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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
STUDY PLAN APPROVAL FORM

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Study Plan Number 8.3.1.2.2.6

Study Plan Title Characterization of the Yucca Mountain Unsaturated-Zone Gaseous - Phase Movement

Revision Number 1

Prepared by: USGS

Date: 8/20/93

Approved:

Susan Jones for J R Dyer 9/30/93
Director, Regulatory and Site Evaluation Division / Date

R.E. Spence 9/22/93
Director, Quality Assurance Division / Date

Effective Date: 10/4/93

RECORD OF REVISIONS

REVISION NUMBER	*REVISION*	*DATE*
R0	Study rationale and plans for one activity Gaseous-phase circulation (Section 3.1)	10/04/90
R1	Revisions based on USGS responses to state of Nevada comments, rewording of references to the Exploratory Study Facility and USGS editorial changes.	03/30/93

ABSTRACT

This study plan describes a single site-characterization activity to evaluate gaseous-phase circulation at Yucca Mountain, Nevada. This activity will contribute to an understanding of the pre-waste emplacement gas-flow field in the presence of open boreholes and the ESF excavations, including an understanding of controlling factors, and transmissive and storage properties for gas flow.

The rationale for this study is described in Sections 1 (regulatory rationale) and 2 (technical rationale). Section 3 describes the specific plans for the gaseous-phase circulation activity, including tests and analyses to be performed, the selected and alternate methods considered, 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 Purpose of the study plan

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

This study plan describes the USGS approach and methods to develop an understanding of the processes that cause gaseous-phase circulation through the unsaturated rock comprising Yucca Mountain based on observations and tests made at one site. The study consists of one activity:

- 8.3.1.2.2.6.1 - Gaseous-phase circulation study

Results of this study will be used in conjunction with data collected from Studies 8.3.1.2.1.1, Characterization of the meteorology for regional hydrology; 8.3.1.2.2.3, Characterization of percolation in the unsaturated zone (surface-based study); 8.3.1.2.2.7, Hydrochemical characterization of the unsaturated zone; and 8.3.1.2.2.8, Fluid flow in unsaturated, fractured rock, to characterize gas circulation through Yucca Mountain.

The numbers (e.g., 8.3.1.2.2.6.1) used throughout this plan refer to specific sections of the YMP Site Characterization Plan (SCP) (U.S. Department of Energy, 1988). The SCP describes the overall site-characterization program including general descriptions of the activity described in detail in Section 3 of this study plan.

Figure 1.1-1 illustrates the relationship of the gaseous-phase movement study within the SCP Geohydrology Program organization. This study is one of nine planned to characterize the unsaturated zone at Yucca Mountain. Seven of the studies are surface-based evaluations. Two studies, 8.3.1.2.2.4 (Characterization of the unsaturated zone in the exploratory-studies facility (ESF)) and 8.3.1.2.2.5 (Diffusion tests in the ESF) will attempt to delineate the *in situ* hydrologic characteristics of rocks beneath Yucca Mountain by utilizing underground ramps and drifts. The single activity in the present study was selected on the basis of a number of factors, including design/performance-parameter needs, available test/analysis methods, test scale, and time requirements. (*Parameter* is used in this plan to mean a property, characteristic, and/or the numerical value of a constant that is used to describe the unsaturated-zone hydrologic system.) These factors are described in Sections 2 and 3.

The description and plans for the gaseous-phase circulation study are presented in Section 3. The description includes (a) objectives and parameters, (b) technical rationale, and (c) tests and analyses. Alternate test and analysis methods are summarized.

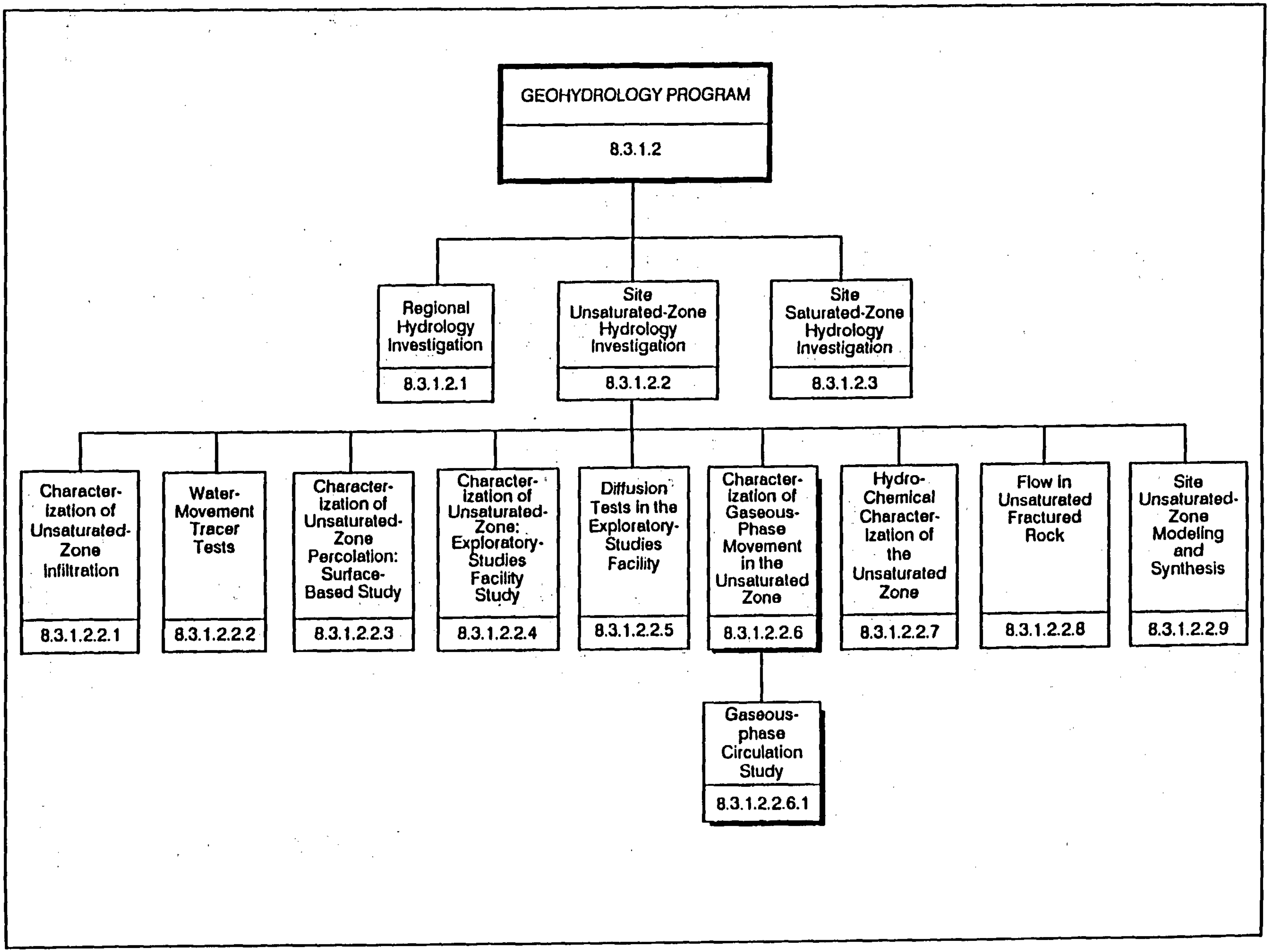

Figure 1.1-1. Diagram showing the location of study within the unsaturated-zone investigation and anization of the Geohydrology Program.

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

1.2 Objectives of the study

The objectives of the gaseous-phase movement study are to (1) describe the pre-waste-emplacement, gas-flow field in the presence of open boreholes and the ESF excavations; (2) develop an understanding of the factors that produce and affect this flow field, including topographic, stratigraphic, and structural controls; (3) determine transmissive and storative properties for gaseous flow; (4) develop a history of air circulation at the instrumented boreholes from the time of drilling until the holes are stemmed, as an aid in evaluating the time following stemming before ambient conditions are restored; (5) determine fracture porosity-gas filled matrix porosity ratios and factors controlling gaseous exchange between the two, and/or the dispersivity of the fracture network to gas flow and transport; (6) determine changes caused in the gas-phase flow field as ESF excavations are advanced beyond open boreholes near the line of the ESF excavations; and (7) to develop a preliminary model of the transport of individual gaseous species.

This study was developed in response to the recognition, following a presentation by Doral Kemper (Kemper and others, 1986) in January 1986, that there is potential for substantial topographically affected gas circulation through Yucca Mountain. At the time of Kemper's presentation the phenomenon was little recognized, and its potential significance to repository performance was unknown. Since 1986, gas circulation at Yucca Mountain crest through open boreholes has received much preliminary study, whose results have been published (Weeks, 1987; Kipp, 1987b; and Thorstenson and others, 1990). Work at the USW UZ-1 (Yang and others, 1985) supports the absence of thermal-topographic gas flow at that site.

The data in these papers can be very briefly summarized as follows. About 1.3 x 10^6 m^3/yr of gas exit USW UZ6s, with 80 percent of the flow from the upper 30.5 m of the borehole. All of the rock gas sampled to date from the top 100 m of the Tiva Canyon formation has a post-bomb ^{14}C signature. These observations, documented in detail in the cited publications, show that substantial thermal-topographic gas flow occurs at the location of USW UZ6s and USW UZ6 on Yucca Mountain crest, and that gas flow of undetermined magnitude might be anticipated at Yucca Mountain crest under natural conditions. The observations to date are that the thermal-topographic flow is primarily very shallow and thus the effects on performance assessment remain indeterminate.

The main focus of the study has been, and continues to be, to measure flow, temperature, and composition of the gas circulating to or from the two boreholes, with the emphasis to date being on the thermal topographic flow in USW UZ6s. Boreholes USW UZ6 and USW UZ6s were drilled in 1984 and 1985 to provide access for unsaturated-zone instrumentation, and still remain open through thick sections of the unsaturated zone. The wells are as yet unstemmed, and thus continue to provide a target of opportunity to study gaseous-phase circulation. These two boreholes are particularly appropriate to the study of gas circulation at Yucca Mountain because of their location at Yucca Mountain crest, where the thermal-topographic effects are maximized, and their central (N-S) location with respect to the proposed repository block. They are the only presently open boreholes at Yucca Mountain crest that penetrate the welded tuffs of the Tiva Canyon formation and the Topopah Springs formation through and below the proposed repository horizon.

Tests in other boreholes as they are drilled will be performed at the same time that the gas permeability testing and hydrochemical study of pre-pumping is taking place prior to the stemming process. These boreholes will represent various topographic regions of the mountain. The unsaturated- zone hydrochemistry and air permeability studies will provide information which can be used for interpretations by the gas phase circulation study.

Tests in open boreholes near the line of the proposed ESF excavations will help to determine the effects of ESF excavations on the gas-phase flow field. Additionally, tracer testing conducted between boreholes constructed from ESF excavations and the open boreholes near the line of the excavations may be conducted to further quantify these changes.

Figure 1.2-1 shows the location of Yucca Mountain in southern Nevada, where the gaseous-phase movement tests will be performed. Figure 1.2-2 shows the location of some of the boreholes to be used in the study. Figure 1.2-3 is a schematic showing the relative locations of the two wells (USW UZ-6 and USW UZ-6s), as well as those of neutron access holes (USW N71-N76 and USW N93-N95) for which ancillary data on gas pressure and composition are to be collected. Figure 1.2-4 shows a generalized cross section of Yucca Mountain, showing the open sections of wells USW UZ-6 and USW UZ-6s.

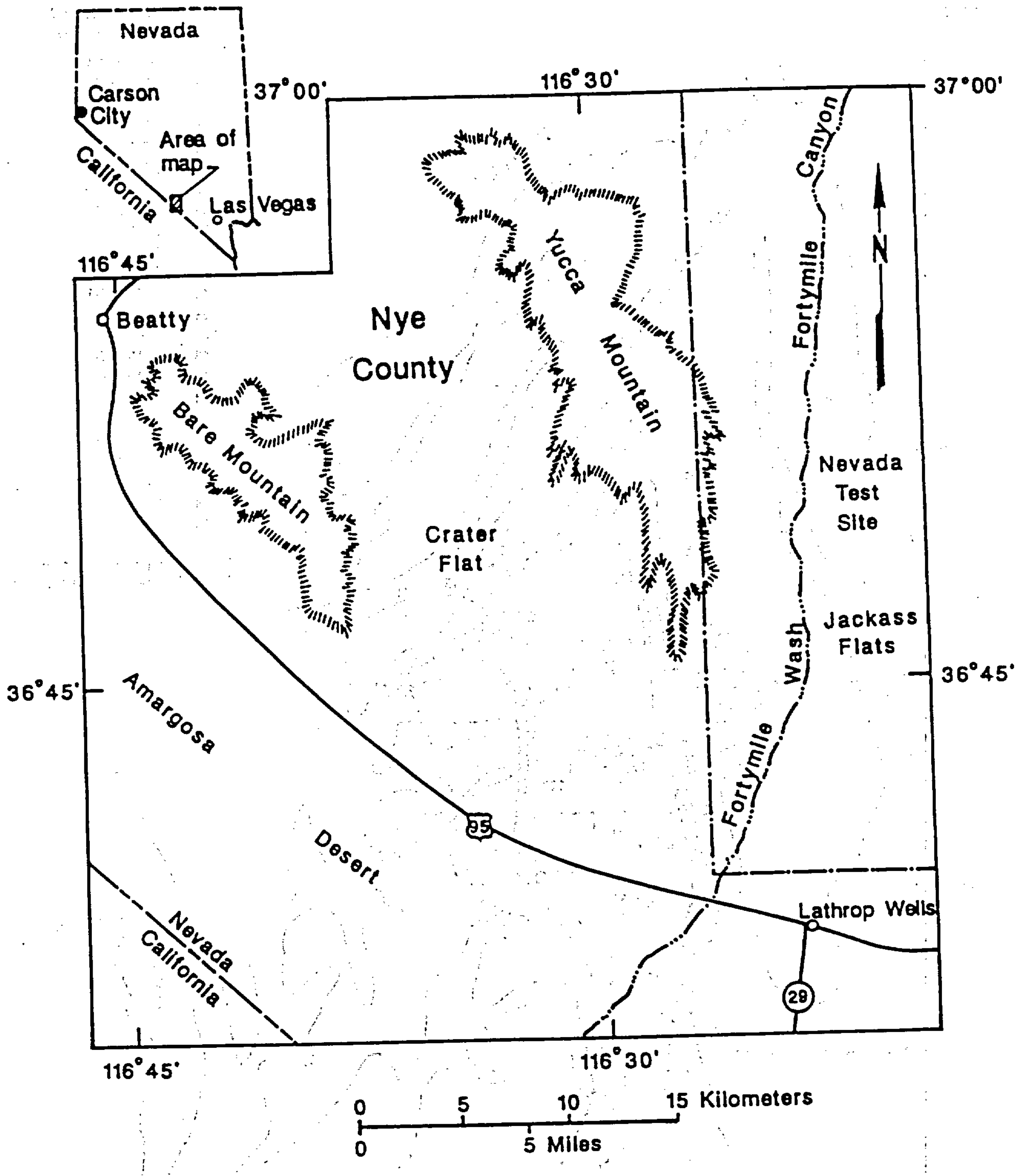

Figure 1.2-1. Map showing the location of Yucca Mountain.

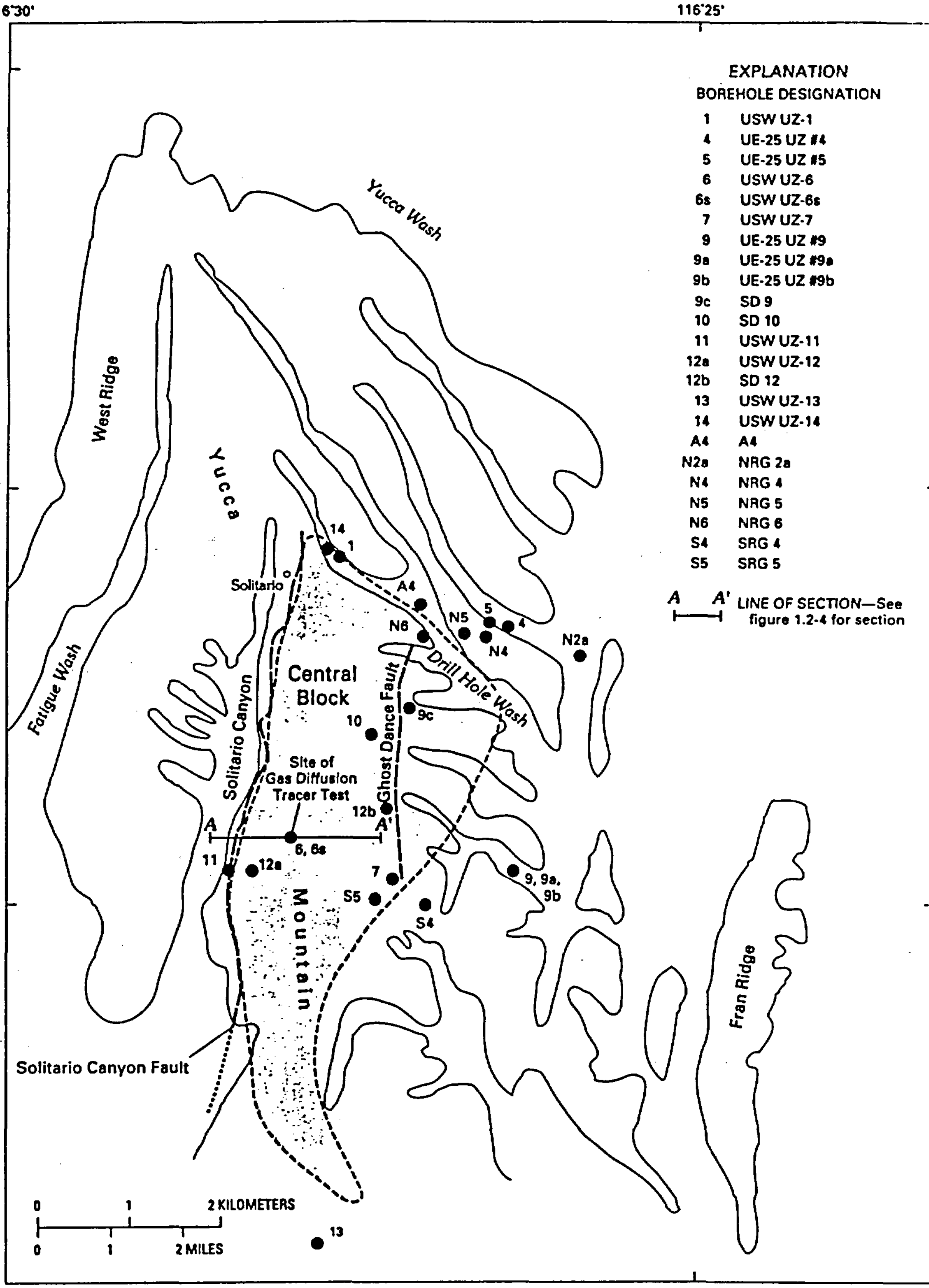

Figure 1.2-2. Map showing the location of some of the boreholes to be used in the gaseous-phase circulation study.

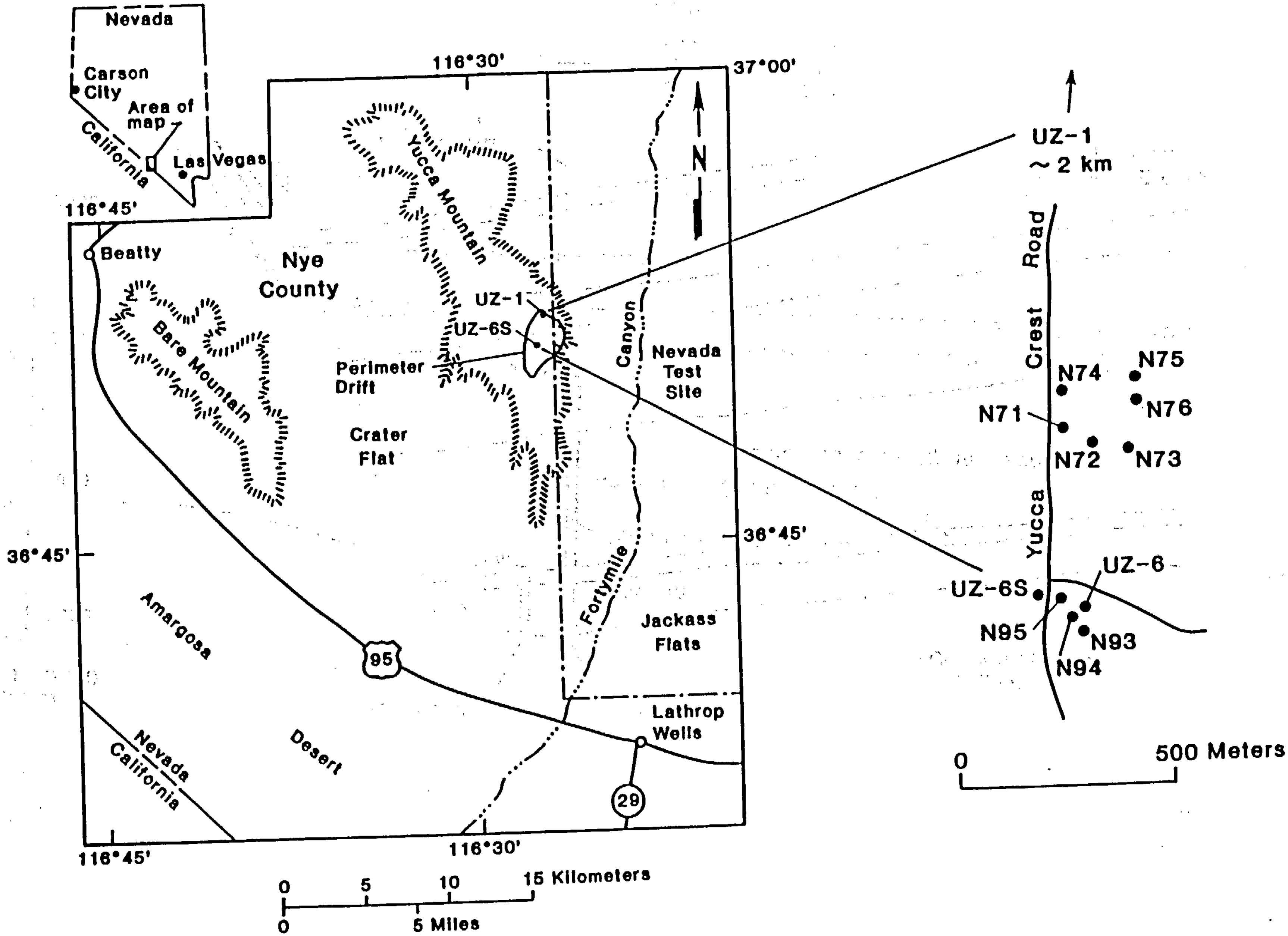

Figure 1.2-3. Schematic showing relative locations of wells used for observations in this study.

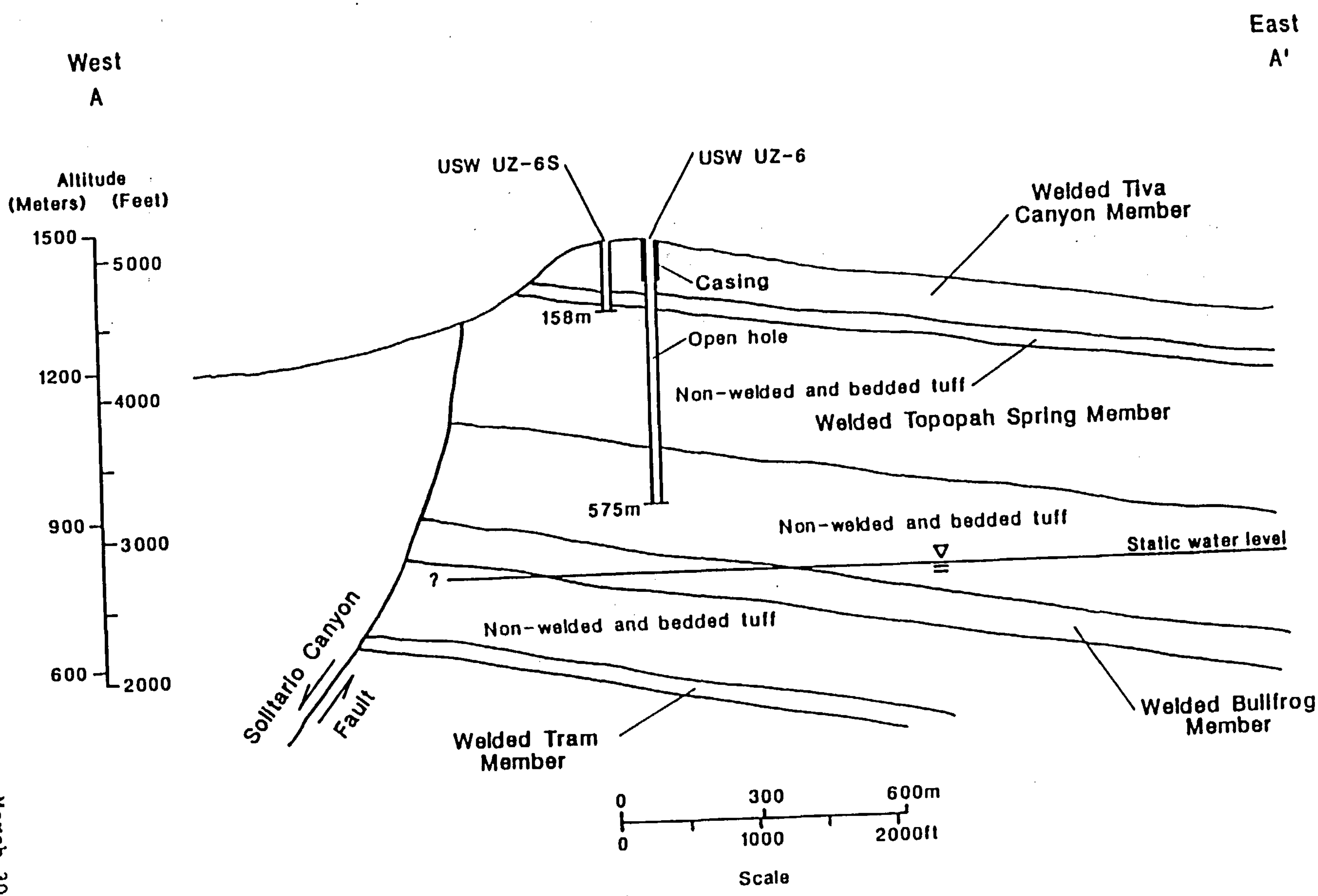

Figure 1.2-4. Generalized east-west cross section of Yucca Mountain showing boreholes USW UZ-6 and USW UZ-6s.

1.3 Regulatory rationale and justification

The overall regulatory-technical relations between the SCP design and performance informational 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 provided in Section 4.2.

Project-organization interfaces between the gaseous-phase circulation study (8.3.1.2.2.6) 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.

Parameter identification is given for the regulatory rationale and justification for most studies conducted as part of the Yucca Mountain Project. However, such a rationale is only appropriate if the processes being studied or modeled are well understood. Gaseous-phase circulation in fractured-porous rock due to topographically-induced density variations and to barometric changes, on the other hand, is not well understood. Hence, a primary objective of this study will be to develop an understanding of the process, determine the most relevant transport properties for gaseous transport, develop tests for identifying such parameters, and to determine those parameters at several sites at Yucca Mountain. The process understanding and methods developed in this study will be used in the studies of unsaturated-zone percolation -- surface-based (Study 8.3.1.2.2.3), in the characterization of the unsaturated zone in the ESF (Study 8.3.1.2.2.4), and in the study for hydrochemical characterization of the unsaturated zone (Study 8.3.1.2.2.7). These broader-scope studies will provide most of the parameters for the final modeling of gaseous-phase circulation for repository performance assessment.

Information derived from the study will principally support the predictions of radionuclide releases to the accessible environment (Issue 1.1). Study results will also provide information for the resolution of the issue concerned with releases from the repository engineered-barrier system (Issue 1.5).

This study plan updates and substantially shortens the list of regulatory and design issues to which this investigation applies, based on current thinking.

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

This issue requires that the geologic setting, engineered-barrier system, ramps, drifts, boreholes, and seals be selected and designed so as to limit the cumulative releases of radionuclides for 10,000 years

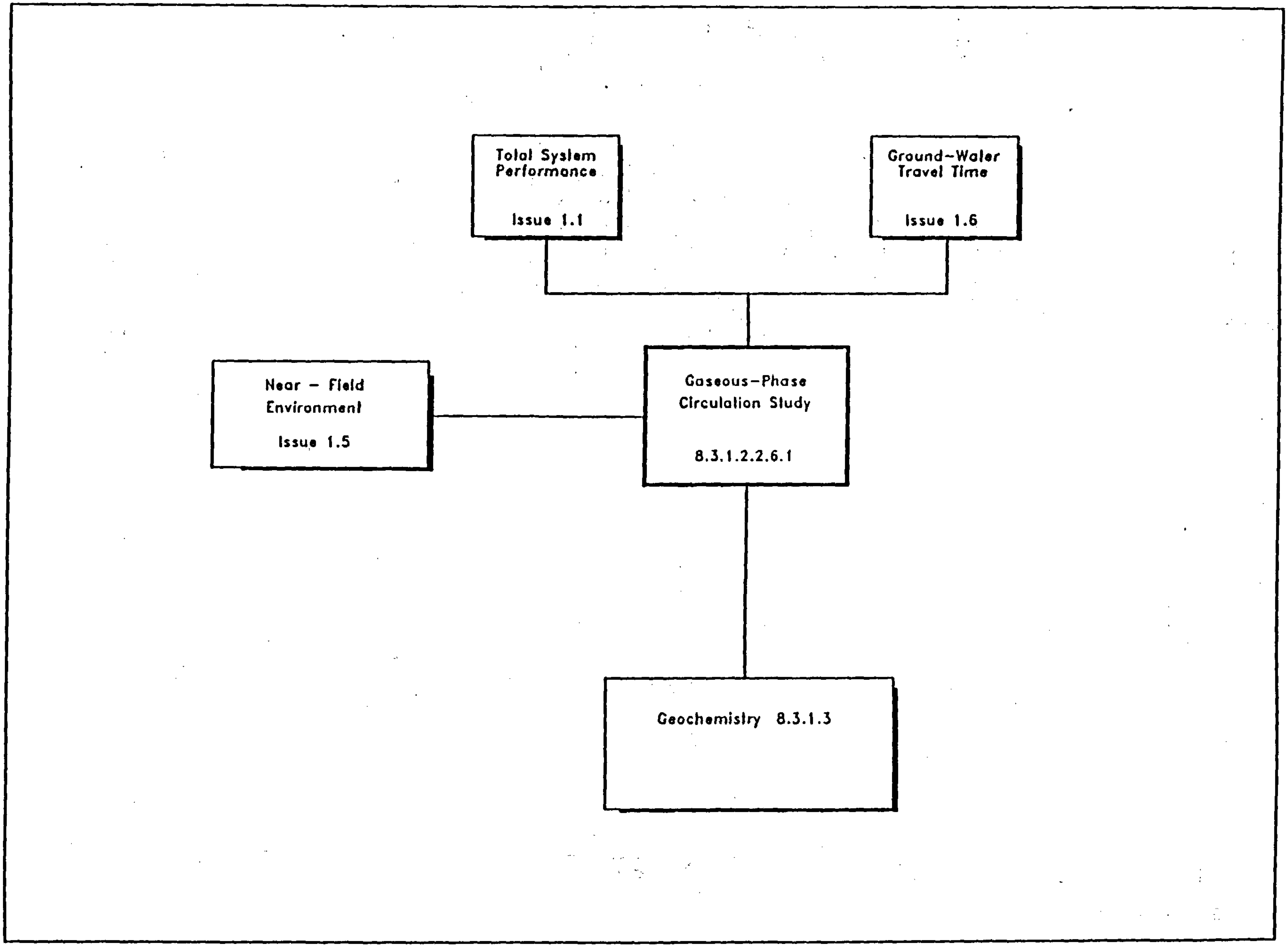

Figure 1.3-1. Diagram showing the organization interfaces of the unsaturated-zone gaseous-phase circulation ly with YMP performance and design issues and o site-characterization programs.

following permanent closure of the repository. Site information from the gaseous-phase movement study will be used to satisfy the requirements of supporting performance parameters. These will be used to address complementary cumulative distribution functions (CCDFs) for the unsaturated-zone gas pathway for the nominal (Class E) scenario.

Performance parameters for the nominal case supported by this study are bulk permeability and effective drained porosity within the Tiva Canyon member of the Paintbrush tuff. Additional performance parameters include profiles of partial pressure of CO_2; and profiles of carbon-14 concentrations. One calculation employing supporting parameters for the resolution of Issue 1.1 is the calculation of gaseous-phase carbon-14 transport in unsaturated-zone units in conjunction with carbon-14 transport model calibration and verification.

Site hydrologic properties of the unsaturated zone estimated from flow and pressure measurements in this study, such as fracture interconnectedness, effective porosity, and flux distributions, are required for the calculation of the specific-discharge field in unsaturated-zone units. Gas composition and temperature profiles from the boreholes and the delay index for fracture-matrix gas interactions, will also be used in calculating the gaseous-phase carbon-14 transport in unsaturated-zone units overlying the repository horizon.

Because the repository horizon is in the unsaturated zone, release of radionuclides into the gaseous phase must be considered. For the expected case, this may be the dominant transport mechanism. Site information on transmissive properties, fracture and drained matrix porosity (and the interaction between the two), chemistry and temperature of gaseous-phase movement from the present study will contribute to assessing the performance of the engineered-barrier system. Host-rock hydrologic properties evaluated by this study will be useful for computer modeling of scenarios for release rates.

Performance Issue 1.5
(Release rates of waste package and engineered barrier systems)

The results of this study will also support resolution of performance issues concerned with releases from the engineered barrier system. Because the repository is in the unsaturated zone, release into the gas phase must be considered. The principal concerns are for carbon-14 on the exterior of cladding and assembly components. However, there is considerable uncertainty in the release rates, mechanisms, and exact locations of carbon-14.

Site information from this study will support Issue 1.5 by providing information on the host rock hydrologic properties. The applicable performance measure is concentrations of radionuclide species in the gas phase, and the performance parameter goal is that hydrologic properties of the TSw be known with accuracy sufficient to calculate differences in flow through the near-field rock resulting from anticipated (and unanticipated) events.

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 [10 CFR 60.122(b)(8)] - Favorable Condition 8 (unsaturated-zone hydrogeologic conditions) through Issue 1.1. The study also has indirect applications to the higher-level findings for the geohydrology qualifying and disqualifying conditions through Issues 1.1.

Data generated by this study will be used indirectly and in a limited capacity in the assessments of repository postclosure performance (Issue 1.11). Unsaturated-zone information on gaseous-phase movement will be used in developing some design requirements for shaft and borehole seals (Issue 1.12).

Design Issue 1.11
(Characteristics and configurations of the repository and repository-engineered barriers)

Site information of initial air and borehole-temperature profiles from the gaseous-phase movement study will be used in conjunction with many other data in resolution of Design Issue 1.11. Proper configurations of the repository engineered barriers will require a detailed understanding of the geohydrologic environment. Data generated by this study may be used in thermal modeling of the environment to insure adequate barrier designs.

Design Issue 1.12
(Characteristics and configurations of shaft and borehole seals)

This issue is concerned with developing seals needed for shafts, ramps, exploratory boreholes, and the underground facility. Site information on the convective movement of air and temperature variations at ground surface will be applied to the design and placement of the anchor-to-bedrock plug-seals. Data on gaseous-phase movement and convective airflow may be used to explore the possible consequences of designing the repository ventilation to either minimize or maximize air flow from the repository. Natural and engineered barriers would more effectively minimize the risk of ground-water contamination due to deep percolation of radionuclide-bearing leachate if the ventilation system were designed to maximize air flow from the repository. However, gaseous radionuclide releases would be maximized. Potential benefits and risks involved in different strategies for repository ventilation can be evaluated, in part, using data provided by this study.

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 and test justification

Understanding the geohydrologic environment encompassing the unsaturated zone beneath 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. The geologic evaluation of the site is a multi-discipline problem. Investigations are planned to study the geochemical and geologic characteristics (8.3.1.3, Geochemistry; 8.3.1.4.2, Stratigraphy and structure; and 8.3.1.15.1, Thermal and mechanical properties). It is not within the scope of this study plan, however, to discuss these studies in detail. The reader is referred to the Site Characterization Plan (SCP) and associated study plans for descriptions pertaining to the particular studies or activities of interest. This study plan discusses only the gaseous-phase movement tests.

The technical rationale for this study is to quantify gaseous flow through and water-vapor flux from the unsaturated geohydrologic units of Yucca Mountain. Work to date has shown abundant gas flow due to barometric fluctuations and to thermal-topographic effects at the open boreholes USW UZ6 and USW UZ6s (Weeks, 1987; Kipp, 1987b; and Thorstenson and others, 1990). However, these data do not demonstrate the natural flow of gases through Yucca Mountain in the absence of open boreholes. The data do provide a mechanism by which it should be possible to establish the pressure potential field and the distribution of air permeabilities in the vicinity of USW UZ6 and USW UZ6s. These data, combined with constraints on flow rates provided by the ^{14}C isotopic signature of the gases, could provide information to calculate flow in the vicinity of USW UZ6 and USW UZ6s after the holes are stemmed. Similar data from additional boreholes as they are drilled as well as data provided by air-permeability testing conducted as part of the UZ percolation surface-based study (8.3.1.2.2.3), may provide a knowledge of the permeability distribution over much of the mountain, allowing calculation of natural flux of gases in the system. Based on the open-borehole data, significant topographically-affected convective gaseous flow may occur through the unsaturated fractured rock comprising Yucca Mountain. The primary concern of this circulation, in terms of radioactive waste disposal, is the possibility of substantially accelerated gaseous radionuclide transport from the repository horizon to the atmosphere.

As additional boreholes become available, they will be utilized for gaseous-phase circulation studies. These data, along with data gathered from the studies mentioned in Section 1.3 of the study plan, will be used to develop and calibrate a model for gas circulation in Yucca Mountain as part of study 8.3.1.2.2.9.

A lesser consideration of gaseous circulation is its effect on moisture distribution in the mountain. Because the atmospheric air that enters the mountain generally contains less water vapor than the soil gas discharged, gaseous-phase movement tends to dry the materials comprising the unsaturated zone. Under natural conditions, such drying probably has only a minor effect on the potential for percolation through the repository horizon. Drying due to gaseous-phase movement will mainly affect areas between washes, whereas infiltration and most deep percolation probably occurs in ephemeral stream channels during runoff. However, under conditions that would prevail if the repository were constructed, gaseous-phase circulation should be greatly enhanced by the high rock temperatures produced by heat from the waste. This enhanced circulation could result in significant drying that reduces the potential for deep percolation and leaching of radioactive waste.

In evaluating the effects of gas flow - under natural and repository conditions - at Yucca Mountain, the following concepts should be kept in mind. Flow surveys at USW UZ6s made at selected times over several years document that 80 percent of the flow at USW UZ6s occurs in the top 32 m of the borehole. Both the flow and gas chemistry data suggest that ambient-gas circulation enhances flux only in the upper near-surface portion of Yucca Mountain. This enhanced shallow vertical flux must be considered in assessments of thermal drying of the mountain. The fact that high-volume flow in borehole USW UZ6s results from a thermal gradient of only a few degrees Celsius suggests that the presence of a repository could substantially enhance thermally driven circulation. However, no evidence of such circulation in the deep system of the Topopah Spring exists at this time (Thorstenson and others, 1990; Thorstenson, 1991).

Two boreholes (USW UZ-6 and USW UZ-6s) (Figures 1.2-2 and 1.2-3) were drilled in 1984-1985 on the crest of Yucca Mountain to obtain baseline data on ambient moisture content, moisture tension, rock temperatures, gas-pressure potential, and the chemical and isotopic composition of soil gas, based on instrumentation and monitoring techniques similar to those used at USW UZ-1 (Montazer and others, 1985; Yang and others, 1985). These boreholes have not been stemmed and remain partially open to the atmosphere over significant intervals of the unsaturated zone. USW UZ-6 is open from the bottom of the casing at 99 m (324 ft) to its total depth of 575 m (1,887 ft) (Whitfield, 1985); and USW UZ-6s is open from 1 m (3 ft) to 158 m (519 ft). Substantial gas exchange has occurred between subsurface gas in the vicinity of these boreholes and the atmosphere, due both to barometric pumping and to topographically affected convective airflow through the holes.

Barometric pumping occurs when atmospheric pressure changes at land surface. The corresponding pressure change at depth in the unsaturated zone lags the pressure change at land surface (Barraclough and others, 1966; Purtyman and others, 1974; Weeks, 1987), resulting in a pressure imbalance that causes rock surrounding a borehole to transmit air. When flow is from the atmosphere to a borehole, dry air of atmospheric composition is drawn into the rock surrounding the hole. This air, and at times formation air as well, is later expelled to the atmosphere during land-surface atmospheric pressure drops. In flat terrain, volumes of inflowing and outflowing air will be nearly balanced, but the inflowing atmospheric air is generally drier than that of the rock gas in equilibrium with soil-moisture tension, and also tends, on an annual average, to be cooler than the rock because of the geothermal gradient. Thus, barometric pumping will produce net vapor and heat transport from the borehole. In addition, subsurface and atmospheric gases will become mixed within a zone around the borehole, altering the chemical and isotopic compositions of the subsurface gas from those prevailing under natural conditions. These effects of drying, cooling, and mixing may take several months to a few years to dissipate following stemming, thus adversely affecting the ability of the boreholes to yield information on baseline (pre-drilled) conditions.

Topographically-affected convective airflow in boreholes is due to the fact that air columns in holes that tap unsaturated, fractured rock are in communication (via fractures) with atmospheric air at outcrops at lower altitudes than the top of borehole casings (Kemper and others, 1986; Weeks, 1987). In winter, the atmospheric column of air extending up from the interconnected outcrops is colder, drier, and hence denser than air in the rock-borehole system. Thus, air enters the rock at outcrops and exits the subsurface through the boreholes. During summer, the density contrast is reversed, with the hotter atmospheric air being less dense than that in the rock-borehole system. Hence, air will tend to enter boreholes and discharge from outcrop areas. This topographically induced air circulation has been observed in the boreholes drilled on the crest of Yucca Mountain. This circulation will affect the downhole distribution of temperature, moisture, and gas chemistry.

Both atmospheric-pressure pumping and convective airflow appear to be occurring at USW UZ-6 and USW UZ-6s (Figures 1.2-2 and 1.2-3). USW UZ-6 is more strongly affected by barometric pumping, however, because the bottom 300 m (1,000 ft) of this hole is uncased below the level of the Solitario Canyon floor. This 300-m- (1,000-ft-) thick zone probably is not affected by topography, and barometrically-induced pressure changes at these depths greatly lag barometric fluctuations at land surface. USW UZ-6s, on the other hand, is uncased only above the level of the Solitario Canyon floor, and the downhole pressures can equilibrate quickly with atmospheric pressure changes due both to the shallow depths of the borehole and to its horizontal proximity to the outcropping rock along the west side of Yucca Mountain.

Convective airflow due to the topographic effect has also been observed in the annulus of USW UZ6, which consists of the gap between the 12-m deep 66-cm (40-ft deep, 26-in) surface casing and the underlying 60-cm deep open hole surrounding the 98-m deep 50-cm (320-ft, 20-in) inner casing. Other wells at which flow has been monitored include neutron holes USW UZ-N93, USW UZ-N94, and USW UZ-N95, all located on or within several ft of the USW UZ-6 drill pad. Spot measurements of flow, temperature, and relative humidity were made at various times in wells USW UZ6, the annulus of USW UZ6, USW UZ6S, and the various neutron holes from February 1986 through May 1989. In addition, records of flow, temperature, and relative humidity were obtained at well USW UZ6S from December 1987 through May 1989. Flow records for well USW UZ6 indicate that air intake and exhaust alternate on a nearly daily basis. Much of the air exchange in well USW UZ6 arises from barometrically induced pressure differences between land surface and a highly fractured zone of the Topopah Spring member occurring at a depth between 340 and 400 m. The top of that zone is about 230 m below the floor of Solitario Canyon, and the intervening less fractured rocks prevent rapid equilibration of rock gas pressure at depth with that of the atmosphere.

Well USW UZ6S, the annulus of well USW UZ6, and the neutron holes all tap highly fractured rocks of the moderately to densely welded Tiva Canyon member. Rock-gas pressure in these rocks equilibrates rapidly with atmospheric pressure due both to vertical air movement through the crest of Yucca Mountain and to horizontal movement through the nearby hillside outcrops. Hence, flow in these wells is dominated by pressure differences arising from a thermally induced density contrast between atmospheric air and rock gas. Measurements indicate that airflow to or from these wells is highly seasonal, with almost continuous air exhaust from the wells during November-March, little net flow in April-May or September-October, and predominately air intake during June-August. Because of geothermal heating, air exhaust dominates over air intake, and the net exhaust for well USW UZ6S is estimated to be about 1,300,000 cubic m/year (Weeks, 1992).

Temperature and relative humidity measurements in wells USW UZ6 and USW UZ6s indicate that air typically exhausts at a temperature of 17-18 °C, and is water-vapor saturated whenever air has been exhausting continuously for more than a few hours.

Rock-gas samples have been collected periodically from the flowing air streams in the open boreholes for analysis of gas chemistry, including the major atmospheric gases, methane, CO_2, and the ^{13}C and ^{14}C isotopic composition of the CO_2. The major gases occur in the rock gas at concentrations indistinguishable from those of air, but the rock gas contains about four times as much CO_2 as air (Thorstenson and others, 1990). Build-up of CO_2 in the unsaturated zone is widespread and typical, and generally attributed to root respiration and microbial activity (Thorstenson and others, 1983).

Analyses indicate that methane concentrations in rock gas are quite depleted (0.05-0.2 ppmv) versus their concentration in air (about 1.7 ppmv). Methane consumption in well-drained soils, presumably due to microbial action, has only been recently recognized, but appears to be widespread (Harris and others, 1982; Keller and others, 1983; Stallard and others, 1988; Striegl and Ishii, 1988). Because methane is depleted and carbon dioxide is elevated in subsurface gases beneath Yucca Mountain relative to their concentrations in the atmosphere, monitoring of these gases may provide important data on the magnitude and extent of seasonal atmospheric air inflow to the boreholes. Methane in particular may prove to be a reliable atmospheric-air tracer.

Results of the carbon-isotope determinations are given in detail by Thorstenson and others (1990) and are only summarized here. The relative concentrations of ^{13}C in rock-gas CO_2 relative to ^{12}C indicate that the ^{13}C is depleted by about 17 per mil relative to the PDB standard, compared to a depletion of about 8 per mil in air. Such rates of depletion are indicative of root respiration as a source of the CO_2. Measurements of ^{14}C activity indicate that rock gas throughout the Tiva Canyon unit near Yucca Mountain crest contains ^{14}C in concentrations in excess of the modern air standard, indicating that the CO_2 has been transported into the rock following the advent of nuclear weapons testing. Rock gas from the Topopah Spring member, on the other hand, contains CO_2 with C-14 activities that are less than those of modern air, and hence represents air in place before the first nuclear weapon detonations. These measurements represent the strongest indication yet available that gas circulation occurs through rock comprising the crest of Yucca Mountain under natural conditions.

In summary, the preliminary observations described above indicate that large quantities of gas circulate through open boreholes at Yucca Mountain. This circulation has almost undoubtedly affected the subsurface-gas and -moisture chemistry, and quite possibly significantly dried rock in the vicinity of the boreholes. It is important that these effects be quantified to the extent possible before these boreholes are stemmed and instrumented. In addition, the observations indicate the potential for substantial natural convection even in the absence of open boreholes, suggesting that the drying hypothesized above is indeed possible, and in need of additional study. The study-plan rationale is to develop, from the monitoring of open boreholes in various topographic regions at Yucca Mountain, an understanding of gaseous-phase circulation and its effects on subsurface moisture and chemistry.

2.1.2 Parameters and testing strategies

Relations of site parameters determined by this study to design and performance parameters are used as a basis for developing the technical rationale of the planned work. Throughout the following sections of this plan, references are made to parameter categories and activity parameters. These terms are used as a means of tracing information from site-characterization activities to design- and performance-assessment issues resolutions (SCP 8.3.2 - 8.3.5). The activity parameters associated with the gaseous-phase circulation activity in Table 2.1-1 are listed in Section 3 under the description of the activity. The activity parameters are grouped by the parameter categories and model components shown in Figure 2.1-1. 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 models, and (3) to test hypotheses that support conceptual models.

Many of the activity parameters listed in Table 2.1-1, although not required directly for resolving performance and design issues, are required to accurately model parameters that are directly required for performance and design purposes. Numerical models will be used as a principal approach to assess whether the data collected to describe the present and expected geohydrologic characteristics provide the information required by the performance and design issues.

Within the limited scope of this study, as many approaches as feasible will be used to determine the factors that control gaseous-phase circulation and to estimate the magnitude of the various relevant parameters. Gas-composition profiles of naturally-occurring trace gases will be determined and compared to concentration profiles of various trace gases injected into the well bore and/or disseminated in shallow boreholes in rock outcrops along the Solitario Canyon face and in the washes dissecting the east dip slope of Yucca Mountain. These trace-gas profiles will indicate pathways from various depths in the wells to the atmosphere and may give an indication of anisotropy for bulk pneumatic conductivity. These tracer tests, as well as some tests involving tracer injection and pump back, may give information on effective fracture porosity, and on a lumped parameter including matrix diffusion and matrix block size and shape that governs trace gas interchange between the fractures and the matrix. Profiles of $^{13}CO_2$ and $^{14}CO_2$ composition in conjunction with data on preferential flow paths and on effective air-filled porosity for gas transport (including effects of fracture-matrix transfer) will be used to estimate retardation of CO_2 transport due to sorption and to gas-liquid-solid interactions (Thorstenson and others, 1983).

Monitoring of gaseous circulation with time and measurement of flow profiles with depth in open boreholes should provide data that can be used to determine bulk pneumatic conductivity by model calibration. Flow interference tests using existing wells may, if successful, provide additional information on bulk pneumatic conductivity and on effective air-filled porosity.

2.1.3 Hydrologic hypotheses

The unsaturated-zone hydrologic hypotheses describe in general terms the manner in which water and gases move through the unsaturated zone. The testing and refinement of hypotheses provide a logical and systematic approach to improving our understanding of how the geohydrologic system functions, the result being an improved conceptual model which, in turn, leads to increased confidence in the geohydrologic program (Figure 2.1-1). The hypothesis component shown in Figure 2.1-1 is tied to Table 2.1-2, which lists the pertinent hypotheses for the unsaturated zone. The table also shows the objective and approach of the activity that is directly involved in testing these hypotheses.

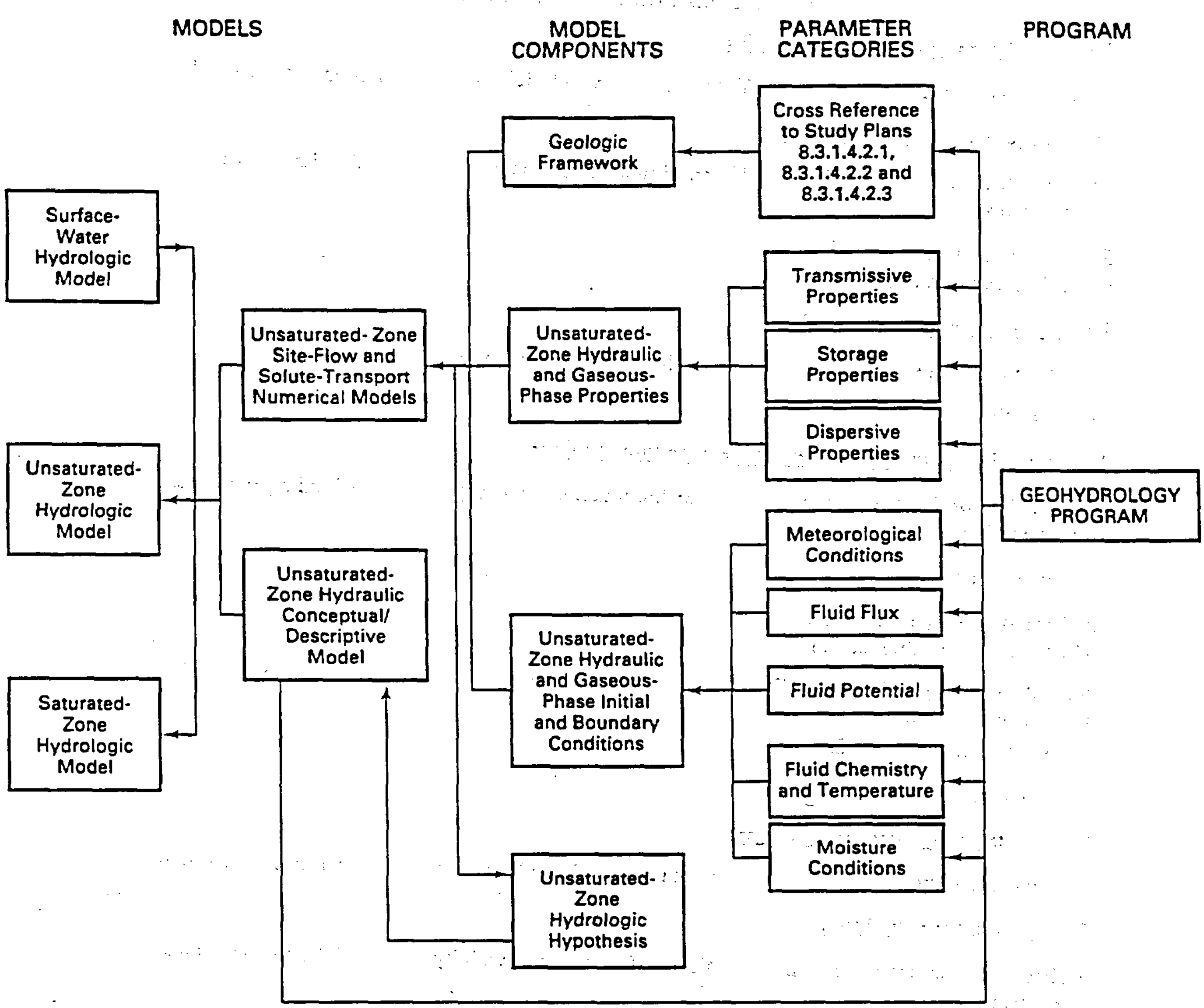

Figure 2.1-1. Logic diagram of Geohydrology Program, including model components and parameter categories.

Table 2.1-1. Activity parameters derived from this study

Site parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
	Gaseous-phase circulation study; 8.3.1.2.2.6.1	
Unsaturated-zone transmissive properties		
Fracture interconnectedness	Yucca Mountain and vicinity	All units penetrated
Unsaturated-zone storage properties		
Delay index for fracture-matrix gas interaction	Yucca Mountain and vicinity	All units penetrated
Ratio of drained fracture to drained matrix porosity	"	"
Unsaturated-zone fluid potential		
Barometric pressure	Yucca Mountain and vicinity	All units penetrated
Gas potentials	"	"
Unsaturated-zone fluid chemistry and temperature, and age		
Delay index for fracture-matrix gas interaction	Yucca Mountain and vicinity	All units penetrated
Gas composition	"	"
Radioactive-isotope activity, C^{14} (Cross-reference 8.3.1.2.2.7)	"	"
Stable-isotope composition, d C^{13}, d H^2 (deuterium), d O^{18} (Cross-reference 8.3.1.2.2.7)	"	"
Temperature profiles	"	"
Unsaturated-zone moisture conditions		
Relative humidity	Yucca Mountain and vicinity	All units penetrated
Unsaturated-zone fluid flux		
Delay index for fracture-matrix gas interaction	Yucca Mountain and vicinity	All units penetrated
Flow direction, air	"	"
Flow velocity, air in surface-based boreholes	"	"
Flow-velocity profiles	"	"
Flux distribution, gas	"	"
Ratio of drained fracture to drained matrix porosity	"	"
Water-vapor flux	"	"

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

Hypothesis	SCP number	Activity objectives
Temperature-driven or barometrically driven gas flow can result in water vapor transport, especially within the interconnected fractures of the TCw and TSw units.	8.3.1.2.2.6.1	To investigate gas-transport mechanisms and provide evidence of gas-flow directions, fluxes, and travel times. The approach will be to analyze gas and water-vapor samples taken from surface-based vertical boreholes.
Temperature-driven gas flow can result in the rapid transport of various gas species from the deep unsaturated zone to land surface, increasing the potential for gaseous radionuclide release from a nuclear waste repository to the atmosphere.	8.3.1.2.2.6.1	To investigate gas-transport mechanisms, based on gas-flow rates to or from open boreholes, gas temperature and gas composition profiles, gas isotopic composition, and gas tracer tests.
Temperature-driven gas flow can result in net water vapor transport from the unsaturated zone at Yucca Mountain that results in decreased deep percolation through the repository horizon.	8.3.1.2.2.6.1	To investigate gas-transport mechanisms, to monitor flow rates and relative humidity of discharged gas, to determine bulk pneumatic conductivity data, and to simulate natural convection in absence of boreholes.

2.1.4 Hydrologic model

In assuming that the overall hydrologic system within the unsaturated zone at Yucca Mountain can be described by conventional theories of fluid storage and movement in porous and fractured media, the present and probable future spatial distribution and magnitude of hydrologic parameters can be predicted from an appropriately constructed hydrologic model. The successful development of a calibrated numerical model of the hydrologic system will increase confidence that the geohydrologic framework, distribution of input parameters, and nature of initial and boundary conditions are appropriate for utilization in performance and design analyses.

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 fluid movement in unsaturated, porous soils and flow in saturated, fractured rock, there is no conventional theory for describing gas or 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). The gas-phase model, 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 natural gas circulation under Yucca Mountain.

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 field 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 a numerical hydrologic model simulates the natural geohydrologic system. The sensitivity of the performance measure to various parameters can, nevertheless, be investigated, and such a model can be used as a tool to improve understanding of the functioning of each zone, to test hypotheses, and to guide further data collection.

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.

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

The area of study to date is located on the crest of Yucca Mountain along the west edge of the repository block. The present study area is highly subject to topographically-affected gas circulation, due to both the steep slope of the Solitario Canyon face and to steep slopes in Ghost Dance Wash and other nearby washes on the east face of the mountain. This is particularly fortunate in that the phenomenon of gaseous-phase movement is maximized and hence readily studied.

The present area of study is not intended to be representative of the repository scale, but to develop an understanding of potential gas-flow effects on repository conditions. An understanding of gaseous-phase circulation and its effects on subsurface moisture and chemistry is necessary for fluid flow modeling and an adequate representation of the repository. Additional open boreholes, located in various topographic regions around Yucca Mountain, will be studied to help define the gas-phase circulation of the entire repository area.

2.2.2 Accuracy and precision of methods

Selected and alternate methods for testing in the single activity of the study are summarized in tables at the end of the activity description (Section 3.1). Methods of measurement were selected on the basis of their availability and adaptability for use in the field, whether they provided the necessary accuracy and precision, their reliability in the field environment, and, for parameters to be continuously monitored, whether the instruments provide data that could be recorded electronically. Tradeoffs exist in the use of various instruments, and, where needed, redundant methods are used. For example, hot-wire anemometers provide the greatest accuracy and precision of those in common usage for the anticipated range in air velocity to be recorded in wells USW UZ-6 and USW UZ-6s (de la Cruz, 1982). However, the hotwire anemometer cannot be used to determine flow direction. Hence, both hotwire anemometers and propeller anemometers will be used, the hotwire anemometer to determine flow magnitude and the propeller anemometer to determine flow direction. In general, the instruments chosen should provide data of sufficient accuracy to fulfill the needs of the study. The accuracy and precision of the various instruments and of the measured values are described in the technical procedures. Whether the magnitude of pressure response to the flow interference tests and tracer concentration response to the gas tracer tests will be sufficiently large that they exceed those that could be characterized as noise is uncertain, and can only be evaluated after the tests are run.

2.2.3 Potential impacts of activity on the site

The testing activity described in this study plan will have little or no impact on the natural-state site conditions. No new drilling, trench construction, or road construction is proposed. Natural-state conditions may be altered by the open-borehole circulation, but such alterations would occur regardless of whether the study is performed. No offroad vehicle activity is planned, although there will be some offroad foot traffic.

The potential exists that the gases introduced during the Yucca Mountain crest tracer tests might result in residual gas concentrations that could interfere with future tests. However, sulfur hexafluoride (SF_6) was introduced into the drilling air injected in well USW UZ-6 at a concentration of 1 ppmv (part per million by volume) throughout its entire depth. In addition, SF_6 was added at 1 ppmv to the air used in drilling well USW UZ-6s for the first 88.4 m (290 ft) of its depth. Freon 12B1 ($CBrClF_2$) was added at 1 ppmv during the remainder of the drilling (to a total depth of 158.2 m [519 ft]). The SF_6 concentration from air sampled from well USW UZ-6s is below the detection limit of about 10 pptv (parts per trillion by volume), although the concentration of F12B1 remains at a tens of parts per billion in the section of the hole open in the nonwelded unit. The well has caved or bridged to a depth of 136.6 m (448 feet), and no samples can be obtained from that well for the Topopah Spring welded unit. SF_6 has been sampled at a concentration of about 90 ppbv from the nonwelded tuffs underlying the Topopah Spring welded unit in well USW UZ-6, but concentrations in the welded Topopah Spring unit is in the tens of pptv range. Based on these observations and the fact that gas tracers will be introduced only in the Tiva Canyon welded unit and only in much smaller volumes than they were during drilling, it is anticipated that residual gas tracer concentrations will drop below their detection limits within a few months of the tests.

Additional tracer tests, which may be conducted from the ESF excavations, present the same contamination potential as described above.

2.2.4 Time required versus time available

A current schedule of work and reports is given for the gaseous-phase circulation activity in Section 5.1. The gaseous-phase monitoring schedule will be constrained by the drilling and stemming of surface-based boreholes, before and after which time open-borehole circulation cannot be measured.

3 DESCRIPTION OF ACTIVITY

This study consists of one activity:

- o 8.3.1.2.2.6.1 - Gaseous-phase circulation study

Plans for this activity are described in Section 3.1.

3.1 Gaseous-phase circulation study

3.1.1 Objectives

The objectives of this activity are to:

1. determine the air circulation in currently open boreholes USW UZ-6, USW UZ-6s, (Figure 1.2-2) and other selected unsaturated-zone boreholes as a function of barometric pressure and air temperature;

2. reconstruct the air-circulation history for these boreholes from the time of construction to the time of measurement based on modeling or by empirical relations derived from time-series analysis of weather records;

3. determine zones in which most of the gas exchange has occurred based on logging flow, temperature, and gas composition with depth;

4. based on these observations, predict the time required following stemming for baseline moisture, temperature, and gas-composition conditions to be reestablished;

5. determine, by flow, pressure, and gas-composition measurements in single holes, and by cross-hole-interference tests, the near-field air conductivities, storativity, and anisotropy of the Tiva Canyon welded unit and, possibly, the Topopah Spring welded unit; and

6. develop a suite of data that can be used to develop and calibrate a model for gas circulation in Yucca Mountain.

3.1.2 Rationale for activity selection

This is the only activity selected to satisfy the objectives of the study plan (Section 1.2). The rationale for the activity selection is the same as the study rationale (Section 2.1). Briefly, this rationale is to develop an understanding of gaseous-phase circulation in the unsaturated zone and its effects on rock moisture and rock gas chemistry. The results of this activity will be important in the assessment of transport of gaseous radionuclides. If gas-phase circulation, as determined from these studies, appears to be sufficient to reduce deep percolation to the repository horizon by instead exhausting the infiltrated water to the atmosphere, additional open-borehole studies may be needed. Likewise, even if the gas-phase circulation is inadequate to cause significant drying, it may be sufficient to substantially enhance the discharge of gaseous radionuclides to the atmosphere. In this case as well, open-borehole studies of gas-phase circulation may be needed at other locations on Yucca Mountain.

3.1.3 General approach, methods, and analyses

This section describes the proposed approach and methods to be used in collecting data that will be used to develop an understanding of convective flow of gas through Yucca Mountain. However, this study is the first of its kind, and few guidelines are available to conduct it by. Consequently, it will be necessary to make changes and adjustments to methods and procedures during field work.

In this study, data have been collected on gas flow to or from wells USW UZ-6 and USW UZ-6s, along with its temperature, relative humidity, and composition. In addition, flow, temperature, and composition profiles have been developed by logging the holes seasonally. Data will continue to be collected at USW UZ-6 and 6s and at other boreholes representing other topographic regions. These data, along with data on air temperature, relative humidity, and barometric pressure, will be analyzed using a code that simulates flow of variable-density fluids to provide data on the distribution of bulk effective pneumatic conductivity with depth. A variety of tracer tests will be performed. In summer, tracer-tagged air will be injected into wells USW UZ-6, USW UZ-6s, or both, and points where the tracer is emanating into the atmosphere will be determined by sampling gas from the shallow soil cover along the Solitario Canyon face and in the east-slope washes extending near the wells. A series of injection and withdrawal tests will also be performed in an attempt to determine the ratio of drained fracture porosity to drained matrix porosity, and to determine a lumped parameter that describes tracer diffusion from the fractures to the matrix. Finally, a test may be run by placing permeation tubes, each containing a different tracer, in shallow holes drilled in outcrops along the Solitario Canyon face, in the Ghost Dance Wash, and in other outcrops along the east face of Yucca Mountain. The test will be performed during the winter season of strong exhaust from the wells and tracers will be monitored by sampling the exhaust streams in well USW UZ-6s and possibly the annulus of USW UZ-6. The main information gained from this test will be concerned with the fracture interconnectivity between outcrops and well bores and with the winter pattern of gas circulation through Yucca Mountain. In addition, the spatial and temporal distribution of various natural tracers in the boreholes will be analyzed to validate or refine the conceptual model and to help determine flow paths for gaseous-phase circulation. Tracer tests may also be conducted between ESF excavation boreholes and surface-based boreholes in line with the ESF excavations.

Figure 3.1-1 summarizes the organization of the gaseous-phase circulation study. 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 during testing. Figure 3.1-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the activity parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed boxes, respectively.

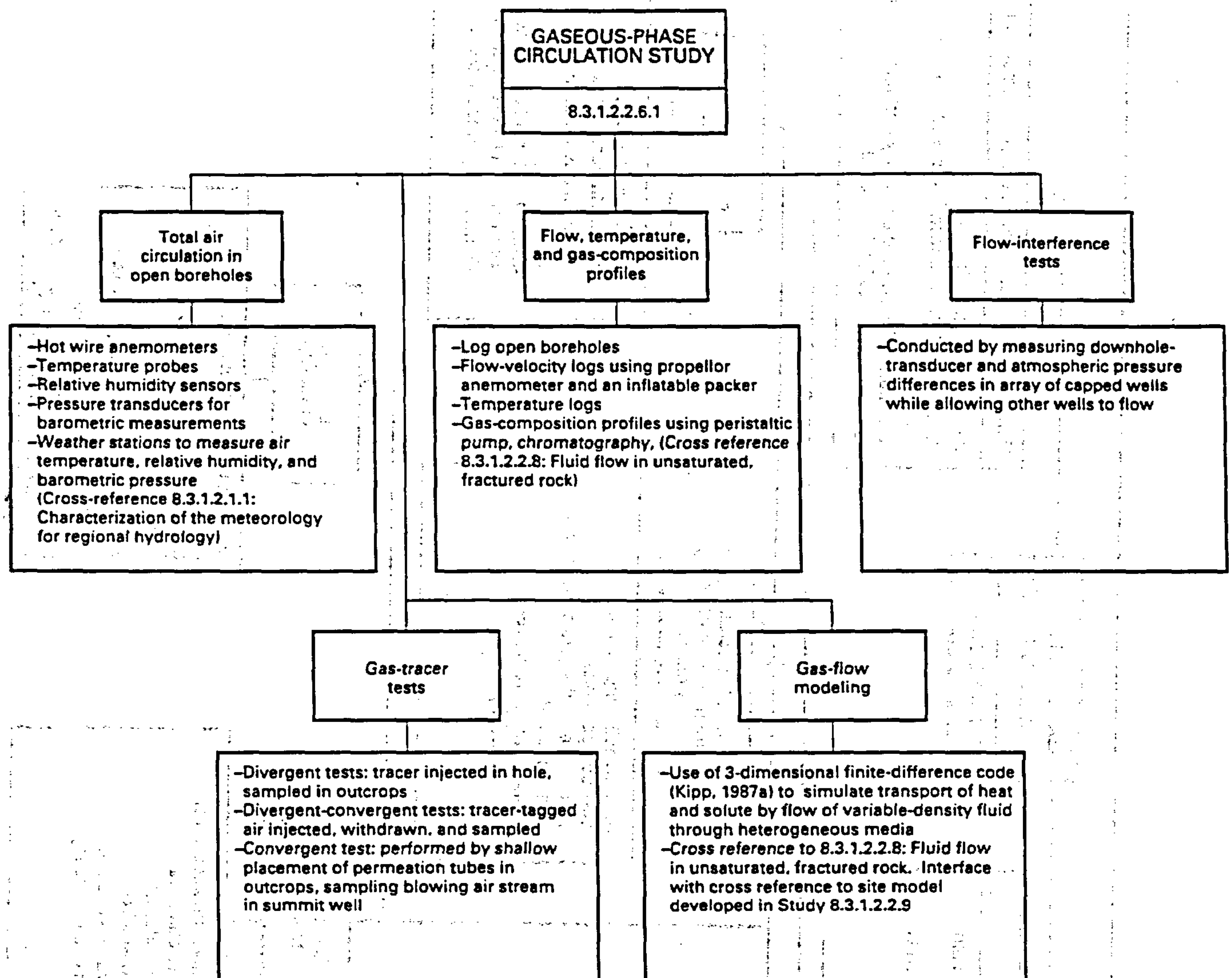

Figure 3.1-1. Logic diagram of gaseous-phase circulation activity showing tests, analyses, and methods.

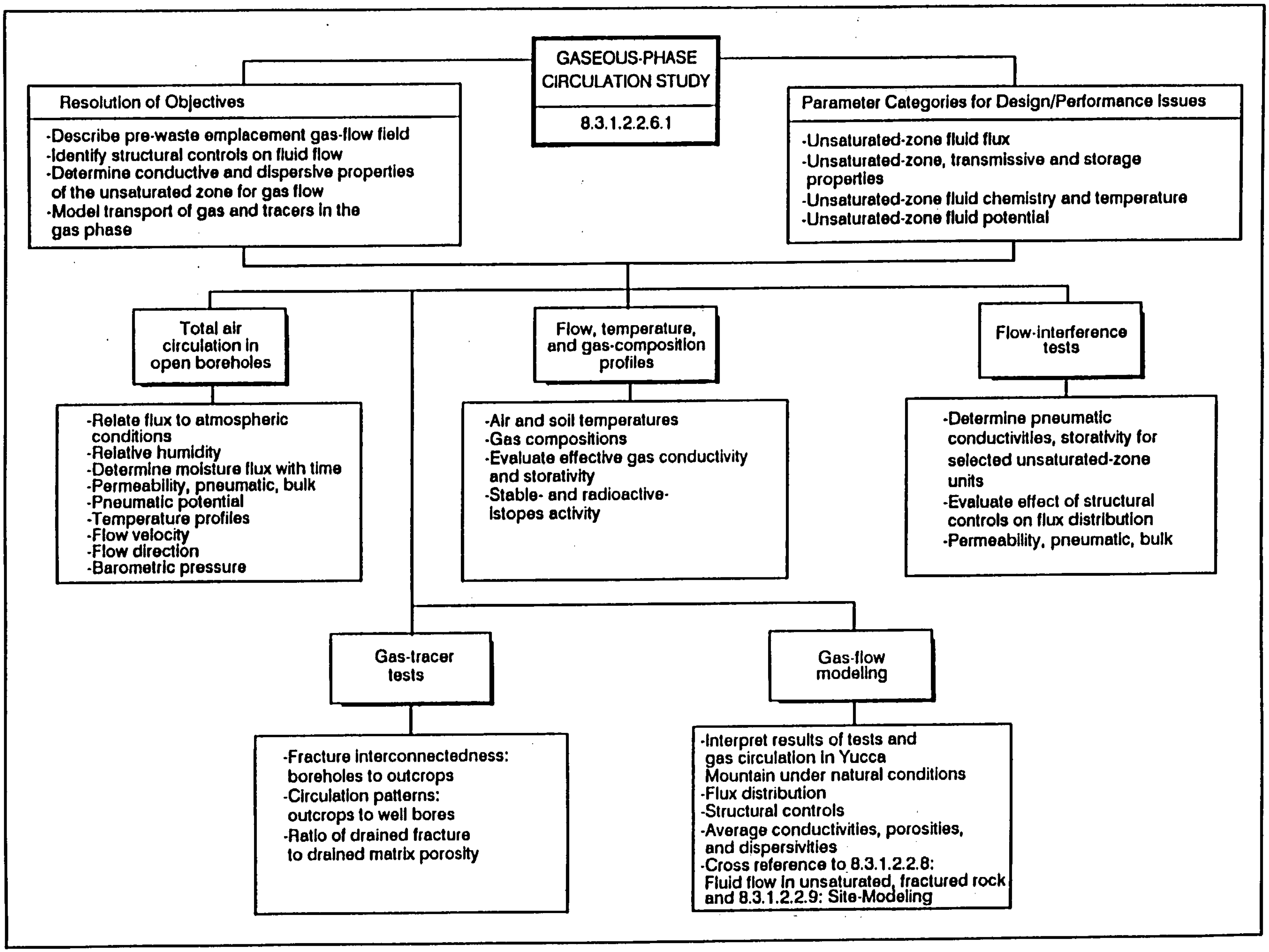

Figure 3.1-2. Logic diagram of gaseous-phase circulation activity showing tests, analyses, and site parameters.

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

The methods utilized in this activity will provide information that is approximately representative of the repository block. Tests will involve sampling, *in situ* testing, and passive *in situ* monitoring of the unsaturated-zone gaseous components beneath Yucca Mountain. Sampling will be conducted in open boreholes, including but not limited to, USW UZ-4, USW UZ-5, USW UZ-6, USW UZ-6s, USW UZ-13, NRG holes, SRG holes, and neutron access holes USW N71-N76 and N93-N95.

Flow, temperature, and gas-composition profiles will be obtained as well as data from open-borehole monitoring, flow-interference tests, and gas-tracer tests. These data will be used to calibrate a numerical code that simulates the temporal and spatial distribution of flow within the boreholes. An understanding of gaseous-phase movement under present conditions will be useful to model and predict flow under potential future repository conditions after the rocks at depth have been greatly warmed by the waste.

This study plan updates the Site Characterization Plan, based on current information and thinking.

3.1.3.1 Construction details of existing boreholes

This study has relied to date on the collection of data from existing boreholes, and is designed around the constraints imposed by their construction, as described in this section. Well USW UZ-6 was drilled to a depth of 12.2 m (40 ft) using a 76.2-cm (30-in) diameter hammer. At that depth, 66.0-cm (26-in) diameter casing was set and cemented in place using 5.4 cubic m (189 cubic ft) of cement, which was pumped to surface around the casing annulus. All indications are that the annulus around this casing is well sealed. The hole was continued to a depth of 103.9 m (341 ft) using a reverse vacuum air drilling technique and a 61.0-cm (24-in) bit. Intermittent problems of sidewall caving occurred throughout the time this section of the hole was being drilled, so 50.8-cm (20-in) casing was set to a depth of 98.8 m (324 ft), the point of refusal. The well had filled to a depth of 100.9 m (331 ft), and 6.0 cubic m (210 cubic ft) of cement was tremied into the hole. However, this only brought cement to the bottom of the casing. The cement was drilled out with a 43.2-cm (17-in) bit, but materials caved, and the 61.0-cm (24-in) annulus and hole appear to be completely interconnected. The well was continued to a depth of 566.3 m (1,858 ft) with the 43.2-cm (17-in) bit. The open hole from the bottom of the 50.8-cm (20-in) casing, 98.8 m (324 ft) to a depth of 115.8 m (380 ft), the approximate base of the Tiva Canyon welded unit, is extremely rugose, and could not be readily sealed with an inflatable packer. Access is available to the annulus between the 61.0-cm (24-

in) hole and 50.8-cm (20-in) casing through a 7.6-cm (3-in) pipe nipple. However, the hole below the surface casing is extremely rugose, and it is difficult to lower even anything as small as a sampling tube into the hole without hanging it up, or once lowered, retrieving it. Hence, it is not practical to measure flow, temperature, or gas composition profiles through the Tiva Canyon unit in well USW UZ-6.

Smooth sections of hole exist at widely separated intervals within the Topopah Spring welded unit in well USW UZ-6 and these are the sections where point measurements of flow velocity will be measured. However, only the top 91.4 m (300 ft) of the Topopah Spring welded unit is exposed in outcrop, and the outcrop is located about 304.8 m (1,000 ft) laterally from well USW UZ-6. Only this section would be anticipated to exhibit topographically-affected circulation, although the entire thickness of the Topopah Spring welded unit should show the effects of barometric pumping.

Well USW UZ-6s was drilled using an Odex system to a total depth of 158.2 m (519 ft). The Odex casing was pulled, and 0.9 m (3 ft) of surface casing remain in the hole. Well UZ-6s had caved back and/or bridged at a depth of 136.6 m (448 ft) by the time a television camera log was obtained in September 1985. The television log indicates that the hole is quite rugose, but that smooth sections occur every 6.1 m (20 ft) or so that would provide suitable stations for flow measurements and for isolating flow by use of an inflatable packer.

About 90 boreholes have been drilled in the vicinity of Yucca Mountain to depths of 6.1 to 18.3 m (20 to 60 ft) to provide access for neutron logging. Three of these (USW N93-N95) will be used to monitor possible pressure effects of shutting in wells USW UZ-6 and USW UZ-6s, and will be sampled during the divergent-flow and convergent-flow tracer tests to be conducted on well USW UZ-6s. These neutron holes and six others located near the crest of Yucca Mountain (USW N71-N76, Figure 1.2-3) will also be sampled to provide additional gas chemistry data. These holes are steel-cased to within about 0.3 m (1 ft) of the bottom, and thus provide access for point measurements of pressure and of gas chemistry.

All other open boreholes to be studied will be drilled using traced air as the circulation fluid, and will be of variable sizes.

3.1.3.2 Total air circulation in open boreholes

Air circulation in the open boreholes will be measured and related to barometric pressure changes and air temperature changes. This relationship can then be used to determine air flow under long-term conditions. Data from well USW UZ-6 will provide information mainly on barometrically induced air flow in the Topopah Spring welded unit, and those for USW UZ-6s mainly on topographically-affected air flow in the Tiva Canyon welded unit. Data from other open boreholes will provide gas-flow information for various topographic regions of Yucca Mountain.

Data on total airflow and on heat and vapor transport from the open holes will be obtained by instrumenting boreholes with recording hot-wire anemometer flowmeters, propeller anemometers, temperature probes, and relative-humidity probes. Readings from these probes will be recorded hourly using automated programmable data loggers.

Simultaneous records of air temperature, relative humidity, and atmospheric pressure will be obtained from the existing weather station located near USW UZ-6 (Figure 1.2-2) and at a weather station to be installed on the west side of Yucca Mountain near the Solitario Canyon floor. The weather-station data will be used to develop empirical and/or numerical simulation models to compute total borehole circulation. Existing data from the USW UZ-6 weather station will allow reconstruction of the air-circulation history in the boreholes at Yucca Mountain, either by empirical relations derived from time-series analysis or by modeling, from the time of construction until the present.

In addition to total air circulation, the total discharge of water from boreholes as water vapor and of carbon as CO_2 will be estimated. Water-vapor flux will be estimated by computing the saturated water vapor density of the wellbore air at its recorded temperature and multiplying that value by the volumetric air discharge (or intake) and by its relative humidity. Carbon fluxes will be estimated by multiplying the volumetric outflux of air by its average CO_2 concentration as determined by periodic sampling (Thorstenson and others, 1990). Preliminary estimates indicate that a large net volume of liquid water (30 cubic m) has been discharged from September 1986 to March 1989 from USW UZ-6s. As a matter of perspective, if a radius of influence of 91.4 m (300 ft) were assumed, the discharged water amounts to 1.2 mm water depth from the area of influence, equal to an infiltration rate of 0.5 mm/year. Moreover, it is unlikely, considering that the liquid water content of the unsaturated rocks is about 0.5 cubic m per 10 cubic m of rock, that the water vapor discharge will materially affect moisture content in the unsaturated zone at the crest of Yucca Mountain.

3.1.3.3 Flow, temperature, and gas-composition profiles

Data on the seasonal contribution to flow and transport from geohydrologic units will be obtained by periodically logging open boreholes to determine depth profiles of air-flow velocity, air temperature, and rock-gas composition. These data will be used to assess the impact of convective gas flow on baseline or ambient conditions at different levels in the hole and to determine the zones at which most of the gas exchange has occurred.

3.1.3.3.1 Flow profiles

Flow-velocity logs run in open boreholes will be made by mounting a propeller anemometer or a hot-wire anemometer in a measuring tube equipped with an external inflatable packer that forces the entire flow through the tube. Flow containment is required at USW UZ-6s because of the rugosity of the hole

(Palaz, 1985) and the expected rugosities of future boreholes, which would cause the air-flow velocity to vary widely both with vertical and horizontal position in the open hole. The anemometer will be adapted for use with a logging truck. Flow measurements will be made in the casing and at each of the locations where the hole is relatively smooth down to the depth at which flow velocities are too slow to be measured.

Flow velocity logs will be made in open boreholes by lowering an anemometer to successive depths at which the hole is relatively smooth. A flow confinement system, similar to that used with the flow-measuring lowering device, will be used when large, rugose holes are sampled. Measurements will be made to a depth at which flow velocity is too slow to measure.

3.1.3.3.2 Temperature profiles

Temperature logs will be obtained using the temperature-logging tool that is standard with the GMC logging truck. Logs will be obtained both running down- and up-hole at a rate of 3.0 m/min (10 ft/min) to minimize lag in tool-response time to ambient temperature.

3.1.3.3.3 Gas-composition profiles

Gas samples will be obtained by lowering weighted nylon tubing down-hole to depths selected from the temperature and flowmeter logs. In particular, gas samples will be collected from depths over which the flow rate changes significantly. Also, if flow appears to enter the hole over a significantly wide interval, gas will be sampled at intermediate points within that interval. Gas samples will also be obtained from the nonwelded tuff units and at or near contacts between welded and nonwelded tuff units. Finally, gas samples will be obtained at or near points where temperature anomalies are identified during temperature logging. If all of the above criteria result in a large interval that is still unsampled, additional sampling points will be added to provide reasonably complete sampling coverage with depth. Gas will then be pumped to land surface using a peristaltic pump.

Gas compositions to be determined include, but are not limited to, CO_2, CH_4, CCl_3F (F-11), CCl_2F_2 (F-12), SF_6, and $CBrClF_2$ (BCF or Freon 12B1). Analyses will be made by gas chromatography. The chromatograph-integrator systems are calibrated by analyzing commercially available standards of known gas composition between sample runs. Current plans call for the use of atmospheric air as a working standard for CO_2, CH_4, F-11, and F-12, as deviations from atmospheric composition are of primary concern for these gases. Atmospheric fluorocarbons F-11 (trichlorofluoromethane) and F-12 (dichlorodifluoromethane) have been used previously to determine diffusion parameters in unsaturated rocks (Weeks and others, 1982). Similarly, relative changes in CH_4 may prove to be reliable atmospheric tracers.

Air standards will be run after samples for two or three depths have been analyzed. Primary standards, consisting of gases of known composition, will be analyzed daily. Both SF_6 and BCF, which were introduced into the unsaturated zone during drilling activities, should be present in concentrations significantly greater than atmospheric. Standards of known composition will be used as the working standard for these gases; standards will be analyzed again after samples for two- or three-depth increments have been analyzed.

In addition to trace-gas compositions, isotope data on $^{13}CO_2$ and $^{14}CO_2$ of samples collected from various depths will be obtained. Data on $^{13}CO_2$ will be obtained on whole-gas samples by mass spectroscopy, and data on $^{14}CO_2$ will be obtained by trapping CO_2 in a KOH solution, converting it to benzene, with scintillation counting of the synthesized benzene. Details on these analyses are provided in Study 8.3.1.2.2.7, Hydrochemical characterization of the unsaturated zone.

3.1.3.4 Flow-interference tests

The annulus in well USW UZ-6 and the interconnected open hole to a depth of about 115.8 m (380 ft) are open to the Tiva Canyon welded unit, as is the entire open section of well USW UZ-6s. The three neutron holes (USW N93-N95) on the USW UZ-6 pad are all open through approximate 0.3-m (1-ft) intervals in the upper part of the Tiva Canyon unit. If the Tiva Canyon welded unit is sufficiently fractured that it behaves as a porous medium, or if one or more of the various wells are interconnected by fractures, information can be gained on permeability, air-filled porosity (through the storativity term, defined as air-filled porosity, divided by mean formation-gas pressure in the transient gas-flow equations), and/or fracture interconnectedness between wells by running flow-interference tests on these wells. It is anticipated that these tests would be run by placing an inflatable packer in well USW UZ-6 at a depth of 115.8 m (380 ft) to isolate the Tiva Canyon welded unit from the underlying Topopah Spring welded unit in that well. Both the annulus and the well would be capped and equipped with taps for measuring the differential pressure between the wells and atmosphere. The three neutron holes will also be capped and tapped, as will well USW UZ-6s. Once differential pressures in the various holes seem fairly stable, say as determined by monitoring overnight, well USW UZ-6s will be opened and measurements begun on its flow rate. Differential pressure readings will be obtained from both well USW UZ-6 and its annulus and from the neutron holes for a period of a few hours or until changes in barometric pressure interfere with the anticipated interference effects. This typically will be from about 0800 to 1100, a period during which the barometric pressure is quite stable before it begins its afternoon diurnal decline. Because about 80 percent of the flow from or into well USW UZ-6s originates or is lost in the interval from 7.6 to 32.3 m (25 to 106 ft) (Thorstenson and others, 1990), no attempt will be made to repeat the test using an inflatable packer. Based on these observations, it appears that too little additional flow isolation could be achieved to yield worthwhile information.

Whether or not any changes in pressure differential that can be attributed to flow from USW UZ-6s are detected, similar tests will be run by sealing all the wells overnight and allowing the annulus of well USW UZ-6, well USW UZ-6s, and neutron hole USW N94 to flow, each on a separate day. Flow measured in wells USW N93 and USW N95 is too small to even consider attempting to measure interference based on letting them flow.

Flow interference tests may also be conducted at other open boreholes as needed.

Flows induced by temperature and barometric effects may be inadequate to produce measurable pressure interference in the nearby wells. Air injection or withdrawal tests will be conducted in packed-off intervals of well UZ-6s as part of the Unsaturated Zone Percolation-Based Studies (8.3.1.2.2.3). During these injections, shutin pressures will be monitored in N93, N94, N95, UZ6, and the UZ6 annulus. These tests may provide better data for analysis of interference tests than those obtained from naturally-induced flow. Shut-in tests may also be conducted at other open boreholes.

Depending on the nature and quality of the data obtained, they will be analyzed to determine the permeability and air-filled porosity of the medium, using an appropriate analytical equation that describes flow in porous media (Weeks, 1978) or in fractured rock (Raghaven, 1978), using the approach of Katz (1959) to relate these equations to gas flow. Alternatively, if no analytical equations exist to adequately describe the encountered flow and boundary conditions, the data may be analyzed by numerical simulation.

A possible complication in these tests is the fact that the fractured rocks comprising Yucca Mountain behave as a double-porosity medium, with rapid pressure migration in the fractures that bleeds slowly into the much less permeable rock matrix. This effect was identified and analyzed for in fractured rock of the Topopah Spring unit, as described by Montazer and others (1985).

In that case a lumped parameter termed the delay index, β, describes the interaction between changes in gas pressure in the fracture and movement of the gas into the matrix due to viscous flow. The delay index for viscous flow is defined as

$$\beta = \frac{C k_m \bar{p}}{\mu N_{dm} l^2},$$

where C = dimensionless matrix block shape factor, L^0;

k_m = matrix permeability, L^2;

$\bar{p}$ = mean pressure during test, $ML^{-1}T^{-2}$;

μ = dynamic viscosity of air, $ML^{-1}T^{-1}$;

N_{dm} = air-filled matrix porosity, L^0;

and l = representative matrix block dimension, L.

Some possibility exists that this viscous flow index can be identified from the flow-interference data, as Moench (1984) did for hydraulic tests on water wells at Yucca Mountain. However, for the proposed tests, both the effects of allowing a well to flow and those arising from atmospheric pressure changes at land surface will affect the data, and it may be difficult to separate out the effects of double-porosity viscous flow.

It is recognized that the chances of success from these tests are small. However, if successful, they will provide data on the flow properties of the Tiva Canyon welded unit that will not be otherwise available for many years.

3.1.3.5 Gas-tracer tests

Three types of gas-tracer tests will be performed, including divergent-flow tests, divergent-convergent flow tests, and convergent-flow tests.

3.1.3.5.1 Divergent-flow tests

One divergent-flow test will be performed by injecting tracer-tagged air into well USW UZ-6s and sampling the annulus of well USW UZ-6, wells USW UZ-N93, USW UZ-N94, and USW UZ-N95. During the divergent-flow test, all wells except UZ6s will be sealed to the atmosphere and sampled from tubing using a peristaltic pump. Such sealing is necessary to avoid complicating the flow field by allowing multiple sources of airflow into or from the Tiva Canyon member. In addition, gas samples will be collected from various points on the west and east flanks of Yucca Mountain by inserting 1.6-mm (1/16-in) ID stainless steel tubes to the point of refusal in shallow soil cover and then withdrawing a 10-cc syringe sample after a single flushing. The concept for this approach is that the tracer-laden gas will move through discrete fractures until it reaches the soil-covered outcrops, where it will diffuse out radially, to be present in a wider column of soil. The time of first arrival of the tracer in the wells may be identifiable, but the soil sampling will involve prospecting for the gas tracer. Hence, the areal distribution of trace-gas emanation from the mountain may be detectable, but first arrival times probably cannot. This test will be conducted in summer and will indicate the presence of interconnected fractures between well USW UZ-6s and the other wells and between well USW UZ-6s and the outcrops during the period of net intake of air to the wells. Detection of tracer will also help delineate the summer circulation pattern and may give qualitative information on the principal direction of anisotropic permeability.

The tracer to be used will be selected on the basis of toxicity, solubility, and sorptivity. Because it is desired to duplicate natural flow conditions as closely as possible during the injection test, injection will be from surface into the entire thickness of open hole. Depending on results, a later injection test may be performed by injection into a discrete interval isolated by inflatable packers.

3.1.3.5.2 Divergent-convergent flow tests

The divergent-convergent flow tests will be conducted by injecting tracer-tagged air into USW UZ-6s for a short time, allowing the injected air to sit in place for an interval, then pumping and sampling the injected air. The well will be pumped until the tracer is essentially gone and the test repeated with a longer shut-in period. These tests are being performed to determine the ratio of drained fracture to drained matrix porosity and to obtain an estimate of the magnitude of a lumped parameter,

$$\alpha = \frac{CD_e}{l^2}$$

where α = diffusive-flux delay index for equilibration of gas composition between fracture and matrix, T^{-1};

C = shape factor for the matrix blocks, L°;

D_e = effective diffusivity of the trace gas into the matrix block, L^2/T;

and l = characteristic length of matrix blocks, L.

It is important to recognize that this diffusive flux delay index α differs from the viscous flux delay index β described above. Some trace-gas viscous-flux transport will occur into the matrix to the fractures during injection and from the matrix to the fractures during withdrawal that will complicate the interpretation of the tracer test data. However, it is anticipated that these effects can be sorted out by appropriately varying the shut-in period.

Fracture-matrix transfer of the gas tracers may be the dominant factor affecting the shape of the tracer breakthrough curve, and dispersivity of the fracture network probably cannot be identified from tracer tests. On the other hand, if fracture-matrix transfer is slow, it may be possible to determine dispersivity by a curve-matching technique (Sauty, 1978, for example), or by trial-and-error fitting of a breakthrough curve simulated by a numerical transport code to the measured curve.

3.1.3.5.3 Convergent-flow tests

During the winter season of strong well exhaust, at least one convergent-flow test will be conducted by emplacing permeation tubes containing one of various gas compounds suitable to act as gas tracer in shot-hole type access holes in outcrops along both the Solitario Canyon face and in one or more washes along the east flank of the mountain. Well USW UZ-6s will be allowed to exhaust freely and gas samples will be collected from the blowing air stream. Other wells will be shut in to avoid unduly complicating the flow field. As many as five or six different tracers will be used simultaneously in order to identify the outcrop units that contribute flow and to test a current hypothesis, based on the amount of CO_2 exhausted, that much of the winter flow represents updip migration of gas from the east flank of the mountains.

Additional tracer tests may be conducted between the ESF excavation boreholes and nearby surface-bored boreholes (NRG holes).

The results of the various tracer tests will be useful input to the numerical model developed to simulate gaseous-phase circulation. Results from the divergent- and convergent-tracer tests will help determine whether the various microunits comprising the Tiva Canyon unit (Scott and Bonk, 1984) behave as separate units controlling air flow. Some information on permeability anisotropy based on tracer breakthrough at outcrops should be obtained. If the gas composition equilibriates quickly between the fracture network and the drained matrix porosity relative to its transit time from the outcrop to the well, and if the thickness of the flow zone can be identified within reasonable limits from the composition profile with depth in well USW UZ-6s, an estimate of air-filled porosity can be obtained from doublet theory (Collins, 1961, p. 181-182) or by transport simulation using a numerical code. All of these parameters will prove useful characterizing the Tiva Canyon Member for models of $^{14}CO_2$ and other gaseous radionuclide emanations from the repository to the atmosphere. Information obtained from these tests will also be useful in the design of the gas-tracer tests planned in the USW UZ-9-drillhole cluster (Figure 1.2-2), as described in Study Plan 8.3.1.2.2.3 (Characterization of percolation in the unsaturated-zone -- surface-based study).

3.1.3.6 Gas-flow model

A major challenge of this study is to determine the magnitude of natural flow through the fractured rocks of Yucca Mountain in response to thermal-topographic and barometric effects. This is true because the effects are small and are complicated by the extreme spatial variability of the fracture network. Consequently, a three-dimensional gas-flow and -transport model based on a three-dimensional finite difference code to simulate heat and solute transport by the flow of variable-density fluid through heterogeneous porous media (Kipp, 1987a) will be formulated and calibrated using the flow and gas chemistry data collected from well UZ-6s. This code has previously been used to simulate thermal-topographically induced convective gas flow through an idealized cross-sectional geometry that very crudely approximates Yucca Mountain (Kipp, 1987b). Details of the assumptions inherent in the modeling approach are given in that paper. This model will be refined by incorporating the topography of both the west and east faces of Yucca Mountain as a series of steps. The six-degree dip of the beds will be incorporated, and a third dimension will be added so that convergent flow toward the well can be simulated. The permeability of the various layers comprising the microunits of the Tiva Canyon member, as mapped by Scott and Bonk (1984), will be systematically varied in repeated simulations to determine the distribution, within physically plausible limits (Neuman, 1973) of permeability among the layers that provides the best match between measured and simulated flow. Some measure of air-filled porosity may also be obtained based on the lag between flow in the well and barometric and temperature changes. In addition, if the convergent-flow tracer test successfully provides concentration-breakthrough data at well USW UZ-6s, additional refinements in effective air-filled porosity can be determined. Once a calibrated model is obtained, natural circulation through the mountain can be estimated, again within certain plausibility limits, by simulating the mountain without the well. These simulations will also provide data on the permeability of the Tiva Canyon member that can be used in other studies to simulate the effects of the completed repository on gas circulation through Yucca Mountain.

In addition to determining the convective circulation of air through Yucca Mountain under natural conditions, a goal of this study is to estimate the total circulation through the boreholes since the time they were drilled. The numerical finite-difference code will be cumbersome for this application. Hence, historic flow in the wells will be estimated by performing a regression analysis of measured flow versus barometric pressure, change in barometric pressure, and air temperature in order to develop a regression equation that can be used to compute flow from barometric and temperature records for periods when flow measurements are not available.

3.1.3.7 Methods summary

The parameters to be determined by the tests described above are summarized in Table 3.1-1. Also listed are the selected and alternate methods for determining parameters and the current estimate of the parameter-value range. The alternate methods will be utilized if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, only the most common methods are included in the table. The selected methods in Table 3.1-1 were chosen primarily on the basis of their availability, adaptability to field use, and whether they provided sufficient accuracy for the study purposes over the anticipated range of measurement. The expected ranges of site parameters have been bracketed by previously collected data and are shown in Table 3.1-1.

3.1.4 Quality-assurance requirements

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

The tracing and configuration management of computer codes to be employed in this activity will be performed under YMP-USGS QMP-3.03 (Software Quality Assurance). The qualification of preexisting data to be used in this activity will be performed under AP-5.9Q (Qualification of Data or Data Analyses Not Developed Under the Yucca Mountain Project Quality Assurance Plan).

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

Table 3.1-1. Summary of tests and methods for the gaseous-phase circulation activity
[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site parameter	Expected range
	Total air circulation in open boreholes	
Air temperature using a thermistor (summer) (selected)	Temperature profiles	Temperatures are expected to range between -5 and 30 °C
Air temperature using a thermocouple (winter) (selected)	"	"
Air temperature calculated from geothermal gradient-rock physical properties (alternate)	"	"
Relative humidity measured with relative-humidity probe (for summer conditions) (selected)	Relative humidity	5 to 100%
Relative humidity measured by wet-bulb depression (for winter conditions) (selected)	"	"
Pressure measured by a digital-barometer type pressure transducer (selected)	Barometric pressure	84 to 88 kPa
Pressure measured by a mercury manometer (alternate)	"	"
Pressure measured by a Bourdon gauge (alternate)	"	"
Flow velocity using a propeller anemometer (selected)	Flow velocity	0 to 20 m/s
Flow velocity using a hot-wire anemometer flow meter (selected)	"	"
Flow direction using a propeller anemometer (selected)	Flow direction, air	Flow direction will be either up or down in the boreholes

Table 3.1-1. Summary of tests and methods for the gaseous-phase circulation activity continued

[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site parameter	Expected range
	Flow, temperature, and gas-composition profiles	
Gas sampling by lowering plastic tubing down casing and pumping with peristaltic pump (selected)	--	--
	Flow, temperature, and gas-composition profiles - continued	
Gas composition (including tracers) by gas chromatography (selected)	Gas composition	CO_2 CH_4 CCl_3F(F-11) $CCClF_2$(F-12) SF_6 $CBrClF_2$
Gas composition (including tracers) by mass spectroscopy (alternate)	"	"
Determine activity of $^{14}CO_2$ by benzene synthesis and scintillation counting (selected)	Radioactive isotope activity, C^{14}	Post-bomb to 2% of Modern
Determine $^{14}CO_2$ activity using conventional gas counter (alternate)	"	"
Determine $^{14}CO_2$ activity using Van der Graf accelerator (alternate)	"	"
Determine stable-isotope concentration by mass spectroscopy (selected)	Stable-isotope composition, d C^{13} d H^2 (Deuterium) d O^{18}	 -8 to -24°/oo -60 to -120°/oo +10 to -20°/oo
Temperature logs will be obtained by using a standard temperature logging tool (selected)	Temperature profiles	Temperatures are expected to range between -5 and 30 °C
Temperature calculated from geothermal-gradient rock physical properties (alternate)	"	
Temperature profile using inplace transducers (alternate)	"	"

Table 3.1-1. Summary of tests and methods for the gaseous-phase circulation activity continued

[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site parameter	Expected range
Use a propeller anemometer in a measuring tube with inflatable packer. Adapted for use with logging truck (selected)	Flow-velocity profiles	Downhole flow velocities are expected to range between 0 and 20 m/s
	Flow-interference tests	
Fracture interconnectness by flow-interference tests (Section 3.1.3.3) (selected)	Fracture interconnectedness	--
	Gas-tracer tests	
Fracture interconnectedness determined from gas-tracer tests performed by shallow burial of permeation tubes along western scarp of Yucca Mountain (selected)	Fracture interconnectedness	--
Ratio determined by injection-withdrawal tests (selected)	Ratio of drained fracture to drained matrix porosity	.02 to .0001
Delay index determined by injection-withdrawal tests (selected)	Delay index for fracture-matrix gas interaction	10^{-4} to 10^{-6}/sec
Gas sampling from boreholes for tracer and isotope. Sample air stream blowing from summit wells (selected)	--	--
Gas sampling from stemmed boreholes for tracers and isotopes. Cross reference to 8.3.1.2.2.7 (Unsaturated-zone hydrochemistry characterization) (alternate)	--	--
	Gas-phase modeling	
Infer flux distribution by 3-D computer modeling of variable-density fluid flow through heterogeneous media (selected)	Flux distribution, gas water-vapor flux	--

Table 3.1-1. Summary of tests and methods for the gaseous-phase circulation activity continued
[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site parameter	Expected range
Determine potentials by 3-D computer modeling of variable-density fluid flow (selected)	Gas potentials	80 to 90 kPa
Determine potentials empirically by discrete measurement throughout Yucca Mountain (selected)	"	"
Determine potentials with other models (cross reference to 8.3.1.2.2.9) (alternate)	"	"

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 gas travel times (Issues 1.1 and 1.6).

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. Sections 2 and 3 use logic diagrams and tables to summarize specific relation between tests and analyses methodologies and site-characterization parameters determined from this study. Table 4.2-1 provides additional parameter relations.

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

Table 4.2-1 shows the specific technical information relations between SCP design- and performance-parameters needs and site parameters to be determined in this study. The relations were developed using model-based parameter categories (see Figure 2.1-1) that provide common terminology and organization for evaluation of site, design, and performance information relations.

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

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

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

Table 4.2-1. Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance			(SCP 8.3.5.13)	
Performance Measures:	(Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.) CCDF, nominal case, release scenario class E, water pathway release CCDF, nominal case, release scenario class E, gas pathway release				
		Parameter Category: Unsaturated-zone transmissive properties			
Effective porosity (Fracture network)	Repository area; Unsaturated-zone units, overburden	Goal: Mean, Variance, Autocorrelation length Current: NA, NA, NA Needed: Low, Low, Low	Fracture interconnectedness	Yucca Mountain crest and vicinity	8.3.1.2.2.6.1
Effective pneumatic porosity (Fracture network)	Repository area; Overburden	Goal: Mean, Variance, Autocorrelation Length Current: Low, Low, Low Needed: High, Low, Low			
Profiles of Darcy velocity of air flow (Ambient, rock mass pore spaces)	Repository area; Unsaturated-zone units, overburden	Goal: To be determined Current: Low Needed: High			

Table 4.2-1. Design and performance issues and parameters supported by results of this study - continued

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
Profile of carbon-14 concentration (Ambient, rock mass pore spaces)	"	Goal: To be determined Current: Low Needed: Medium	Gas composition	Yucca Mountain crest and vicinity	"
			Radioactive-isotope activity, C^{14} (Cross-reference 8.3.1.2.2.7)	"	"
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
			Stable-isotope composition, C^{13}, H^2 (deuterium), O^{18} (Cross-reference 8.3.1.2.2.7)	Yucca Mountain crest and vicinity	"
			Temperature profiles	"	8.3.1.2.2.6.1

Table 4.2-1. Design and performance issues and parameters supported by results of this study - continued

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
		Parameter Category: Unsaturated-zone fluid flux			
q_u: average flux through repository area in unsaturated zone (scenario class E, nominal case)	Repository area; Unsaturated zone	Goal: <0.5 mm/yr Current: Medium Needed: High	Delay index for fracture-matrix gas interaction	Yucca Mountain crest and vicinity	"
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	Flow direction, air	"	"
		Parameter Category: Unsaturated-zone fluid flux			
			Flux distribution, gas	Yucca Mountain crest and vicinity	"
			Ratio of drained fracture to drained matrix porosity	"	"
			Water-vapor flux	"	"

Table 4.2-1. Design and performance issues and parameters supported by results of this study - continued

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.5	Waste package and repository engineered-barrier system release rates			(SCP 8.3.5.10)	
Performance Measures: Concentration of radionuclide species in gas phase, liquid waste, and absorbed to solid phases within the near-field host rock.					
		Parameter Category: Unsaturated-zone transmissive properties			
Host-rock hydrologic properties (waste package environment)	Primary area; TSw2	Goal: Properties known with accuracy sufficient to calculate differences in flow through the near-field rock resulting from anticipated and unanticipated events Current: Low Needed: High	Fracture interconnectedness	Yucca Mountain crest and vicinity	8.3.1.2.2.6.1

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

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

- o 8.3.1.3.7 Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment; and
- o 8.3.1.3.8 Studies to provide the required information on retardation of gaseous radionuclides along flow paths to the accessible environment.

The unsaturated-zone investigation (8.3.1.2.2 - Studies to provide a description of the unsaturated-zone hydrologic system at the site) is directed at solving the problems associated with the fundamentals of liquid water and gas flow at Yucca Mountain. The five USGS studies that have been developed to solve this problem are the (1) Characterization of unsaturated-zone infiltration (Study 8.3.1.2.2.1), (2) Characterization of unsaturated-zone percolation (Studies 8.3.1.2.2.3 and 8.3.1.2.2.4), (3) Characterization of gaseous-phase movement in the unsaturated zone (Study 8.3.1.2.2.6), and (4) Hydrochemical characterization of the unsaturated zone (Study 8.3.1.2.2.7). Gas flow in the unsaturated zone has an important hydrologic role to quantify vapor flux, as it may be opposite in direction to liquid flow. Gas flow also may be an important mechanism in the transport of radionuclides to the accessible environment. Also, data from this study can be used to test the physical plausibility of the model studies of Ross and of Buscheck that show substantial buoyant flow.

The gaseous-phase movement study interfaces with all other studies and activities addressing the phenomena associated with gas flow. These include all activities yielding air conductivities from packer tests with gas injection in boreholes, cross-hole tests, and gas-tracer tests. The results of the testing will be used in two- and three-dimensional simulations of the natural-hydrologic system (Study Plan 8.3.1.2.2.8 - Fluid flow in unsaturated, fractured rock and Study Plan 8.3.1.2.2.9 - Site unsaturated zone modeling and synthesis).

In addition, results from the gaseous-phase movement study will be applicable to the following investigations. Tracer tests and determination of vapor fluxes and permeabilities will be useful in Investigations 8.3.1.3.7 (Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment) and 8.3.1.3.8 (Studies to provide the required information on retardation of gaseous radionuclides along flow paths to the accessible environment). In Investigation 8.3.1.3.7, the pertinent study is 8.3.1.3.7.1 (Retardation sensitivity analysis) which involves determining the significance of the geochemical and physical processes affecting transport, and compiling a conceptual geochemical-geophysical model of Yucca Mountain to be used as a basis for integrated, three-dimensional, transport calculations. Data from the gaseous-phase circulation study will be directly applicable to 8.3.1.3.7.1.

In Investigation 8.3.1.3.8, the objective is to supply input data for calculations of gaseous radionuclide transport from the repository to the accessible environment. Data needed for 8.3.1.3.8.1 (Gaseous radionuclide transport calculations and measurements) to be supplied by the gaseous-phase circulation study are gas-phase composition, mechanisms of gaseous transport, and flow paths for gaseous transport.

5 SCHEDULE AND MILESTONES

5.1 Schedule

A tentative schedule for the work covered by this study plan is presented in Figure 5.1-1. The proposed schedule summarizes the logic network and reports for the activity described in this study. The schedule information includes the sequencing, interrelations, and relative durations of the described activity. Specific durations, and start and finish dates for the activity 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 field-work schedule in this study plan is governed by the schedule for drilling and stemming of boreholes. As currently planned, open boreholes will be prepumped to remove trace drilling air, injection-tested, postpumped to remove trace injection gas, the gasses analyzed chemically and isotopically, and gas phase circulation testing completed before it is stemmed. Prior to stemming, a tracer test will be performed between the outcrop and borehole during the strong-exhaust period during the preceding winter. After stemming of the boreholes is completed, additional work associated with the surface-based percolation study and the UZ hydrochemistry study will commence.

As stated in Section 1.3 of the study plan, the process understanding and methods developed will be used in the study of surface-based, unsaturated-zone percolation (Study 8.3.1.2.2.3), ESF unsaturated-zone percolation (Study 8.3.1.2.2.4), and hydrochemical characterization of the unsaturated zone (Study 8.3.1.2.2.7). The results of these broad-scope studies and the results from gaseous-phase circulation studies will provide most the parameters for the final modeling of gaseous-phase circulation for repository performance assessment. Final modeling of gaseous-phase circulation will be done as described by YMP-USGS SP 8.3.1.2.2.9 (Site unsaturated-zone modeling and synthesis).

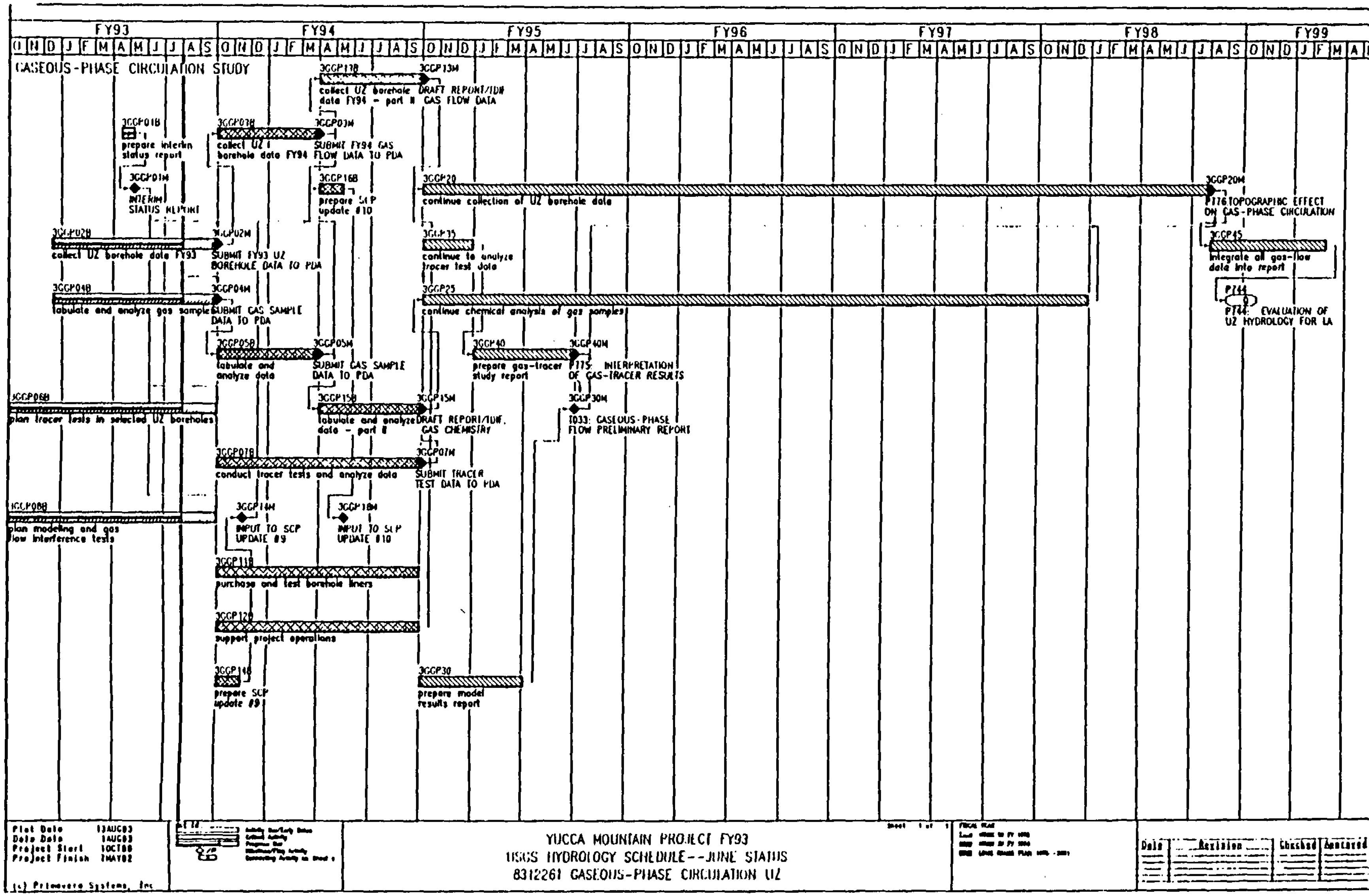

Figure 5.1-1. Summary network for UZ gaseous phase movement study.

5.2 Milestones

The level, number, and title of milestones associated with the gaseous-phase circulation study are summarized in Table 5.2-1.

The information presented in Table 5.2-1 represents major events or important summary milestones associated with the activities presented in this study plan. Specific dates for the milestones are not included in the tables, as project schedules have been revised from those originally stated in Section 8.5 of the SCP, and are subject to further change due to ongoing planning efforts.

Table 5.2-1. Milestone list for work-breakdown structure number 1.2.3.3.1.2.6 (SCP 8.3.1.2.2.6)

Milestone number	Milestone	Milestone level
3GG01M	NRC approval of study plan	3
G001M	Work authorization 1.2.3.3.1.2.6	3
G007M	Gas flow progress report	3
P17A	Open file report	3
P775	P775: Interpretation of gas-tracer results	3
P776	P776: Topographic effect on gas-phase circulation	3
T032M	Results of air-flow interference tests	3
T033M	T033: Gaseous-phase flow preliminary report	3

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