U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

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

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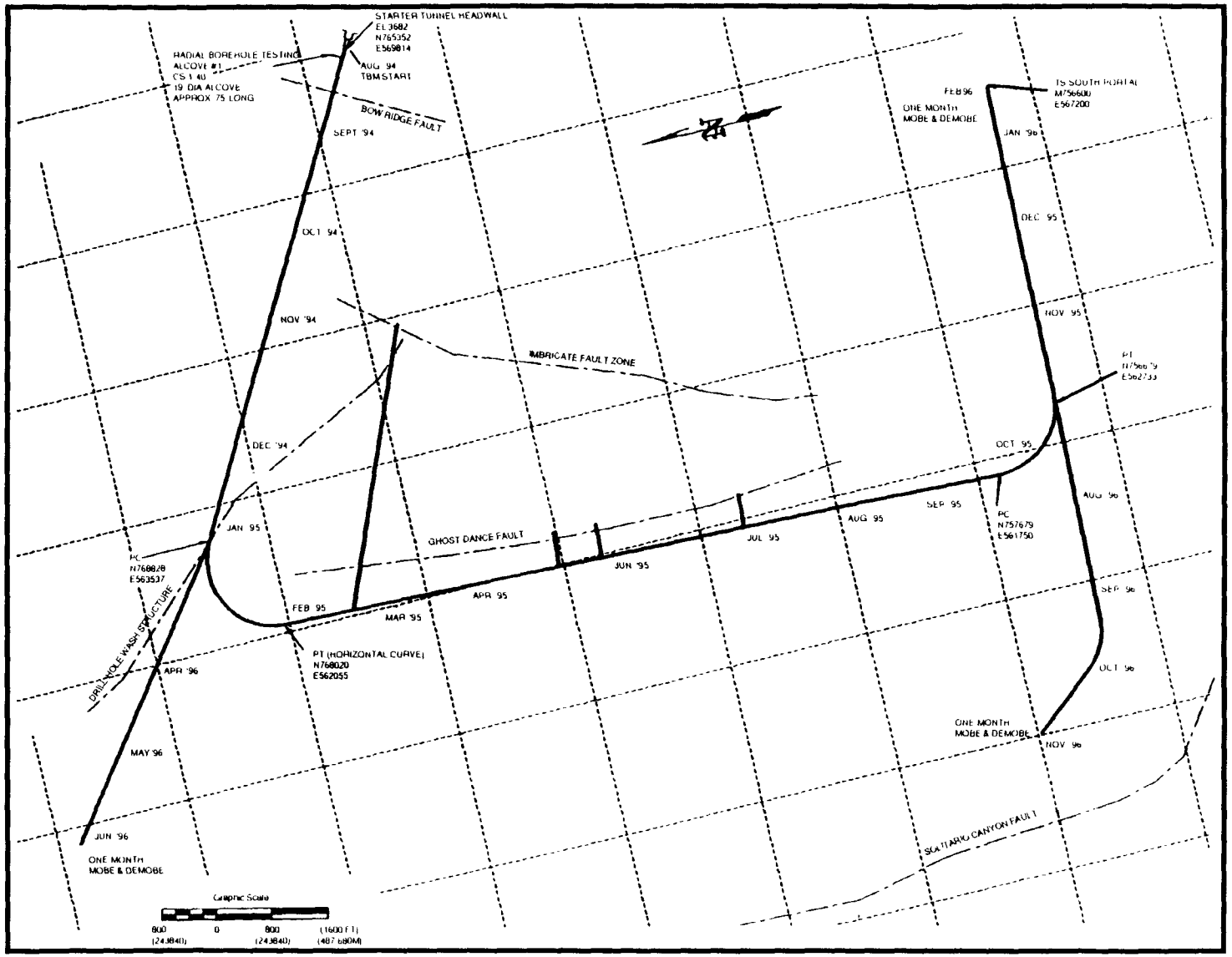
Outline

- Unsaturated zone studies in the Exploratory Studies Facility
- Purpose and objectives of study
- Rationale for study
- Description of test activities
- Unsaturated zone studies in the starter tunnel
- Summary

Exploratory Studies Facility Tunnel Boring Machine Advance Time Line Illustration



As of 10-1-93

LEGEND

FAULT ZONE ———— - - - -

RAMP CONFIGURATION ———— ————

REFERENCE GRID ———— - - - - -

BOREHOLE LOCATION ————

COMMENTS

NORTH PORTAL BOX CUT FACE AT CS 0+00

ALCOVE #1 APPROXIMATELY LOCATED AT CS 1+40

TWO THOUSAND FEET GRID ENGLISH COORDINATES ARE BASED ON THE NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE

DIMENSIONS AND ELEVATIONS ARE SHOWN IN FEET FEET ARE ROUNDED TO ZERO DECIMAL PLACES WHERE DISCREPANCIES BETWEEN ELEVATIONS AND GRADIENTS OCCUR DUE TO ROUNDING, ELEVATIONS WILL GOVERN

STARTER TUNNEL CONFIGURATION AND AZIMUTH FOR THE FIRST 200 FT (60 960 m) IS BASED ON TITLE II PACKAGE 1A DESIGN DRAWINGS

EXISTING DRILLHOLE LOCATIONS ARE BASED ON FIELD SURVEYS PROPOSED DRILLHOLE LOCATIONS ARE BASED ON INFORMATION CONTAINED IN THE WORK PROGRAMS

FAULT TRACE LOCATIONS EXCEPT FOR THE BOW RIDGE FAULT ARE APPROXIMATIONS BASED ON AT DEPTH PROJECTIONS OF INFORMATION FOR USGS OPEN FILE REPORT 84 494, PRELIMINARY GEOLOGIC MAP AND SECTIONS BY SCOTT AND BONK THE BOW RIDGE FAULT TRACE IS AN AT DEPTH PROJECTION BASED ON PRELIMINARY FIELD WORK FROM ON GOING ROCK AND SOIL INVESTIGATIONS

SCHEDULE BASED ON EXCAVATION RATE OF 300 FEET/WEEK

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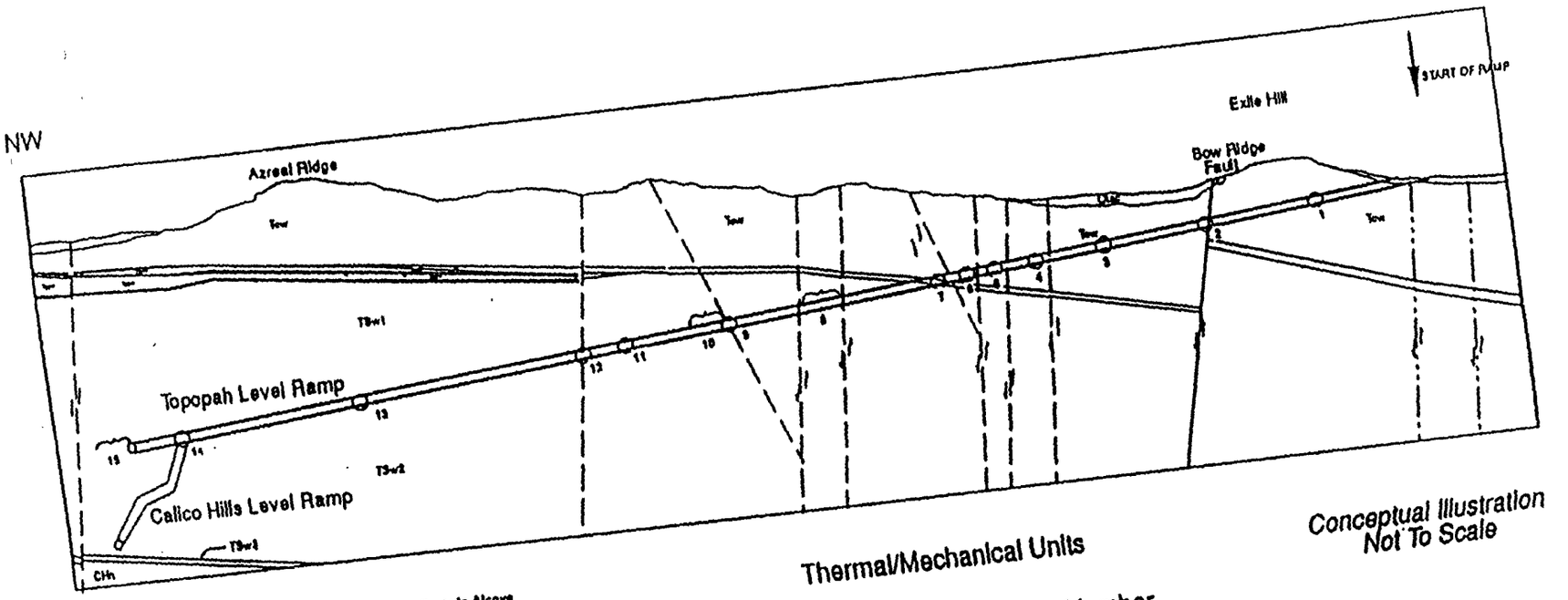
NORTH RAMP

NW

SE



Conceptual Illustration
Not To Scale

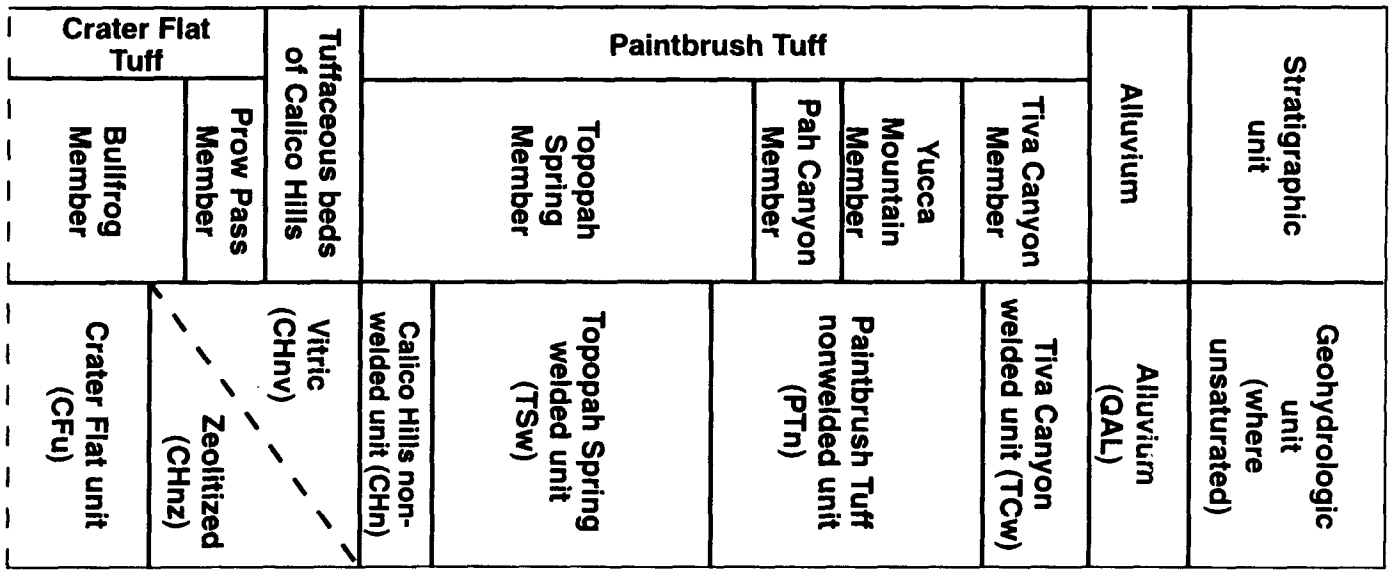
Alcove Number	Tests in Alcove
1	Anisotropy Test (RBT, Hydrochemistry)
2	Hydr. Properties of Major Faults (Bow Ridge), Hydrochemistry, In-Situ Seals Test
3	Anisotropy Test (RBT), Hydrochemistry, Plate Loading, In-Situ Seals Test
4	In-Situ Seals Test
5	Contact Test (RBT), Hydrochemistry, In-Situ Seals Test
6	Anisotropy Test (RBT), Hydrochemistry, Plate Loading, Diffusion
7	Contact Test (RBT), Hydrochemistry, In-Situ Seals Test
8	Geomechanical Attributes of the Waste Package Environment, Repository Horizon Near-Field Hydrologic Properties
9	In-Situ Seals Test
10	UDBR, Overcore Stress, Heater Experiment in TSw1, Plate Loading
11	Anisotropy Test (RBT), Hydrochemistry
12	In-Situ Seals Test
13	Hydrochemistry, In-Situ Seals Test
14	Excavation Effects
15	Hydr. Properties of Major Faults (Drill Hole Wash Structure), Hydrochemistry

NOTE: Alcove locations shown in brackets indicate general uncertainty in specific location of alcove.

Thermal/Mechanical Units

Tcw	Tiva Canyon Member
PTn	Yucca Mountain Member Pah Canyon Member
TSw1 TSw2	Topopah Spring Member
TSw3	Topopah Spring Member
CHn	Tuffaceous Beds of Calico Hills
TZZ	Zeolite-Vitric Contact in Calico Hills (TZZ) (Not Present on This Section)

Diagram Showing the Relation of Geohydrologic Units to Stratigraphic Units



Note: Figure not to scale

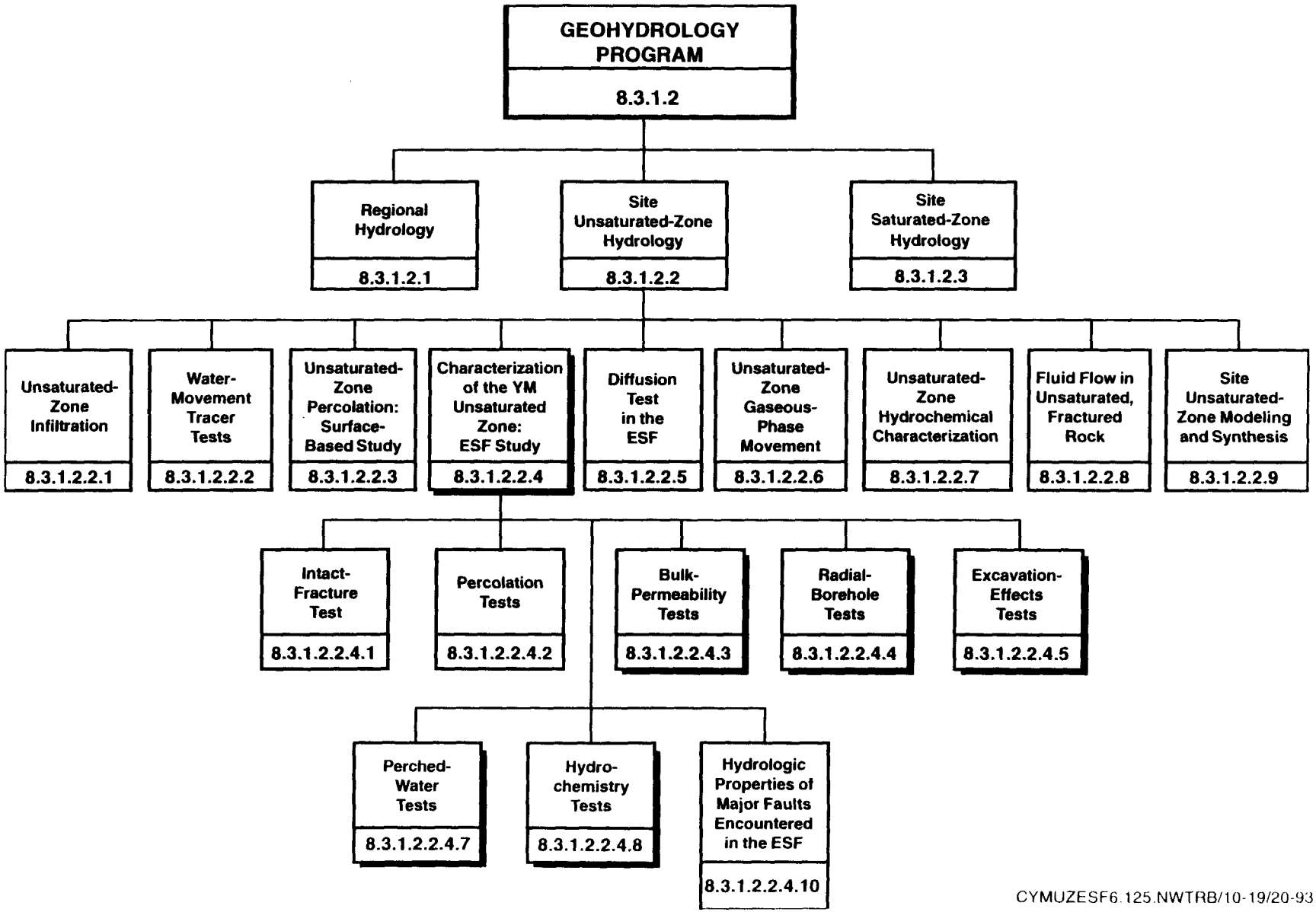
Unsaturated Zone Studies in the Exploratory Studies Facility

- **Construction Phase Tests**
  - Radial borehole tests, Gary LeCain, PI
  - Excavation effects tests, Falah Thamir, PI
  - Perched water tests, Charles Peters, PI
  - Hydrochemistry tests, Charles Peters, PI
  - Major faults tests, Gary LeCain, PI

- **Post-construction Phase Tests**
  - Intact fracture tests, Gary Severson, PI
  - Percolation tests, Falah Thamir, PI
  - Bulk permeability tests, Gary LeCain, PI

Only construction phase tests will be discussed

Diagram Showing the Location of the Exploratory Studies Facility Characterization of the Yucca Mountain Unsaturated Zone Study within the Unsaturated Zone Investigation and the Geohydrology Program



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Purpose of Study

- Provide hydrologic parameter input for the resolution of design and performance issues
- Provide an understanding of the impacts of ramp and drift construction on the *in situ* hydrologic characteristics
- Contribute to an understanding of the *in situ* hydrologic characteristics of the unsaturated zone

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

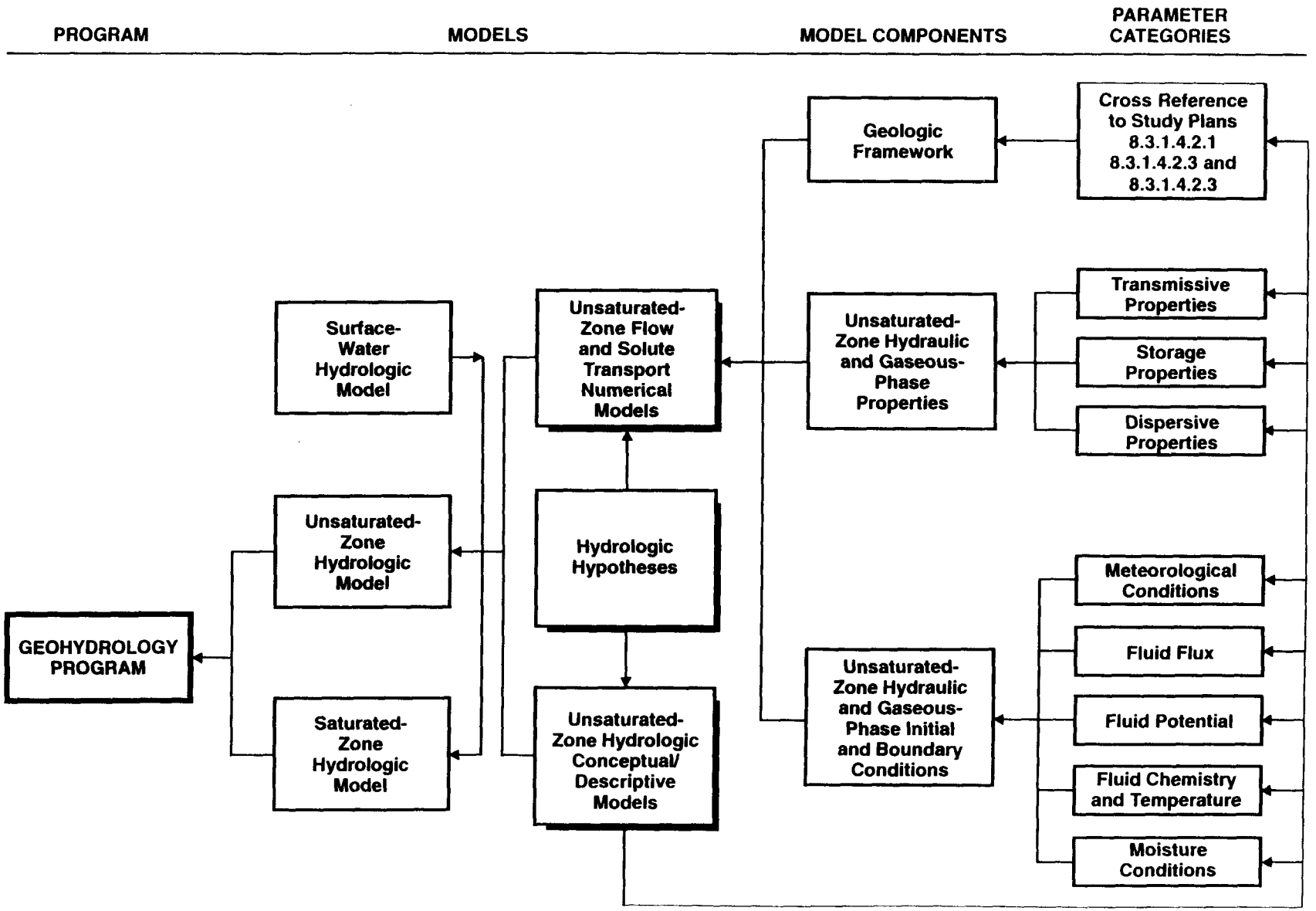
Objective of the Study
Technical Objectives

- **Characterize the *in situ*, unsaturated-zone hydrologic conditions**
  - **Core and fluid samples**
  - **Borehole logs**
  - ***In situ* borehole testing and monitoring**

- **Characterize the spatial distribution of present-day fluid flow within the unsaturated zone**

- **Characterize gas and vapor flow in the unsaturated zone**

Logic Diagram of Geohydrology Program, Including Model Components and Parameter Categories



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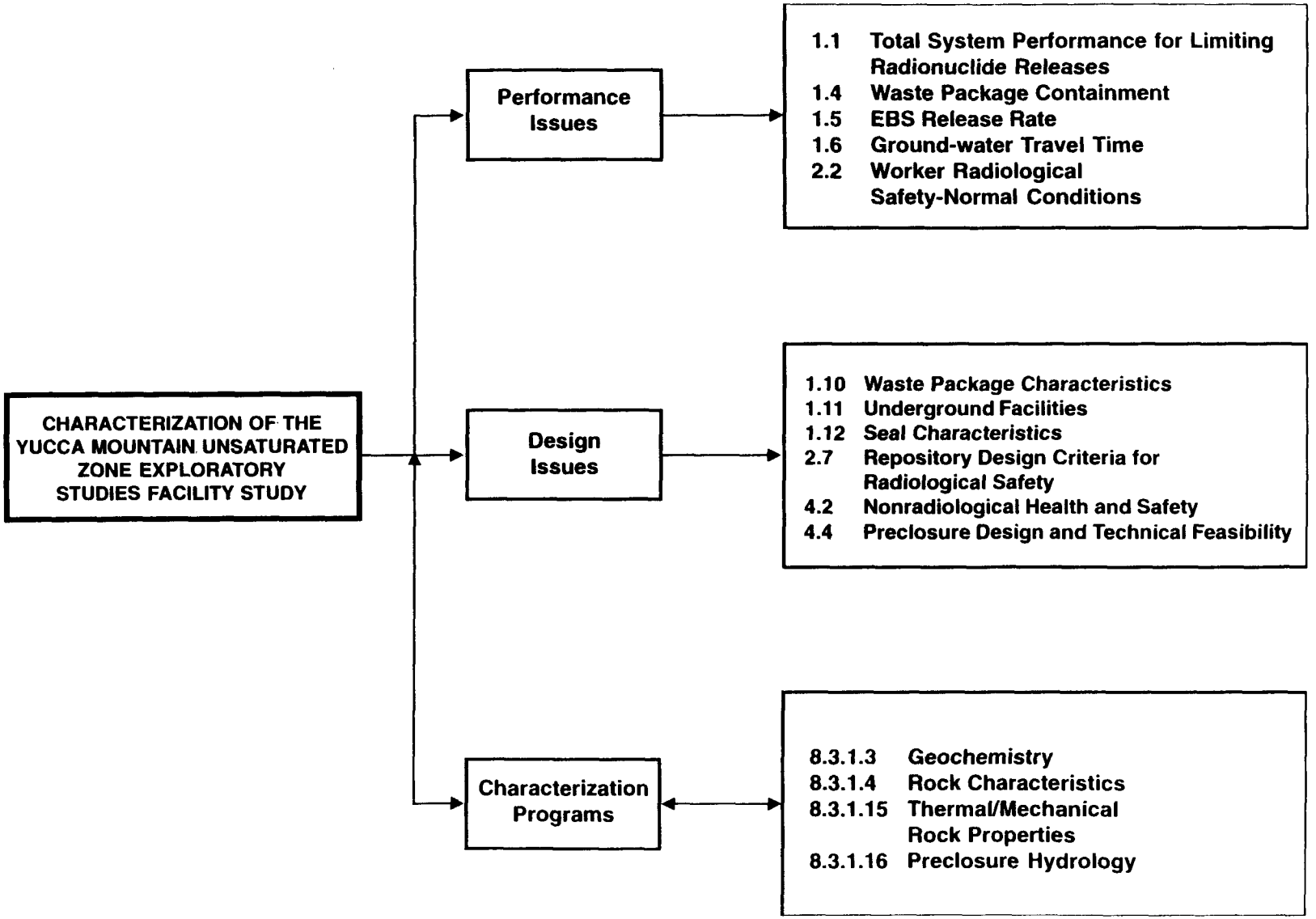
Objectives of the Study
Regulatory Objectives:
Design and Performance Issues

- Provide hydrologic data for calculations of unsaturated-zone ground-water travel time
- Provide hydrologic data for the predictions of radionuclide releases to the accessible environment
- Provide hydrologic properties data to design analyses of the underground facility, repository seals, and waste packages

Diagram Showing Interfaces of the Exploratory Studies Facility Characterization of the Yucca Mountain Unsaturated Zone Study with Yucca Mountain Performance and Design Issues and Other Site-Characterization Programs



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Rationale for Study

- Hydrologic testing in the Exploratory Studies Facility (ESF) will supplement and complement surface-based testing
- The ESF provides an opportunity to evaluate hydrologic parameters for a wide range of scales
- The ESF provides a testing environment that is suitable for three-dimensional characterization of the hydrologic properties of the rock mass
- The effects of excavation on the host rock can be studied directly in the ESF
- ESF tests will provide data for multiscale numerical modeling of the unsaturated zone

Description of Test Activities

- Activity objective
- Rationale for activity selection
- Test description for activity

Radial-Boreholes Tests

Activity objectives

- Quantify gas permeability and anisotropy of the hydrogeologic units within the unsaturated zone
- Estimate tortuosity and effective porosity of drained flow paths within the unsaturated zone hydrogeologic units
- Quantify the boundary effects at the hydrogeologic unit contacts
- Compare pneumatic and hydraulic test results, especially at the hydrogeologic unit contacts

Radial-Borehole Tests

Rationale for activity selection

- Hypothesized that most fractures in the unsaturated zone are devoid of significant liquid water (Montazer and Wilson, 1984; Wang and Narasimhan, 1985)
- Upward movement of water vapor may indicate the potential for upward movement of gaseous radionuclides
- Downward water movement may indicate the potential for radionuclide-solute transport
- Downward flowing water may be diverted laterally

Radial-Borehole Tests

Test description

- Four test programs for testing in two ramps
  - Air permeability-anisotropy testing within hydrogeologic units
  - Air-injection testing across the hydrogeologic contacts
  - Long-term monitoring of selected boreholes
  - Water-injection testing at the contact sites

Radial-Borehole Tests

Test description: Gas-injection and -withdrawal methods

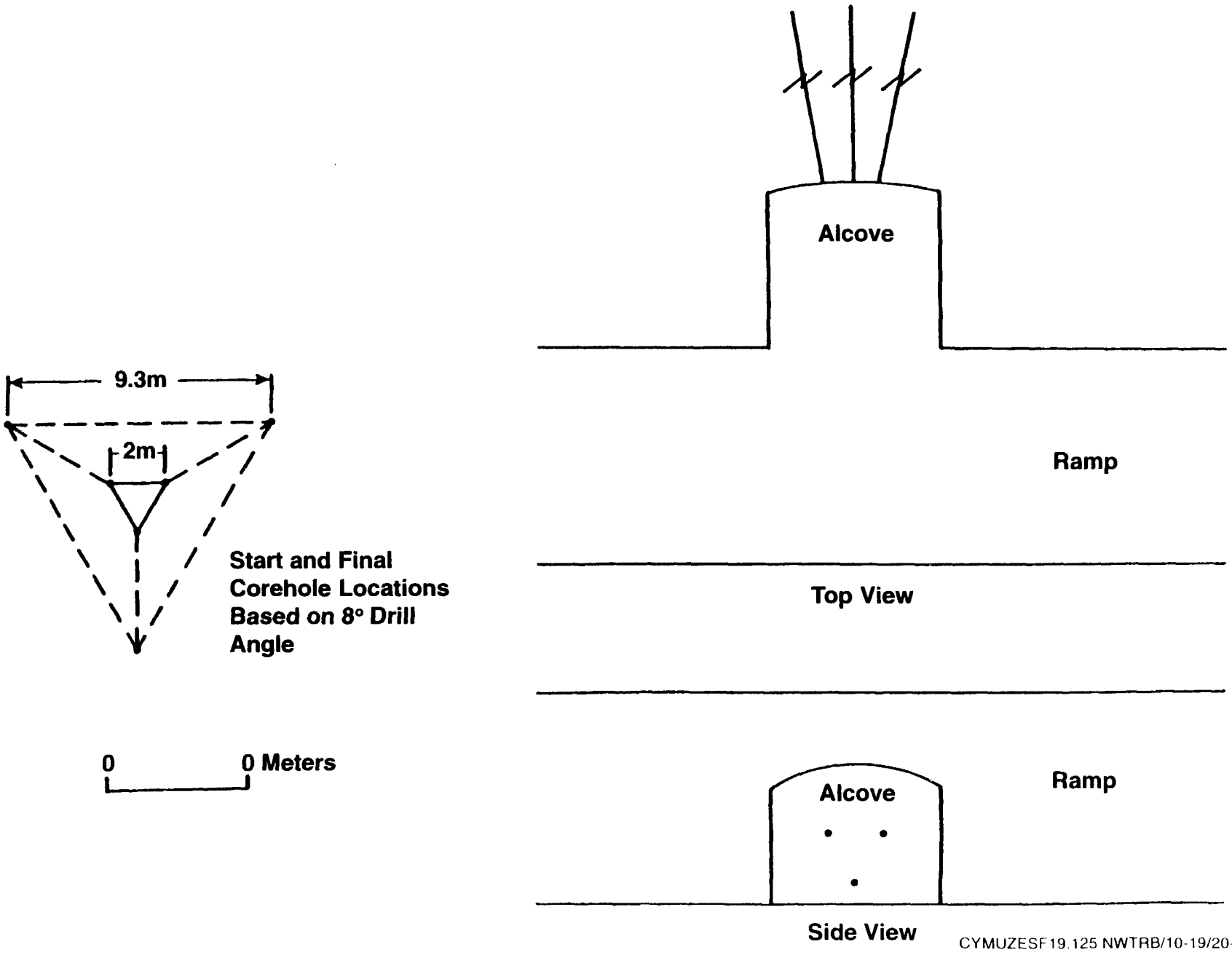
- **Single-hole, constant-flow-rate, transient tests**
- **Single-hole steady state, gas-injection and -withdrawal tests**
- **Cross-hole, constant-flow-rate, transient tests**
- **Cross-hole, steady-state, gas-injection and -withdrawal tests**

Radial-Borehole Tests

Test description: Air-permeability anisotropy testing

- Conducted in three cored boreholes drilled from an alcove
- Boreholes configured in an expanding equilateral triangle
- 30-meter long boreholes to extend beyond excavation disturbed zone
- Core samples collected for unsaturated zone hydrochemistry and matrix properties

Schematic of Permeability: Anisotropy Borehole Configuration



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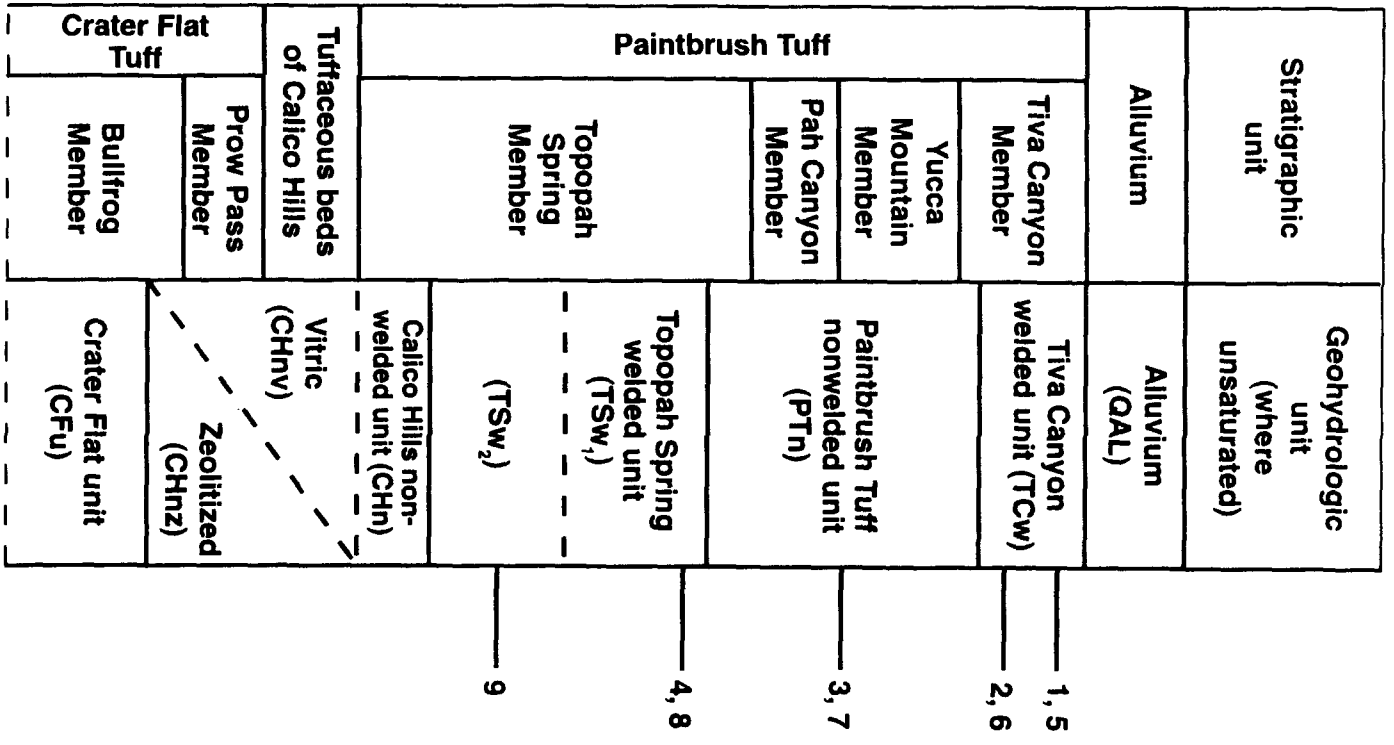
Radial-Borehole Tests

Test description: Air-permeability anisotropy testing

- Quantify permeability, anisotropy, effective porosity, and tortuosity
- Packers installed in boreholes for air injection and monitoring
- Conduct single- and cross-hole pneumatic testing
- Nine preliminary sites selected; final sites to be selected during construction
- Long-term monitoring up to five years following testing

Stratigraphic Locations Of Permeability-Anisotropy Test Sites



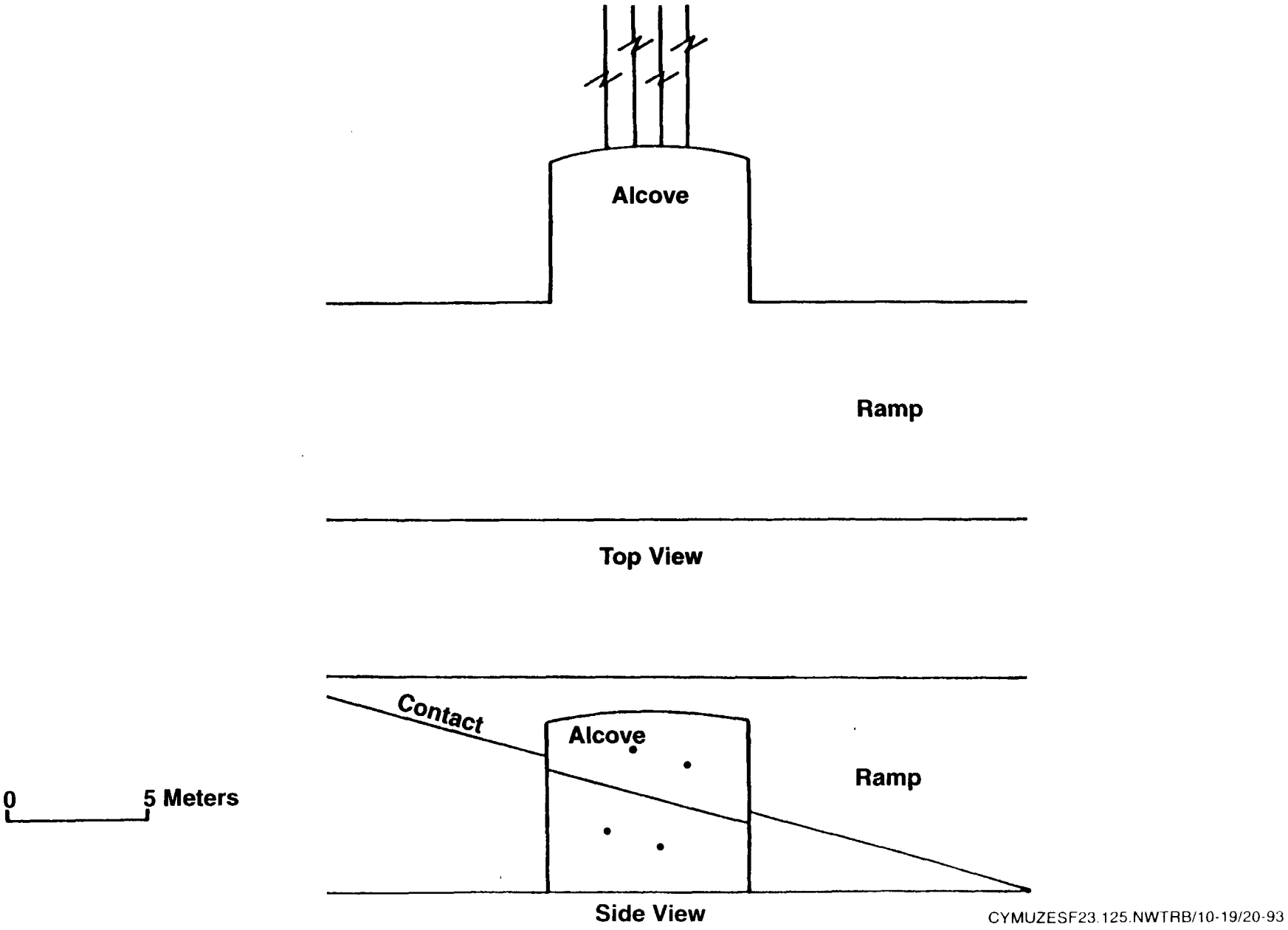
Note: Figure not to scale

Radial-Borehole Tests

Test description: Air-injection testing

- Conducted in four cored boreholes drilled from an alcove
- Boreholes configured in a rectangular pattern
- 30-meter long boreholes to extend beyond excavation disturbed zone
- Core samples collected for unsaturated zone hydrochemistry and matrix properties

Schematic of Geohydrologic Contact Borehole Configuration



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Radial-Borehole Tests

Test description: Air-injection testing

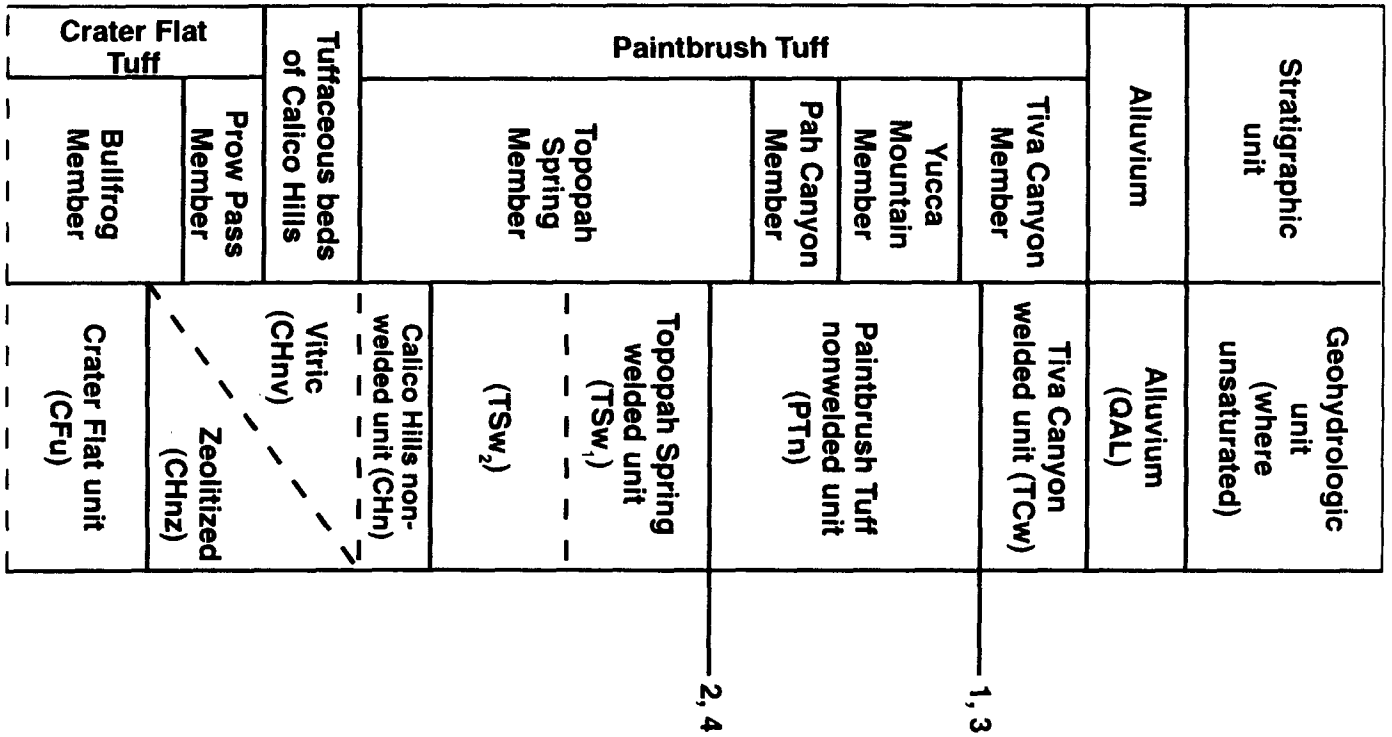
- Quantify hydrogeologic contact effects on air and water flow
- Packers installed in boreholes for air injection and monitoring
- Conduct single- and cross-hole pneumatic testing
- Four preliminary sites selected, additional sites could be selected
- Long-term monitoring up to five years following testing

Radial-Borehole Tests

Test description: Long-term monitoring

- Instrument and monitor intervals in selected boreholes, up to five years
- Detect barometric influences, water movement, and/or construction effects
- Gas samples periodically collected during monitoring

Stratigraphic Locations of Geohydrologic Contact Test Sites



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Radial-Borehole Tests

Test description: Water-injection testing

- Conducted in boreholes at completion of long-term monitoring
- Use injection and monitoring boreholes
- Determine usefulness of effective air permeability in calculating hydraulic conductivity

Excavation Effects Test

Activity objectives

- Estimate the magnitude and extent of modification of the hydrologic properties in the Topopah Spring welded unit caused by excavation of the ESF

Excavation Effects Test

Rationale for activity selection

- Excavation in fractured rocks can significantly alter the physical properties of the rock near an underground opening (Montazer,1982)

- Permeability before and after excavation is a parameter required by other ESF tests to estimate errors in hydrologic properties caused by construct

- Evaluation is needed to determine the significance of excavation effects and to develop methods to correct for changes in hydrologic properties caused by excavation

Excavation Effects Test

Test description: Evaluation parameters needed

- Pre-mining fracture permeability, rock stress, and water saturation
- Stress changes, fracture deformation, and permeability changes resulting from excavation
- For excavation effects to be considered significant
  - Changes in fracture permeability need to be measurable
  - Final permeability values need to be statistically different from initial values

Excavation Effects Test

Test description: General approach

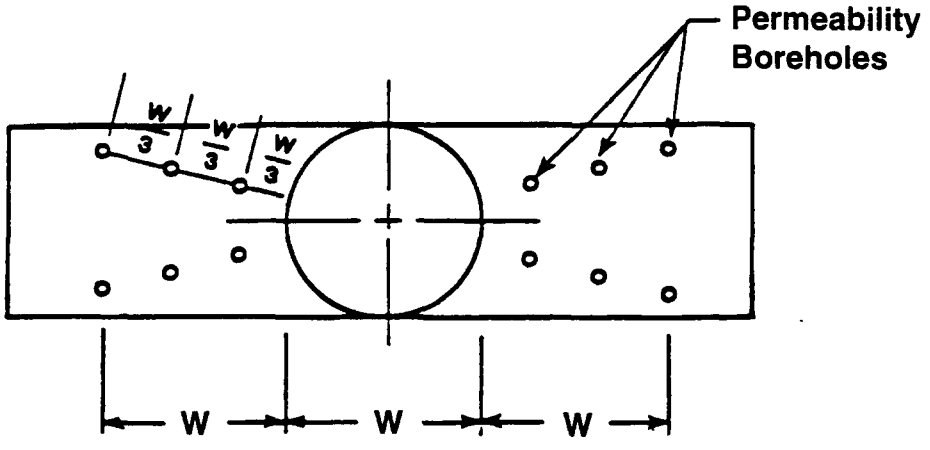
- Tests conducted from alcoves on both sides of planned excavation
- Boreholes drilled parallel to proposed ESF opening
- Air-permeability testing before and after excavation
- *In situ* stress and mechanical property measurements conducted before, during, and after excavation

Excavation Effects Test

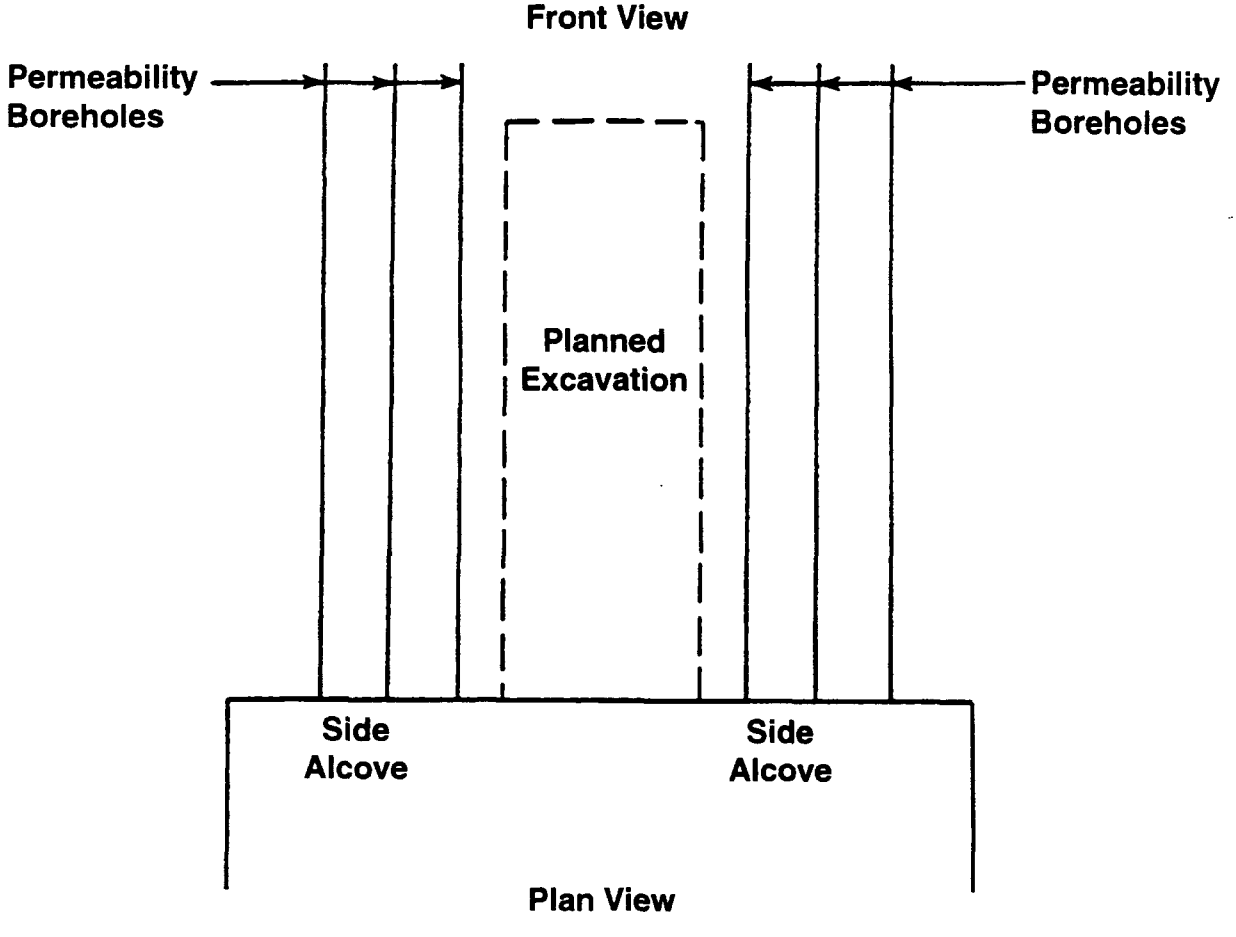
Test description: Statistical approach

- Initial statistical test is required to verify that changes in permeability are measurable and that final permeabilities are statistically different
- Statistical test measurements are repeated at several locations to minimize prediction uncertainty
- Predicted permeabilities only valid in areas where *in situ* physical properties, stress, and excavation methods are the same

Excavation Effects Test Plan for the Initial Evaluation and Statistical Approach



W = Excavation Diameter (Or Width)

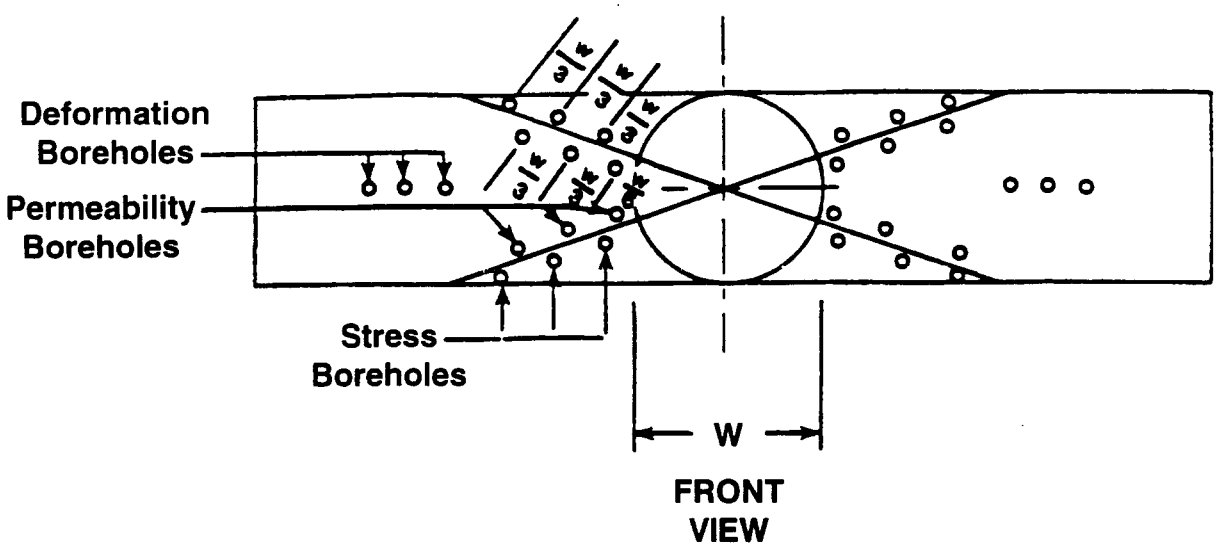


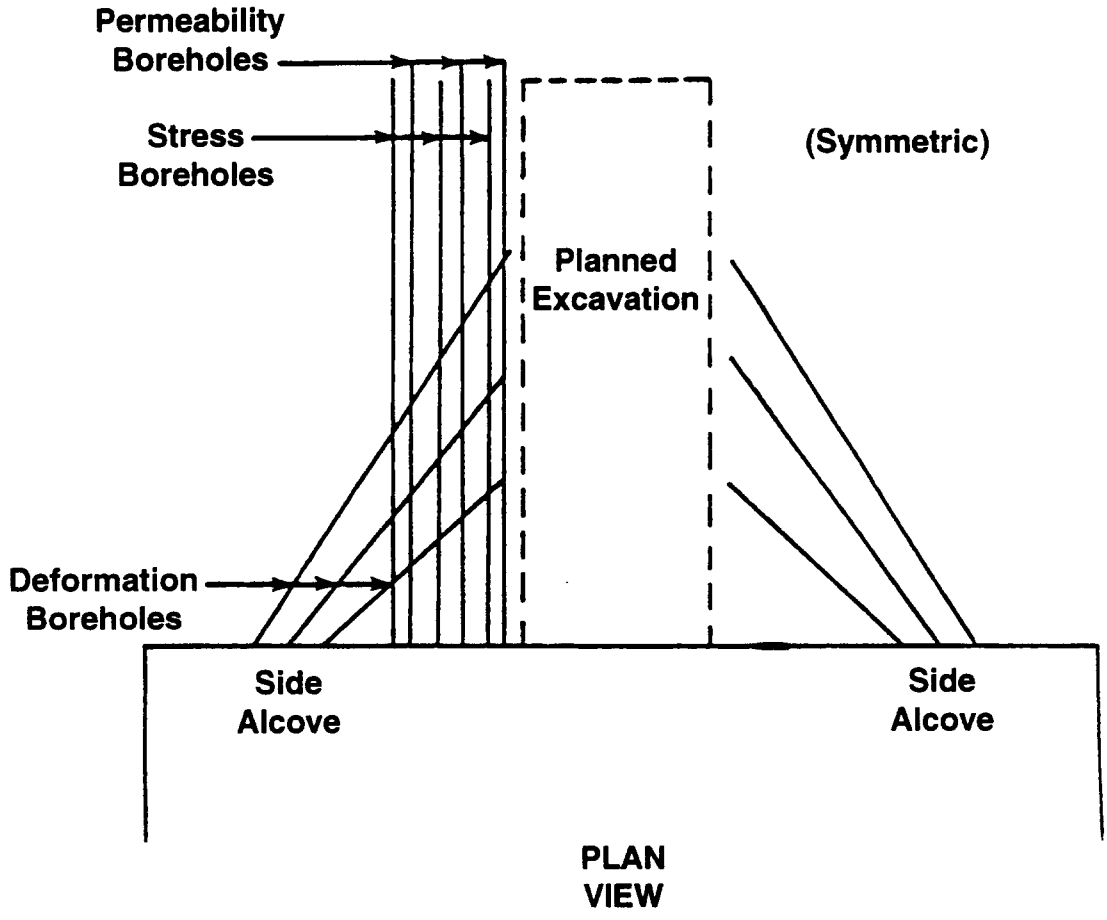
Excavation Effects Test

Test description: Physical approach

- Deterministic approach where all parameters are measured
- Measured parameters are used to support geomechanical model
- Coupled hydrologic-mechanical model is used to analyze results and to predict excavation effects where *in situ* conditions are different

Excavation Effects Test Plan for the Physical Approach





W = Excavation Diameter (or width)

Perched-Water Test

Activity objectives

- Detect the occurrence of any perched water
- Estimate the hydraulic properties of perched-water zones
- Determine the implication of the existence of perched-water zones on water flux, flow paths, and travel times

Perched-Water Test

Rationale for activity selection

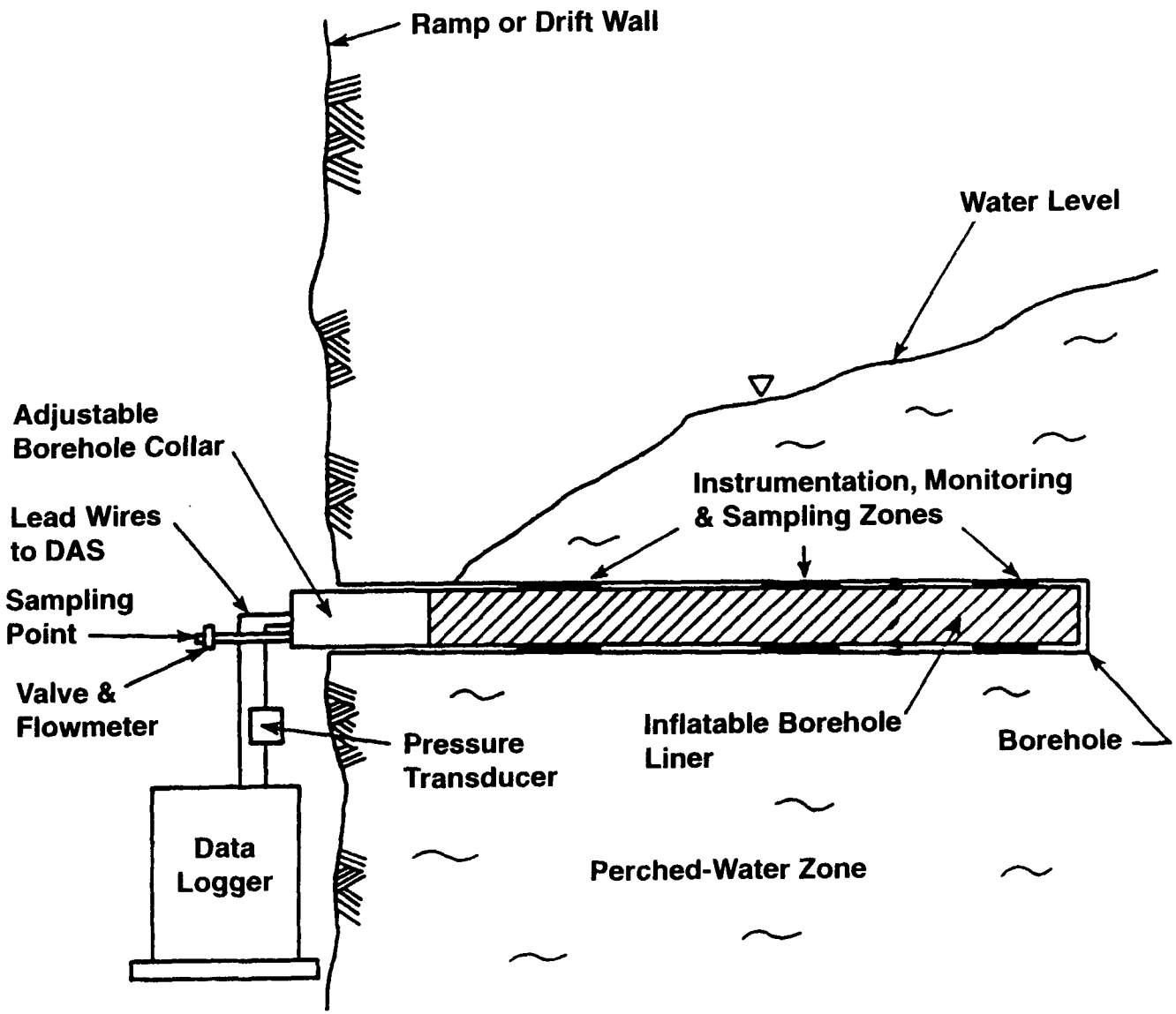
- Perched water may imply a particular flow path for water in the unsaturated zone (Montazer and Wilson, 1984)
- Perched-water ages can be used to estimate ground-water travel times
- Conceptual unsaturated zone model indicates perched water may occur within or immediately above the PTn or CHn hydrogeologic units
- Presence of, or potential for, perching of water in the host rock could interfere with construction, operation, and performance of a potential repository
- Perched water could cause modification of geochemical interactions, transport processes, flow paths, and travel times

Perched-Water Test

Test description

- Test will be conducted if perched water is encountered in the Exploratory Studies Facility
- If perched water is detected, hydraulic tests and chemical sampling will be initiated as soon as the area in the Exploratory Studies Facility is accessible
- Flow-rate measurements will be conducted if large inflows of perched water are encountered
- Boreholes will be drilled into perched-water zones for sampling, testing, and monitoring

Schematic Diagram of Instrumentation of a Perched-Water Zone Within the Exploratory Studies Facility



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Perched-Water Test

Test description: Seepage measurements

- Seepage rates estimated prior to borehole drilling
- Boreholes drilled and instrumented for flow-rate determination
- Perched-water sampling for hydrochemical analysis

Perched-Water Test

Test description: Instrumentation

- Packers and/or lines installed in boreholes
- Sampling ports connected to access tubing at each instrument station
- Pressure transducers, tensiometers, and/or thermistors (thermocouples)

Hydrochemistry Test

Activity objectives

- Collect and preserve core samples for extraction of unaltered water and gas
- Collect *in situ* water, water vapor, and gas samples from boreholes in the Exploratory Studies Facility
- Obtain hydrochemical and isotopic data for interpretation of transport mechanisms, flow direction, and travel time of water and gas in the unsaturated zone
- Determine the geochemical evolution of unsaturated zone water using hydrochemical and isotopic techniques

Hydrochemistry Tests

Rationale for activity selection

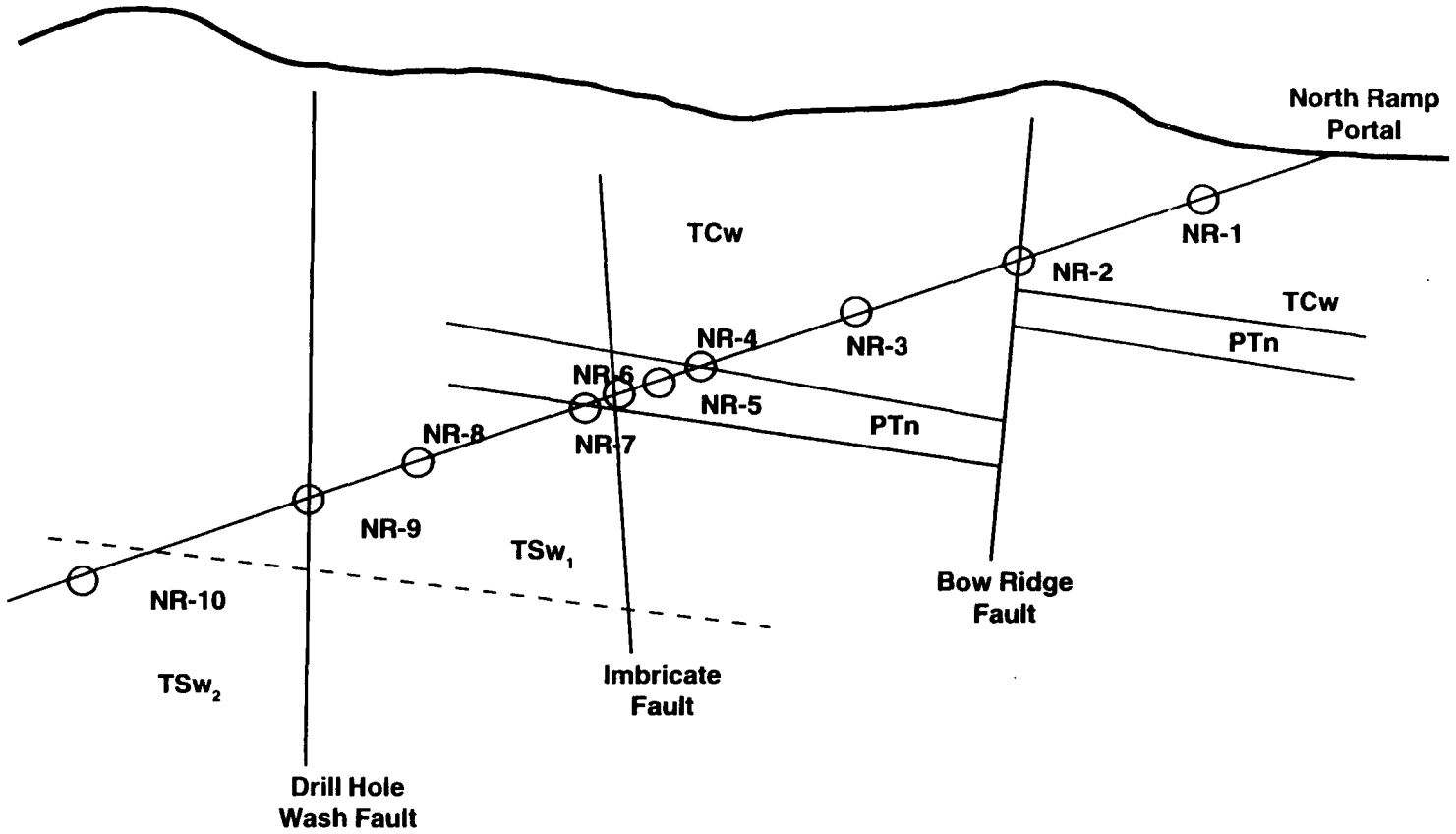
- Evaluate flow and storage of gas and water within repository block
- Unsaturated zone chemistry and gas distribution will help evaluate chemical transport and flow processes within the repository
- Pore-water chemistry and mineralogical data will be input to geochemical models to provide information on rock-water reactions in the unsaturated zone
- Provide information on solubility and reactivity of the natural geochemical environment in the unsaturated zone and of the artificial environment created by the engineered-barrier systems

Hydrochemistry Tests

Test description: Gas sampling

- Hydrochemistry gas samples will be collected from boreholes drilled for other Exploratory Studies Facility tests
- Short (1-2 m), small-diameter boreholes drilled close behind the TBM to provide gas samples representative of pre-mining conditions
- Long borehole (~45 m) will be drilled from alcoves at selected locations for the collection of core and gas samples

Generalized Location of Boreholes in the North Ramp for Use in the Exploratory Studies Facility Hydrochemistry Test



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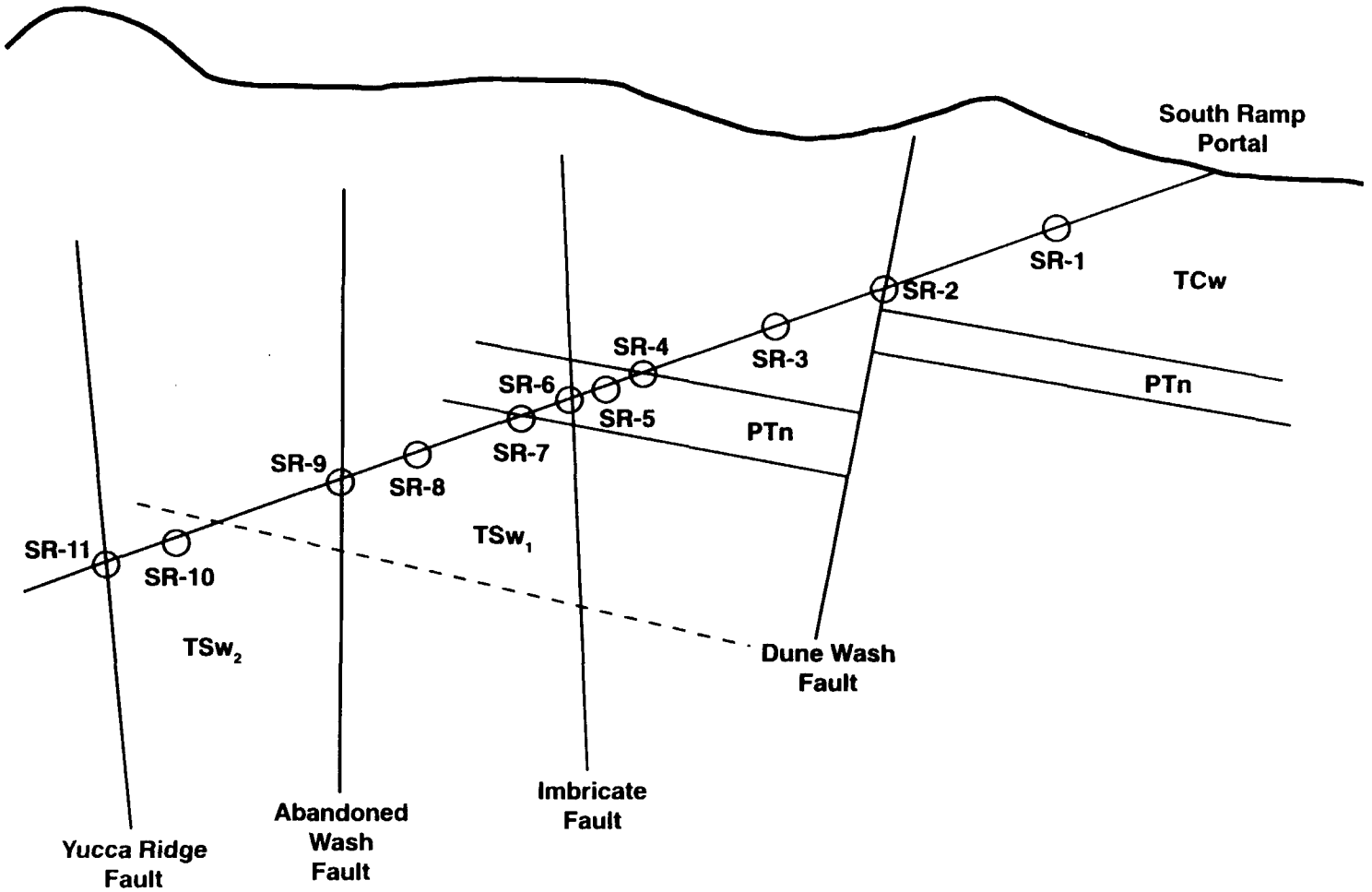
Generalized Location of Boreholes in the South Ramp for Use in the Exploratory Studies Facility Hydrochemistry Test



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Hydrochemistry Tests

Test Description: Instrumentation

- Gas and water sampling from boreholes will utilize access tubing in the packer-instrument systems
- Peristaltic pumps will be used to collect gas and water samples from boreholes
- Samples for isotopic composition, $^{13}C/^{12}C$ ratio, ^{14}C samples, and ^{3}H will be collected
- Inflatable liners and absorbent material may be used to sample water from moist zones in boreholes

Hydrologic Properties of Major Fault

Activity objectives

- Measure pneumatic and hydraulic permeability, porosity, and anisotropy of major faults and associated fault zones
- Conduct long-term monitoring for vertical flow of gas, water vapor, and water in major faults
- Conduct tracer tests to estimate the tortuosity and effective porosity of major faults

Hydrologic Properties of Major Faults

Rationale for activity

- Yucca Mountain contains and is bounded by west-dipping, high-angle, normal faults that may serve as pathways for or barriers to fluid flow
- Expected that hydraulic conductivity varies along faults and fault zones
- Generally believed that major faults effect flow in the unsaturated zone
- Additional understanding of the factors controlling fluid flow in major faults must be obtained to meet site characterization requirements

Hydrologic Properties of Major Faults

Test description

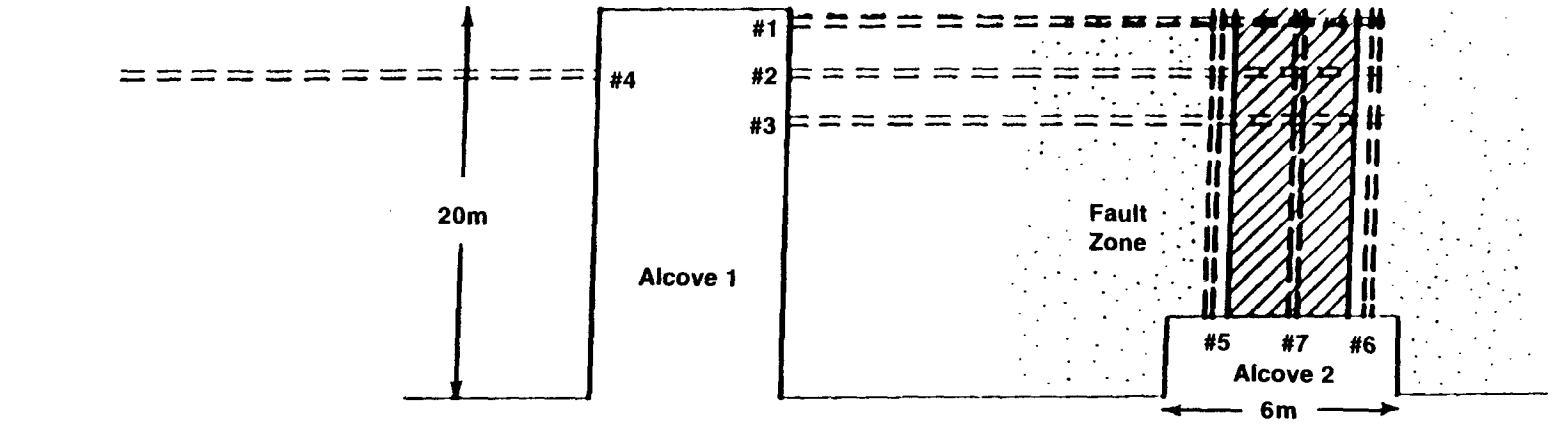
- To quantify the fault and fault-disturbed zone (FDZ) permeability and porosity, it is necessary to quantify undisturbed tuff
- Equipment and test configuration were designed to maximize the testing range and allow for test modification
- Single-hole and cross-hole testing will be conducted

Hydrologic Properties of Major Faults

Test description: Alcoves and boreholes

- One fault-parallel and one fault-straddling alcove at each fault test location
- Boreholes drilled from alcoves to test undisturbed rock, fault-disturbed zone, and fault
- 30 m maximum length of boreholes

Schematic of Major Faults Alcoves and Borehole Configuration



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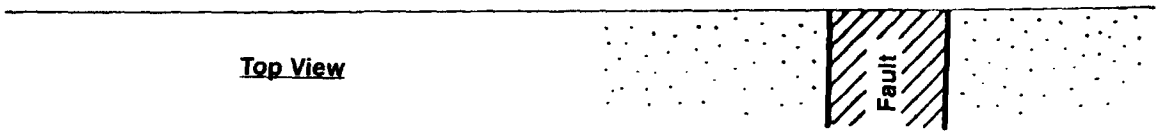
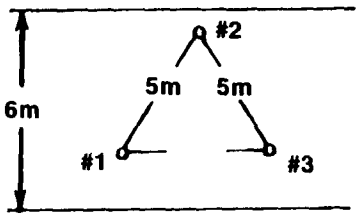
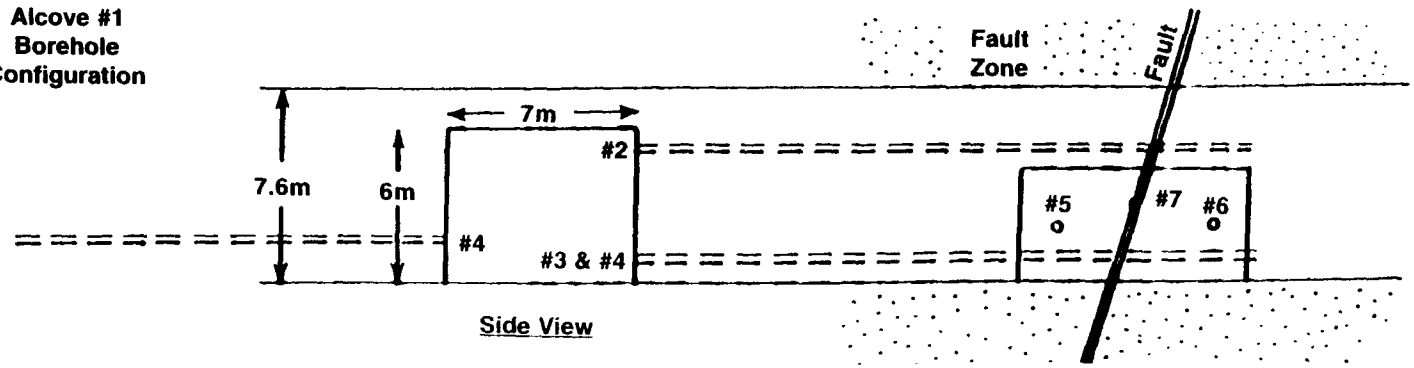




Alcove #1
Borehole
Configuration



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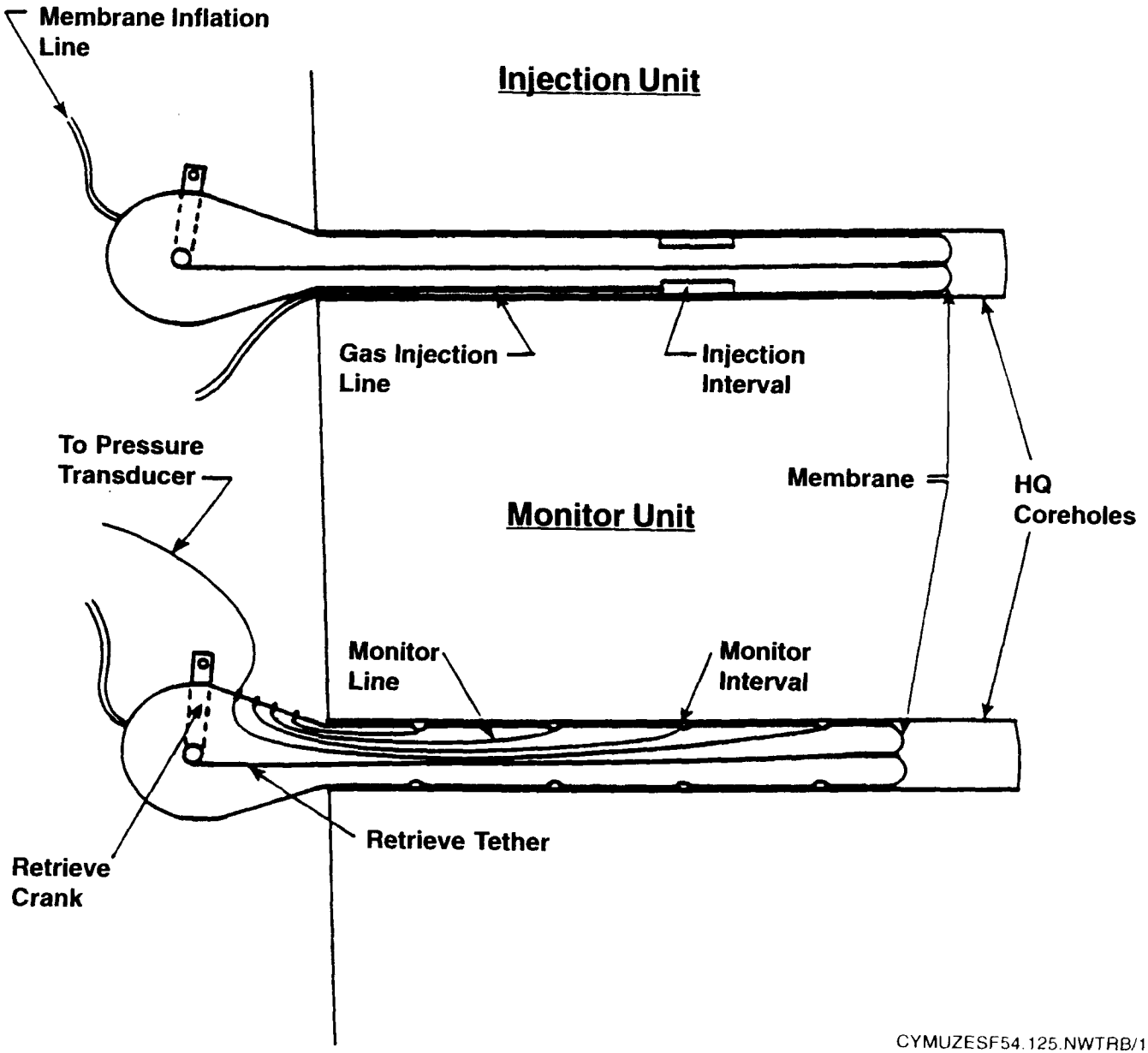
Hydrologic Properties of Major Faults

Test description: Pneumatic testing

- Single- and cross-hole pneumatic testing in both alcoves
- Results from initial single-hole testing used to design borehole layout
  - Provide preliminary estimates of permeability and data for scoping calculations
- Cross-hole test configurations determined from results of single-hole testing
- Cross-hole pneumatic testing characterized the permeability anisotropy within the fault-disturbed zone and the fault

Schematic of SEAMIST System Showing Injection and Monitor



Hydrologic Properties of Major Faults

Test description

- Cross-hole tracer testing will be used to estimate tortuosity in fractures
- Cross-hole hydraulic testing provides the opportunity to compare pneumatic and hydraulic test results
- Boreholes will be instrumented for long-term monitoring

Unsaturated Zone Studies in the Starter Tunnel

- Started mining the first alcove in the starter tunnel for conducting unsaturated zone Exploratory Studies Facility studies
- Conducted initial (prototype) sampling of gas samples from short, hammer-drilled, boreholes
- Will conduct hydrochemistry, gaseous-phase circulation, and radial boreholes tesing in borehole drilled in the alcove

Summary

- **Results will be used in the resolution of Yucca Mountain Project performance and design issues concerned with fluid flow within the unsaturated zone**

- **Principal applications will be in**
  - **Assessment of ground-water and gas travel times**
  - **Design analysis related to the underground repository facility**

- **Issues concerned with the waste-package containment and engineered-barrier system will use information resulting from this study**