13 _{C/} 12 _{C, and D/II)} Pore water hydrochemical compositions	••	8.3.1.2.2.7.2
30. 1993				Radioactive-isotope activity in liquid phase (³ H and ¹⁴ C)	*	56

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		Table 7.1-1 Design and	performance issues and param	eters supported by results of t	his stikly	
		.			• • • •	
Des i gn Pa	and Performance arumuters	Parameter Location	Parameter Goal and Confidence (Corrent and Needed)	Site Parameters	Parameter Location	Site Activity
issue 1.	.6	Pre-waste-emplacement, groun	d-water travel time		(SCP 8	.3.5.12)
Perform	nce Measures: Gro Gro Gro	ound-water travel time ^e , Jopo ound-water travel time ^e , Cali ound-water travel time ^e , Cali	pah Spring welded unit (secon co Hills non-welded, vitric u co Hills non-welded, zeolitiz	dary reliance) nit (primary reliance) ed unit (primary reliance)		
		Parameter Category:	Unsaturated zone fluid chemis	try and temperature, and age	,	
) 			с. ,	Stable-isotope ratio in liquid phase	Yucca Hountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.2
		,		Water quality, cation and anions	N	••
		Param	eter Category: Unsaturated-zo	ne fluid flux		
Distance	e atong flow paths	s Controlled area; 15w	Goal: >10 m (100%) Current: Medium Needed: Low	Gas flow paths, hydrochemical determination	u	8.3.1.2.2.7.1
		Controlled area; CHnv	Goal: >2.5 m (100%), >25 m (80%) Current: Low, Low ^f Needed: High, Hedium	Gas travel times, hydrochemical determination		*

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Table 7.1-1 Design an	d performance issues and parame	ters supported by results of t	his study	· · ·
Design and Performance Parameter Location Parameters	Parameter Goat and Confidence (Current and Needed)	Site Paraneters	Parameter location	Site Activity
A Pre-waste-emplacement, gro	nd-water travel time		(SCP	3.3.5.12)
erformance Measures: Ground-water travel time ^e , Cal	ico Hills non-welded, zeolitize	ed unit (primary reliance)		
Para	ameter Category: Unsaturated-zon	ne fluid flux		
listance along flow paths — Controlled area; CHnz	Goal: >2.5 m (100%), >25 m (80%) Current: Low, Low ^f Neccled: High, Medium	Water flow paths (¹⁸ 0/ ¹⁶ 0, D/H), pore waters	Yucca Mountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	6.3.1.2.2.7.2
		Water travel times (¹⁴ C and ³ K)	H	**
Usete package characterist	(cs (postclosure)	I	(SCP	8.3.4.2)
Performance Measures: Quality of liquid water that	can contact the container			
Parameter Categoly	: Unsaturated zone fluid chemis	try and temperature, and age		×
Mineralogy and water Repository area; quality: rock-water Repository block: ISw2 interaction at elevated temperature	Current: Needed: High	Pore gas composition	*	8.3.1.2.2.7.1

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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 Heasures. Qui	ality of liquid water that can	contact the container			
	Parameter Category: N	hisaturated zone fluid chemist	try and temperature, and age		
Mineralogy and water quality: vadose water composition	Repository area; Repository block: ISw2	Current: Needed: High	Radioactive isotope activity in gas phase (³ H and ¹⁴ C)	Yucca Hountain 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/II)	••	4
•			Pore water hydrochemical compositions	•	8.3.1.2.2.7.2
			Radioactive isotope activity in liquid phase (³ H and ¹⁴ C)	bi L	**
			Stable isotope ratio in Liquid phase	M	
			Water quality, cation and anions	•	*

Table 7.1-1 Design and performance issues and parameters supported by results of this study Site Activity Parameter Location Site Parameters Parameter Goal and Parameter Location Design and Performance Confidence Parameters (Current and Needed) (SCP 8.3.3.2) Seal characteristics Issue 1.12 Performance Measures: Quantity of water Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age 8.3.1.2.2.7.1 Yucca Hountain vertical Pore-gas composition Goal: Elemental boreholes; Unsaturated Chemistry of waters (if 1 concentration similar to any); in faults, zone (all units those contained in SCP Including sediment penetrated by ò Table 4.6 site-vertical boreholes) content Current: Low Needed: Hedium Radioactive-isotope activity in gas phase (³H and ¹⁴C) Stable isotope ratio in gas phase (¹⁸0/¹⁶0, 13C/12C, and D/H) 8.3.1.2.2.7.2 Pore water hydrochemical June compositions 30, ... Radioactive isotope activity in tiquid phase 1993 (³H and ¹⁴C) :

Design and Performance Pa Parameters	arameter Location	Parameter Goal and Confidence (Current and Needed)	Site Paraneters	Parameter Location	Site Activity
ssue 1.12 Seal characteristics				(SCP 8.3.3.2)	
erformance Measures:					
	Parameter Category: U	usaturated-zone fluid chemist	ry and temperature, and age		
			Stable-isotope ratio in liquid phase	Yucca Nountain vertical boreholes; Unsaturated zone (alt units penetrated by site-vertical boreholes)	8.3.1.2.2.7.
			Water quality, cation and anions	**	
ssue 4.4 Reposito	ery construction, oper	ation, closure, and decommiss	ioning technologies	(SCP 8	.3.2.5)
erformance Heasules: Removal rat	e equal to rate of in	flow		·	
			<u> </u>		
	Past ame	ter Lategory: Unsaturated zon	e fluid flux		
aturat water inflow Repor	itory incitities;	Goal: Actual inflow rate to accuracy of +/- 10 gpm	Gas flow paths, hydrochemical determination	"	8.3.1.2.2.7.
•		Luccent: Low			

Table 7 1.1 Design and performance issues and parameters supported by results of this study

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Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter location	Sile Activity
ssue 4.4	Repository construction, oper	ation, closure, and decommiss	ioning technologies	(SCP 8.3.2.5)	
rformance Neasures:	Paramo	ter Category: Unsaturated-zoi	ne fluid flux		
			Gas travel times, hydrochemical determination	Yucca Hountain vertical boreholes; Unsaturated zone (all units penetrated by site-vertical boreholes)	8.3.1.2.2.7.
			Water flow paths (¹⁸ 0/ ¹⁶ 0, D/H), pore waters		8.3.1.2.2.7. ,
		•	Water travel times (¹⁴ C and ³ H)	•	**

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