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1989 Status Report: The Yucca Mountain Project Prototype Testing Program

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Yucca Mountain Project

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ABSTRACT

The Yucca Mountain Project is conducting a Prototype Testing Program to ensure that the Exploratory Shaft Facility (ESF) tests can be completed in the time available and to develop instruments, equipment, and procedures so the ESF tests can collect reliable and representative site characterization data. This report summarizes the prototype tests and their status and location and emphasizes prototype ESF and surface tests, which are required in the early stages of the ESF site characterization tests.

1989 STATUS REPORT:
THE YUCCA MOUNTAIN PROJECT
PROTOTYPE TESTING PROGRAM

I. INTRODUCTION

The US Department of Energy's Yucca Mountain Project Office (Project) is preparing to investigate the Yucca Mountain area (Fig. 1), approximately 100 mi northwest of Las Vegas, Nevada, to determine the site's suitability for a repository to safely isolate high-level nuclear waste from the accessible environment. The design of the repository and the assessment of the waste-isolation capabilities of the natural barriers require a thorough characterization of subsurface discontinuities, such as fractures and faults, and of water and its movement. This investigation will include characterizing the site by obtaining geologic, geochemical, hydrologic, and other geotechnical information and building the Exploratory Shaft Facility (ESF) to conduct underground tests. The Project is conducting a Prototype Testing Program to ensure that the ESF tests can be completed in the time available and to develop instruments, equipment, and procedures so the ESF tests can collect reliable and representative site characterization data. This report summarizes the prototype tests and their status and location and emphasizes ESF and surface prototype tests, which are required in the early stages of the ESF site characterization tests.

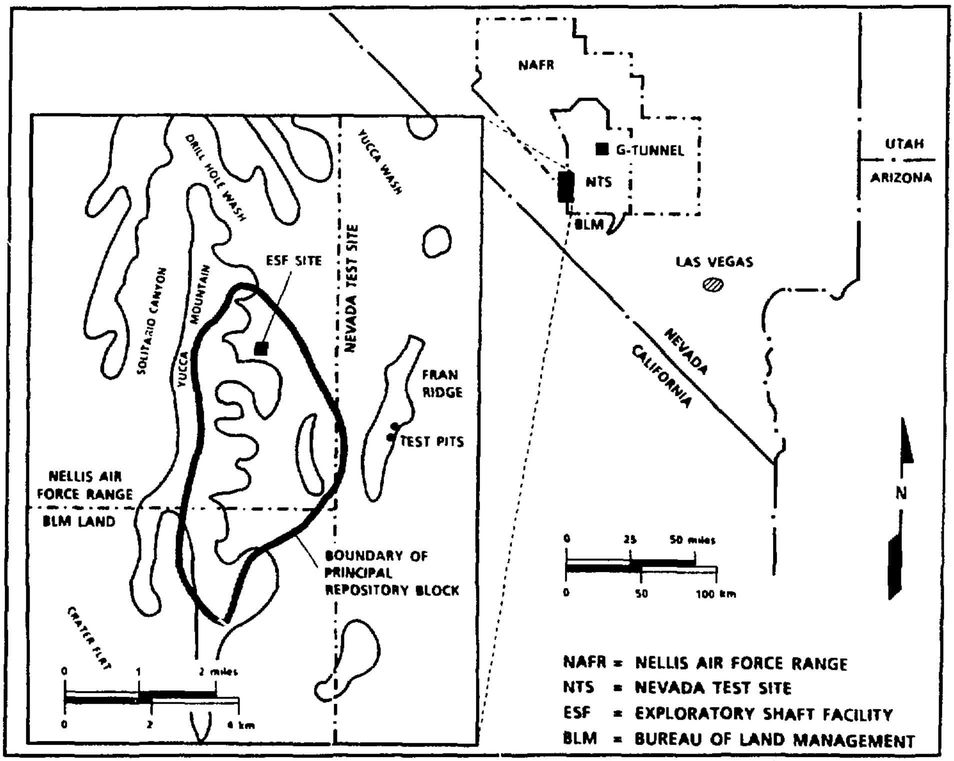


Fig. 1. Location map of the Yucca Mountain area showing the ESF, Nevada Test Site, G-Tunnel, and the Fran Ridge test pits.

A major product of the Prototype Testing Program will be a set of technical procedures for use during site characterization. The Prototype Testing Program will also provide the opportunity for personnel to become thoroughly familiar with equipment and procedures before they are used to characterize the Yucca Mountain site. The Project participant organizations that will be conducting the site characterization are also involved in the Prototype Testing Program and include Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), and Lawrence Livermore National Laboratory, in association with the US Geological Survey (USGS). LANL is coordinating the prototype testing activities related to the planned underground tests at the ESF, and Reynolds Electrical & Engineering Co., Inc.; Fenix & Scisson, Inc.; and Holmes & Narver, Inc., are providing field support.

The Prototype Testing Program is being conducted in several locations. The majority of the tests use the G-Tunnel Underground Facility (G-Tunnel) below Ranier Mesa on the Nevada Test Site (NTS). At 1250 ft below the earth's surface, G-Tunnel provides lithostatic loading (i.e., the weight of the overlying rock column) and stress conditions comparable to those at similar depths in the ESF and allows investigators access to both welded and nonwelded tuffs similar to those that underlie Yucca Mountain (Fig. 2). Prototype tests are also being conducted in a test pit located on the east flank of Fran Ridge at the NTS, at locations off the NTS, and at the investigators' institutions.

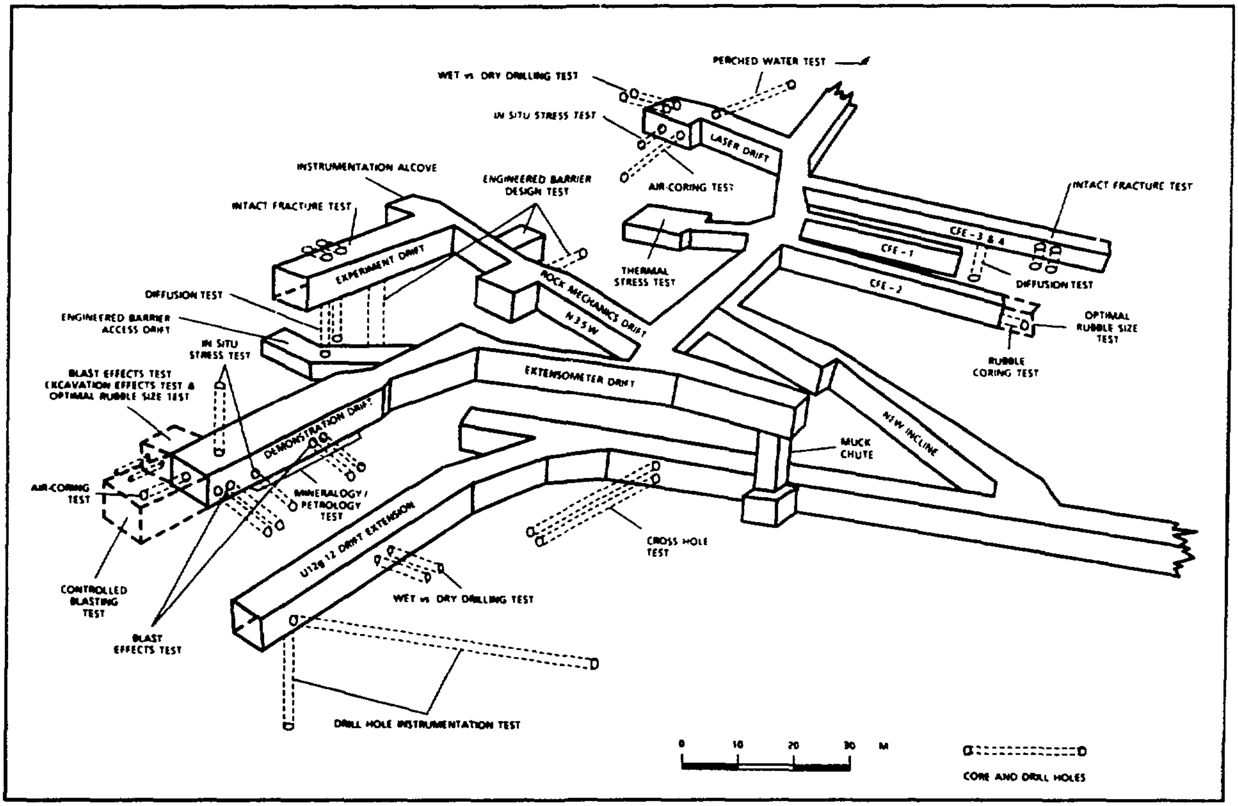
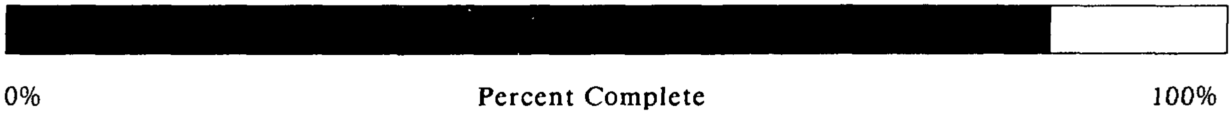


Fig. 2. Layout of G-Tunnel and the prototype tests conducted there.

II. ESF PROTOTYPE TESTS

Underground Geologic Mapping *(G-Tunnel and Fran Ridge)*



Underground geologic features of the excavated surfaces of shafts and drifts will be mapped in the ESF. Photogrammetry, which uses photographs to create maps, relies on an oriented, rail- or pedestal-mounted camera to photograph a close-range survey of a surface, such as a drift wall. Overlapping photos provide stereographic images, which are oriented by survey locators visible in the image, and the visible features are digitized with a plotter. The resulting data can be used to construct scale maps or for a variety of computational purposes.

To provide a safe environment for workers, the exploratory shafts (ES) will be lined soon after their excavation. Thus, the geologic mapping must be fast, accurate, and carefully coordinated with the construction activities because, once the shaft lining is in place, additional mapping will not be possible. Photogrammetry provides a mapping method that satisfies these requirements, and the possible application of these methods to mapping fracture characteristics such as aperture, orientation, and roughness is of particular interest. The major objectives of this prototype test are to develop photogrammetric mapping methods, equipment, and data reduction techniques for application to shafts and drifts; to test alternate mapping methods in the event of a temporary breakdown of the photogrammetric equipment; and to develop formal procedures and train personnel. Photogrammetry will be conducted in the G-Tunnel to simulate conditions in the drifts and in open surface pits at Fran Ridge that simulate conditions in the exploratory shafts; however, the two shallow test pits must be deepened to allow full-wall photographic coverage.

Completed mapping activities include the design, fabrication, and field testing of the specialized camera mounts in the drifts (Fig. 3) and shafts (Fig. 4). Preliminary results from the photogrammetric mapping are very promising. Computer-produced maps are as accurate as the line control survey (required to provide a reference baseline), are faster than hand-mapping, and are repeatable, which is an important quality assurance (QA) feature. Computer plotting methods will be refined further for application to ESF data that must meet rigid QA standards. Proposed alternative mapping methods use oriented devices to measure features observed on the shaft or drift walls. A goniometer to measure fracture characteristics will be

Fig. 3. Camera equipment to map drifts in G-Tunnel.

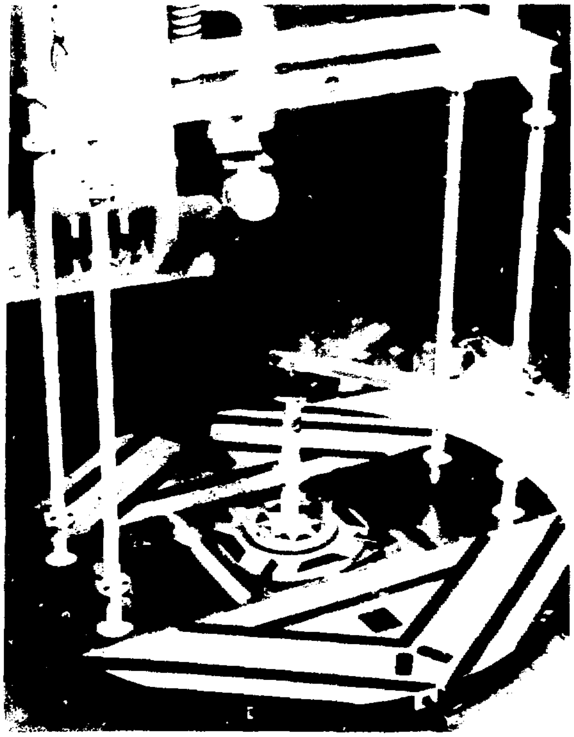


Fig. 4. Shaft-mapping platform with center camera mount and strike rail.

mechanically oriented to the same rail or pedestal used as a camera mount. A hand-held gyroscopic compass being developed will also be tested: magnetic compasses cannot be used because the steel sets used for drift support and local natural magnetic anomalies cause local distortions in the earth's magnetic fields.

Air Coring *(G-Tunnel)*

The diverse tests planned for the ESF will require drilling several different types of holes. The most recent compilation shows that more than 1,400 holes, totaling 38,000 ft of cored or drilled hole, are required to support ESF testing requirements. Drilling normally uses water or a mixture of water, air, and a foaming agent to cool the bit, to control the amount of dust produced, and to reduce the likelihood of drill rods becoming stuck or lost. There are concerns that water introduced into formations during drilling operations could invalidate the hydrologic data obtained from the ESF tests. The air coring prototype test is evaluating air as a circulating medium to eliminate introducing water into the rock formations.

There is extensive information on horizontal drilling, air mixes (i.e., air foam and air mist), and hard rock environments; however, documented information on horizontal air coring in hard fractured rock (vitrified volcanic tuff) in a mining environment is meager. The purpose of the prototype air coring test is to develop air coring into a viable cost- and time-effective technique, to refine the technique for application to the specific needs of the ESF testing program, and to train personnel to perform the coring.

The air coring prototype test is complete. The test was conducted in fractured, welded tuffs in G-Tunnel, a similar environment to what will be encountered in the ESF. Two horizontal holes were successfully air cored (Fig. 5). Technical parameters evaluated during the test included drill bit designs, penetration rates, bit life, core quality and percent

Fig. 5. Horizontal air-coring equipment in G-Tunnel.

recovery, hole deviation and stability, equipment performance, and coring methods. The impregnated bits exhibited exceptional durability, averaging 120 to 160 ft/bit during difficult coring. Average penetration rates of the holes were 6 to 8 ft/6-hr shift in welded tuff and almost 20 ft/6-hr shift on holes in nonwelded tuff. A 50-ft hole was used to demonstrate dust control methods, equipment, and procedures for safe air-coring operations, and a 150-ft hole demonstrated the technical feasibility for air coring small-diameter holes in welded, fractured tuff.

Dust Hazards Associated with Air Coring *(G-Tunnel)*

A concern with air coring is the creation of airborne dusts and fibers that could become a significant health hazard to personnel. This hazard would be substantially lessened by using a drilling fluid. Consequently, the test on dust hazards was conducted to determine if the air contaminants created during air coring can be sufficiently controlled using available dust control/collection equipment to ensure compliance with health and safety standards. The objectives of this prototype test are to evaluate the potential exposure of personnel to airborne silica, zeolite fibers, and nuisance dusts and to evaluate the effectiveness of commercial dust control equipment to mitigate these hazards. If this equipment performs less than satisfactorily, additional engineering controls, administrative controls, and protection devices (such as respirators) will be incorporated to augment the equipment.

Pretest evaluation of the dust collection equipment indicated that actual airborne concentrations during the test might approach or exceed allowable concentrations for silica dust. Therefore, in addition to the dust collection equipment installed on the drill shaft exhaust system, measures were implemented for the field test: ventilation air was diluted to reduce fugitive emissions; personnel were fitted with respirators and trained in work practices that reduce dust emissions; exhaust air from the dust collector was ducted to the main exhaust system; and traffic in the test area was limited.

The field test was completed in G-Tunnel in association with the prototype air coring test, and dust emissions were monitored around the connections in the dust collection equipment. A hand-held photometer reading indicated the initial emissions were above allowable exposure levels. The test was stopped, the tunnel was cleared by the ventilation system, and modifications were made to the dust collection system that further reduced these fugitive emissions. The final test results indicated that the dust-collection equipment and other exposure controls were effective in reducing dust emissions to acceptable levels. No zeolite fibers were detected in airborne particulate samples, and crystalline silica was not detected in airborne particulate samples, but it was detected in the dust collection filters, indicating the dust collection system was effective in reducing silica exposures. All of the controls contributed to effective mitigation of dust hazards during the prototype air-coring test. The dust and exposure controls used during the prototype test are recommended for all air-coring projects at Yucca Mountain (the specific recommendations are detailed in the Final Dust Hazard Assessment Report prepared by the Industrial Hygiene Group at LANL).

Evaluation of Effects of Wet and Dry Drilling on *In Situ* Hydrologic Conditions *(G-Tunnel)*

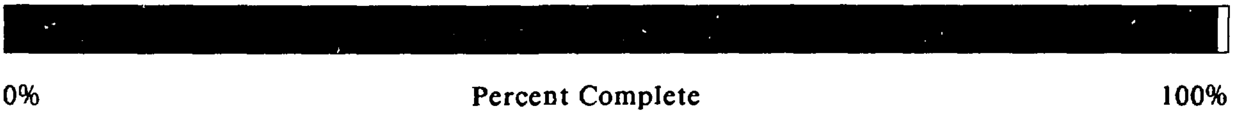
The purpose of this test is to determine how air and water, when used as drilling fluids in tuffaceous rocks, affect the *in situ* hydrologic conditions of the rock matrix surrounding the borehole. Alteration of these *in situ* hydrologic conditions could have a significant effect on hydrologic experiments performed in or near boreholes, on instruments installed in the boreholes, and on geophysical logging.

This prototype test includes a sequence of field, laboratory, and hydrologic-modeling activities. The field activities involve drilling two pairs of horizontal boreholes in rock similar to the ESF: one pair will be drilled into a fractured welded tuff, and the second pair will be drilled into a nonwelded tuff. Within each pair of boreholes, one will be air cored and the other will be cored using a water-based drilling fluid. When the boreholes have been completed, a series of experiments using neutron moisture and television logging techniques will be conducted to measure *in situ* conditions, and core samples will be taken. In the laboratory, experimental analyses will provide data for comparing lab samples, geophysical logs, and borehole sensors in both welded and nonwelded tuffs. Hydrologic models will be built to predict the simultaneous storage and flow of liquid water, water vapor, pore gas, and heat in the near-field environment of each borehole and to describe cross-hole effects between each pair of wet- and dry-cored boreholes. The models are used to predict the effects of air and water drilling in welded and nonwelded matrices.

The prototype test has demonstrated the feasibility of many of the test procedures. Successful television and neutron moisture logs were conducted in the four boreholes that resulted in a revised and approved neutron logging procedure for safety concerns. Core samples were collected and analyzed, and preliminary analysis suggests that there are differences in the hydrologic effects of wet and dry drilling. Hydrologic modeling is in the developmental stage.

During drilling, one wet-drilled hole inadvertently intersected one of the dry holes. However, the instruments' design in the dry hole prevented a significant loss of data, and all damaged instruments were repaired or replaced within 48 hr. This accident may provide some useful data and enhance our understanding of the differences between wet- and dry-drilling methods. This experience also underscored the importance of a prestart drilling survey to situate and align the drilling machine. This action is frequently not taken as the probability of intersecting another hole is assumed to be very low.

Drill Hole Instrumentation *(G-Tunnel)*



A thorough description of moisture and related hydrologic characteristics that govern unsaturated flow is a major element of the site characterization work proposed for the ESF. Well-coordinated installation of instruments as soon as possible after drilling a borehole will capture data representing the closest approximation of preconstruction conditions. The response of hydrologic conditions to the ESF's influence will provide invaluable data on the dynamic response of the unsaturated zone to changes in hydrologic boundary conditions. Thus, it is essential that the instruments installed in the boreholes function properly: equipment failure could cause the loss of valuable data.

The major objectives of this prototype test are to develop methods for installing instruments in boreholes that ensure hydrologic continuity with the surrounding tuff and isolation within a selected interval of the borehole and to develop techniques for calibrating and verifying the accuracy of the instruments while they are in place. Work on this prototype test is divided into three phases: engineering design, laboratory testing, and field testing. The engineering design phase will determine necessary instruments and develop detailed requirements for placing them. The laboratory testing phase will use a simulated borehole to evaluate the performance of candidate instruments systems. Instrument designs that prove successful in the laboratory will be installed and tested (Fig. 6) in a G-Tunnel borehole.


Fig. 6. Packer and instrument assemblies being prepared for insertion in a horizontal borehole.

Completed work includes purchasing test equipment and designing a low-pressure sealing system (packer assembly) for isolating instruments in the boreholes. A prototype instrument package consisting of packers; sensors to monitor pressure, temperature, and other parameters; and control lines was built and tested in the laboratory. A 50-ft vertical and 150-ft horizontal borehole was drilled in G-Tunnel and fitted with instruments to test the equipment under field conditions. These instruments were monitored for several months with periodic performance checks and sensor recalibration. The test results were documented and methods and procedure are being developed and completed. In the future, the instruments may be removed and checked in a laboratory to validate their performance in the field. Then, new instrument packages, with sensors that were improved as a result of the first tests, could be field tested in G-Tunnel.

Cross-Hole Pneumatic and Hydraulic Characterization *(Arizona)*

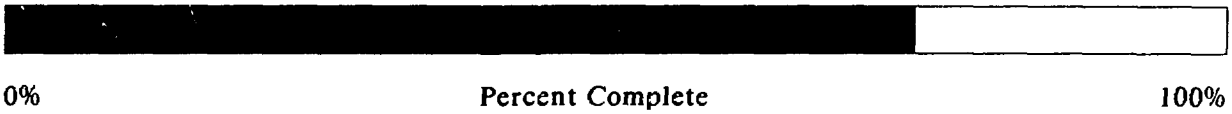
Several tests are proposed for measuring the hydraulic properties of the rock units surrounding the ESF. These tests, referred to as cross-hole tests, will use two boreholes to inject and extract fluids. This prototype test will develop a standardized system for hydraulic and pneumatic tests that can be used in the ESF cross-hole tests.

The major objectives of this prototype test are to develop test configurations that detect lateral flow along a hydrogeologic contact and measure the permeability of a known fault and to develop methods for obtaining and analyzing these data. The test system consists of several components, including test hardware, support software, technical procedures, data analysis techniques, and field-testing configurations. Developing, testing, and refining each of these components during the prototype test will increase the likelihood that the proposed ESF cross-hole tests will be successful. A standardized test system will also enable investigators to maintain consistency as they conduct and interpret tests, thus facilitating the comparison of results obtained from different tests.

Cross-hole testing relies on two boreholes: an active borehole and a passive borehole. Fluids are injected into the active borehole, and the passive borehole is used to collect any fluids that migrate and to observe the response of the hydrogeologic contacts between the boreholes. The cross-hole test is a series of tests in which investigators evaluate fractures in both boreholes and then test both the fractured and unfractured segments of the active borehole. In cross-contact testing, two parallel boreholes are drilled and cored on either side of the contact. The boreholes and the extracted core are logged to identify changes in lithology and to characterize fractures. Core samples are used for laboratory measurements of hydrologic properties, and the resulting data are compared with similar information obtained from the cross-hole testing. In fault testing, boreholes are drilled into a fault zone and logged in a fashion similar to cross-contact testing. Fault testing will investigate fracture locations and the relationship between gas permeabilities and water potential in the fault zone and test water injection to measure permeability.

Preliminary testing was performed at existing vertical holes in Arizona. Test instruments were installed, calibrated, and tested, and the procedures were refined in the boreholes: this preliminary testing can now be extended for use in the horizontal holes at G-Tunnel. Laboratory tests on core samples were begun to evaluate how stratigraphic contacts might act as barriers to downward-moving fluids. This work provides data for modeling cross-contact flow and will help define the equipment and configurations necessary to perform the field experiments.

Perched Water *(G-Tunnel)*



This prototype test will develop methods for characterizing any perched water zones that may be encountered during ESF construction. The characteristics of any zones of perched water must be thoroughly evaluated because of their indirect impact on performance assessment calculations. This prototype test will investigate and develop methods for measuring rates of seepage of perched water into a shaft or drift, for measuring hydraulic heads within a perched zone, for collecting representative water samples, and for conducting aquifer tests within the perched water zone. The prototype test will be conducted in a unique location in the tuffs exposed in the G-Tunnel, where a perched water zone has been encountered.

This test consists of three phases: (1) development and laboratory testing of methods and equipment, (2) field testing of methods and equipment, and (3) evaluation of methods and development of written technical procedures. Major elements of the work include developing dry-drilling techniques for borehole construction to optimize water-sample collection; developing techniques for installing monitoring instruments in boreholes; developing methods for sampling groundwater in the perched zones; adapting methods for conducting aquifer tests in what are expected to be relatively low-permeability materials; and preparing formal written procedures. Currently, instrument holes have been air cored in G-Tunnel and field testing is in progress.

Mineralogy/Petrology Studies *(G-Tunnel, Fran Ridge, and Solitario Canyon at Yucca Mountain)*

This prototype test is designed to determine the methods, time, and effort that will be required to collect and document rock samples gathered from Yucca Mountain. These samples will be used to determine the stratigraphic variability of the host rock, the alteration and transport history of the underlying tuff, and the mineralogy of fractures and faults in local tuffs. The test's major objectives are to develop techniques to remove small samples from rock faces, to develop optimal methods for obtaining bulk rock samples from excavated material, to determine optimal sampling sizes for various proposed tests, and to develop formal procedures for sampling activities in the ESF.

Sampling in G-Tunnel began after a mining operation was conducted to replicate the conditions and types of sample materials (blast rubble) expected in the ESF. Surface outcrop samples were collected to examine alteration of fractures in the Topopah Spring Member and to determine the stratigraphic sequence of the rock column that will be penetrated by the shafts. To determine the sample size and distribution necessary to characterize the chemical, mineralogical, and modal texture variability of the Topopah Spring Member, samples were collected laterally and vertically along an outcrop of the Topopah Spring tuff in Solitario Canyon. Similar sampling techniques were implemented at the muck pile at the Fran Ridge test pits to determine the time required to collect and document representative bulk rock samples and samples with special features. To determine the time requirements, handling procedures, and optimal sample size for samples with special features taken from underground exposures, samples were removed from tunnel exposures in Fran Ridge, G-Tunnel, and T-Tunnel. The results of the Yucca Mountain fracture alteration and stratigraphy activities will provide the general basis for forecasting relevant conditions and parameters in the ESF, verifying these forecasts, and identifying the reasons for any differences.

Planned prototype mineralogy/petrology studies include completion and approval of procedures, completion of sample analyses, and additional sampling of unique alteration material identified in another tunnel at the NTS.

Tracers *(G-Tunnel)*

Fluids will be used during ESF construction to control dust, and many of the proposed hydrologic tests will inject liquid tracers into the tuff surrounding the ESF. These introduced fluids may locally alter the hydrologic conditions; therefore, it is important to be able to identify introduced fluids in joints, faults, etc. Tracers in liquids or gases can provide a means of distinguishing among many possible sources of those fluids. However, successful application of a tracer requires that it move with the fluid in a predictable fashion and that it not be significantly retarded as the fluid moves.

The purpose of this prototype test is to identify a suite of nonreactive, nontoxic chemical tracers that can be used to tag all liquids used during ESF construction and operations and during hydrologic testing. Several different tracers are required so fluids used in selected tests can be uniquely tagged. In addition to identification and characterization of the selected tracers, formal procedures will be developed for use in the ESF. The test program consists of two phases--a literature review to evaluate potential tracers and laboratory measurements of the sorption behavior of tracers in the tuff. During the literature search, investigators evaluated the suitability of specific tracers for gas and liquids and identified published methods for injection, sampling, and analysis of tracers. Tracer suitability is based on criteria such as cost, toxicity, environmental stability and reactivity, and detection limits. The laboratory phase of the test program characterizes the chemical, mineralogical, and physical properties of the tuff that influence tracer sorption. The proposed test program is based on a theoretical model that considers the actual process of sorption. Preliminary test results indicate that sodium bromide and sulfur hexafluoride are acceptable tracers for liquid and gas respectively.

Pore Water Extraction *(G-Tunnel and USGS Laboratories in Denver, Colorado)*

Knowledge of the composition of pore fluids is critical to assessing waste-package performance and the behavior of radionuclides in the unsaturated zone. The purpose of this prototype test is to determine the feasibility of using triaxial and uniaxial compression equipment to extract pore water from unsaturated, welded and nonwelded tuff. The equipment squeezes water and gas out of rock pores so the fluid's chemical composition can be analyzed. If pore water chemistry is significantly affected by the extraction process or if the method yields insufficient volumes of fluid for analysis, an alternative method of fluid extraction must be developed to provide this essential data before the ESF is begun.

The testing will be designed and conducted at the USGS laboratory in Denver. The test samples are cylindrical cores provided by the rubble coring prototype test in G-Tunnel. In the triaxial compression method, fluid pressure is applied to compress and confine the sides of the sample, while metal pistons apply the greatest stress to the ends of the sample. Results from previous tests demonstrated that pore water can be extracted from nonwelded tuffs with this method; however, because welded tuffs are brittle, they break when placed under the high compressive stresses needed to extract the pore water. As the rock breaks, the sleeve that separates the rock from the fluid is ruptured, which causes the confining fluid to contaminate the rock and the pore water.

A major part of this prototype test involves developing a uniaxial compression technique for use on welded tuffs. The uniaxial compression method differs from the triaxial method in that fluid is not used to confine the sides of the sample. Rather, the geometry of the compression equipment itself encloses the sample and prevents the expansion of the sample perpendicular to its axis (Fig. 7). Therefore, the uniaxial compression method offers an effective way to extract pore water from brittle welded tuffs without the risk of contamination. Preliminary testing of the uniaxial compression rig has demonstrated that water can be extracted from welded tuffs with pore water contents greater than 6.4%. Although adding nitrogen gas at the top of the chamber during peak compression substantially increases fluid recovery, previous testing demonstrated that subjecting rocks to high levels of compressive stress is likely to change the chemistry of the pore waters. Thus, the compression techniques must be refined and tested to ensure that the composition of the pore waters is not altered by the extraction process and that the most effective extraction techniques are developed.

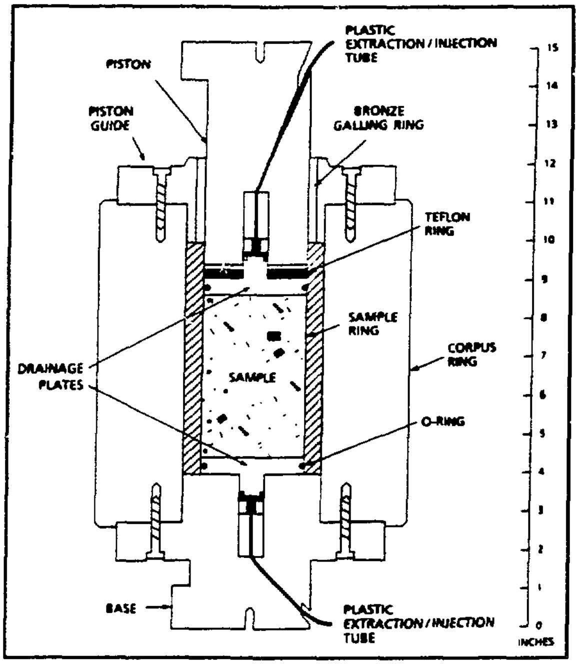
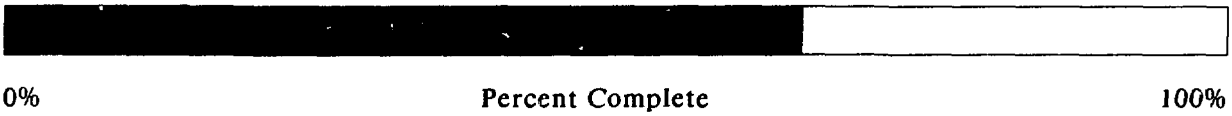


Fig. 7. Uniaxial compression rig.

Intact Fracture *(G-Tunnel)*



The welded tuffs at Yucca Mountain contain numerous fractures, and a significant portion of the proposed ESF characterization will focus on describing these fractures. Their hydrologic properties will be a significant input to the computer models used to describe flow and transport mechanisms: proposed ESF tests will collect samples of rocks that contain fractures for laboratory measurements of flow and transport.

It is particularly important that the sampling process result in minimal disturbance of the fracture and that the laboratory testing equipment can reproduce the *in situ* conditions of temperature, stress, and moisture content (Fig. 8). The major objectives of this test are to evaluate, and modify as necessary, equipment used to obtain intact fracture samples, to conduct laboratory testing, to develop methods for preserving fracture integrity throughout sample collection and preparation, and to evaluate the effectiveness of the proposed laboratory testing for hydrologic characterization of the fractures.

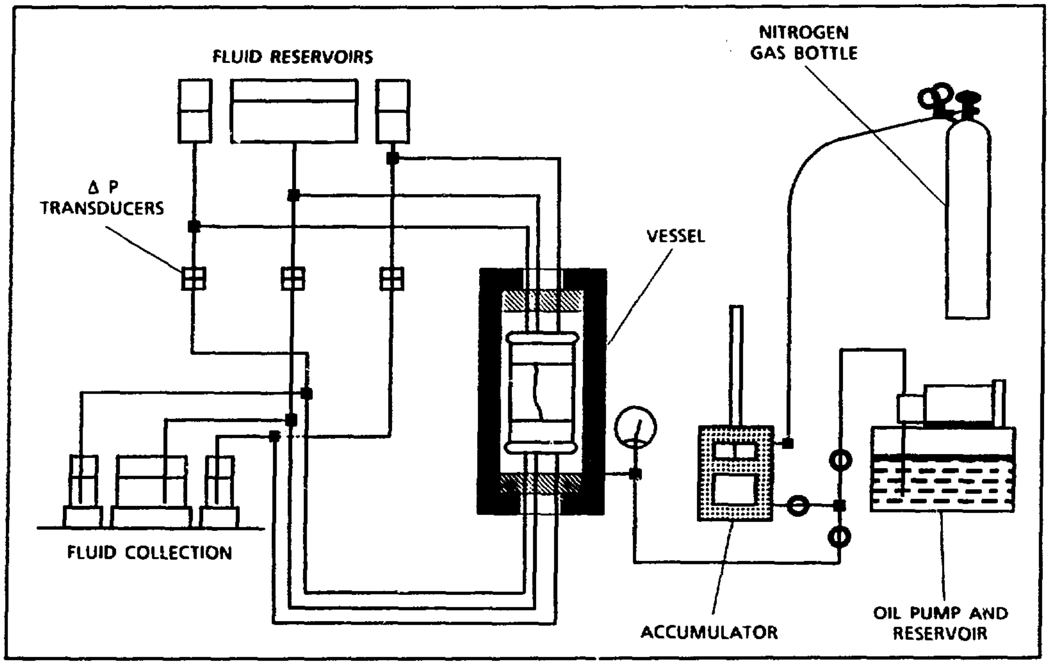


Fig. 8. Laboratory equipment for the prototype intact fracture test.

To ensure that samples contain fractures both parallel and perpendicular to the axis of the cylindrical core, exposed fractures on drift walls in G-Tunnel were mapped before sample collection was begun. Several 10-in.-diameter samples were air cored from welded and nonwelded tuffs. In the laboratory, the samples will be instrumented to monitor hydrologic characteristics within and adjacent to the fractures. In these tests, investigators will evaluate relationships between applied stress and fracture permeability for various degrees of water saturation, tracer flow and transport, and possible channeling of flow. The test results will provide input to the development of computer models describing flow and transport.

A mock-up of the radial fracture configuration has been studied. Work in progress includes sampling; preliminary computer modeling; development of preliminary test procedures; and evaluation of special designs, techniques, and materials for determining flow path geometries. Planned work included selecting and evaluating sampling instruments; developing, evaluating. and comparing test designs; and evaluating the feasibility of performing special tracer and flow tests on the samples.

Diffusion *(G-Tunnel)*

The diffusion test proposed for the ESF will measure the rate of solute diffusion into water-filled (or partially filled) pores of the tuffs in the unsaturated zone at Yucca Mountain. Solute diffusion is likely to be an important mechanism for retarding the water-borne transport of nonsorbing radioactive species, and *in situ* diffusion measurements can be used to derive diffusion coefficients for use in performance assessment calculations. The purposes of the prototype diffusion test are to develop and test a system for injecting tracers; to develop techniques for overcore sampling of the test zone; and to measure diffusion rates in unsaturated, welded and nonwelded tuff.

Conducted in two exposed rock units in G-Tunnel, the samples are representative of the exposed tuffs in the ESF. An injection hole is drilled, and a packer assembly is placed in the hole to isolate the injection zone from the rest of the borehole. A tracer fluid is then injected into the tuff surrounding the hole for a predetermined period. At the end of the injection period, the injection system is removed from the borehole and a core is taken from the surrounding tuff. This core is sectioned, and the sections are crushed and leached with water to extract the injected tracer. The spatial distribution of tracer within the core is then used to calculate diffusion coefficients.

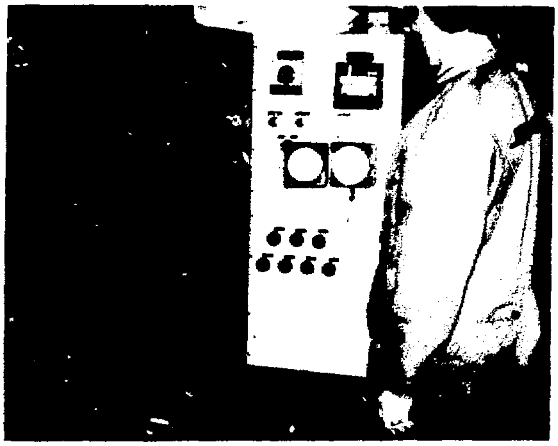


Fig. 9. The instrument console in G-Tunnel.

The tracer assembly and instrument control panels are complete (Fig. 9), and field testing has begun. Field activities have included air coring three boreholes, two in a welded tuff unit and one in a nonwelded unit. Two of the three holes had a small-diameter, tracer injection hole drilled at the bottom, into which the diffusion tracer was injected (Fig. 10) and the holes were sealed. The diffusion process will continue for several months, after which the bottom interval of the test holes will be overcored. The recovered core will be taken to a laboratory for analysis to measure the extent of diffusion.

Preliminary attempts at overcoring the nonwelded tuff surrounding one of the injection holes provided an inadequate quantity of recovered core. Equipment is being further refined to enhance the percentage of core recovered. Other activities in diffusion test coring operations included measuring the drill bit and rock temperature and geophysical logging to measure moisture re-equilibration in the rock adjacent to the hole. Results of these studies were used in planning the wet and dry drilling tests and may prove useful in analyzing the diffusion test.

Fig. 10. This probe injects diffusion tracers into welded and nonwelded tuffs.

Rubble Coring *(G-Tunnel)*

During site characterization in the ESF at Yucca Mountain, rock samples will be required for determining pore water chemistry. But first, it must be demonstrated that the techniques for obtaining the rock samples do not affect the results of water analyses. Previously, rock samples used for testing have been obtained from wet-drilled boreholes, which could affect pore water chemistry. In the ESF, blast rubble will be available for sampling. However, before the rubble is used, investigators will determine whether the rubble is contaminated with chemicals from explosives or with fluids used during excavation and construction.

The purpose of the rubble coring test is to develop a coring technique with an insignificant effect on the pore water chemistry of the sample rock, to identify and assess problem areas, and to determine the approximate costs and time required for dry coring rubble samples. The prototype test was conducted with blast rubble and, for comparison, with cores obtained from unblasted rock. Unblasted samples from welded and nonwelded tuffs in G-Tunnel were obtained both by dry coring and by chipping the rock with a chisel to determine the effect, if any, of drilling on the analytical results. Pore gas samples were also extracted and analyzed for carbon dioxide, methane, sulfur hexafluoride, and volatile organics.

The results of the geochemical analyses are being evaluated with computer statistical and graphics programs to determine any differences between blast rubble and non-rubble samples and between cored and chipped samples. This data will be used to develop the most appropriate sampling technique for pore water characterization studies at Yucca Mountain.

Optimal Rubble Size *(G-Tunnel)*

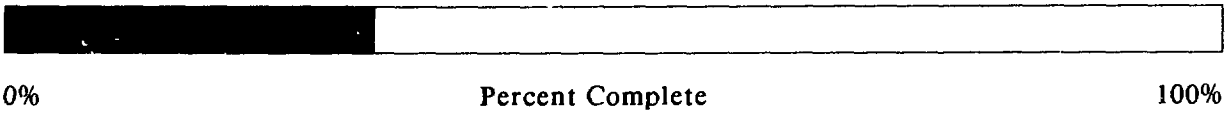
Blast rubble from ESF construction is being considered as a source for rock samples. However, before rubble can be used, it is necessary to determine the optimal size of a rubble block that can be successfully cored to produce an uncontaminated sample. It must also be determined whether the samples are contaminated by blasting or exposure to the atmosphere and whether the heat generated during blasting has an effect on the samples.

This prototype test will determine whether large fragments of rubble (greater than 6-in. diameter) have a center region that is not altered significantly by the blasting process and whether that unaltered region can be air cored to obtain a sample for hydrologic and pore water analyses. The major components of this prototype test are collecting rubble samples; physically analyzing the core to identify structural damage; and developing recommendations for the optimal size of rubble samples that will provide representative, undisturbed samples of the host rock.

Fig. 11. Rubble sample clamped for coring.

Accomplishments have included collecting blast rubble samples in G-Tunnel: four 12-in.-diameter welded and nonwelded cores have been collected to provide data on pre-coring and pre-blast chemistry. A sample-holding stand for coring irregular-shaped rubble was also designed and fabricated (Fig. 11).

Controlled Blasting and Blast Effects *(G-Tunnel)*



The Site Characterization Plan requires installing many instruments near active mining. Drill and blast mining can produce significant structural damage to the rock surrounding the excavation. In the ESF, such damage could alter the hydrologic properties of the tuff or adversely affect the stability of the drift openings. Smooth-wall blasting techniques have been proposed to excavate the ESF because they can minimize rock damage. A smooth-walled excavation will also minimize air resistance associated with ventilation air flow, thereby improving the efficiency of the ventilation systems.

This two-component investigation will describe close-range blast pulses and stress responses generated by controlled blasting methods during mining in the host rock. The objectives are to provide a controlled blast that can be used to evaluate the effects on instruments and to develop a technique to measure the extent of blast damage. The prototype blast effects test is specifically designed to measure stress and vibrational disturbances resulting from controlled blasting and to assess the impact of these blast effects on instruments from hydrologic investigations close to the construction. This investigation will examine the potential instrument and corehole damage during blasting and will explore ways to improve performance through changes in instrument design or test procedures. The investigation will also create procedures and criteria to assess blast damage on structures and equipment located near the excavation.

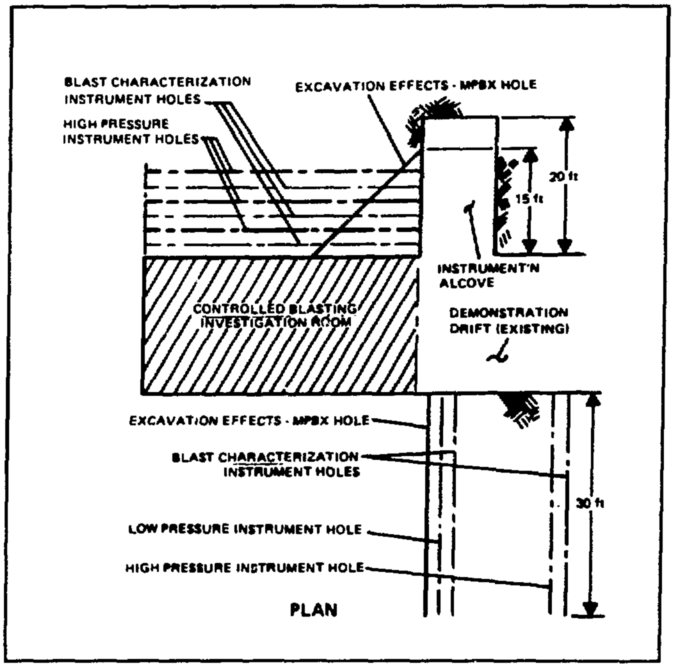
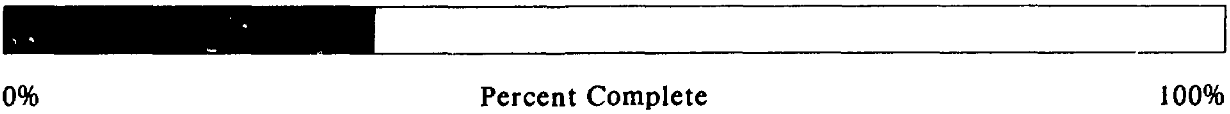


Fig. 12. Design of the controlled blasting and excavation effects prototype tests in G-Tunnel.

In G-Tunnel, an instrument alcove will be excavated at right angles to the proposed location for the controlled blasting investigation room (CBI), and holes will be drilled from the instrument alcove parallel to the CBI (Fig. 12).

Instruments in these holes will record the effects of four controlled blasts and will be subsequently modified as necessary to render them less susceptible to damage from excavation.

Excavation Effects *(G-Tunnel)*



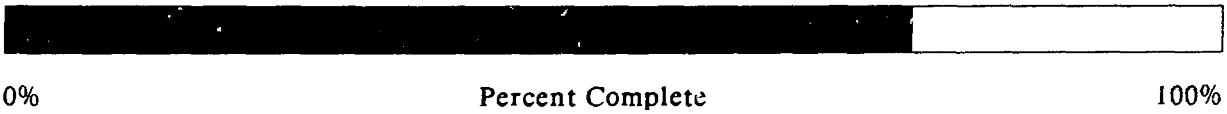
Standard drill and excavation practices can cause stress-induced fractures and enhance transport of gas or liquids in the rock zone immediately surrounding the shaft and drifts. The purpose of the prototype excavation effects test is to develop, refine, and test methods and equipment for measuring stress changes and consequent permeability changes that occur in rock adjacent to a drift as it is being excavated. The instrumentation to measure stress and deformation will be developed in this prototype test, whereas the permeability measuring instrumentation will be developed in the cross-hole pneumatic and hydraulic test.

These instruments will be evaluated as a system in this prototype test. The test results should answer several questions--is the test design practical? are the instruments sufficiently rugged to survive the blast accelerations? will the instrument holes themselves survive the blast effects? and what modifications are required to ensure success in the ESF?

Six air-drilled holes will be used to make stress and permeability measurements (Fig. 12). Fracture deformation will be measured from two horizontal holes: the holes will be logged using a deviatometer (to measure alignment), a fibre optical television camera, and neutron moisture, porosity, and gamma-gamma logs. These logs are used to estimate the initial condition of the holes close to the proposed site before the experimental phase of the prototype excavation effects test. Two multiple point borehole extensometers will measure fractured rock displacement (strain), and three stress deformation gauges will measure changes in stress. To measure permeability, the test will use air-injection packer assemblies.

The prototype excavation effects test is dependent on the start of the controlled blasting test to create the required drift area and instrument alcove and runs concurrently with it to study the blasts. Specific instruments have been developed and fabricated as a result of other test programs conducted at G-Tunnel (the instruments used to measure permeability changes during the excavation effects test were developed and fabricated during the cross-hole pneumatic and hydraulic test and are available).

In Situ Stress *(G-Tunnel)*



Tuffs at Yucca Mountain are under stresses caused by lithostatic load and by tectonic stresses superimposed on the lithostatic load. The total stress on the in-place rock are referred to as *in situ* stresses. Rock samples expand (also referred to as recovery or relaxation) different amounts in different directions, depending primarily upon the orientation and magnitude of the stress field in the region from which the sample has been removed. Data on *in situ* stresses are necessary input in thermal stress models and models used to assess the stability of underground openings and to determine failure criteria for rock excavations. Therefore, knowledge of *in situ* stress is fundamentally important in the process of repository design.

The purpose of this prototype test is to evaluate the field procedures and instruments and to compare alternative methods of determining *in situ* stresses under conditions similar to those expected in the ESF. This prototype test will compare two stress-measuring techniques: the anelastic strain recovery test and the overcore stress test. These methods relieve the stresses from a rock and then measure its change in size and shape as it recovers. Laboratory work includes preparing, calibrating, and testing instruments and testing heterogeneities in selected cores to relate them to variations in field measurements. Field work at G-Tunnel includes measuring the stresses and deformations and describing the number, spacing, condition (whether filled with mineral matter or not), and orientation of fractures in the recovered core. Analyses will consist of data reduction and interpretation.

The anelastic strain recovery test measures the anelastic (creep) recovery of oriented core immediately after its retrieval from the subsurface. Measurements on core from three differently oriented boreholes are used to calculate the direction and magnitude of the principal stresses. The overcore stress test, which is conducted in two phases, provides analogous information to the anelastic strain recovery test. In the first phase, a borehole dilatometer is used to determine the *in situ* rock mass modulus of deformability by measuring the volumetric change of a dilatable membrane in contact with the borehole wall. In the second phase, overcoring is used to relieve the stresses on the borehole, and strain gauges register the changes in the size and shape of the inner hole as the rock recovers from the removal of stress. The results of the two measuring techniques are compared to determine which method is most appropriate for testing planned in the ESF.

Work is continuing in this prototype test. A readiness review has been completed, and several holes have been drilled and instrumented. Gauges have been calibrated, and testing is in progress.

Thermal Stress *(G-Tunnel)*

Canisters containing high-level nuclear waste in the repository will deposit large quantities of heat. This heat will induce high horizontal stresses around the emplacement drifts, where the stress state at ambient temperature is dominated by vertical stresses. The changing stress conditions may cause blocks of rock to shift, new fractures to form, or existing fractures to change in aperture. Heat-induced changes in rock properties may affect the stability of underground openings and may alter characteristics of fluid flow in the surrounding rock. Thermal stress testing will be performed during site characterization to evaluate the effects of heat loads on drift stability and to provide data to validate models used to predict the thermomechanical behavior of a rock mass.

The purpose of this prototype test is to develop and refine methods and equipment and to train personnel. Successful completion of the test will ensure that thermal stress measurements can be scheduled and completed in the short time available and that the test results are an accurate representation of the effects of thermal stress. The prototype testing will take place in the demonstration drift at G-Tunnel, with associated analyses and laboratory work performed by SNL.

The thermal stress test will heat a significant portion of the roof of a repository-scale drift with two rows of linear heaters. During the early phases of test development, stress changes in the roof were to be measured with a flatjack. However, scoping analyses revealed fundamental difficulties with the method, and plans have been modified along a more conventional route, relying primarily on displacement measurements. The current design involves heating a large rock mass in the roof of the drift at G-Tunnel and measuring the stresses applied to, and the strains that develop in, the rock as it is heated for 180 days. Most of the required instruments and equipment have been procured, and investigations are continuing to find effective ways to implement the test and make the measurements. Current efforts include evaluation of stress gauges for use in high-temperature environments, preparation of test procedures and safe operating procedures, and design of software for the data acquisition system.

Equipment and Instrument Development and Demonstration *(G-Tunnel)*

Many of the experiments planned for the ESF use equipment and instruments that require testing and calibration under conditions similar to those at the ESF. The activities in this prototype test will provide information on the adequacy and reliability of these equipment and instruments. Present activities include evaluating hydraulic chain saws, high-pressure flatjacks, and multiple point borehole extensometers in G-Tunnel. The hydraulic chain saw and high-pressure flatjacks are required to support the heated block experiment and the rock mass response experiments planned for the ESF. The hydraulic chain saw and flatjack test measurements have resulted in refined technical procedures and improved equipment.

Engineered Barrier Design *(G-Tunnel)*

The long-term effects of heat deposited in the rock by waste packages are unknown but must be evaluated to understand and predict the responses of the waste package and the natural environment during the period required for waste isolation. The relationship between the thermal load and the initial flow of fluid and gas away from the heat source (and then, as the waste cools, the flow back towards the heat source), is of particular interest. Also of interest is the relationship of thermally induced changes in stress to the flow behavior and chemical alteration that may occur as a result of heating, drying, and rewetting the rock.

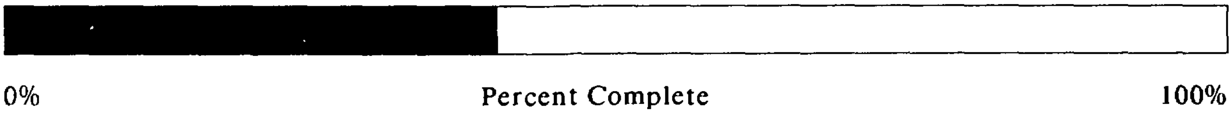
The primary purpose of the prototype engineered barrier design test is to evaluate the effectiveness of measurement techniques for monitoring the hydrologic and thermomechanical behavior of the near-field rock mass during a heating and cooling cycle. The prototype test will consist of laboratory tests and field tests conducted in G-Tunnel. Laboratory testing calibrates and tests instruments before their field test and investigates various grouting materials to seal or isolate sections of boreholes. The field work is conducted in four phases that include incremental heating and decremental cooling of the rock concurrent with continuous data collection.

This prototype test simulates a horizontal waste-emplacement scheme by horizontally orienting a heater in a small-diameter alcove (Fig. 13); the vertical emplacement configuration will be evaluated in subsequent prototype tests. Boreholes, drilled at various orientations relative to the heater, contain the instruments that gather data describing properties of the rock and fluids. The borehole instruments include psychrometers to measure water potential in the pores of the rock; thermocouples to measure temperature; neutron- and gamma/gamma-density-logging tools to measure moisture content; an electromagnetic measurement system to monitor moisture content between boreholes; pressure transducers to monitor air pressure inside sealed boreholes; data acquisition and recording equipment; and inflatable packers, flow

Fig. 13. Personnel inserting the heater assembly in the heater alcove for the horizontal test.

heating and cooling cycle are used to infer the hydrologic and thermal environment around the heater borehole and, ultimately, to assist in the development of models. Instrument performance will be evaluated by recorded data; visual inspection; and, if necessary, post-test calibration. Following the test cycle, several grouted and sealed boreholes will be overcored to inspect and assess the condition of the seals and the instrumentation. Currently, the heating cycle, data acquisition, and neutron and electromagnetic logging have been performed. The horizontal-emplacement testing is complete, and preparations for the vertical test are under way.

Infiltration *(USGS Laboratories in Denver, Colorado)*



Previous research on infiltration has focused on agricultural soils or other unconsolidated media--very little research has been done on unsaturated flow in media similar to the ESF. Therefore, it is necessary to improve our understanding of flow mechanisms in unsaturated matrix and fractures. This prototype test is being conducted to design instruments to monitor liquid and tracer movement through a large block of fractured, welded tuff. Conducted in the USGS laboratories, the following systems are being tested: sand bed infiltrometer, thermocouple psychrometer, porous ceramic-cup tensiometer, porous plate and vacuum pump, video probe, and single- and cross-hole injection systems.

Completed activities include equipment design, development, acquisition, assembly, initial calibration, and testing. A refined drill frame is drilling samples and instrumentation blocks for single- and cross-hole injection tests. The nitrogen-gas injection equipment has been tested and is in use in fracture zones and cross-holes. Calculations of pressure drops, tests for leak detection, and borehole testing of the matrix have been conducted. A prototype packer system has been designed and fabricated to facilitate placing the tensiometers in 0.5-in. drill holes. The tensiometer and data acquisition systems are being tested on tuffaceous samples, and thermocouple psychrometers to measure water potential have been calibrated. Reservoir systems to supply water to the samples are being developed and tested. Tests are being conducted on samples to determine the effects of air-entrapment on matrix infiltration: computer simulations have been used to predict these effects, and the results of the numerical model and experimental data will be used for future comparison and refinement of the models.

Bulk Permeability *(Edgar Mine in Idaho Springs, Colorado)*

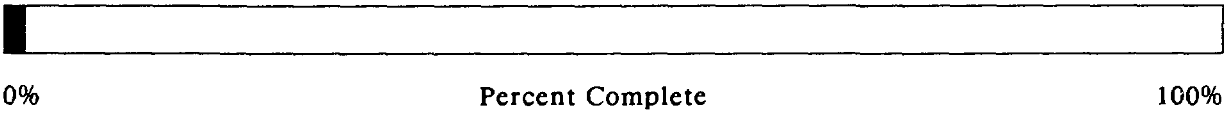
Flow modeling in an unsaturated fractured medium is a highly specialized discipline currently in its infancy. The test will increase our understanding of flow systems and help verify modeling results by designing instruments to measure bulk permeability and to determine the feasibility of conducting air permeability tests within fractured, welded tuff.

The test is being conducted by the USGS at a field site in Colorado. Activities include selecting an appropriate test site; designing and testing a straddle packer/manifold system; calibrating and testing the instrument package; drilling, core-logging, permeability-testing, and tracer-testing boreholes; and evaluating the resulting data. The boreholes are to be arranged in a frustum configuration with the central borehole drilled horizontally and three surrounding boreholes directionally drilled at 25# from the central borehole and 106# from each other. This design was chosen to maximize the number of permeability tests that can be conducted while minimizing the number of boreholes needed.

The following activities have been conducted. Based on saturation conditions, fracture characteristics, accessibility, and availability, the Edgar Mine in Idaho Springs, Colorado, was chosen from a group of potential sites in Nevada, Arizona, and Colorado. Conceptual and detailed designs of the packer system were completed, and packers and support equipment has been purchased. Detailed designs for the packer injection manifold and flow control manifold (including regulators, solenoid valves, transducers, and miscellaneous support equipment) have been completed. Pressure transducers have been calibrated, and tests were run to evaluate drift characteristics. Ongoing activities include assembly and calibration of equipment before testing it in the field and arranging utility connections and delivery of the nitrogen supply. The packer system, which isolates various intervals during the bulk permeability tests, will be fabricated when the instruments are received.

Field work will consist of mapping the drift and drilling, television-logging, and core-logging boreholes. The final phase of the field program will be single-hole injection testing at prescribed intervals in each of the boreholes to determine the scale dependence of the calculated permeabilities and estimated aperture distribution. The data will then be evaluated for future applications.

Radon Emanation *(G-Tunnel)*



Radon is a product of the radioactive decay of uranium, which occurs naturally in silicic rocks such as tuff. Radon, which may be released as a gas from tuffs, decays to radioactive particles that pose a health hazard if they are inhaled. Measurements of radon emanation rates will be conducted to assess potential hazards to workers. The purpose of the prototype test is to develop procedures and evaluate equipment for measuring the radon emanation rate and for determining the relationship between airflow and radon concentration in drifts.

The prototype test may be conducted in G-Tunnel to obtain preliminary data on radon emanations from a jointed, welded tuff rock mass. In the test, a recently mined drift will be sealed and a ventilation system capable of flushing the sealed space will be installed. Radon concentrations and atmospheric conditions will be monitored while the equilibrium level is established. This equilibrium level will be compared to control measurements on an intact sample and in a sealed borehole. The chamber will be repeatedly flushed and allowed to re-equilibrate to establish a relationship between airflow rate and radon concentration.

III. SURFACE PROTOTYPE TESTS

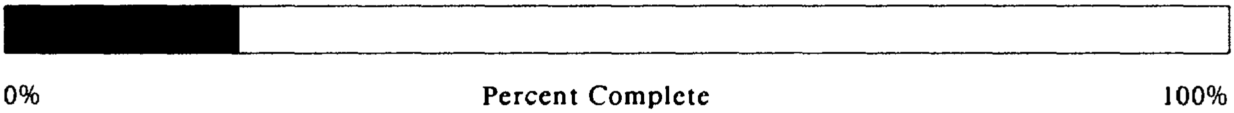
Integrated Data Acquisition System *(Drill Hole UZ-1 at Yucca Mountain and Fran Ridge)*

Characterizing the hydrologic environment at Yucca Mountain requires the assimilation and analysis of data obtained from diverse sources. Data will be gathered from field sites spread over more than 40 sq km and stored for subsequent analysis. The purpose of the integrated data acquisition system (IDAS) prototype test is to develop the necessary equipment, shelters, and procedures to reliably collect and store site-specific data for the characterization of percolation in the unsaturated zone. The IDAS is being designed and tested to scan, record, transmit, and store sensor readings, and it must ensure that monitoring can continue for 3-5 years without deterioration of its abilities. Its equipment and procedures will ensure that high-quality data are efficiently gathered during site characterization.

The IDAS system must meet certain technical, management, and QA objectives. The system must be developed to minimize measurement error; protect the integrity of the data; minimize the costs of collecting and storing the data; facilitate data management; provide flexibility for future technological improvements and multiple modes of sensor operation to enhance borehole utilization; and provide timely warnings of system failure to ensure against unacceptable loss of data.

The IDAS prototype test is in progress with many key aspects of the testing complete. The prototype IDAS shelter was constructed and installed at Drill Hole UZ-1, and the power and cooling systems were tested. The Gemlink Telemetry Station Land Generator was installed at Fran Ridge. The prototype microwave network, which transmits data to the storage facilities (temporarily established at the Technical Building), was installed and tested at four sites. Preliminary communication tests between the temporary storage site, Fran Ridge, and UZ-1 resulted in error-free data transmission. All Phase I IDAS software was coded, tested, and installed on ARC-1, ARC-2, and UZ-1 computers at the NTS. Testing will continue to evaluate the reliability of data transmission and equipment over an extended time.

Dry Drilling for Unsaturated-Zone Drill Holes *(Tooele, Utah, and Miocene Paintbrush tuff on the NTS)*



To drill boreholes and obtain samples without conventional drilling fluids, which could interfere with hydrologic test results, the Project has planned a program to develop and test drilling equipment that would combine dry, dual-wall drilling, in a larger-than-standard size, with a dry coring capability. Dry, dual-wall drilling is an industry standard; however, dry coring is an unusual application. Specific objectives of the prototype drilling test are developing and evaluating drilling and coring equipment, methods, and procedures and providing a technical basis for refining the planned site characterization drilling program.

Both wireline and pneumatic retrieval systems for dry coring will be evaluated. Drilling and coring will be accomplished using compressed air or vacuum-driven air with trace amounts of sulfur hexafluoride gas added to allow evaluation of sample contamination. Evaluated drill systems include down-the-hole hammers, open-center roller-cone and diamond-impregnated coring bits, the air drilling/coring systems mentioned above, dust-collection systems, and borehole-wall cleaning systems. The drilling/coring portion of the prototype drilling test will be conducted in two phases. Twenty days of Phase I drilling were conducted near Tooele, Utah, in silicified limestone (Fig. 14). This drilling enabled the initial evaluation of dust control, air drilling and collection of cuttings (using both conventional and reverse circulation), and pneumatic and wireline retrieval systems. Equipment modifications are planned before prototype drilling is resumed, which will continue either as Phase I drilling in volcanic rocks off the NTS or as Phase II drilling.

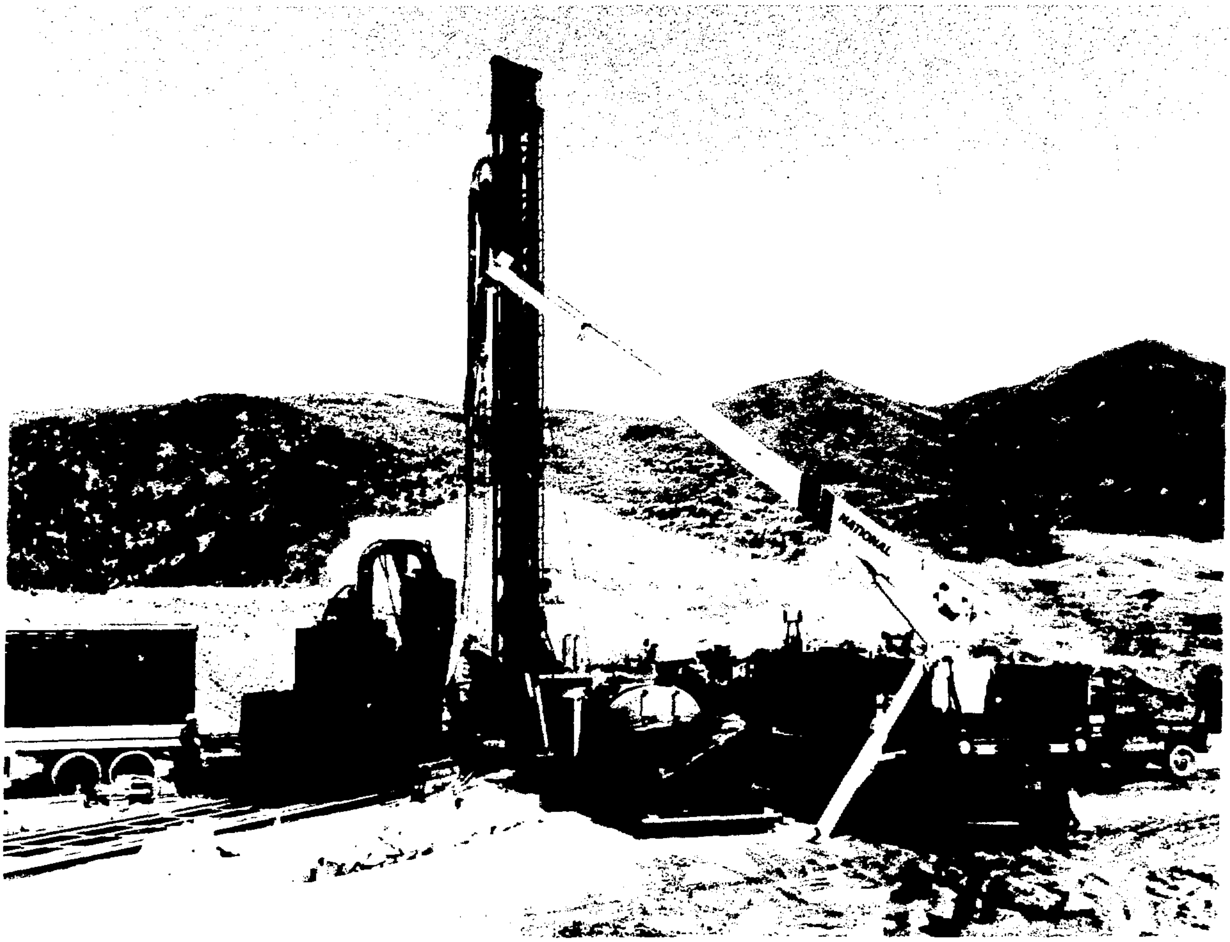
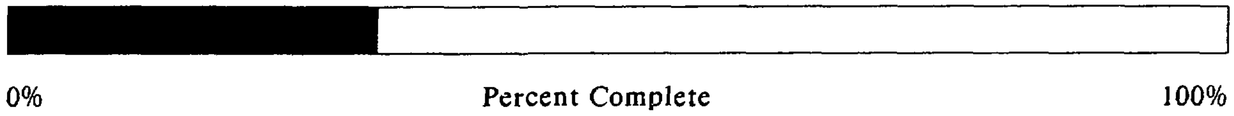


Fig. 14. Equipment on site in Tooele, Utah, during Phase I drilling.

Phase II drilling is planned at the NTS in Miocene Paintbrush tuff, about 5 mi southeast of the potential Yucca Mountain repository site. Phase II will continue equipment evaluations begun during Phase I and will begin evaluations of site-specific applications of equipment and methods in volcanic tuffs. Procedures recently approved for sample management will be field tested and evaluated during the prototype dry-drilling activity. Two holes, with 8-in. and

12-in. diameters, will be drilled to a 1,100-ft depth. A comparison will be made of the two holes' quality and geophysical log response because the systems are somewhat different for the two sizes.

Vertical Seismic Profiling *(Well G-4 at Yucca Mountain)*



As part of the characterization activities, a series of boreholes will be drilled and fitted with instruments to gather data for various studies. One study involves the use of vertical seismic profiling (VSP) to characterize fractures and other subsurface discontinuities. In VSP, the ground surface is vibrated, which sends sound waves into the subsurface. The waves are reflected and refracted by discontinuities such as fractures, faults, and depositional surfaces and recorded by instruments (geophones) located in boreholes. With computer analysis, characteristics such as fracture spacing and orientation may be inferred. Successful completion of the prototype test will mean that VSP can be accomplished efficiently during site characterization activities and that adequate data are generated.

The prototype VSP test will be conducted in the vicinity of Well G-4 at Yucca Mountain. Major activities include solving logistical problems with the seismic equipment, such as ensuring that the large vehicle-based vibrators can gain access to the site; preparing the site; removing the casing from the borehole; and evaluating the data to refine the seismic profiling techniques.

IV. SUMMARY

Many of the prototype tests will contribute to the goal of ensuring that experiments in the ESF will produce representative data. The written procedures developed by the Prototype Testing Program and training personnel who will participate in the ESF testing program will contribute significantly to ensuring that data collected during the ESF experiments will be correct, well documented, and defensible during the licensing process. Planning for the layout and scheduling of experiments in the ESF involves consideration of the time required for the various experiments and of the potential for interference among the tests. Nearly all the prototype tests include a comparison of the actual versus the expected results of the prototype tests include a comparison of the actual versus the expected results of the experiments. These comparisons will help define potential interference among the prototype tests and will contribute to the planning of the layout of experiments in the ESF.

Project investigators have made significant progress in developing and implementing the Prototype Testing Program. The underground geologic mapping work is progressing well: early results have led to significant improvements in methods, equipment, and computer software. The work on air-coring technology and dust hazard assessment has been completed. The results of these prototype tests demonstrate that air drilling can be used effectively to drill horizontal holes and that the dust created can be handled so it does not create air contamination or health hazards. Information to assess the effects of fluids introduced during drilling and excavation activities and the means for tracing these fluids, will be derived from the prototype evaluation of wet and dry drilling, the prototype diffusion test, and the prototype tracer test. These hydrologic tests have been started, in addition to drill hole instrumentation, cross-hole pneumatic and hydraulic testing, and two diffusion tests. Identification and evaluation of water tracers have begun, and a preliminary suite of nonreactive, nontoxic chemical tracers has been developed. Equipment and methods for extracting pore water are under continuing evaluation, and notable success has been achieved with the extraction process using nonwelded tuff.

The mineralogy/petrology sampling studies are under way, and improved sampling and analytical procedures have been developed based on the preliminary results. As part of the cross-hole pneumatic and hydraulic prototype test and the intact-fracture test, methods for measuring flow within fractures and along stratigraphic contacts are being investigated and will facilitate evaluation of the potential effects of fluids. Hardware and methods for collecting intact-fracture samples were evaluated in preparation for sampling in G-Tunnel, and preparation has begun for laboratory tests on intact-fracture samples. Experiments for evaluating the effects of blasting and excavation on the host rock will provide information on the means to estimate and restrict the extent of fracturing in the host rock.

The thermal stress prototype test is approved and scheduled. The horizontal-emplacement phase of the engineered barrier system prototype test is complete, and preparations are under way to conduct the vertical-emplacement test. A laboratory test facility for the prototype infiltration test has been constructed, and large blocks of tuff have been acquired for testing. The surface-based seismic profiling experiments may be used to determine the extent of such fracturing after excavation has occurred.

The objective of the Prototype Testing Program is to provide the opportunity for the Project investigators to develop or refine methodology, techniques, and equipment to lessen any risk to successfully performing tests during site characterization. Experience gained from these prototype activities will allow researchers to refine technical procedures and equipment. Protection of the waste-isolation capability of the Yucca Mountain site during construction and experimentation in the ESF requires that alteration of the hydrologic characteristics of the rock surrounding the ESF be minimized. Insights into alterations caused by construction or the ESF test program and methods to limit the extent and effects of alteration are being derived from many of these prototype tests.