YUCCA MOUNTAIN PROJECT PROTOTYPE TESTING

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ABSTRACT

The U.S. DOE is responsible for characterizing the Yucca Mountain site in Nevada to determine its suitability for development as a geologic repository to isolate high-level nuclear waste for at least 10,000 years. This unprecedented task relies in part on measurements made with relatively new methods or applications, such as dry coring and overcoring, for studies to be conducted from the land surface and in an underground facility. The Yucca Mountain Project has, since 1988, implemented a program of equipment development and methods development for a broad spectrum of hydrologic, geologic, rock mechanics, and thermomechanical tests planned for use in an Exploratory Shaft during site characterization at the Yucca Mountain site. A second major program was fielded beginning in April 1989 to develop and test methods and equipment for surface drilling to obtain core samples from depth using only air as a circulating medium. The third major area of prototype testing has been during the ongoing development of the Instrumentation/ Data Acquisition System (IDAS), designed to collect and monitor data from down-hole instrumentation in the unsaturated zone, and store and transmit the data to a central archiving computer. Future prototype work is planned for several programs, including the application of vertical seismic profiling methods and flume design to characterizing the geology at Yucca Mountain.

The major objectives of this prototype testing are to assure that planned Site Characterization testing can be carried out effectively at Yucca Mountain, both in the Exploratory Shaft Facility (ESF), and from the surface, and to avoid potential major failures or delays that could result from the need to re-design testing concepts or equipment.

This paper will describe the scope of the Yucca Mountain Project prototype testing programs and summarize results to date.

PROTOTYPE TESTING IN SUPPORT OF EXPLORATORY SHAFT TESTING

Site Characterization testing in the ESF is planned to investigate the conditions in the welded tuff at the proposed repository depth of approximately 1100 feet, as well as characterize the overlying welded and nonwelded tuffs and evaluate the effects of excavation that may influence the results of planned tests. Mapping and testing in the shafts will begin during the construction phase. Any delay or failure of tests could result in costly stand-by charges for construction resources and delays to the entire underground testing program. In addition, the durations and requirements for all the underground testing must be well defined and understood so that sequencing of operations and allocation of resources (i.e. drilling, ventilation air) can be managed efficiently. For these reasons the Prototype Testing Program was conducted in G-tunnel in Rainier Mesa on the Nevada Test Site in 1988 and 1989.

The objectives of the program were to test, evaluate and develop instrumentation, equipment, and methods for planned ESF tests. The test designs and procedures must not only provide confidence that they will result in data representative of the Yucca Mountain site, but that they are compatible with the stringent Quality Assurance controls that provide documentation in order that the test results are acceptable to support a license application to the Nuclear Regulatory Commission. In addition to technical confidence, the program also provided an opportunity to develop management practices to coordinate among the ten organizations and many investigators who will be responsible for conducting these same or similar operations at Yucca Mountain.

The G-tunnel facility, originally constructed for nuclear weapons testing in the 1960s, extends about a mile through nonwelded volcanic tuffs into Rainier Mesa, where it intersects a wedge of welded Grouse Canyon tuff, with an overburden of about 1430 feet (Fig. 1). This location is called the G-tunnel Underground Facility (G-TUF) (Fig. 2). These welded and nonwelded tuffs in the G-TUF were used by the Yucca Mountain Project for rock mechanics and heater tests starting in 1980. The similarity between the rock types and lithostatic load at the G-TUF and the proposed repository level makes G-tunnel well suited for feasibility testing. There are, however, differences that must be recognized when evaluating the results of G-TUF testing. The welded Grouse Canyon tuff exposed in G-tunnel is about 40 feet thick, highly fractured, and composed of alternating rubble beds and ash-flow tuffs, and so represents an environment less homogeneous and in general more fractured than the massive Topopah Springs tuff (1000 feet thick) at Yucca Mountain. The degree of zeolitic and argillic alteration in G-tunnel is greater than that at the proposed repository horizon, but is probably similar to that in the unsaturated zone underlying the proposed repository level. Lastly, there is more annual precipitation and hence greater infiltration at Rainier Mesa, which stands about 3000 feet higher than the crest of Yucca Mountain.

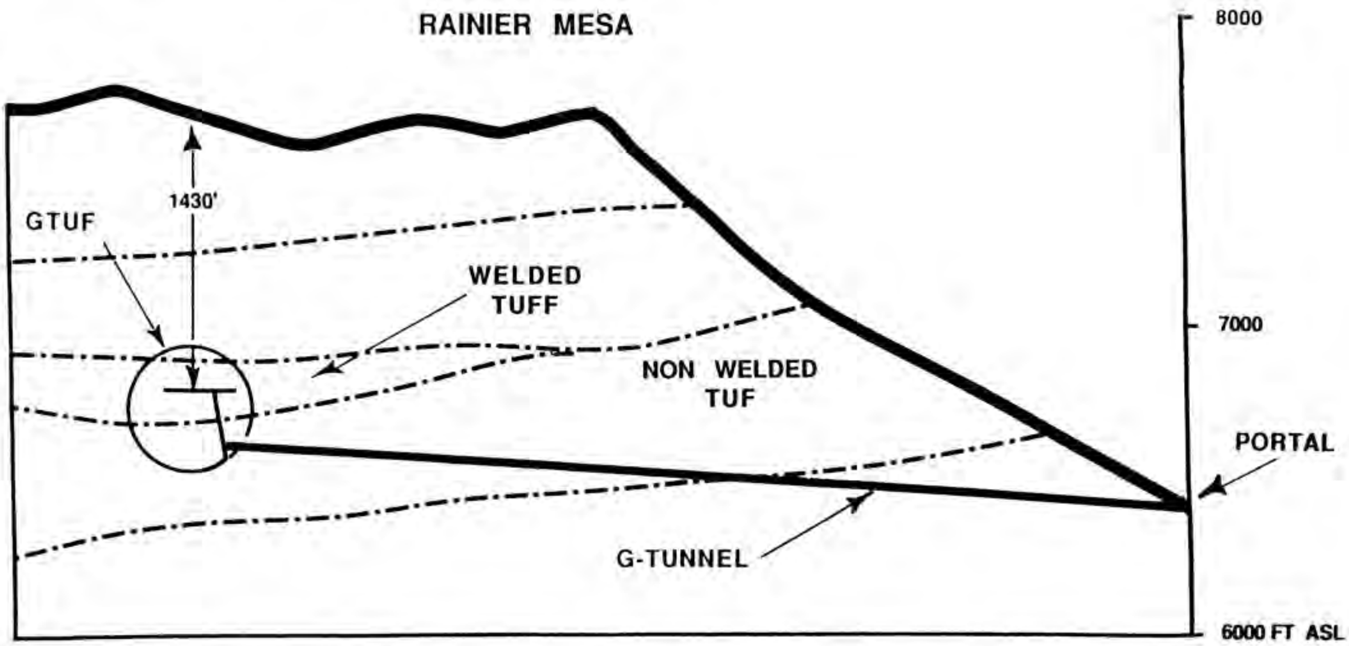

Fig. 1. Generalized Cross Section Through G-Tunnel.

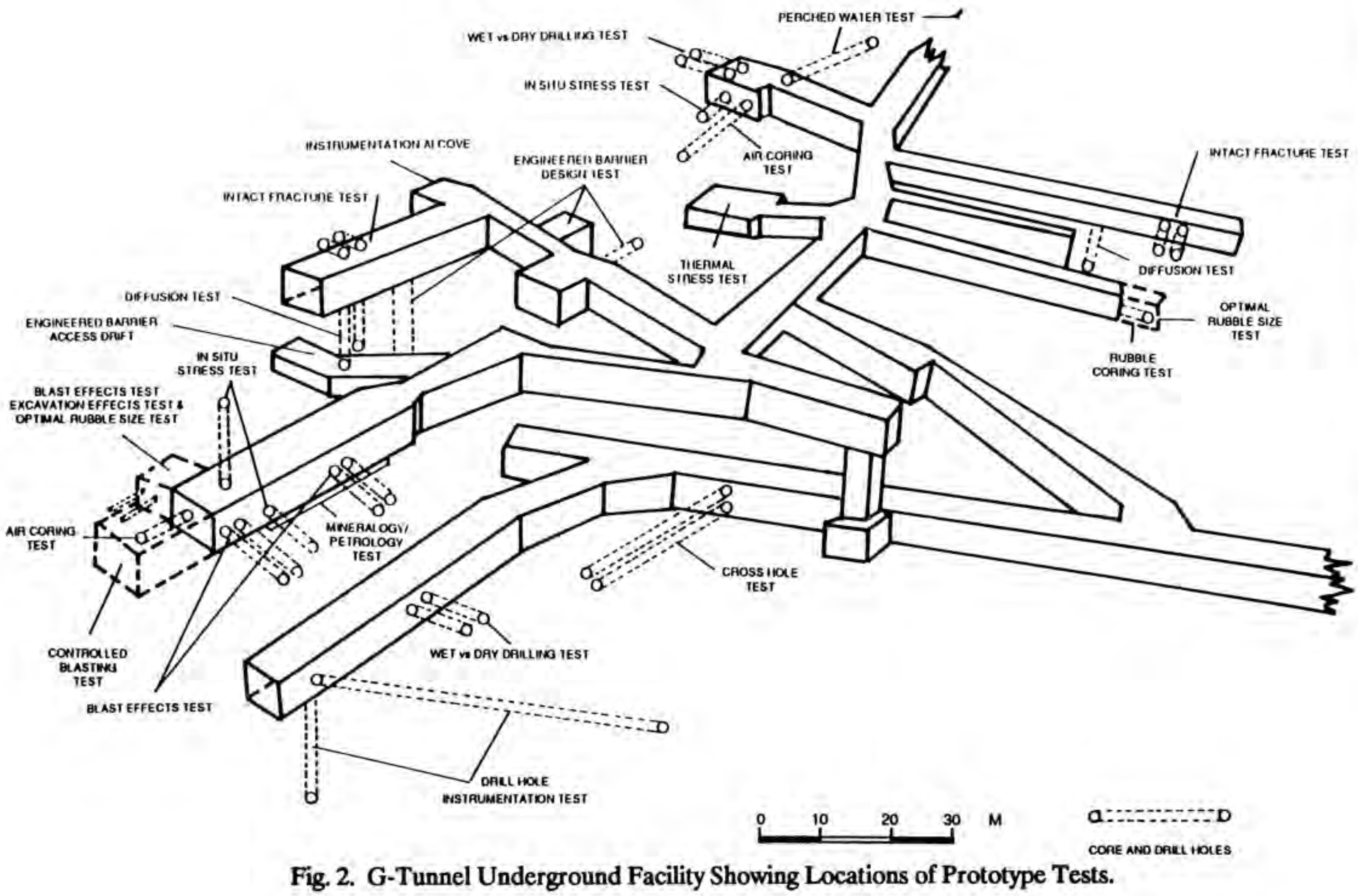

Fig. 2. G-Tunnel Underground Facility Showing Locations of Prototype Tests.

The Prototype Testing Program consisted of investigations spanning a range of disciplines, including geology, hydrology, geochemistry, rock mechanics, combined thermal and mechanical effects, and drilling and mining methods.These investigations are summarized below.

A significant number of tests planned for the ESF will depend on accurate geologic mapping of the shafts and drifts in considerable detail. Accurate mapping of fractures is of particular importance to hydrologic characterization of Yucca Mountain. Present plans call for a combination of full coverage stereoscopic mapping and conventional mapping. Testing of the stereoscopic equipment has been carried out by the U.S. Bureau of Reclamation in the G-TUF repository-scale Demonstration Drift. Testing involved various aspects of the proposed mapping procedure including wall-cleaning techniques using an air-water mist, stereoscopic photography, and laser surveying to provide extremely precise locations of features vital to generation of the final, highly detailed maps. In addition, methods of determining bearing geometrically, using a goniometer and hand-held gyrocompass, were tested.Data derived from prototype mapping in the G-TUF have been used to develop and test photogrammetric mapping procedures and evaluate results in the laboratory utilizing an analytical plotter.

During site characterization in the ESF, rock samples will be needed from which pore-water chemistry can be reliably determined. Consequently, part of the prototype effort by the USGS addresses sampling strategies and techniques.Because all or part of the ESF may be constructed using the drill-and-blast method, blast rubble of various sizes from mining operations in G-tunnel has been collected to determine the minimal size that can be successfully cored to produce a plug sample, uncontaminated by either gas or liquid blast chemicals and their by-products, to be used for hydrochemical and isotopic pore-water analysis. Evaluation will be based on comparison of pore water in plug samples from blast rubble with pore water extracted from cores obtained from intact wall rock. A second objective is to develop procedures to collect, log, seal, label, transport, and store rubble samples to prevent evaporation and to maintain structural and chemical integrity of the samples. A part of this effort focuses on perfecting an air coring technique that can acquire smooth, unbroken cores of appropriate sample size and that are not heated excessively during coring. To evaluate effectiveness of the technique, results are compared with analyses of chip or rubble samples from the same sample material.

Many tests planned for the ESF will utilize dry drilling in order to minimize contamination by drilling fluids that could affect the outcome of sample analyses. However, documented experience pertaining to air coring in hard, fractured rock in a mine environment is meager. As a consequence, several prototype tests conducted in the G-TUF included development and demonstration of dry drilling as a significant part of the overall test effort and, in some cases, this largely became the focal point of the test because of the problems encountered. An initial prototype drilling test was conducted by Los Alamos National Laboratory to develop air coring into a viable cost and time effective technique, to refine the technique for application to specific needs of the ESF testing program, to train personnel needed to perform the ESF drilling, and to establish health and safety practices for dry drilling. Two horizontal holes (150 feet and 50 feet) were air cored in densely welded, fractured tuff to simulate expected difficult drilling conditions at Yucca Mountain. This test evaluated standard drilling techniques, modified slightly for air circulation, to determine if they could meet ESF requirements. A standard core drill (Longyear 38) was used. Results demonstrate the viability and applicability of air coring to ESF requirements, although dry drilling has proven to be more difficult than wet drilling. A track-mounted drill rig with hydraulic outriggers and orientation control is now specified for future use to greatly improve the efficiency of underground drilling operations. General findings are that loss of air volume due to friction increases with hole depth and reduces flushing effectiveness, the volume of flushed air and cuttings that enter the dust collector must be regulated by the driller, and the RPM of the drill bit should be decreased with depth to facilitate smooth drilling.

A concern associated with air coring in the underground environment is the potential creation of a significant health hazard to investigators and support personnel because of the increased generation of airborne dust and fibers that would normally be mitigated by a drilling fluid such as water. In conjunction with the air coring test described above an assessment was made of the potential exposure of workers to airborne silica, zeolite fibers, and nuisance dust so that proper controls and physical protection devices can be incorporated into procedures involving air coring in the ESF. Also, an evaluation was made of the effectiveness of commercial dust control equipment when attached to the drilling apparatus during air coring.

The effects of drilling fluids on the in situ hydrologic conditions of the formation in the unsaturated zone at Yucca Mountain must be known before any boreholes are drilled in the ESF. Alteration of in situ hydrologic conditions of the rock matrix surrounding boreholes could have a significant impact on hydrologic experiments performed in or near boreholes, instrumentation installed in boreholes, and geophysical logging. To minimize the possibility of contaminating an area where an unsaturated zone hydrologic test is to be conducted in the ESF, the extent of drilling fluid penetration in the rock matrix and fractures must be accurately estimated. This can be accomplished in part by acquiring data to support appropriate unsaturated-zone hydrologic models. Field activities have been conducted by the U.S. Geological Survey in G-tunnel to compare results obtained from wet- and dry-drilled boreholes to determine how the drilling fluids affect the ambient hydrologic conditions of the formation. The G-tunnel activities consisted of coring two pairs of horizontal boreholes; one pair was drilled into fractured, welded tuff and the second pair was drilled into nonwelded tuff. Of each pair of boreholes, one was air cored and the other used water as the drilling fluid. Borehole geophysical and television camera logging was conducted prior to emplacing instrumentation to monitor the change with time of environmental conditions near each borehole and to establish ambient background moisture and temperature conditions appropriate to each tuff unit. Laboratory measurements of in-situ water saturation in core samples from each borehole were also made.Empirical data from the borehole measurements can subsequently be used to calibrate and validate hydrologic models being developed for Yucca Mountain.

Borehole packer and instrumentation systems to measure and monitor hydrologic conditions will be emplaced at several locations in the ESF. Installations during construction will need to be done efficiently to minimize delays in ESF construction and to ensure that monitoring is initiated prior to any significant changes related to excavation of underground openings. In this regard, systems originally tested by the USGS in simulated boreholes in the laboratory were field tested in horizontal and vertical boreholes in G-tunnel.The objectives of this test were to develop methods for efficiently installing instrumentation packages in boreholes in tuff surrounding the ESF so as to ensure both hydrologic continuity with the surrounding tuff and isolation of the instrumentation from portions of the borehole remote from the measuring location. Additionally, techniques are being developed for in-place calibration or verification of the accuracy of the instrumentation. Three isolated intervals in each of two boreholes were instrumented and were monitored over a 1-year period.

Fracture-flow characteristics are an important consideration for hydrologic characterization of the unsaturated zone at the Yucca Mountain site. As a consequence, prototype work in G-tunnel has been conducted by the USGS to develop and test methods to collect individual intact fracture core samples in a manner that will minimize any effects on the hydrologic properties of the fractures. Intact fracture samples will subsequently be used to develop methods and procedures for conducting laboratory tests related to characterizing hydrologic properties. G-tunnel testing has addressed the collection of fractures oriented radially and axially with respect to the sampling borehole. Radial fractures have been collected in satisfactory condition, but considerable trouble has been experienced in getting minimally disturbed axial fracture samples. It is hypothesized that binding by cuttings has caused the core to break off at unwanted places. Future plans call for using a different core-barrel configuration and/or a lexan liner.

In the event that perched water might be encountered during construction of the ESF at Yucca Mountain, work has been conducted to evaluate methodology and equipment for measuring rates of seepage from walls of an underground excavation, for measuring hydraulic head of a perched water body, for collecting representative samples, and for performing aquifer tests within the perched zone. Field work to date has consisted of coring four holes in perched water zones in the G-TUF and outfitting one hole with a packer and instrumentation system.

Tests to characterize in-situ stress are part of the activities to assess the geomechanical properties of rock at the Yucca Mountain site. Prototype work was initiated at G-tunnel by the USGS to test field procedures and instrumentation and to compare alternative methods of determining the in-situ stress in welded tuffs under conditions very similar to those expected at the ESF. The objective of the effort was to compare results of anelastic strain recovery and overcore stress test methods, but only the latter method has been addressed to date. Three locations in the G-TUF have been tested; two were drilled with air and one with water. Considerable difficulty was encountered in this effort, associated largely with dry drilling in fractured rock, and successful dry overcoring to retrieve borehole instrumentation was particularly difficult to achieve. Such difficulties resulted in much time allotted for testing to be consumed in addressing drilling problems. Although the original objectives for prototype stress measurements have not yet been met, lessons learned regarding methods for dry overcoring in fractured formations will be used to evaluate plans for further work.

Diffusion tests proposed for the ESF will measure the rate of solute diffusion into water-filled, or partly filled, pores of the tuffs in the unsaturated zone at Yucca Mountain. In-situ measurements of diffusion can be used to derive diffusion coefficients for use in performance assessment calculations, as solute diffusion is likely to be an important mechanism for retarding the water-borne transport of nonsorbing radioactive species. Prototype work by Los Alamos National Laboratory at G-tunnel involves pressurized injection of a tracer into the tuff at the end of a shallow, vertical borehole. After a predetermined period, the tuff surrounding the injection zone is overcored and the resulting core is sectioned and analyzed for tracer concentrations. The tracer distributions are used to calculate the in-situ diffusivities of solvents in the tuff. This test requires non-routine dry drilling and overcoring and has not been completed because of overcoring problems similar to ones experienced in other prototype tests.

Effects of heat generated by waste packages on the surrounding rock mass must be evaluated to understand and predict the response of the waste package and the natural environment during the period required for waste isolation at Yucca Mountain. Of particular interest are the relationships between the thermal load and the initial flow of fluid and gas away from the heat source and, then, the flow back toward the source as the waste cools. Prototype work in G-tunnel has been conducted by Lawrence Livermore National Laboratory that simulated a horizontal waste-emplacement configuration. A heater was emplaced horizontally in a small-diameter heater alcove. Boreholes, drilled at various orientations relative to the heater, contained instruments that monitored selected parameters, i.e., temperature, moisture content, air pressure, etc.This experiment was conducted in the Grouse Canyon welded tuff to simulate, as much as possible, expected conditions in the proposed repository host rock at Yucca Mountain. Plots of hydrologic parameters as a function of radial distance from the heater have provided results that confirm basic elements of the conceptual model of predicted environmental conditions. Prototype testing simulating vertical emplacement of a waste package is planned for a future date.

Many experiments planned for the ESF use equipment and instruments that require development and demonstration under conditions similar to those at the ESF before they are used under rigid Quality Assurance practices. An on-going effort in the G-TUF by Sandia National Laboratories has focused on evaluating and demonstrating reliability of such items as high pressure flatjacks, multiple-point borehole extensometers, remote convergence monitoring equipment, anelastic strain recovery equipment, and hydraulic chain saws designed for rock cutting. It is expected that other items may require evaluation in G-tunnel or another environment similar to the ESF prior to use at Yucca Mountain.

Not all of the prototype and developmental work planned to be executed in the G-TUF has been accomplished. Prototype activities in the G-TUF have been suspended because of budgetary constraints and a delay in the schedule for construction and testing in the ESF at Yucca Mountain. Planned prototype work either unfinished or not initiated include evaluations of controlled blasting techniques, effects of blasting on test instrumentation, effects of excavation on hydrologic properties, effects of thermal stress on rock properties, changes in rock characteristics associated with vertical emplacement of waste canisters, and further developmental work on dry drilling and coring methodology.

PROTOTYPE DRY DRILLING AND CORING FOR SURFACE-BASED APPLICATION

The Yucca Mountain Project is developing and testing dry dual-wall reverse circulation drilling and dry coring systems to be used for deep unsaturated zone boreholes to be drilled from the surface. Prototype testing of the initial concepts began in April 1989. The objectives of this prototype testing are to (1) provide core and drill cuttings in as uncontaminated condition as possible, (2) provide a borehole wall as clean and smooth as possible for future downhole testing, and (3) avoid contamination of the adjacent formation with conventional (liquid) drilling fluids. The ultimate objective of this prototype test is to ensure that the methods used will meet the requirements of the deep unsaturated zone site characterization program without undue adverse impact on the site's ability to isolate waste.

The concept is a new application of dual-wall drilling commonly used in the southwestern U.S. for gold exploration, combined with a wireline retrieval coring system. The dual-wall drill pipe assures air circulation and serves as temporary casing for the air coring (Fig. 3). The coring is done through an open centered bit on the dual-wall pipe, in advance of the dual-wall drilling.

The sequence used for dry coring is to core 20-40 feet in advance of the dual-wall system using air as the circulating fluid, pull the coring string out of the hole, and then advance the borehole with the dual-wall system system to the bottom of the cored zone. The wireline coring system is then lowered through the dual-wall pipe and open-centered roller-cone or cleanout bit, and the process continued.

Zones not requiring core will be drilled using a down-the-hole air hammer or an open-centered roller-cone bit. The air hammer drilling will generate fine to coarse cuttings while the open-centered roller-cone bit will generate large chunks of rock the size of the opening in the bit and as long as eight inches.These cuttings or larger samples are lifted by the circulating air, pass through a large-radius gooseneck pipe at the top of the drill string, and are recovered in the dust collection system. Finer cuttings remaining in the airstream are collected in a large double cyclone/filter system.

To date, air-coring has been successful to 530 feet. Drilling was curtailed due to wetter conditions than expected at test drill sites in Utah. Plans are to drill to 1700 feet during the next development phase, limited by the capacity of the available drill rig. A larger drill rig is being fabricated, in preparation for the drilling at Yucca Mountain, which must penetrate unsaturated section as thick as 2600 feet.

Much has been learned about the size constraints on the design of open-centered roller cone bits and bearing life, about the sample handling and dust control systems, and benefits and limitations to several air-circulation systems (i.e. conventional versus reverse circulation, with and without vacuum assist, in dry and wet ground). Conventional circulation appears to be the most promising method for drilling with air through rock that contains sporadic

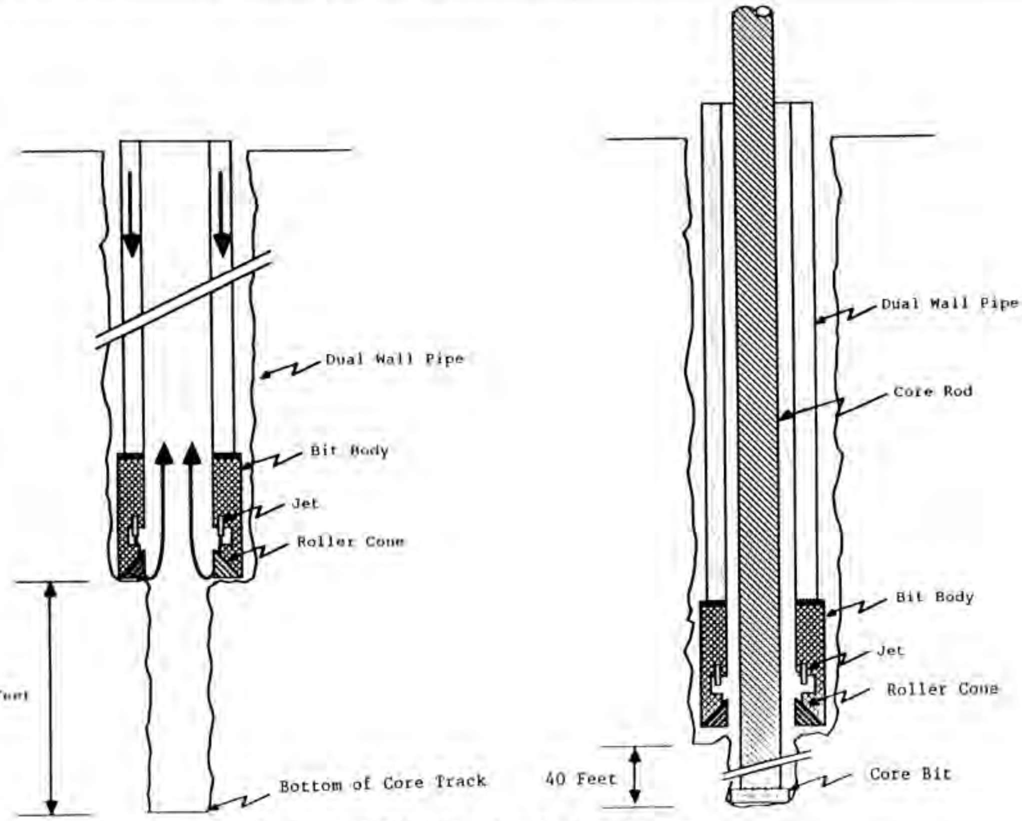

Fig. 3. Dual Wall Drilling/Coring System.

inflow of water. This may be a factor should perched water be encountered during dry drilling at Yucca Mountain.

PROTOTYPE INSTRUMENTATION/DATA ACQUISITION SYSTEM

The Instrumentation/Data Acquisition System (IDAS) is designed by the USGS to support the collection of data from instruments emplaced in boreholes penetrating the unsaturated zone at Yucca Mountain. The IDAS consists of a network of shelters wired to down-hole instrumentation, linked telemetrically to a control archiving computer. Each shelter houses analog-to-digital converters, computers to archive data and to control the system functions, environmental control systems, security systems, and communication equipment.

To date, two prototype shelters have been constructed, a large portion of the controlling software has been developed, and the existing system has been field tested to measure system performance against design criteria for recording, transmitting, and storing sensor readings. Some modifications are still needed to incorporate 'field changes' into a final design for shelter production.

ADDITIONAL PLANNED PROTOTYPE TESTING

Several new methods or applications are currently planned for additional prototype testing. Two systems have been designed to apply vertical seismic profiling methods to the unsaturated zone at Yucca Mountain. Neither of these has been field tested at Yucca Mountain due to environmental permit constraints. Another study of surface run-off includes plans to construct at least one flume to evaluate the suitability of the current stage-sensing instrumentation systems, and to perform simulated run-off events to test and calibrate the instrumentation. One major unknown is how well the flume will be able to handle the bed-load moved during storm events.

SUMMARY AND CONCLUSION

As surface-based and underground drilling technology and experience is developed, more complex combinations of tests and instruments will be tested in boreholes. Many of the techniques developed individually during the prototype testing described above will be combined or sequenced in planned site characterization boreholes. The prototype testing will at this point become feasibility testing leading to the use of proven concepts and techniques for site characterization testing.

The experience gained through the prototype field-testing program to date in G-tunnel and elsewhere has made great progress toward closing the gap between the conceptual planning of site characterization field activities and the development of detailed methods, instrumentation and other supporting equipment necessary to conduct the field program at Yucca Mountain.

ACKNOWLEDGMENT

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