LA-11844-MS

UC-802
Issued: December 1994

The Yucca Mountain Project Prototype Air-Coring Test, U12g Tunnel, Nevada Test Site

James M. Ray
Jon C. Newsom*

DISCLAIMER

*Consultant, Newsom Industries, Citrus Heights, CA 95621.

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

DISCLAIMER

CONTENTS

THE YUCCA MOUNTAIN PROJECT PROTOTYPE AIR-CORING TEST, U12g TUNNEL, NEVADA TEST SITE

by

James M. Ray and Jon C. Newsom

ABSTRACT

The Prototype Air-Coring Test was conducted at the Nevada Test Site (NTS) G-Tunnel facility to evaluate standard coring techniques, modified slightly for air circulation, for use in testing at a prospective nuclear waste repository at Yucca Mountain, Nevada. Air-coring technology allows sampling of subsurface lithology with minimal perturbation to ambient characteristic such as that required for exploratory holes near aquifers, environmental applications, and site characterization work.

Two horizontal holes were cored, one 50 ft long and the other 150 ft long, in densely welded fractured tuff to simulate the difficult drilling conditions anticipated at Yucca Mountain. Drilling data from seven holes on three other prototype tests in nonwelded tuff were also collected for comparison. The test was used to establish preliminary standards of performance for drilling and dust collection equipment and to assess procedural efficiencies. As problems were encountered or conditions varied, improvements, modifications, and procedural changes were made to improve the coring operations.

The Longyear-38 drill achieved 97% recovery for HQ-size core (~2.5 in.), and the Atlas Copco dust collector (DCT-90) captured 1500 lb of fugitive dust in a mine environment with only minor modifications. The impregnated bits exhibited exceptional durability (120-160 ft/bit) in very difficult dry coring. Average hole production rates were 6-8 ft per 6-h shift in welded tuff and almost 20 ft per shift on deeper holes in nonwelded tuff. Lexan liners were successfully used to encapsulate core samples during the coring process and protect core properties effectively.

The Prototype Air-Coring Test demonstrated that horizontal air coring in fractured welded tuff (to at least 150 ft) can be safely accomplished by proper selection, integration, and minor modification of standard drilling equipment, using appropriate procedures and engineering controls. The test also indicated that rig logistics, equipment, and methods need improvement before attempting a large-scale dry drilling program at Yucca Mountain.

I. INTRODUCTION

A. Background Information

The U.S. Department of Energy (DOE) established the Yucca Mountain Project (YMP), formerly the Nevada Nuclear Waste Storage Investigations Project, to conduct site characterization studies of Yucca Mountain, Nye County, Nevada, for a prospective nuclear waste repository. A mined Exploratory Shaft Facility (ESF) is planned as part of the site study. Before ESF construction, certain prototype tests such as the Prototype Air-Coring Test are being conducted in the G-Tunnel underground facility (GTUF), formally designated as U12g, in Rainier Mesa at the Nevada Test Site (NTS) (see Fig. 1).

The U.S. Geological Survey (USGS) hydrologists are concerned that water introduced to formations while drilling could make hydrologic data from many of the ESF tests questionable (Montazer, 1985a, 1985b, 1986). Core drilling is normally done with water or a mixture of water, air, and foaming agent as a circulation medium to reduce the likelihood of drill rods being lost or stuck in the hole. The Prototype Air-Coring Test was designed (Ray and Newsom, 1987a) to determine the feasibility of continuously coring dry horizontal holes underground in a fractured hard rock.

1. Dry Coring for Site Characterization. Numerous tests are planned for site characterization at Yucca Mountain to acquire data on geologic, hydrologic, geomechanical, geochemical, and waste package environment characteristics. The diverse nature of the testing requires several different types of holes. The most recent compilation of ESF hole requirements (Ray and Newsom, 1988) shows that over 300 holes totaling more than 10,000 ft will be cored using air. The information and data made possible by testing in G-Tunnel enhances ESF planning and should produce significant cost benefits.

2. Comparative Geologic Settings for the GTUF and ESF. Yucca Mountain is located at the western boundary of the Nevada Test Site's southwest corner (Fig. 1), and G-Tunnel is located in the north-central part of the NTS. The prospective repository horizon at Yucca Mountain lies well above a very deep water table (Robison, 1984) in the unsaturated zone as does the GTUF. The concern of USGS hydrologists is that the sensitive hydrologic parameters of the unsaturated zone may be disturbed by fluids artificially introduced during drilling and coring activities at Yucca Mountain.

Both Rainier Mesa and Yucca Mountain contain extensive sections of volcanic rock. The overburden thicknesses at both the GTUF and planned ESF are similar. The volcanic section at Yucca Mountain contains densely welded and highly fractured tuffs (Scott and Bonk, 1984; Maldonado and Koether, 1983; Scott and Castellanos, 1984), which have mean fracture densities ranging from 8 to 40 fractures per cubic meter (Montazer and Wilson, 1984). The tuffs commonly exceed 20,000 psi compressive strength and compare well to the strengths for welded tuff at G-Tunnel (Langkopf and Gnirk,

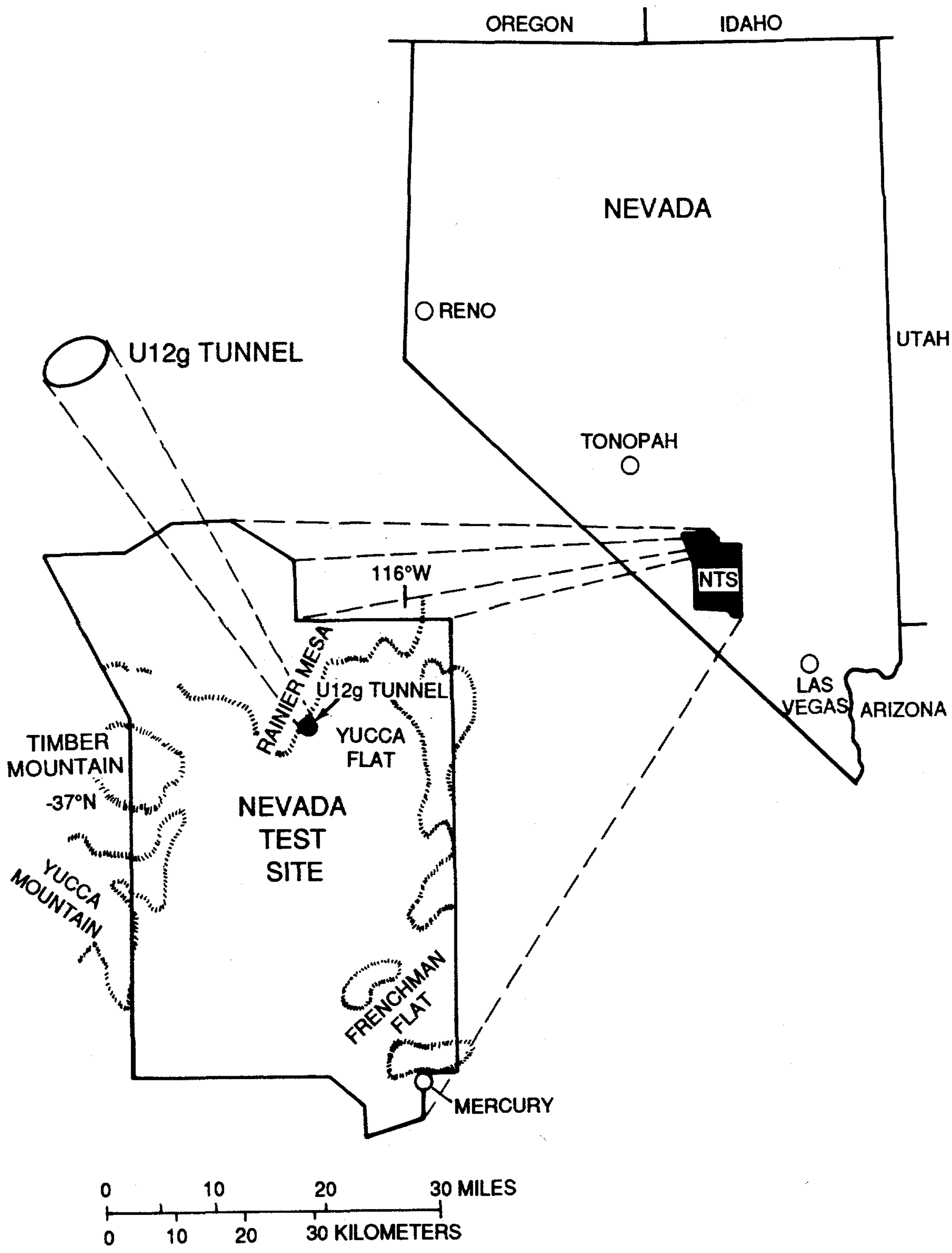


Figure 1. Location map showing relative locations of Yucca Mountain and the GTUF at the Nevada Test Site.

1986). Rock properties at Yucca Mountain are also highly variable (Byers, 1985; Vaniman et al., 1984; Connolly et al., 1983). Those combined characteristics present a formidable challenge to existing drilling technology.

Physical and mechanical rock properties at G-Tunnel and Yucca Mountain are similar (Zimmerman et al., 1986). A general comparison between the Grouse Canyon Member (G-Tunnel) and the Topopah Spring Member (Yucca Mountain) was itemized by Connolly et al. (1983). Also, Langkopf and Gnirk (1986) reported many similarities between Topopah Spring and Grouse Canyon for rock characteristics such as number of fractures, joint roughness, joint apertures, and rock mass classification indices. Based on these rock properties, the evaluation of drilling and dust collection in G-Tunnel's geologic setting is reasonably applicable to Yucca Mountain.

B. Limited Relevant Experience

A review of current technology through professional contacts and literature was supplemented with an examination of assorted case histories. These case studies provided information relevant to the objectives and requirements of the Prototype Air-Coring Test. There is extensive information on horizontal drilling, air mixes (i.e., air foam and air mist), and hard rock environments. However, documented experience is meager for air coring horizontally in hard fractured rock in a mine environment.

Review of dry-drilling case histories, not itemized in this report, suggests that downhole air percussion hammers could dry-drill densely welded tuff at rates in excess of 300 ft per 6-h shift. In cases where core is not required but accurately drilled holes are needed, the downhole hammer drilling technique could reduce drilling time by ~80%. The potential cost benefits merit further investigation.

Four of the most pertinent case histories are summarized below. Each case attempted dry drilling; three horizontally and one vertically.

1. Case History #1. The first case involved prototype horizontal drilling in limestone for eventual application to underground stimulation and production of bitumen from adjacent tar sands (Best et al., 1985). The Alberta Oil Sands Technology and Research Authority tested a prototype rig on the surface by drilling into a limestone face using air with a dual pipe system.* After just a few feet of penetration, trouble began when circulation was lost to fractures. Mud was then used as the circulation medium, and a depth of 300 ft was ultimately achieved. The introduction of mud precluded further evaluation for application to Yucca Mountain.

Communicated via telephone on February 11, 1987 from Jack Suggett, Alberta Oil Sands Technology and Research Authority, to J. M. Ray, Los Alamos National Laboratory.

2. Case History #2. The second case study addressed vertical air-coring in the Bandelier Tuff near Los Alamos, New Mexico (Teasdale and Pemberton, 1984). The Bandelier air-coring and the G-Tunnel test involved similar rock type, air circulation medium, and a wireline retrievable coring system. The Bandelier hole was completed to 210 ft, but the vertical orientation presented different hole cleaning problems from those experienced in horizontal coring. The extensive equipment modification, control of compressor pressure and volume, and less restrictive dust control requirements were unlike the G-Tunnel test. Certain aspects of the test in Bandelier Tuff are applicable and were taken into consideration in designing the Prototype Air-Coring Test. However, other parameters (e.g., different bit designs, horizontal coring, thicker overburden) needed to be addressed for application to Yucca Mountain.

3. Case History #3. The third case, similar to case #2, required air-cored holes in the Bandelier Tuff near Los Alamos, New Mexico (Larkin and Speake, 1976). Five horizontal holes for monitoring were dry-cored using wireline core retrieval beneath a solid-waste disposal pit. The operations went mechanically well using a Longyear 44 drill rig. The holes deviated from the vertical as a result of soft zones of nonwelded tuff and reworked tuff (Purtymun et al., 1978). Joints were often filled with clay or caliche, which probably assisted in containing the air circulation. The softer rock, filled fractures, and variable control of air volume and pressures allowed relatively easy drilling. Longer core barrels (up to 20 ft long) were used to produce 63% core recovery. This case history was found after the Prototoype Air-Coring Test was completed. Although the information was not used in designing the G-Tunnel test, it is summarized here because of its relevance.

4. Case History #4. The fourth, and most relevant, case history was hole UE-25h#1, cored at Fran Ridge near Yucca Mountain from December 1982 to January 1983. One objective for this hole was to develop horizontal air-coring techniques in the welded tuff of the Topopah Spring Member.

The drilling-related problems encountered at Fran Ridge are summarized below:

- Loss of air to fractures, causing failure to clean the hole of cuttings.
- Hole sloughing, jammed drill rods, and damaged drill bits.
- Serious drill string vibration, causing bit failure, poor penetration rates, and poor core recovery.
- Highly fractured rock, causing core barrels to jam.

Observations and recommendations on the Fran Ridge experience (Norris et al., 1986) were considered in designing the Prototype Air-Coring Test.

C. Prototype Air-Coring Test Rationale and Design

This test evaluated standard drilling techniques, modified slightly for air circulation, to determine if they could meet ESF requirements. Based on the evaluation of case histories, an idealized match of equipment for prototype testing was recommended (Ray and Newsom, 1987b, 1987c, and 1987d).

1. Scope. The Prototype Air-Coring Test was a field operation requiring two holes (AC-1 and AC-2), which were cored to establish preliminary standards of equipment performance for drilling on other prototype tests and ultimately at Yucca Mountain. As conditions varied, improvements, modifications, and procedural changes were made to improve the drilling operations. However, this report also utilizes data on seven holes from three other subsequent prototype tests (Fig. 2). These holes (XH-1, XH-2, DH-1, DH-2, DH-3, DI-1, and DI-2) are included to take advantage of the opportunity to evaluate additional data and to assess recommendations implemented on these other three tests, which were derived as a result of drilling holes AC-1 and AC-2.

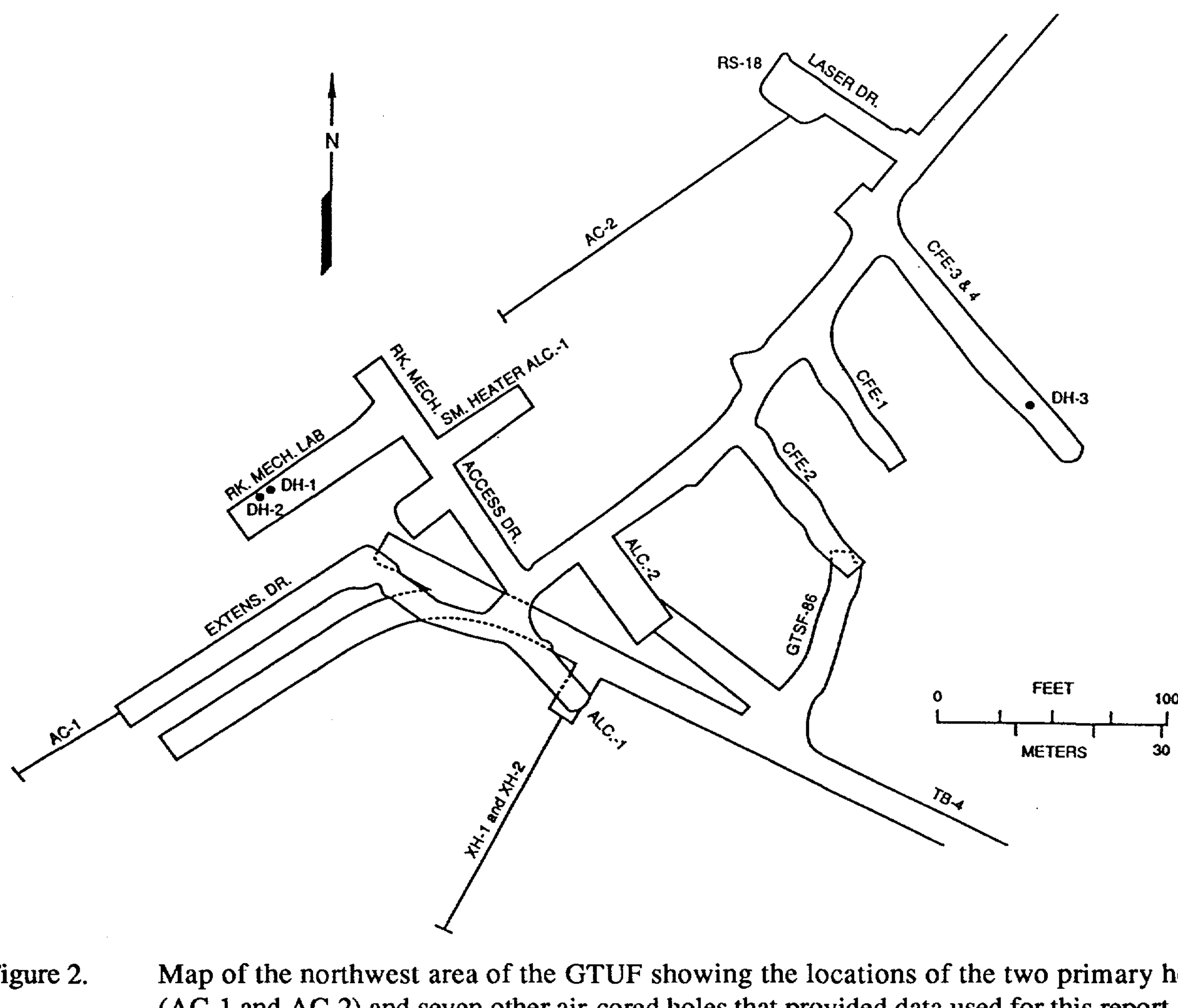


Figure 2. Map of the northwest area of the GTUF showing the locations of the two primary holes (AC-1 and AC-2) and seven other air-cored holes that provided data used for this report.

2. Approach. One hole was core-drilled 50 ft horizontally, and the other was core-drilled 150 ft horizontally (Fig. 3) with only dry air used as the circulation medium.

The approach used for the Prototype Air-Coring Test was driven by the following requirements:

- Holes were to be horizontally cored in fractured welded tuff.
- Coring was not to add moisture to the formation.
- Coring was to produce an HQ-size (~3.790 in.) hole (Diamond Core Drill Manufacturers Association standards).
- A dust control and collection system was to be used and evaluated.
- Hole integrity for hypothetical instrumentation packages was to be evaluated.
- Operations and procedures were designed to reflect anticipated ESF conditions as much as possible.

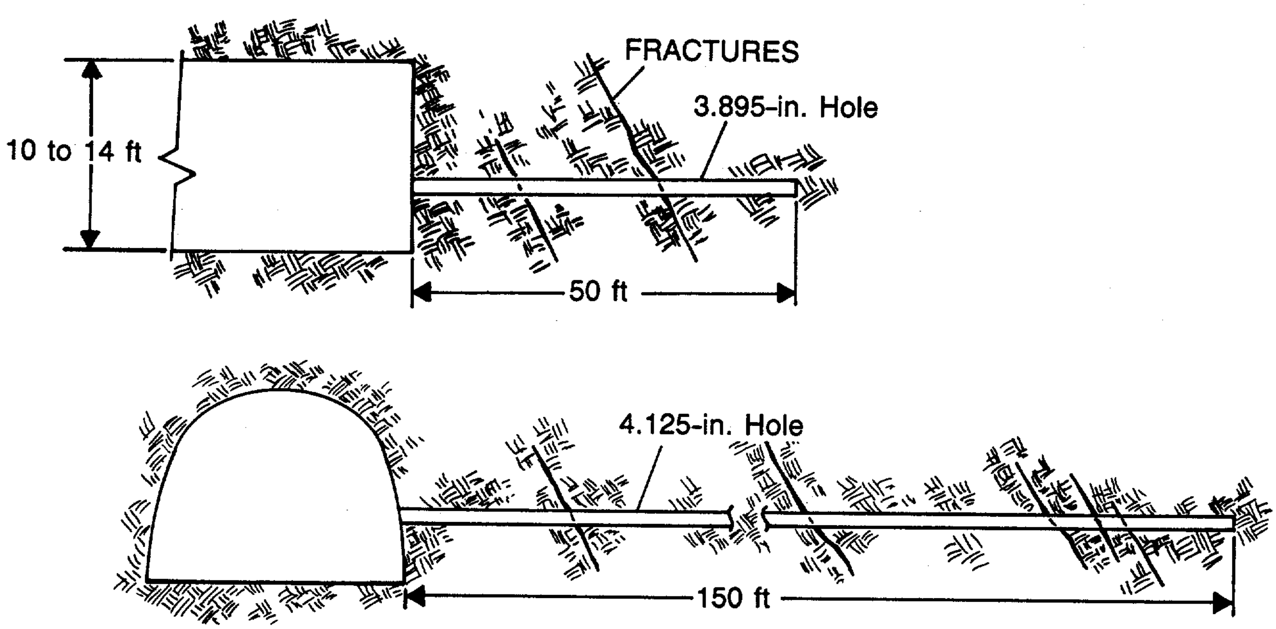


Figure 3. Conceptual (not drawn to scale) diagram of holes for Prototype Air-Coring Test.

A multipurpose drill was originally recommended, but a standard core drill (Longyear-38 electric/hydraulic) was chosen from the available drills. The configuration of equipment is shown in Fig. 4 and labeled in the sketch in Fig. 5. Additional data were recorded during drilling activities associated with the Prototype Cross-Hole Test and the Prototype Diffusion Test. Some information on bit performance during coring for the Drill Hole Instrumentation Test has also been included. These tests also required air-cored holes approximately the same diameter as those in the Prototype Air-Coring Test. However, the siting of the other tests (Fig. 6) was such that different lithologies were encountered, thus allowing comparisons of equipment performance vs. rock type.

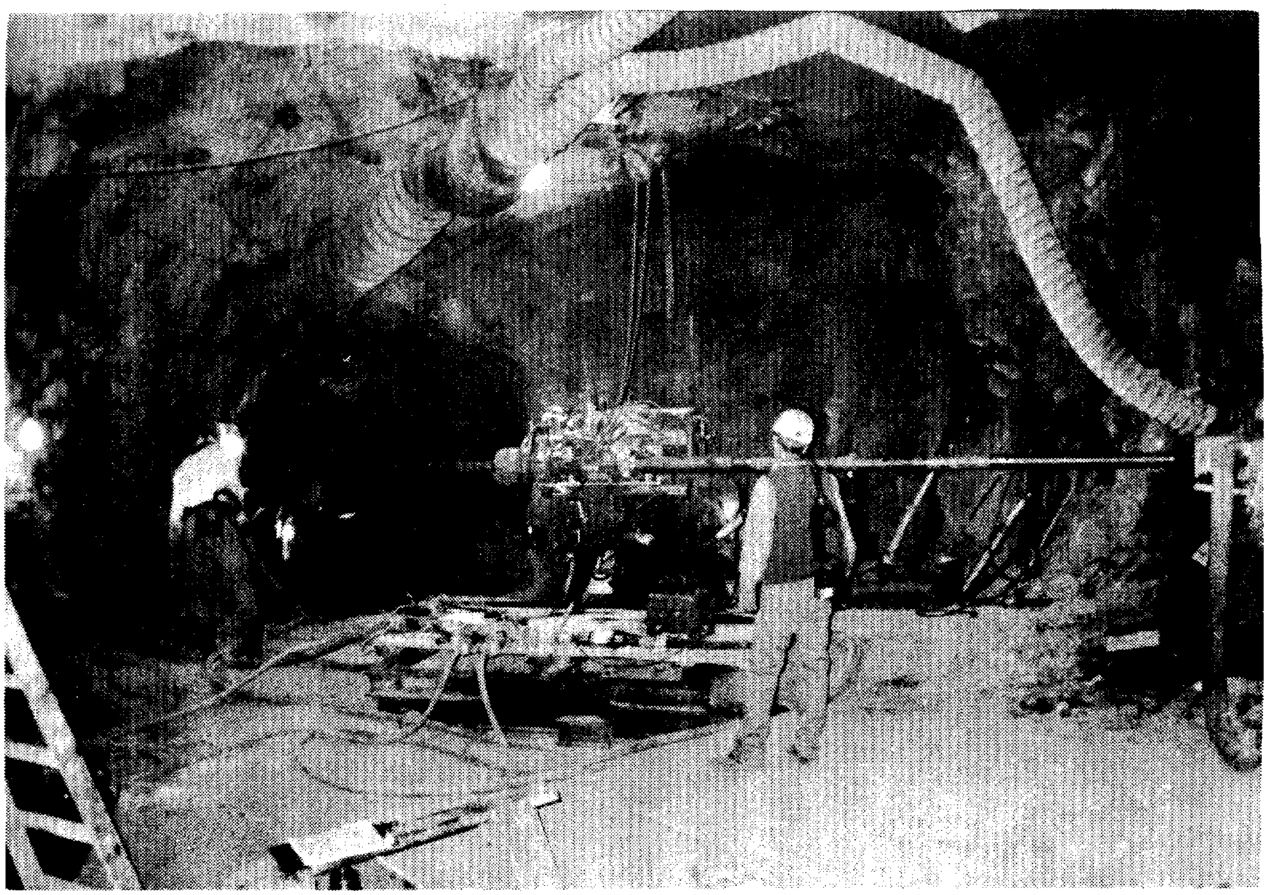


Figure 4. View showing the equipment during operation on Prototype Air-Coring Test hole AC-2 in the Laser Drift at G-tunnel.

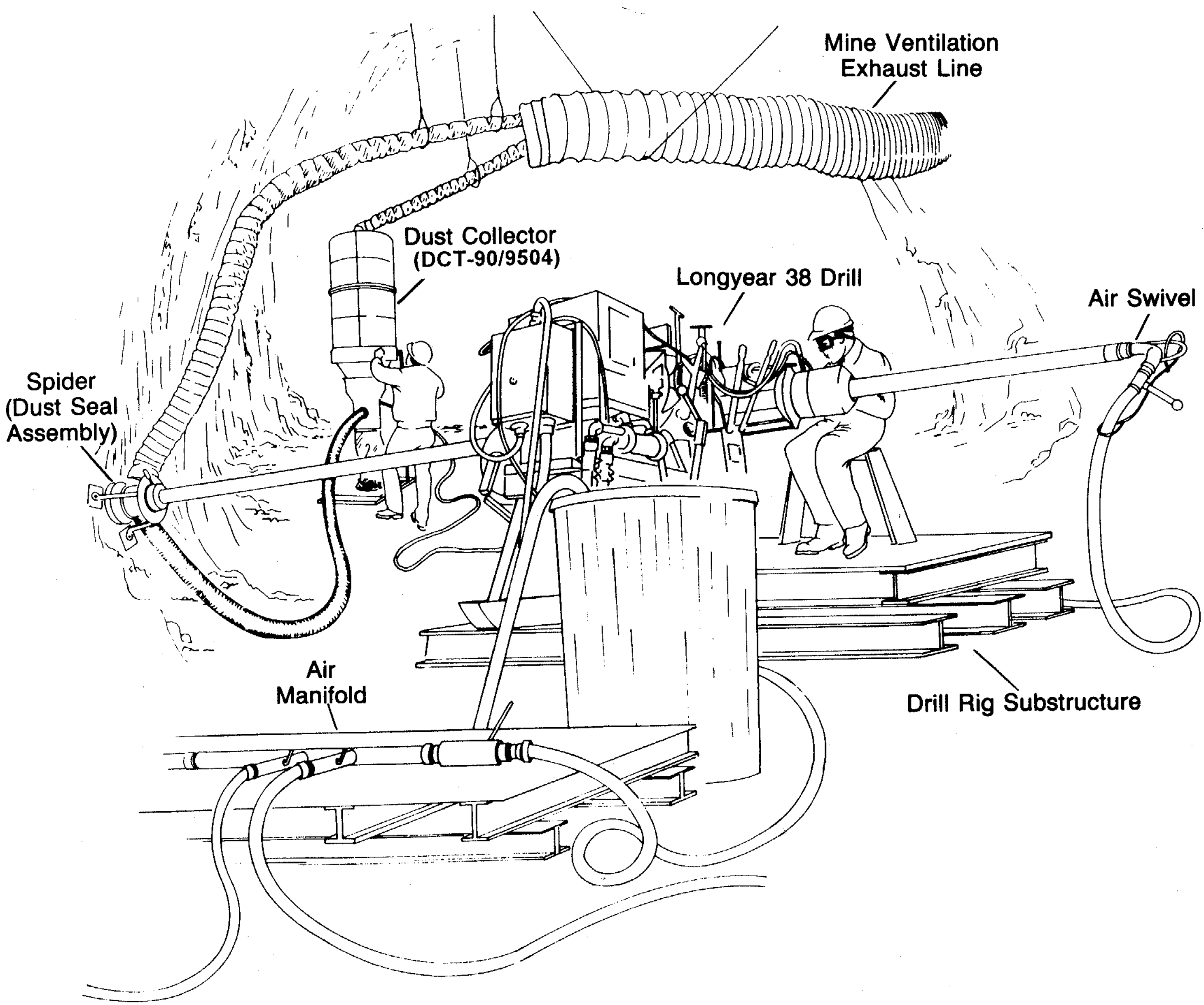


Figure 5. Sketch illustrating the configuration of equipment as used on Prototype Air-Coring Test hole AC-2.

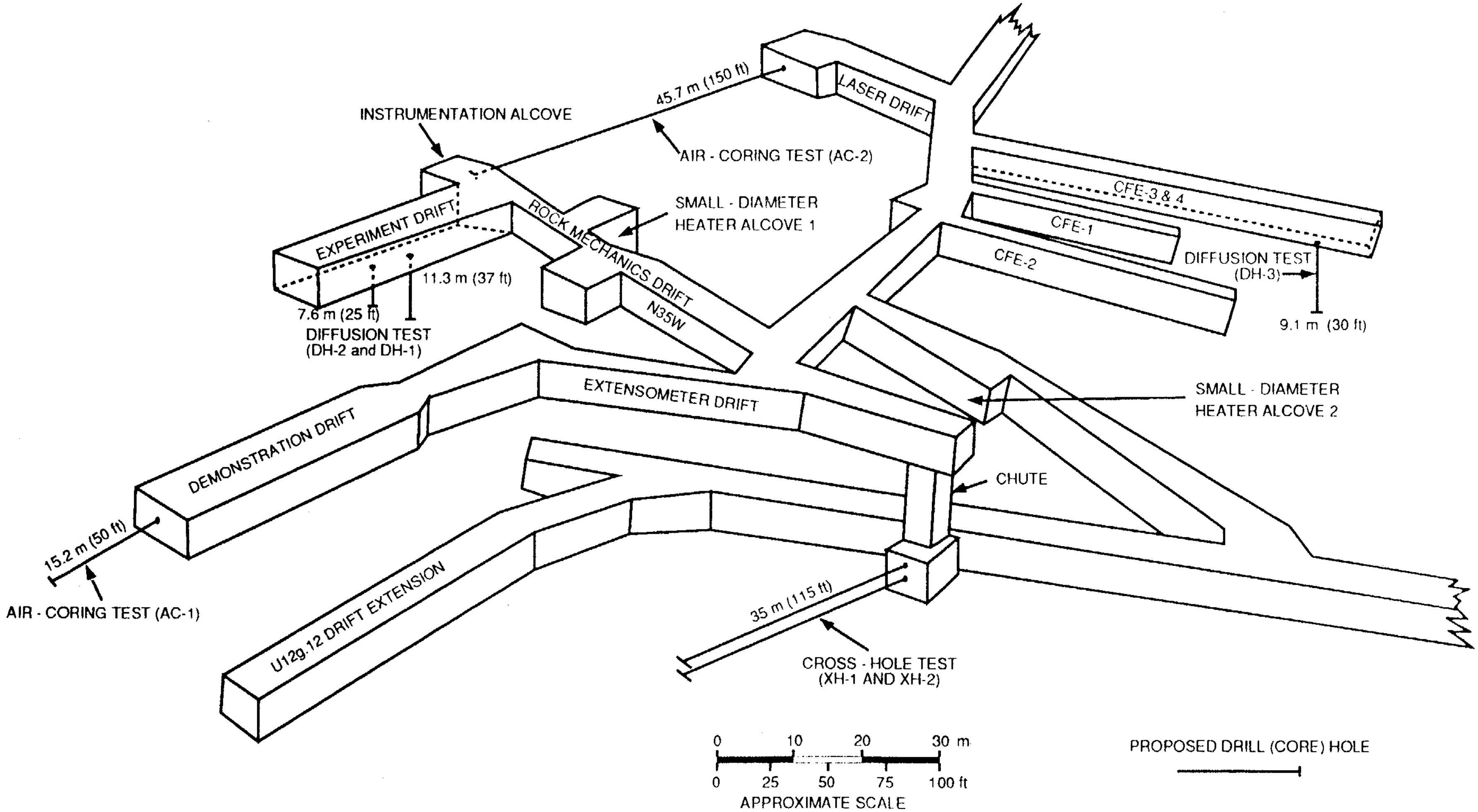


Figure 6. Oblique three-dimensional illustration of the northwest section of G-tunnel showing the relative positions of the air-cored holes evaluated in this report.

3. Objectives. The following objectives were previously listed in a draft proposal for prototype air-coring (Ray, 1985). Several items of desired information were added when Principal Investigators (PIs) for other studies provided their input.

- **Obtain samples** without any added moisture, i.e., as near to natural conditions as possible.
- **Determine hole stability** through sloughing zones that may not remain open or that may be unstable or so fractured that the cuttings bind up the drill rod and cause problems.
- **Produce cores** from holes in unstable or highly fractured lithologies for validation of the coring systems, evaluation of core recovery efficiency, and materials testing by the PIs from other studies.
- **Develop/evaluate procedures to operate instruments** and logging devices in unstable holes; e.g., casing removal, instrument emplacement, and stemming may run concurrently.
- **Evaluate dust control** systems for dry underground drilling relative to operational interface with drilling systems, air requirements, and collaring requirements.
- **Validate the ODEX (see Glossary) method** for underground use while intermittently coring. This objective was contingent upon the availability of a rig capable of percussion drilling underground. The ODEX system provides stability for horizontal holes in badly badly fractured rock.
- **Determine optimum rig performance**; i.e., identify and match the appropriate drilling equipment for the coring, boring, and percussing requirements of other PIs.
- **Evaluate commercially available equipment for coring** and determine what depths can be achieved successfully within acceptable time and cost parameters. Determine what, if any, modifications can be made to available equipment to enhance performance.
- **Determine penetration rates for coring** in hard, fractured tuff.
- **Evaluate hole stabilization by casing advance** intermittent with coring (if equipment is available).
- **Record real-time data** and information on drilling parameters, such as bit thrust, rpm, air system requirements, and vibration.
- **Evaluate air-coring problems**; remedy problems as they are encountered; identify potential problem areas; and develop recommended solutions.
- **Evaluate impact of space constraints** on operational procedures.
- **Develop specific, efficient operating procedures** before beginning work in the ESF.
- **Evaluate safety concerns.**

- **Evaluate time estimates** to provide more accurate input into ESF planning.
- **Provide information on test holes to other PIs.**
- **Evaluate volume of particulates and cuttings generated**, hopper size requirements for coarse particles, time cycle for hopper dumping, and procedural adequacy for safely removing collected drilling products from the immediate work area.
- **Evaluate engineering/design** for each drilling-related system function in advance of experiments fielded in the ESF.

II. TEST RESULTS

A. Equipment Performance and Recommendations

The Prototype Air-Coring Test was very successful. The relative success in completing test objectives is presented in Table I. A time constraint imposed on this test was the need to expeditiously qualify a safe dust suppression system, and therefore it was necessary to focus on certain kinds of equipment and a limited number of procedures. Equipment was changed or redesigned as necessary. Documentation of results and efficiencies were then used to evaluate, recommend, and integrate equipment for future prototype and ESF dry drilling. The results of that approach and subsequent recommendations are summarized in Table II. Because of the many equipment components, the summary is presented in tabulated form for easy reference.

The 50-ft hole (AC-1) was primarily used for validation of the dust collection system, and the 150-ft hole (AC-2) was designed to collect air-coring information. However, both types of information were collected on each hole. AC-2 was purposely sited in Unit B of the Grouse Canyon Member of the Belted Range Tuff to challenge air-coring technology. This unit contains the most densely welded part of the Grouse Canyon Member in the GTUF area (Connolly and Keil, 1985). Extremely hard lenses of flattened pumice fiamme (pronounced fee-ah'-mee) are common in Unit B and contributed to low-angle shearing, sometimes leading to core blockage.

The results of the Air-Coring Test confirm that in many ways dry drilling is more difficult than wet drilling, but with proper planning it is technically and economically feasible. Recommendations resulting from this test (see Table II) show that only minor changes need to be made to make dry air-coring even more efficient, time effective, and safe. Some of the advantages of dry drilling are clean, quiet work conditions; complete containment of drill cuttings; and presumably unaltered core and rock formation because neither is exposed to moisture (see Table III for comparison of core physical properties).

TABLE I. COMPLETION OF OBJECTIVES FOR THE PROTOTYPE AIR-CORING TEST

Objective	Met	Not Met	Partly Met	N.A.	Comment
Obtain Samples	X				
Determine Hole Stability			X		Highly fractured zones were encountered; rod binding by cuttings was encountered; significant sloughing zones were not encountered.
Develop/Evaluate Procedures to Operate Instruments		X			Not yet met except for pretest planning; some logic in place but actual field validation not executed; unstable holes not encountered.
Evaluate Dust Control	X				
Validate the ODEX Method				X	Not funded.
Determine Optimum Rig Performance	X				
Evaluate Commercially Available Equipment for Coring	X				A large assortment of commercially available equipment was evaluated, but a limited array was actually field-tested; 150-ft hole capability was confirmed; depth limitation is an unresolved issue.
Determine Penetration Rates for Coring	X				
Evaluate Hole Stabilization by Casing-Advance				X	Not funded.
Record Real-Time Data	X				
Evaluate Air-Coring Problems	X				
Evaluate Impact of Space Constraints	X				

TABLE I. COMPLETION OF OBJECTIVES FOR THE PROTOTYPE AIR-CORING TEST (cont)

Objective	Met	Not Met	Partly Met	N.A.	Comment
Develop Specific, Efficient Operating Procedures			X		Certain applicable procedures were written and validated within the scope of this test; other procedures are necessary, and we recommend that they be written by appropriate organizations; detailed QA-approved procedures are needed before ESF activities; also see Procedural Performance and Recommendations section of this report.
Evaluate Safety Concerns	X				
Evaluate Time Estimates	X				
Provide Information on Test Holes to Other PIs	X				
Evaluate Volume of Particulates and Cuttings Generated	X				Hopper utilization is not applicable; that equipment would have been used if percussion drilling had been funded.
Evaluate Engineering/Design	X				

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS

Equipment	Plan	Modifications or Changes	Results	Recommendations
Drill Rig	Longyear LY-38 Electric/ Hydraulic	None.	Better control than with air motor. Sufficient torque. This rig worked well for holes requiring several different sizes from RWT to HQ.	For NQ (2.98-in.) and HQ (3.79-in.) dry-cored holes this is ideal rig. The electrical power is quiet, nonfluctuating; it provides necessary power and saves a considerable volume of air that would be needed if air power were chosen. Example: Air power LY-38 uses 875-1000 cfm; LY-24 uses 500 cfm
Drill Rig Substructure	I-Beam platform was rock-bolted to floor beams, cross-stacked, and welded.	None.	Not perfectly stable, very time-consuming setup. Several welds were broken during vigorous drilling activities.	1. Design modular base for faster, more stable setup. 2. Look into self-mobilizing modular base. 3. Procedures need to be written that would help determine the ideal drill height or distance from hole collar.

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS (cont)

Equipment	Plan	Modifications or Changes	Results	Recommendations
Dust Collector	New Atlas Copco DCT-90/9504	Used Atlas Copco DCT-90/9504.	Excellent.	For ESF 1-DCT-90 or 9504 1 smaller unit for small holes. 1 larger unit for possible large percussion holes.
	Modify as needed.	1. Added upper chamber air charger.	1. This helped clean unit.	1. This item is currently on most new models.
		2. Added exhaust adapter to ventline.	2. This prevented exhaust dust contamination.	2. Add exhaust to ventline (as tested).
		3. Added sound-deadening materials.	3. Lowered decibels to acceptable levels.	3. Add sound-deadening material on exhaust area of DCS (as tested).
		4. Built stand.	4. Awkward to mobilize.	4. Design stand that mobilizes easier.
		5. Adjusted flushing air to keep bag in vacuum mode.	5. A. Prevented leaks. B. Vacuum helped clean hole in fractured area.	5. Do as tested.
	Modify collar packoff.	6. A. Added spider arrangement for fastening packoff to wall.	6. A. Worked well.	6. A. Use as built and tested.
		B. Designed rubber packoff for rod seal.	B. Works well when rubber wipers are in good shape.	B. Use as built, modified, and tested; order factory-built rubber wipers.
		C. Brought mine exhaust line to spider area to exhaust minor fugitive dust leaks.	C. Keeps fugitive dust safely contained during time of leak to shutting down of air for repairs.	
			A calculated dust "budget" for AC-2 is presented in Appendix B.9.	7. Plan for site-specific dust collectors to be used in ESF drilling.

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS (cont)

Equipment	Plan	Modifications or Changes	Results	Recommendations
Bits	Test (all) diamond-set, diamond-impregnated, diamond-geoset, carbide. Wide waterways flared on the O.D. were chosen. Some face discharge bits were ordered.	Varied type of cutting surface, matrix materials, diameters of bits, rpm, and weight on bits. Only one face discharge bit tested so far.	Excellent bit life on impregnated bits used in welded tuff. Expect 120-160' on each bit. Penetration rate averaged 7.7' per shift in welded tuff. See graphs in Appendix B.	Use impregnated bits for all moderate and densely welded tuff. Rotate 60-120 rpms. The nonface discharge bits far exceeded expectations, and future tests may show superior performance over face discharge design in hard rock. Face discharge bits help retain the integrity of cores in soft formations. Order bits with wide waterways, flared, and hardened O.D. Bit diameters -- see Table IV.
			Impregnated bits will dull or self-sharpen at different depths when passing through formations that vary in hardness, abrasiveness, and fracture frequency. The bit was pulled and sharpened when drill rate slowed to ~2.5 min per inch in densely welded tuff. Softer matrix will self-sharpen easier than the harder matrix, but will wear out quicker.	Impregnated bits should self-sharpen, but if they slow too much, then pull and resharpen them, or change to bit with softer matrix.
			Geoset and carbide bits drill ~17% faster in nonwelded tuff than do impregnated bits. See graph in Appendix B.1.	Use carbide, geoset, or PCD bits in nonwelded tuffs.
			Face discharge bit plugged.	Others should be tried.
			Actual bit measurements were up to 10/1000" from specification.	All bits need to be accurately measured before use and remeasured when returned. This information needs to be kept in a log book at bit locker.
			Diamond-set bits not tried yet.	Set bits are not expected to hold up as well as impregnated bits, but they will be tried in the future.

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS (cont)

Equipment	Plan	Modifications or Changes	Results	Recommendations
Reaming Shells	Bit diameter plus 0/1000" and plus 5/1000"	Tried diamond set 5/1000" larger than bit diameter.	Good results; should get three bits per reaming shell.	O.D. should be bit diameter plus 5/1000".
Stabilizers	Full hole 3-wing	3 each made of 1 solid piece of metal with 3 air courses milled as deep as permissible. 1 each - spiral-welded stab.	These worked very well. They somewhat reduce hole cleaning efficiency, and rotational torque increases. But they keep hole straighter and keep down vibrations when properly spaced.	Stabilizers are necessary if accuracy is important. See hole deviation survey data, Appendix B.6.
	Determine optimal spacing.			More study on proper spacing should be done.

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS (cont)

Equipment	Plan	Modifications or Changes	Results	Recommendations
Core Barrel	Longyear HQU3	1. Modified by using a split inner barrel and using a Lexan liner inside it.	1. Split inner barrel worked well except for occasional crushing.	1. Use as modified for anticipated drilling. For very soft formations, the barrel can be remachined to allow more air volume to reach bit.
		2. Two relief holes were drilled in the head above the liner area.	2. This prevented the Lexan liner from crushing due to pressure differential.	2. Use as modified.
		3. Modified pump-in head.	3. Made pumping in better.	3. Use as modified.
		4. Adjusted shoe standoff for best air flow with each bit type.	4. This worked well, but testing of different shoe configurations could reduce core blocking problems.	4. Use as modified. Plan for further testing of shoe designs.
	J. K. Smit RWT core barrel	J. K. Smit XRP core barrel.	Did not perform well (as used). It may perform better if used according to plan.	Try to get sample core according to plan.
		Changed to EW core barrel w/inner barrel.	This did not work well as first used, but it did perform as expected when plan was followed.	If any PI wants this size, follow the plan written for RWT barrel in the Air-Coring Test detailed test plan.

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS (cont)

Equipment	Plan	Modifications or Changes	Results	Recommendations
Lexan/ Polycarbonate Liner	Thin polycarbonate inner liner and plastic caps for sealing each end.	Had early problems with crushing. They were eliminated by modifying the head adapter.	No problems after modifications. Worked great. Ends were sealed ~3-4 minutes after retrieval. Physical property data suggest moisture content is protected (see Table III).	Use these any time good quality core is wanted. Liners protect core from damage usually associated with dumping core and preserve *in situ* condition.
Running-Retrieving Tools	Factory underground. Run/retrieval tools.	1. Modified for running dry. 2. Built special tool for running inner barrel back into dry vertical hole.	1. Worked great. 2. Worked great.	1. Use as modified. 2. Use as built.
Drill Rods	HCQ Longyear 3-1/2" O.D. 5' length	None.	Excellent; good strong rod.	Use for all HQ holes and large O-core. Use for casing while coring RWT or EW size end hole. Clean before initial use. Have shorter rods on site.
	EW 5' length	These were used for coring small holes for diffusion test.	This worked. Better than using HQ for turning small core barrel.	Use as planned and tested with HQ rods as casing and stabilizers built for use inside of HQ rod.

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS (cont)

Equipment	Plan	Modifications or Changes	Results	Recommendations
Swivel	Air-water Large flow	King 2J - aluminum with 1-1/2" passage.	Excellent airflow. Light weight.	Use in future. Large flow passages needed for air drilling.
Hydraulic-Operated Drill Rod Holding Device	Not planned.	Not used.	It would have increased drill rod handling efficiency and reduced health hazards. It eliminates working on a platform.	This item should be used for vertical drilling. It would allow rods to be added and removed between drill head and hole collar. The drill head could then swivel to the side for core retrieval, while the holding device keeps the drill rods held safely.
Data Gauges	PSI-air gauge	Changed location.	Excellent indicator of drilling conditions.	A must, use in future. Gauge should be between compressor air line and manifold.
	cfm-air gauge #1	#1 - air line to drill rods.	Excellent indicator of hole conditions/core blocking.	A must, use in future.
	cfm-air gauge #2	#2 - air line to dust collector.		
	Pulldown	On rig.	Hard to read but valuable.	A must, use in future.
	Pullback	On rig.	Hard to read but valuable.	A must, use in future.
	RPM gauge	We added to rig.	Not accurate.	Get better type or count w/stopwatch.
	Torque	On rig.	Good indicator of hole cleaning.	A great help.
				Psi and cfm gauges should be located where driller can see them while drilling; strip-chart data recorders would be extremely useful in evaluating actual performance.

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS (cont)

Equipment	Plan	Modifications or Changes	Results	Recommendations
Survey Tools	Sperry-Sun	None.	Fair; not as accurate as laser sitings (see Appendix B.6)	Use for future readings where accuracy is not critical and quick inexpensive surveys are needed. Additional information on surveying methods are succinctly described by The Robbins Company (1984).
Video Survey	Video inspection and recording of drill holes USGS/SNL	None.	A. Excellent resolution. B. Clean hole quality apparent. C. Allows optimal packer placement. D. Found localized moisture not seen in core (non-Lexaned).	Use in holes where geologic information is needed. Excellent detail of the hole wall is possible by using downhole video cameras with panning and side-scan capabilities such as that used to examine AC-2 by Odum (1988).
Miscellaneous	Misc. tools	Built workhorse/ pipestand.	Very helpful.	Use stand, have pipe vise on location, and have a good assortment of pipe wrenches.
	HQ funnel adapter for diffusion test	Built crude model at welding shop.	Worked fairly well.	To machine an adapter, use drawings as furnished before test and as requested by PI.

TABLE II. EQUIPMENT RESULTS AND RECOMMENDATIONS (cont)

Equipment	Plan	Modifications or Changes	Results	Recommendations
Multipurpose Drill	Ingersoll-Rand CMM-2 Electric/ Hydrostatic (if funded)	Not funded.	N/A.	This drill would reduce mobilizing and setup time; could core drill, bore, and run down-the-hole hammers. These factors would greatly increase the efficiency of operations in the ESF. Some minor modifications are recommended to allow for hole parallelism and to ease core retrieval.
Available Mining Air	1500-3000 cfm @ 115 psi	Two Quincy 1500-cfm x 125-psi compressors were available. Usually only one was running. Other underground equipment was running on the same air system. Used cfm gauges and controls to vary the cfm for flushing.	cfm of air was adequate most of the time, but air pressure fluctuated. This was adequate for coring moderate and welded tuffs. However, being able to reduce air pressure at the drill as well as cfm would help core recovery in very soft formations.	For electric powered drill: Have approximately 600 cfm available for hole cleaning plus 130 cfm for DCS operations. Total = 730 cfm. For air-powered drill: 600 cfm for hole cleaning; 130 cfm for DCS; 1000 cfm for rig power. Total = 1730 cfm. Electric power is recommended, if possible. An air booster compressor is recommended if down-the-hole hammer drilling is used. An alternative would be electrically powered compressors positioned underground. These, however, add considerably more heat to the underground environment than booster compressors do.
		Water traps located in the mine air lines were drained daily.	Water was not visible at drill site after this practice was begun.	Drain water lines as tested.

TABLE III. GRAIN DENSITY OF ROCK (ASTM D854), BULK DENSITY USING WAX XOATING (ASTM D118), SATURATION, POROSITY, AND GAS-FILLED POROSITY (API RP40) FOR RANDOMLY SELECTED SAMPLES FROM AC-2.*

Core Run No.	Lexan Liner (Yes or No)	Depth Int. (ft)**	Grain Density (g/cm^3)	Bulk Dens. (g/cm^3) Natural	Bulk Dens. (g/cm^3) Dry	% Moisture Natural	% Moisture Dry	H_2O Volume (%)***	Porosity (%)	Sat. (%)	Gas-Filled Porosity (%)
7	N	13.2-16.9	2.62	2.173	2.155	0.8	0.9	1.83	17.9	10.3	16.0
16	N	31.0-35.6	2.60	2.248	2.224	1.1	1.1	2.41	14.3	16.8	11.9
25	N	68.4-70.7	2.66	2.193	2.185	0.4	0.4	0.89	17.8	5.0	16.9
31	N	83.0-83.7	2.62	2.155	2.129	1.2	1.2	2.56	18.8	13.6	16.2
36	Y	88.6-92.4	2.61	2.375	2.272	4.3	4.5	10.30	12.9	79.8	2.6
39	Y	100.9-102.0	2.60	2.311	2.176	5.8	6.2	13.49	16.2	83.3	2.7
40	Y	119.6-120.1	2.60	2.282	2.185	4.2	4.4	9.66	15.9	60.6	6.3
49	N	120.1-125.3	2.60	2.154	2.128	1.2	1.2	2.65	18.2	14.6	15.6
50	N	125.3-130.2	2.60	2.224	2.185	1.7	1.8	3.85	16.1	23.9	12.3
Reference Material			2.65								

*Information provided by Holmes & Narver, Inc., Material Testing Laboratory, Mercury, Nevada.
**Random samples selected from each interval.
***"%" by convention; actually 100 x g/cm^3.

Average % moisture (natural) with Lexan liner = 4.8%.
Average % moisture (natural) without Lexan liner = 1.1%
Average % saturation with Lexan liner = 74.6%.
Average % saturation without Lexan liner = 14.0%.

The Longyear-38 Electric Model Drill worked extremely well, with enough torque and low-speed control to adequately handle the HQ drill rods and the HQ U-3 core barrel. The assorted assemblies as configured for the Prototype Air-Coring Test are illustrated in Fig. 7. This figure also shows the wireline draw works used for the running/retrieving system. The running/retrieving tools were modified for running dry. A special tool was fabricated, which pushes the inner barrel assembly (without being latched onto) into dry holes (see dry hole running tool in Fig. 7.)

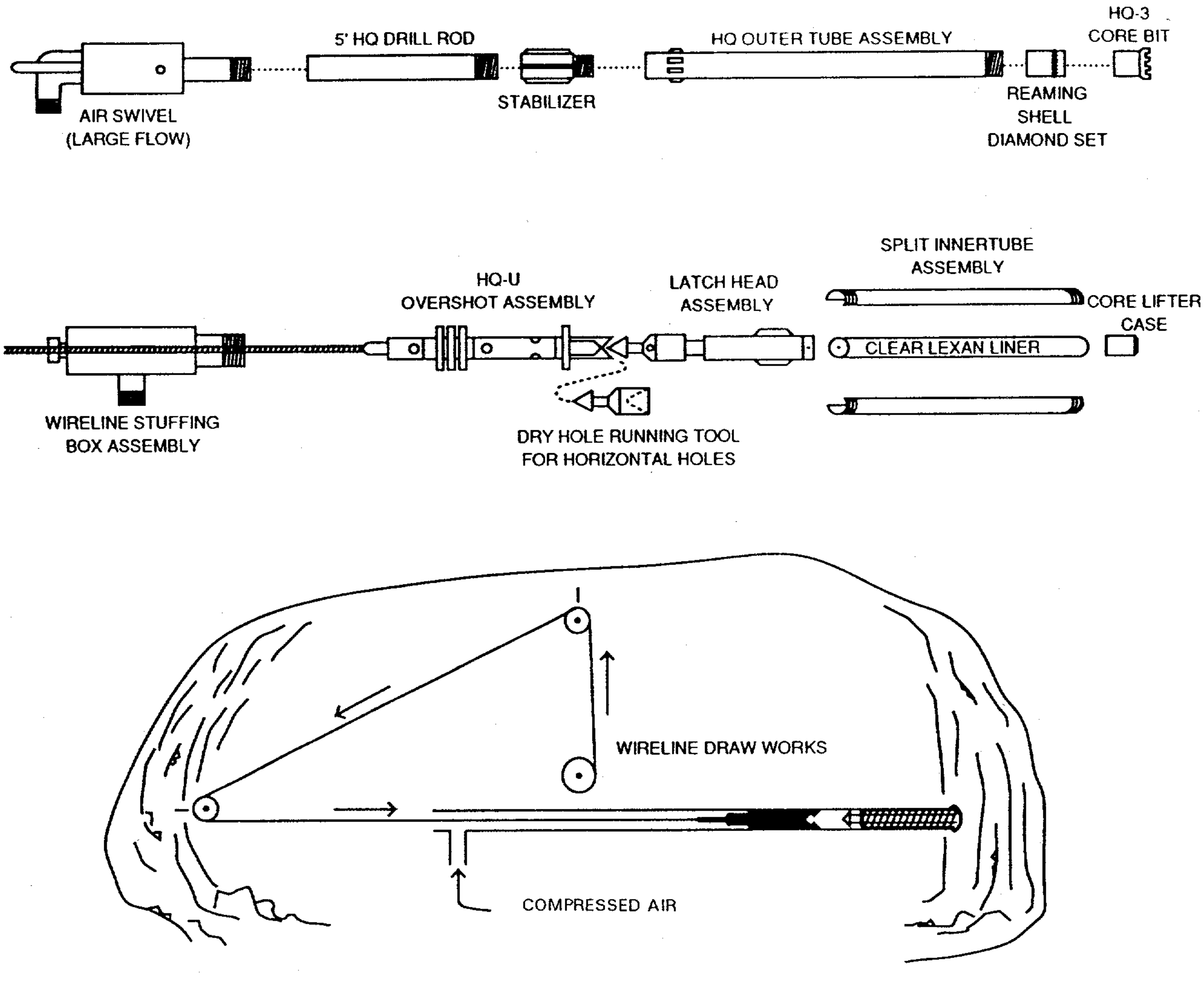


Figure 7. Schematic of assemblies for drill string/core barrel and running/retrieving system.

Only a few kinds of bits were tested due to long bit life and the brevity of the initial two-hole test. The excellent bit life experienced during the Prototype Air-Coring Test is exemplified by the bit shown in Fig. 8. This bit exhibited no unusual ablation after cutting 50 ft of core in hole AC-1 and was used to cut another 38 ft in hole AC-2. After 88 ft of core, the remaining bit life was estimated at 30-35% (see Table IV).

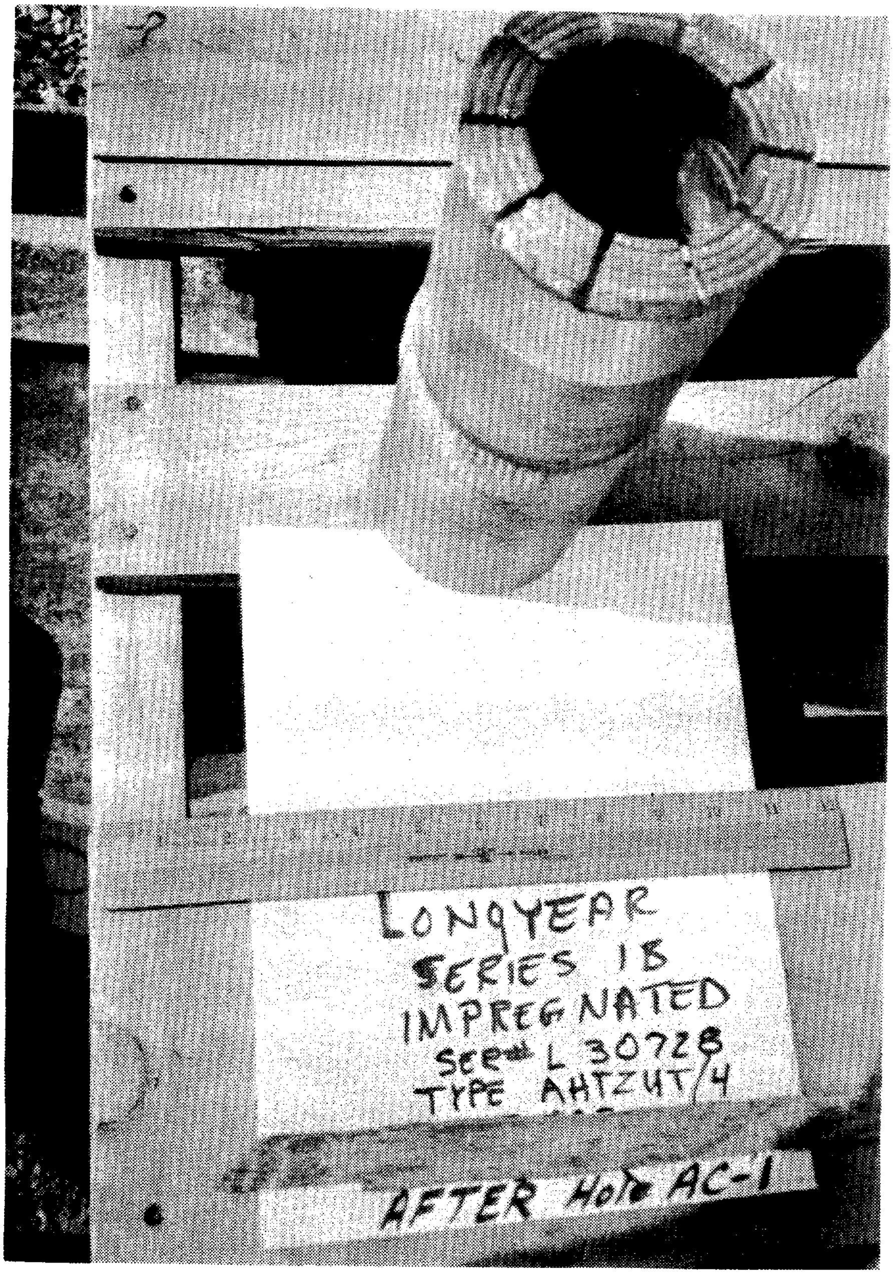


Figure 8. This Longyear impregnated bit showed excellent durability through 88 ft of difficult drilling conditions (50 ft in AC-1 and 38 ft in AC-2).

TABLE IV. BIT USE

Bit Information	AC-1	AC-2	XH-1	XH-2	DH-1	DH-2	DH-3	DI-1[a]	DI-2[a]	Total Feet on Bit	Condition of Bit
L30728 - 3.895" Impregnated Longyear Series 1-B Type AHTZUT/4	50'	 8.2' 29.9'								50.0' 58.2' 88.1'	50% good 40-50% good 30-35% good
L33000 - 4.125" Impregnated Longyear Series 1-B Type AHTZUT/4		88.6'								88.6'	50-60% good
L33001 - 4.125" Impregnated Longyear Series 1-B		21.8'	 115'							21.8' 136.8'	80% good 40% good
8S2333GR - 3.895" Impregnated Face Discharge Christensen		1.5'								1.5'	100% good (plugged)
Tungsten Carbide Longyear				115'				 15'		115' 130'	50% good 50% good
L30726S1 Impregnated Longyear Series 1-B					37'	 25'	 30'			37' 62' 92'	75% good 60-65% good 40-50% good
SYNDAX Sharp-Polycrystalline Diamonds L35004 Longyear									91'[b]	91'[b]	60% good
	50'	150'	115'	115'	37'	25'	30'	15'	91'[b]		

[a]These two holes were part of the Drill Hole Instrumentation Test. The bits used were recommended by the PIs of the Prototype Air-Coring Test.
[b]This hole was incomplete when the bit was inspected after 91' of drilling. Accordingly, only information to that depth is used here and in the graphs in Appendix B. Due to incomplete data, Coring Data Summary Tables for holes DI-1 and DI-2 are not included in Appendix B.

The bit designs were selected based on the anticipated drilling conditions. Figure 9, for example, shows the new Longyear impregnated bit just before spudding hole AC-2. This bit has wider "waterways" for more efficient air flow and a larger flared and hardened outside diameter. These bit characteristics were important to successfully achieving the cored depths of AC-2 in harder more fractured rock. Drilling and bit data from three other tests are included to provide additional information, although every data set is not duplicated for every hole. As stated in the test plan, the PIs for the Air-Coring Test recommended what bits were to be used and how they were to be used for air coring during other prototype tests.

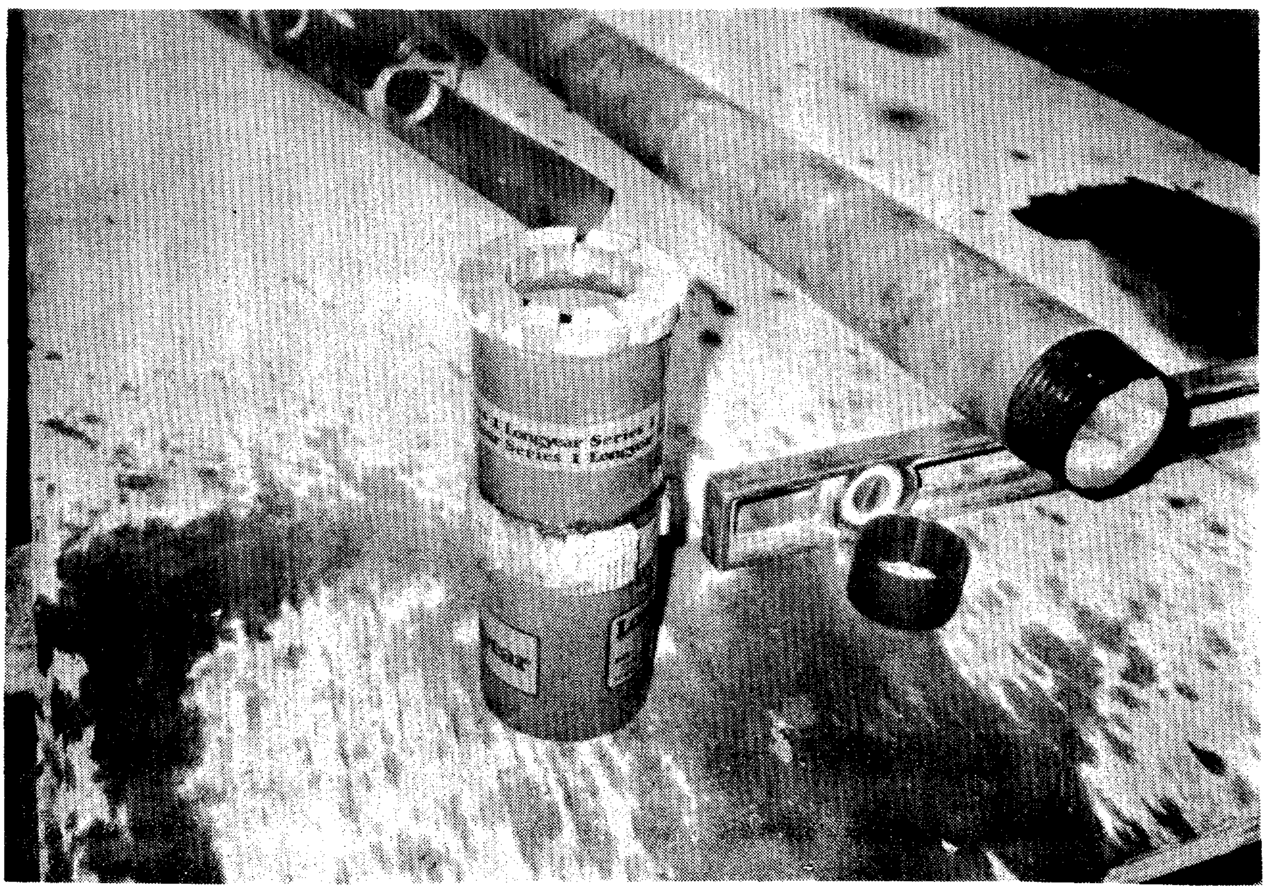


Figure 9. This new Longyear impregnated bit was designed with wider "waterways" and a larger flared and hardened outside diameter to meet the tougher conditions in hole AC-2.

The dust collection system (DCS) worked well with only minor modifications (which were anticipated):

1. An adapter was designed and built to connect the dust collector exhaust to the mine ventilation exhaust system. The adapter was bolted to the DCS, and some sound-suppressing material was added for noise reduction.
2. A pack-off assembly was designed and field-built to seal the rock surface near the collar to the drill rods (see Fig. 10) to prevent drill dust and cuttings from being blown into the mine atmosphere. The factory-built rod pack-off system was used as a beginning framework for the new design. The total dust suppression system (as configured in Fig. 11) worked according to plan when used properly.

B. Procedural Performance and Recommendations

Draft procedures (Appendix B.8) were used as models and modified as necessary. The resulting efficiencies and recommendations regarding these procedures are summarized in Table V.

C. Health and Safety Aspects

1. Dust Collection/Air Sampling. One safety objective for Yucca Mountain drilling activities will be the effective containment of potentially hazardous drill cuttings and dust from the silica-rich tuff (Bish and Vaniman, 1985). The approach to air sampling was provided in the "Detailed Test Plan for Subtask B," WBS 1.2.6.9.4.6.1.B (Skaggs, 1987).

2. Work Environment/Confined Space. Safety aspects to working in a confined space include:

- Handling drill rods, cables, and air hoses requires careful attention and good "housekeeping" standards to keep from getting tangled in moving machinery.
- Air lines, valves, and gauges should be elevated and out of the way to keep workers from tripping on them.
- The number of personnel in the immediate drilling area should be kept to a minimum.
- If a dust leak should occur, confined spaces could present potentially more hazardous situations than larger spaces.

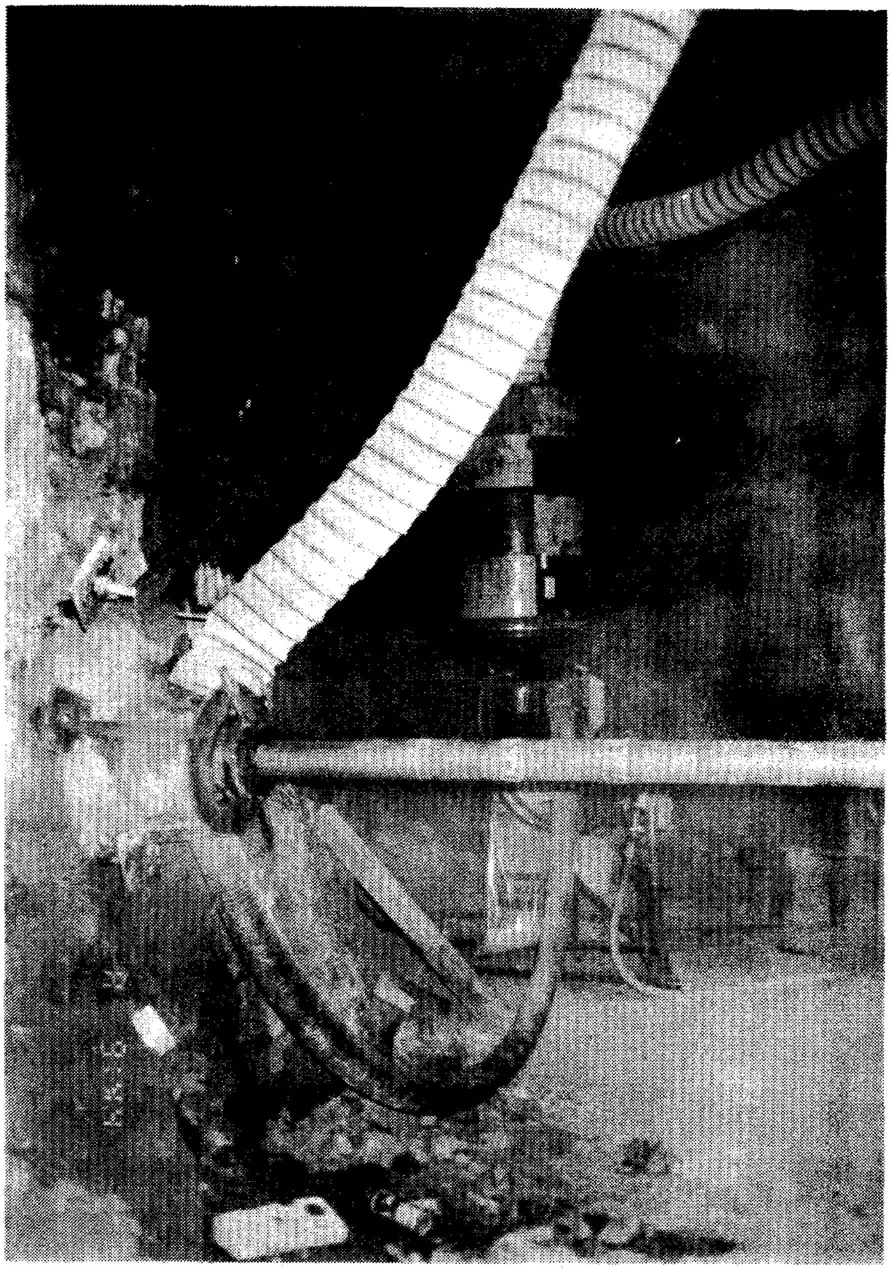


Figure 10. The "spider" pack-off assembly coupled the rock surface near the collar to the drill rods to prevent dust leakage.

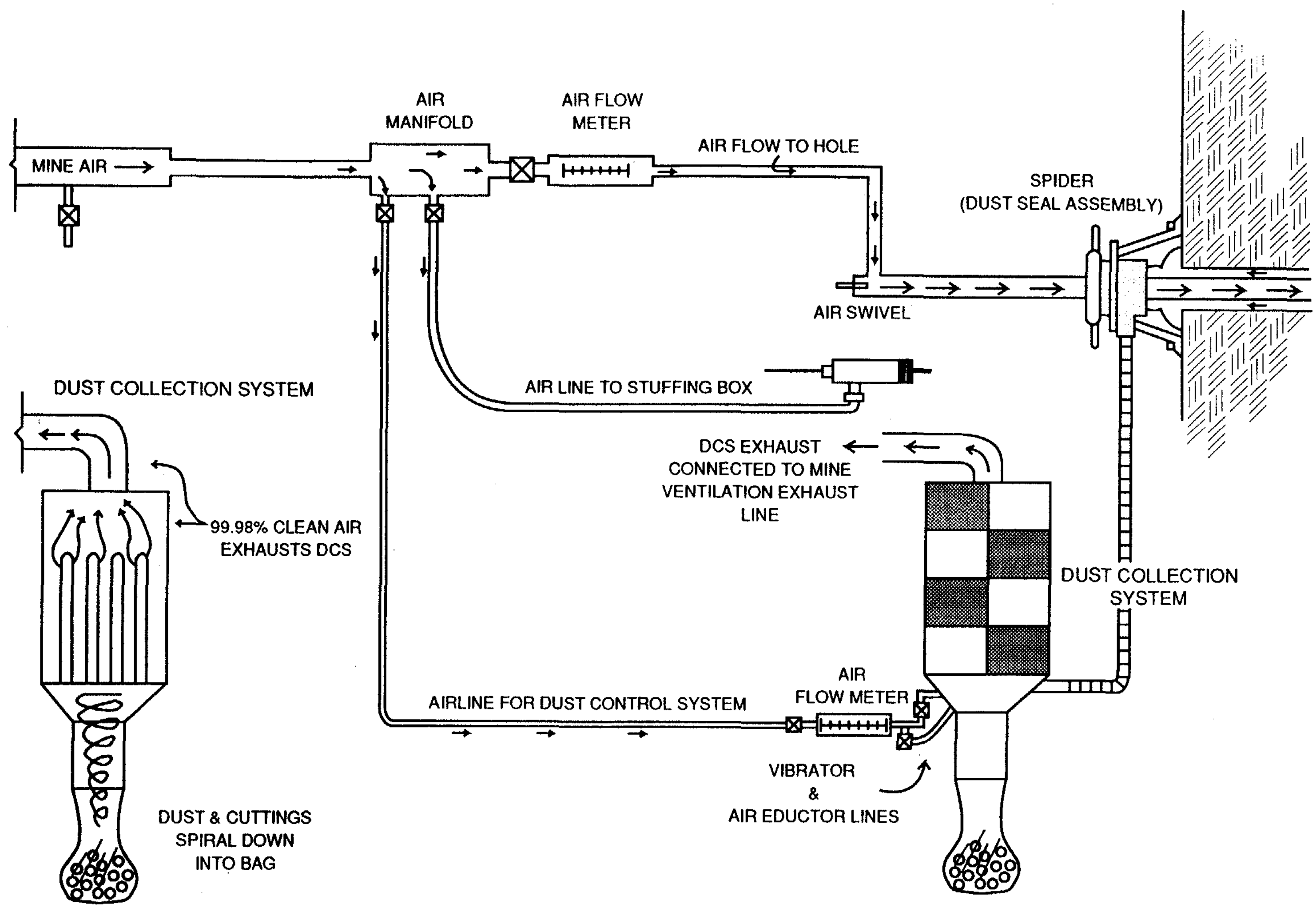


Figure 11. Schematic of air flow through components of dry-air drilling system.

TABLE V. PROCEDURE RESULTS AND RECOMMENDATIONS

Procedures	Plan	Modifications or Changes	Results	Recommendations
1. Core drilling	Written in test plan. See Appendix B.8.	REECo was not accustomed to dry air coring but had no problem adjusting. Mechanical differences are listed elsewhere in this table.	Good.	REECo probably has SOPs that need only minor changes to cover dry drilling.
		Drill rig/platform setup.	Platform not always stable. Drill was not positioned at the optimum distance from spider (on most holes). This made running and retrieving rods and barrel more difficult and time consuming than necessary.	Procedures for positioning drill with respect to safety and ease of operations should be written.
2. ODEX drilling	Not funded.	N/A		
3. Casing removal with hydraulic jacks	Not funded.	N/A		

TABLE V. PROCEDURE RESULTS AND RECOMMENDATIONS (cont)

Procedures	Plan	Modifications or Changes	Results	Recommendations
4. Fishing for stuck or broken tools	See Appendix B.8.	A. Dimensions were recorded for items used on AC-1, AC-2, and XH-1. B. Diffusion test had stuck drill rods and needed tools not listed in plan.	A. Good. B. Several hours were spent before the decision to use a jarring tool to free stuck rods was made.	A. Follow procedures as written. (Formal procedures should be written for Yucca Mountain.) B. Plan for all possible problems in procedures and follow plan for determining best actions.
5. Dust collection	See Appendix B.8.	Cleaning intervals were determined as planned.	Excellent. Mobilizing problems were encountered.	A. Do as planned. B. Train drilling personnel in proper cleaning techniques. C. Moving procedures need to be written.

TABLE V. PROCEDURE RESULTS AND RECOMMENDATIONS (cont)

Procedures	Plan	Modifications or Changes	Results	Recommendations
6. Core handling and other samples	See Appendix B.8.			
	A. Core in Lexan liner.	A. Lexan polycarbonate liners used were the thin type instead of the thicker threaded type.	A. This thinner liner was less expensive to use. It allowed us to cut the unfilled portion of liner off and place only the filled portion in core box.	A. Do as tested. Rewrite procedure for using split inner tube and thin polycarbonate liner.
	B. Bagged cuttings	B. None.	B. Cuttings of great weight and volume are generated by dry coring and drilling. The bags were usually changed before they became too heavy to move easily.	B. Procedures were good here. It is highly recommended that for ESF drilling each drill should have a site-specific dust collection system or else sampling will not be as efficient. The sample could not be identified as to its source. The total bulk becomes unmanageable, and perhaps most importantly, the driller loses an important criterion to evaluate drilling conditions.
7. A. Running and retrieving inner barrel in horizontal hole.	See Appendix B.8.	Some modifications in equipment and procedure were made.	Good.	Rewrite procedures.
B. Vertical running and retrieving of inner barrel in dry hole are needed.	None.	Tools and procedures were field-modified.	Good.	Rewrite procedures.

TABLE V. PROCEDURE RESULTS AND RECOMMENDATIONS (cont)

Procedures	Plan	Modifications or Changes	Results	Recommendations
8. Operation of multipurpose drill	Not funded.			
9. Problem resolution	See Appendix B.8.	None.		Same.
10. Air volume/ air pressure mix	See Appendix B.8.	Air volume was varied to increase drilling dust collection efficiency, but we had little control over psi.	Acceptable for test as drilled.	A. Procedures should be written that outline how the best air flows can be achieved and how pressures affect these changes. B. Contingency procedures should be written for downhole hammer drilling with or without ODEX or some other dual wall method of hole drilling.

TABLE V. PROCEDURE RESULTS AND RECOMMENDATIONS (cont)

Procedures	Plan	Modifications or Changes	Results	Recommendations
11. Drilling log book(s) standardization and maintenance	See Appendix B.8.	None.	Several different sets of information were recorded. Examples: F&S - Underground Core Drilling Report; F&S - Daily Mining Inspection Report; REECo - Core Drilling Shift Report; PI notes on drilling parameters; PI notes on equipment used.	A more comprehensive and integrated log that is standardized and used by each organization would help eliminate inconsistent and redundant entries for ESF purposes.
			Not all information matched between participants because F&S shows daily production differently than does REECo.	
			Some gauges were difficult to read and were read at differing times and depth intervals.	Possible use of strip chart recorder.

TABLE V. PROCEDURE RESULTS AND RECOMMENDATIONS (cont)

Procedures	Plan	Modifications or Changes	Results	Recommendations
12. Moving equipment in confined spaces	Use G-Tunnel operational procedures.	None.	Equipment was damaged by moving with mine mucker. Safety may have been compromised while disassembling and moving the dust collector.	Better procedures need to be written for rigging up/rigging down the drill and dust collector and moving each from one site to another. Additional evaluation is needed for activities in a shaft environment (as opposed to drifts).
13. Hole deviation survey	Left up to PI and surveyor using single shot survey tools.	A. F&S ran a single shot. B. H&N ran a laser line of sight.	A. Readings were not accurate; near collar siting methods need to be changed. B. Fairly accurate, needs more work.	A. Full procedures detailing reading, accuracy, and hole emplacement need to be written for both A and B. Surveying methods are succinctly described by The Robbins Company (1984). Also, see Explanatory Note at the front of Appendix B.6.
14. Hole geophysical survey	PI preference.			PI and REECo should have procedures written before testing. Carroll and Cunningham (1980) have worked on horizontal geophysical investigations in tuff and provide a reasonable basis for further development of procedures.

- Moving of machinery in confined spaces requires extreme caution. Personnel have a greater chance of being trapped between machinery and walls.
- Noise levels are potentially more focused and damaging in confined space.

III. UNRESOLVED ISSUES

A. Multipurpose Drill (MPD) Performance Is Unknown

A multipurpose drill should provide increased operating efficiency in several aspects.

1. Mobility. A self-mobilizing drill could move and set up much faster and safer than a drill that is loaded onto and moved about by a mine mucking machine. This could provide enormous savings of construction time while providing increased safety.

2. Function. The MPD would be "multi-tasking" and able to function in most cases as a heavy-duty coring machine, while being much more capable as a heavy-duty rotary drill. This rotary drilling function allows the use of down-the-hole (DTH) air percussion hammers, dual wall drilling, ODEX drilling, tricone drilling, hole opening, and large diameter overcoring. With the addition of a hole parallelism attachment, multiple parallel holes can be drilled without having to move and reset the drill. The MPD has been recommended (Ray and Newsom, 1987b) as an essential part of prototype and ESF testing but to date has not been funded (also refer to Table II "Equipment Results and Recommendations").

The Prototype Air-Coring Test coreholes were done with a traditional core drill but the MPD is still recommended to reduce the setup time of future tests and for use with DTH air percussion drilling of several holes.

MPD Recommendations:

- Purchase MPD Drill.
- Make modifications to drill as necessary:
  - Add hole parallelism attachment.
  - "Off hole" head swing out or "through the head" modification for wireline core running.
  - Add dual speed hydraulic top head motor feature.
- Use MPD on some planned prototype tests, both wet and dry.
- Test dual wall and ODEX methods with core bits, cone bits, and hollow DTH.
- Thoroughly evaluate the MPD/MPD DTH system; recommend modifications (if necessary) and integrate into ESF planning.

B. Depth Limitations

Depth limitations of horizontal air-coring are unknown; 50 ft and 150 ft have been successfully cored but holes much deeper may be required in the ESF.

Recommendations:

- Extend the 150 ft Prototype Air-Coring Test hole (or some other hole) as far as practical.

C. Efficiency of Drilling Horizontal DTH Air-Percussed Holes Unknown

DTH hammers drill very fast and penetrate 20 to 40 times faster than coring. Many holes are planned where core is not requested by the PI or where core is cut and then the hole is enlarged. These holes can be DTH drilled or drilled with a DTH hole opener after coring. DTH hammers can operate on low pressure air, but this would produce less than 50% efficiency which is not always feasible. DTH hammers can operate on some core drills, but the drill would be damaged so this is not recommended. Also, most core drills do not have sufficient torque at low rpm's for continued use.

Recommendations:

- Test DTH equipment underground with low pressure air in horizontal mode.
- Test DTH equipment underground with mine air booster in horizontal mode.
- Evaluate a hollow DTH tool for underground use.

D. Efficiency of Casing Advancing or Dual Wall System Unknown

G-Tunnel is less fractured than Yucca Mountain, and it is probable that casing of some holes may be required to reach certain depths or to stabilize them for stemming or instrumentation.

Recommendations:

- Test dual wall reverse drilling with standard DTH, hollow DTH, roller cone kerf bit, mill tooth kerf bit, and wireline retrievable coring assembly for dual wall drilling/coring.
- Test ODEX equipment underground for horizontal holes.

IV. TEST CONCLUSIONS

The Prototype Air-Coring Test in G-Tunnel presented the opportunity to generate real-time data to address many of the air-coring uncertainties in planning for drilling in the ESF at Yucca Mountain. The utilization of air-coring data from three other prototype tests provided information (though limited) on the influence of different rock types and bit designs on penetration rates, core quality, and hole deviation. Some of the conclusions and observations that help to resolve air-coring uncertainties are:

A. General

- Underground coring using dry air and Lexan liners can be performed while providing health protection by utilization of appropriate work practices, engineering, and administrative controls.

B. Performance

- Horizontal air-coring in fractured welded tuff (to at least 150 ft) can be accomplished by proper selection, integration, and minor modification of standard drilling equipment, using appropriate procedures and engineering controls.
- Penetration rates (depending on fractures, bit condition, and formation encountered) of approximately 6 to 8 ft per 6-h shift in densely welded tuff and almost 20 ft per shift on deeper holes in nonwelded tuff can be achieved with appropriate drilling equipment/practices.
- Excellent core recovery (≥95%) can be obtained in densely welded tuff and in nonwelded tuff.
- Expected bit life should be 120 to 160 ft/bit on future drilling in similar environments.
- Carbide bits can drill up to 20% faster than impregnated bits in nonwelded tuff and almost 2.5 times faster than impregnated bits in densely welded tuff.

C. Air

- The achievable length of core runs is greatly influenced by fractures.
- Air volume to the hole increases with psi, fracture zones, and fracture characteristics and is often reduced by core blockage, poor hole cleaning, and distance from fractures.
- The volume of flushed air (and cuttings) that enter the dust collector must be regulated by the driller for best operation.
- Approximately 730 cfm of air is needed at location to drill HQ holes while running a DCS and using an electric powered drill.
- Rpms should be decreased with depth to facilitate smooth drilling.
- Approximately 60 rpms should be used with carbide bits in nonwelded tuff.
- The incremental depth test data (see Appendix B.4) show that "friction-loss" (i.e., loss of air volume due to resistance to air flow through conduit) increases with hole depth and reduces the flushing air volume.
- Lexan core liners can be successfully used with only minor field modification.

- Approximately one reaming shell is needed for each three drill bits used.
- Low-pressure (120-psi) mine air is adequate for normal dry air-coring.

D. Areas Where Improvement Is Needed

1. Rig Logistics.

- Mobility - utilize self-mobilizing core drills and MPD for safer and faster mobility.
- Placement - determine criteria for best rig placement to optimize operational efficiency.
- Setup - develop definitive guidelines for faster, safer, and more functional setups (i.e., some setups are virtually unworkable relative to the planned drilling operations).
- Safety - evaluate safety aspects of the above items and develop appropriate guidelines and procedures.

2. Equipment Refinement and Testing for Better Results.

- Test other drills which are planned for ESF work to evaluate performance vs. lithology.
- Conduct a prototype test of air-coring in "shaft-size" space utilizing anticipated equipment prior to ES construction to address problems of drilling in a confined space.
- Develop a hydraulic rod holding device to increase rod handling efficiency.
- Develop mobilization capabilities for safer and faster handling of equipment.
- Develop modular drill setup capabilities for safer and more efficient setup.
- Utilize adequate torque and weight control gauges to help the driller monitor in-hole conditions while drilling.
- Improve inner tube shoe of core barrel assembly (for less core blockage), core catcher spring, and running/retrieving tools for better core retrieval efficiency.
- Core bits need additional evaluation of their matrix properties, performance of diamond set bits vs. impregnated bits, physical design, carbide shape-designs, and size of air and water sources to allow selection of the best bit design for the drilling environment.
- In-hole stabilizers need design refinement of their physical dimensions and best placement in the drill string to improve hole quality and accuracy of direction.
- Improve dust collection collar packoff design to improve serviceability and drilling efficiency.

3. Method Improvements.

- Hole survey measurement accuracy could be improved by improving the data collection methods and the calculating methods.

- Hole logs and notes should be more uniform for better integration and for more complete and accurate information.
- The methods for overcoring should be refined in the near future. This will enhance the probability of success, reduce bit costs, save time, and result in better core quality.
- Procedures in general need improvement.

V. QUALITY ASSURANCE

The YMP notebook containing data presented in this report and the quality assurance level are listed in Appendix C.

ACKNOWLEDGMENTS

The Prototype Air-Coring Test was conducted under the auspices of the Department of Energy, Yucca Mountain Project Office, Las Vegas, Nevada. The authors express their thanks to the following people and their staffs who contributed greatly to the success of this test: Mr. John Talbutt, Sandia National Laboratories (G-Tunnel) NTS; Mr. Lavell Atkinson (G-Tunnel) and Mr. Gene Frye (Area 12), both of Reynolds Electrical & Engineering Co., Inc., NTS, and Bill Garms (Fenix & Scisson); and to Dr. Steve Bolivar (Los Alamos National Laboratory) for performing preliminary sieve analysis on dust samples.

APPENDIX A

HOLE HISTORY/ACTIVITY SUMMARY

1. AC-1

This page intentionally left blank.

HOLE HISTORY/ACTIVITY SUMMARY
1. AC-1

3/23/88

- Completed rigging up Longyear-38, air volume gauge, new air-type swivel, and dust control "spider."
- Started DCS for preliminary evaluation.
- Cored Run #1 with new Longyear 3.895 in.-O.D. impregnated series 1B bit (HQ3WL #L30728) and 3.900 in. set reaming shell.
- Total footage for day = 5.5 ft footage to date 5.5 ft.

3/24/88

- No coring was done this day; entire shift was used:
  - to pull and inspect bit,
  - to disassemble DCS to troubleshoot, and
  - to repair problem (blockage) and reassemble DCS. Added DCT flowmeter.
- Spent rest of shift fabricating rod-wiper pack-off.

3/25/88

- Mounted new rod-wiper pack-off.
- Cored Runs #2 - #3.
- Total footage for day = 8.7 ft; footage to date 14.2 ft.

3/26/88 - 3/27/88

- Shut down for weekend.

3/28/88

- Started coring at ~10 a.m.
- Cored Runs #4 - #6; had core blockage problems and slow drilling.
- Total footage for day = 4.9 ft; footage to date 19.1 ft.

3/29/88

- Requested miners to drain mine air-system water traps.
- Pulled rods and inspected bit; bit condition good (slow drilling was due to core blockage).
- Started coring at ~10 a.m.
- DCS filters not cleaning properly; manual pounding of DCS helped.
- Cored Runs #7 - #8.
- Total footage for day = 5.9 ft; footage to date 25.0 ft.

3/30/88

- Started coring at ~9:15 a.m.
- Added stabilizers at ~11 a.m. between second and third drill rod and above barrel.
- Attempted rough coring for ~30 min; pulled rods to remove stabilizer that was too large on O.D.
- Cored Runs #9 - #10.
- Total footage for day = 1.6 ft; footage to date 26.6 ft.

3/31/88

- Ran incremental depth test (see Appendix B.4).
- Started coring ~9:50 a.m.; core blocked.
- Pulled tools and added proper stabilizer 10 ft above first stabilizer (20.8 ft from bit).
- Fast drilling and smooth running resulted.
- Cored Runs #11 - #13.
- Total footage for day = 4.8 ft; footage to date 31.4 ft.

4/1/88

- Started coring ~9 a.m.; rock seems softer; occasional vibrations.
- Connected large electric vibrator to shake clogged dust from filters; internal DCS vibrators not functioning properly; will be remedied at end of AC-1.
- DCS and drilling operations running very smoothly and with fast penetration.
- Cored Runs #14 - #17.
- Total footage for day = 18.6 ft; footage to date 50.0 ft.
- Total for hole AC-1 = 96.8% recovery.

APPENDIX A (cont)

HOLE HISTORY/ACTIVITY SUMMARY

2. AC-2

This page intentionally left blank.

HOLE HISTORY/ACTIVITY SUMMARY

2. AC-2

<u>4/4/88-4/6/88</u>

- Rigged up for AC-2 in Laser Drift.

<u>4/11/88</u>

- In a.m. rigged core barrel; installed "spider" boot and sulfaset at collar.
- Started coring ~2:15 p.m. with new Longyear 4.125 in. O.D. impregnated Series 1B bit (HQ3WL #L33000) and 4.130 in. set reaming shell.
- Boot seal leaking.
- Cored Run #1 (1.9 ft); pulled core, repaired defective boot seal.
- Total footage for day = 1.9 ft; footage to date 1.9 ft.

<u>4/12/88</u>

- Started coring at ~9 a.m.
- Occasional mine-air fluctuations; as low as 45 psi.
- Changed core catcher spring and adjusted core shoe.
- Cored Runs #2 - #6 (started Run #7).
- Total footage for day = 11.3 ft; footage to date 13.2 ft.

<u>4/13/88</u>

- Started ~8:45 a.m.; completed Run #7; Run #8 blocked at 0.5 ft (horizontal fractures jammed in shoe).
- Spider, pack-offs, and DCS working exceptionally well.
- Wired ventilation duct to top of DCS to reduce noise.
- Air plugged off on Run #11; pulled core; bit still plugged off.
- Cored Runs #7 - #11.
- Total footage for day = 11.2 ft; footage to date 24.4 ft.

4/14/88

- Pulled core barrel; small amount of wet clay in evidence on bit.
- Found shoe stand-off misadjustment causing air blockage.
- Added one stabilizer above core barrel.
- Repaired sulfaset seal between wall and spider.
- Highly fractured formation caused intermittent, severe vibrations.
- Rig shifted from alignment; used "come-along-jack" to straighten and maintain alignment.
- Added second stabilizer 15 ft above first stabilizer.
- Cored Runs #12 - #14.
- Total footage for day = 6.0 ft; footage to date 30.4 ft.

4/15/88

- Started ~9 a.m.
- Run #15, core blocked at 0.6 ft cut.
- Run #16, leakage from worn spider rubber wipers; replaced.
- Run #17, no vibrations, highly fractured core, good recovery.
- Cored Runs #15 - #17.
- Total footage for day = 9.2 ft; footage to date 39.6 ft.

4/16/88-4/17-88

- Shut down for weekend.

4/18/88

- Started ~9 a.m.
- Smooth operations; good core recovery.
- Small amount of moisture in mine air line to DCS noted; suggested miners drain local air line traps.
- Occasional howling and vibrations but fast coring.
- Cored Runs #18 - #20.
- Total footage for day = 14.6 ft; footage to date 54.2 ft.

4/19/88

- Changed rubber wipers in spider.
- Started coring ~9:20 a.m.
- Vibrations during Run #22 caused swivel to unscrew and fall to ground; replaced swivel and tightened.
- Run #23 mild to heavy vibrations; core blocked at 2.5 ft.
- Cored Runs #21 - #23.
- Total footage for day = 11.9 ft; footage to date 66.1 ft.

4/20/88

- Started coring ~9 a.m.
- Noted probable evidence of air loss to fractures; circulation air volume has increased; light return of cuttings noted for short duration.
- After deeper penetration (~3-4 in.) there was a heavy return of cuttings.
- Pulled core Run #24 (2.3 ft long); horizontal fracture extended nearly entire length of core and major vertical fracture dissected core at approximate interval of loss of air volume.
- Runs #25 and #26 had vibrations causing stop and restart at lower RPM.
- Cored Runs #24 - #26 (started Run #27).
- Total footage for day = 9.2 ft; footage to date 75.3 ft.

4/21/88

- Started ~9 a.m.; resumed coring Run #27.
- Run #28 (1.7 ft cut) was rubble; largest piece was 2.5 in.
- Run #29 was rubble.
- Third stabilizer was added 30 ft above second stabilizer.
- Run #30 core blocked at 0.8 ft.
- Run #31 core blocked at 0.7 ft.
- Cored Runs #27 - #31 (started Run #32).
- Total footage for day = 8.4 ft; footage to date 83.7 ft.

4/22/88

- Pulled rods and bit; reran same bit but left out third (outermost) stabilizer.
- Started coring ~1 p.m.
- Intermittent vibrations caused by formation.
- Cored Run #32.
- Total footage for day = 1.7 ft; footage to date 85.4 ft.

4/23/88 - 4/24/88

- Shut down for weekend.

4/25/88

- Started ~9 a.m.; Run #33 blocked at 0.9 ft.
- Started Lexan liner usage on Run #34.
- Possible large fracture; air increase to 300-400 cfm.
- Run #34 was good core run but core apparently blocked at 2.1 ft. Core was not blocked; Lexan liner had collapsed.
- Cored Runs #33 - #34 (started Run #35).
- Total footage for day = 3.0 ft; footage to date 88.4 ft.

4/26/88

- Changed bit to new Longyear 4.125 in. O.D. impregnated Series 1B (HQ3WL #L33001) bit and added third stabilizer.
- Run #36 cored very fast; Lexan liner was crushed ~20 in. from top; pressure-differential relief holes had been placed to eliminate this problem but were obstructed.
- Runs #37 and #38 excellent results; smooth and fast operations.
- Cored Runs #35 - #38.
- Total footage for day = 12.5 ft; footage to date 100.9 ft.

4/27/88

- Started ~9 a.m.; core blocked at 1.1 ft; liner was okay.
- Added newly designed and fabricated DCS exhaust adapter to mine ventilation system; worked great and reduced noise emissions.
- Cored Runs #39 - #41.
- Total footage for day = 7.4 ft; footage to date 108.3 ft.

4/28/88

- Started ~9 a.m.; Run #42; bit seems dull; ended core run and pulled rods and bit out of hole.
- Cored Run #42.
- Total footage for day = 2.1 ft; footage to date 110.4 ft.

4/29/88

- Reran bit from AC-1 (3.895 in. O.D.) and 3.900 in. reaming shell; added one stabilizer at 8.8 ft, one stabilizer at 49.8 ft, and one stabilizer at 90.8 ft.
- Lexan liner crushed at 3.4 ft on Run #43.
- Bit seemed dull on Run #45; only 0.8 ft was cut but core was not blocked.
- Run #46 had bad vibrations; stopped to pull bit; ran new Christensen impregnated green bit, HQ3WL #8S2333GR (marked 3.895 in., but actual O.D. was 3.885 in.); reran used Longyear reaming shell (3.887 in. actual O.D.).
- Finished Run #46; core blocked after 15 in. on new bit.
- Cored Runs #43 - #46.
- Total footage for day = 8.7 ft; footage to date 119.1 ft.

4/30/88-5/1/88

- Shut down for weekend.

5/2/88

- Started ~9 a.m.; Run #47 cut only 0.5 ft.
- Run #48 cut only 0.5 ft; pulled Christensen bit; reran sharpened (this was first time we attempted to sharpen bit out of hole) bit from AC-1 (#L30728); note: all face discharge holes were plugged.
- Run #49 cored 5.2 ft in 66 min; third stabilizer was left out of string; vibrations increased with length of cut; no Lexan liner used this run.
- Cored Runs #47 - #49.
- Total footage for day = 6.2 ft; footage to date 125.3 ft.

5/3/88

- Started ~8:35 a.m.; Run #50 good smooth fast run (4.9 ft cut in 59 min).
- Run #51 running very smooth (5.2 ft cut in 60 min).
- Run #52, Lexan liner was deformed due to abnormal pressure on core block; decision was made not to force core blocks while using Lexan.
- Run #53 cored 2.3 ft in 39 min.
- Cored Runs #50 - #53.
- Total footage for day = 14.9 ft; footage to date 140.2 ft.

5/4/88

- Started coring ~8:40 a.m.
- Run #54 excessive vibration; core was blocked; rubble zone.
- Run #55, fractures may be taking air; highly variable coring rates; liner was torn due to core block.
- Run #56 intermittent vibrations and variable coring rates; core blocked off at 3.3 ft.
- Run #57 quiet and smooth coring for first 17 in.; occasional vibrations rest of run; reached T.D. running smooth.
- Cored Runs #54 - #57.
- Total footage for day = 9.8 ft; footage to date 150.0 ft.
- Total for hole AC-2 = 97.4% recovery.

APPENDIX B

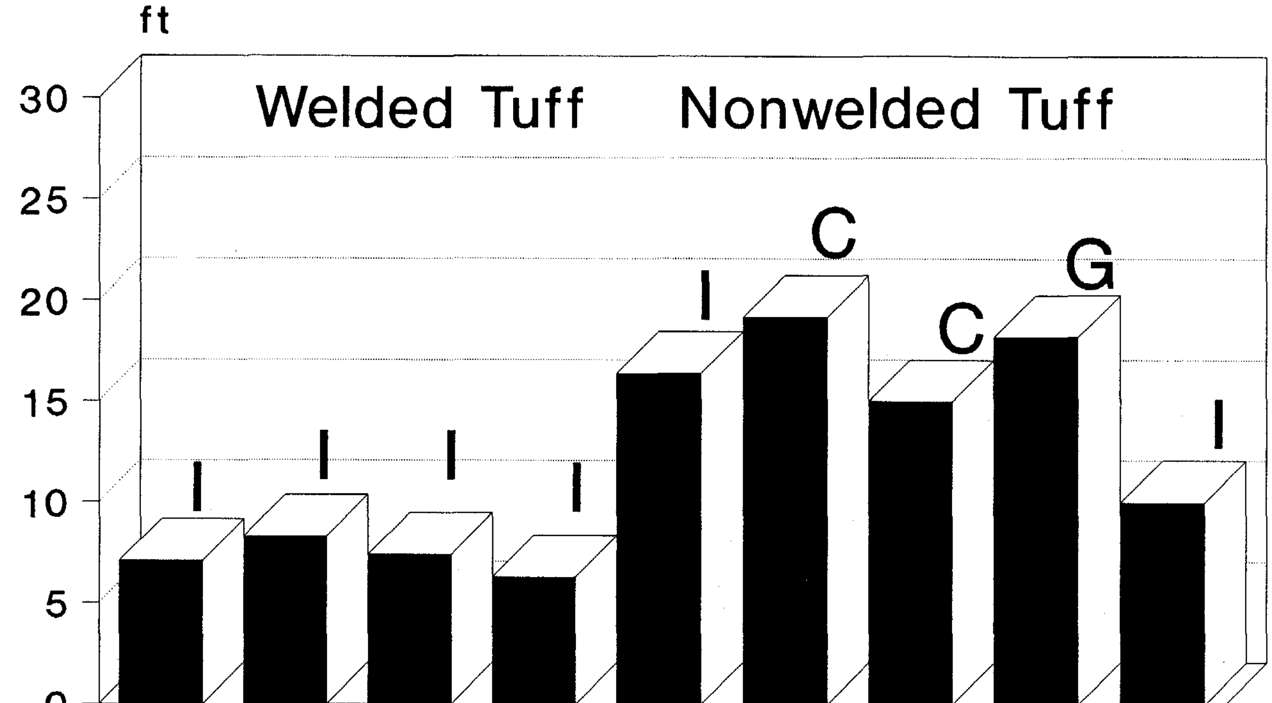
SUPPORTING DATA

1. Coring Data Summary Graphs and Tables

This page intentionally left blank.

AVERAGE SHIFT FOOTAGE

Lithology and Bit Type

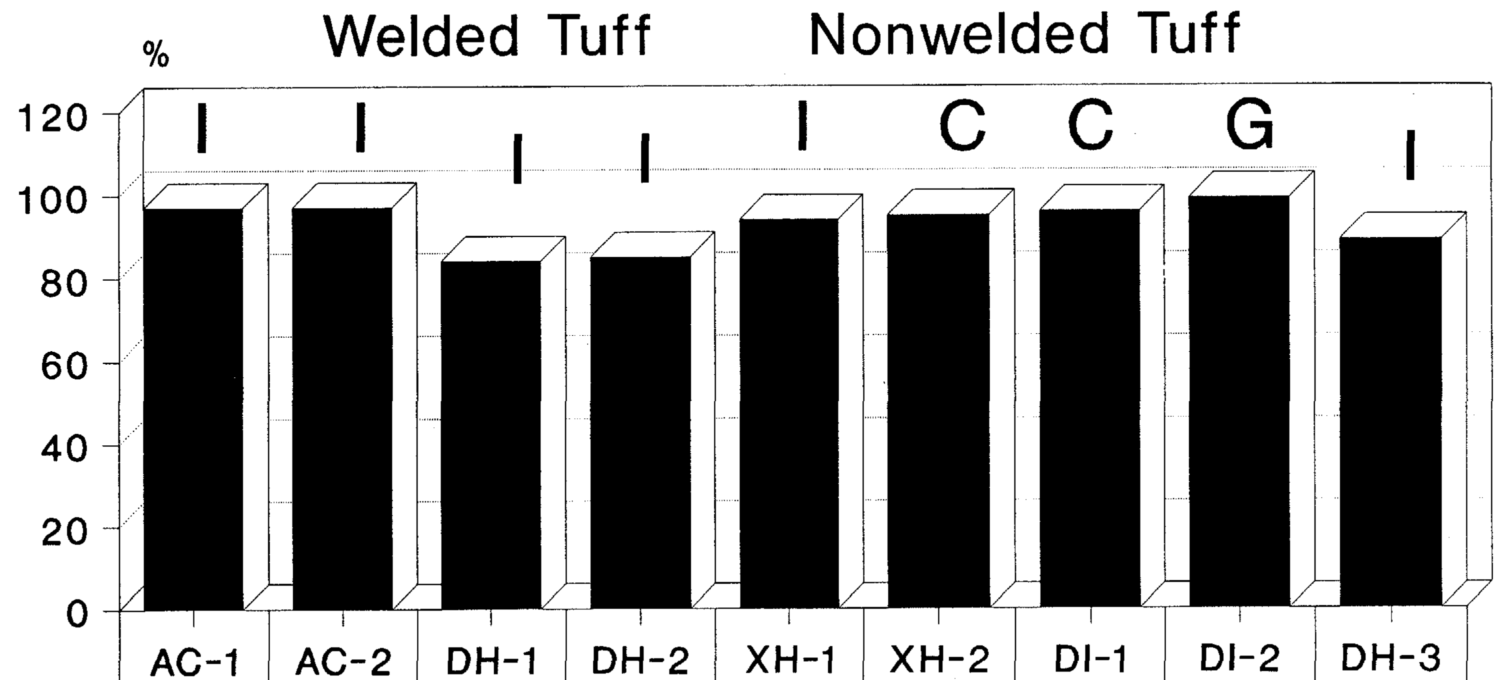


	AC-1	AC-2	DH-1	DH-2	XH-1	XH-2	DI-1	DI-2	DH-3
Footage	7.1	8.3	7.4	6.3	16.4	19.2	15	18.2	10

THESE DRILLING RATES REFLECT SHIFT PRODUCTION EXCLUDING RIG SETUP AND TEARDOWN

I=Impregnated Bit
C=Carbide Bit
G=Geoset Bit

PERCENTAGE CORE RECOVERY
Lithology and Bit Type



	AC-1	AC-2	DH-1	DH-2	XH-1	XH-2	DI-1	DI-2	DH-3
%	97	97	84	85	94	95	96	99	89

■ %

I=Impregnated Bit
C=Carbide Bit
G=Geoset Bit

THE PERCENTAGES LISTED ARE AVERAGE PER HOLE.

CORING DATA SUMMARY TABLES

TEST NAME: AIR CORING
HOLE NAME: AC-1

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage[a]	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
1	0.0	5.5	5.5	4.2	76	3/23/88	5.5	5.5	4.2	76	76
2	5.5	10.3	4.8	4.8	100	3/25/88	8.7	14.2	8.2	94	87
3	10.3	14.2	3.9	3.4	87						
4	14.2	17.1	2.9	2.9	100	3/28/88	4.9	19.1	4.9	100	91
5	17.1	18.5	1.4	1.4	100						
6	18.5	19.1	0.6	0.6	100						
7	19.1	23.1	4.0	4.0	100	3/29/88	5.9	25.0	5.9	100	93
8	23.1	25.0	1.9	1.9	100						
9	25.0	26.1	1.1	0.9	82	3/30/88	1.6	26.6	1.4	88	92
10	26.1	26.6	0.5	0.5	100						
11	26.6	26.8	0.2	0.4	200	3/31/88	4.8	31.4	5.0	104	94
12	26.8	27.4	0.6	0.6	100						
13	27.4	31.4	4.0	4.0	100						
14	31.4	36.5	5.1	5.1	100	4/1/88	18.6	50.0	18.8	101	97
15	36.5	42.3	5.8	4.4	76						
16	42.3	46.4	4.1	5.3	129						
17	46.4	50.0	3.6	4.0	111						
Total			50.0	48.4	96.8			50.0	48.4		97

[a]Average per shift = 7.1 ft.

CORING DATA SUMMARY TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
1	0.0	1.9	1.9	1.9	100	4/11/88	1.9	1.9	1.9	100	100
2	1.9	3.9	2.0	1.5	75						
3	3.9	5.4	1.5	2.0	133						
4	5.4	8.1	2.7	2.0	74	4/12/88	11.3	13.2	10.8	96	96
5	8.1	9.9	1.8	1.7	94						
6	9.9	13.2	3.3	3.6	109						
7	13.2	16.9	3.7	4.0	108						
8	16.9	17.4	0.5	0.6	120						
9	17.4	19.2	1.8	1.8	100	4/13/88	11.2	24.4	11.8	105	100
10	19.2	23.0	3.8	4.0	105						
11	23.0	24.4	1.4	1.4	100						
12	24.4	26.4	2.0	1.7	85						
13	26.4	27.2	0.8	0.8	100	4/14/88	6.0	30.4	5.7	95	99
14	27.2	30.4	3.2	3.2	100						
15	30.4	31.0	0.6	0.7	117						
16	31.0	35.6	4.6	4.6	100	4/15/88	9.2	39.6	9.9	108	101
17	35.6	39.6	4.0	4.6	115						
18	39.6	44.2	4.6	4.5	98						
19	44.2	49.2	5.0	5.0	100	4/18/88	14.6	54.2	14.5	99	101
20	49.2	54.2	5.0	5.0	100						
21	54.2	59.2	5.0	5.0	100						
22	59.2	63.6	4.4	4.4	100	4/19/88	11.9	66.1	11.9	100	101
23	63.6	66.1	2.5	2.5	100						
24	66.1	68.4	2.3	2.4	104						
25	68.4	70.7	2.3	2.3	100	4/20/88	9.2	75.3	9.0	98	101
26	70.7	75.3	4.6	4.3	93						

CORING DATA SUMMARY TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2 (cont)

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
27	75.3	78.9	3.6	3.1	86						
28	78.9	80.6	1.7	1.2	71						
29	80.6	82.2	1.6	1.4	88	4/21/88	8.4	83.7	7.2	86	99
30	82.2	83.0	0.8	0.8	100						
31	83.0	83.7	0.7	0.7	100						
32	83.7	85.4	1.7	1.5	88	4/22/88	1.7	85.4	1.5	88	99
33	85.4	86.3	0.9	1.2	133	4/25/88	3.0	88.4	3.1	103	99
34	86.3	88.4	2.1	1.9	90						
35	88.4	88.6	0.2	0.2	100						
36	88.6	92.4	3.8	3.8	100	4/26/88	12.5	100.9	12.5	100	101
37	92.4	97.4	5.0	5.0	100						
38	97.4	100.9	3.5	3.5	100						
39	100.9	102.0	1.1	1.2	109						
40	102.0	106.0	4.0	4.0	100	4/27/88	7.4	108.3	7.5	101	99
41	106.0	108.3	2.3	2.3	100						
42	108.3	110.4	2.1	2.1	100	4/28/88	2.1	110.4	2.1	100	99
43	110.4	113.8	3.4	3.4	100						
44	113.8	117.2	3.4	3.4	100	4/29/88	8.7	119.1	8.7	100	99
45	117.2	118.0	0.8	0.8	100						
46	118.0	119.1	1.1	1.1	100						
47	119.1	119.6	0.5	0.4	80						
48	119.6	120.1	0.5	0.6	120	5/2/88	6.2	125.3	4.7	76	98
49	120.1	125.3	5.2	3.7	71						

CORING DATA SUMMARY TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2 (cont)

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage[a]	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
50	125.3	130.2	4.9	4.9	100						
51	130.2	135.4	5.2	5.2	100	5/3/88	14.9	140.2	15.3	103	96
52	135.4	137.9	2.5	2.9	116						
53	137.9	140.2	2.3	2.3	100						
54	140.2	141.9	1.7	1.7	100						
55	141.9	144.3	2.4	2.4	100	5/4/88	9.8	150.0	8.0	82	97
56	144.3	147.6	3.3	2.2	67						
57	147.6	150.0	2.4	1.7	71						
Total			150.0 T.D.	146.1	97.4			150.0	146.1		97

[a] **Average per shift = 8.3 ft.**

CORING DATA SUMMARY TABLES (cont)

TEST NAME: CROSS HOLE
HOLE NAME: XH-1

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage[a]	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
1	0.0	5.4	5.4	5.0	92						
2	5.4	10.4	5.0	5.0	100	5/20/88	16.7	16.7	16.3	98	98
3	10.4	15.4	5.0	5.0	100						
4	15.4	16.7	1.3	1.3	100						
5	16.7	18.6	1.9	1.9	100						
6	18.6	23.6	5.0	4.5	90	5/23/88	16.9	33.6	16.4	97	97
7	23.6	28.6	5.0	5.0	100						
8	28.6	33.6	5.0	5.0	100						
9	33.6	38.6	5.0	4.4	88						
10	38.6	43.6	5.0	5.0	100	5/24/88	15.0	48.6	14.4	96	97
11	43.6	48.6	5.0	5.0	100						
12	48.6	53.6	5.0	5.0	100						
13	53.6	58.6	5.0	5.2	104	5/25/88	20.0	68.6	20.3	102	98
14	58.6	63.6	5.0	4.8	96						
15	63.6	68.6	5.0	5.3	106						
16	68.6	72.8	4.2	4.1	98						
17	72.8	77.8	5.0	4.9	99	5/26/88	19.2	87.8	19.0	99	98
18	77.8	82.8	5.0	5.0	100						
19	82.8	87.8	5.0	5.0	100						
20	87.8	92.8	5.0	3.4	68						
21	92.8	97.8	5.0	3.0	60	5/27/88	16.6	104.4	12.7	77	95
22	97.8	102.8	5.0	4.7	94						
23	102.8	104.4	1.6	1.6	100						
24	104.4	109.4	5.0	3.9	78	5/31/88	10.4	114.8	8.6	83	94
25	109.4	114.8 T.D.	5.4	4.7	87						
Total			114.8	107.7	94			114.8 T.D.	107.7	--	94

[a] Average per shift = 16.4 ft.

CORING DATA SUMMARY TABLES (cont)

TEST NAME: CROSS HOLE
HOLE NAME: XH-2

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage[a]	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
1	0.0	5.0	5.0	5.0	100						
2	5.0	10.0	5.0	4.7	94	6/6/88	20.0	20.0	19.1	96	96
3	10.0	15.0	5.0	4.9	98						
4	15.0	20.0	5.0	4.5	90						
5	20.0	25.0	5.0	5.2	104						
6	25.0	30.0	5.0	5.1	102	6/7/88	20.0	40.0	20.4	102	99
7	30.0	35.0	5.0	4.9	98						
8	35.0	40.0	5.0	5.2	104						
9	40.0	45.0	5.0	5.0	100						
10	45.0	50.0	5.0	5.0	100	6/8/88	20.0	60.0	19.6	98	99
11	50.0	55.0	5.0	5.0	100						
12	55.0	60.0	5.0	4.6	92						
13	60.0	65.0	5.0	5.4	108						
14	65.0	70.0	5.0	5.0	100	6/9/88	20.0	80.0	20.2	101	99
15	70.0	75.0	5.0	5.0	100						
16	75.0	80.0	5.0	4.8	96						
17	80.0	85.0	5.0	5.0	100						
18	85.0	90.0	5.0	4.3	86	6/10/88	20.0	100.0	18.0	90	97
19	90.0	95.0	5.0	4.8	96						
20	95.0	100.0	5.0	3.9	78						
21	100.0	105.0	5.0	3.4	68						
22	105.0	110.0	5.0	4.9	98	6/13/88	15.0 T.D.	115.0 T.D.	12.4	83	95
23	110.0	115.0	5.0	4.1	82						
Total			115.0	109.7	95			115.0	109.7		95

[a] **Average per shift = 19.2 ft.**

CORING DATA SUMMARY TABLES (cont)

TEST NAME: DIFFUSION
HOLE NAME: DH-1

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage[a]	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
1	0.0	7.0	7.0	1.1	16	6/20/88	7.0	7.0	1.1	16	16
2	7.0	7.8	.8	3.2	400	6/21/88	0.8	7.8	3.2	400	55
3	7.8	12.8	5.0	4.9	98	6/22/88	9.5	17.3	9.2	97	78
4	12.8	17.3	4.5	4.3	95						
5	17.3	22.3	5.0	4.8	96	6/23/88	10.0	27.3	9.8	98	85
6	22.3	27.3	5.0	5.0	100						
7	27.3	31.4	4.1	4.1	100	6/24/88	9.7	37.0	7.7	79	84
8	31.4	32.5	1.1	0.5	48						
9	32.5	37.0 T.D.	4.5	3.1	68						
Total		37.0	37.0	31.0	84			37.0	31.0		84

[a]Average per shift = 7.4 ft.

CORING DATA SUMMARY TABLES (cont)

TEST NAME: DIFFUSION
HOLE NAME: DH-2

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage[a]	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
1	0.0	6.5	6.5	4.7	72	6/29/88	6.5	6.5	4.7	72	72
2	6.5	10.8	4.3	3.4	79	6/30/88	10.3	16.8	8.2	80	77
3	10.8	12.3	1.5	1.3	86						
4	12.3	14.4	2.1	0.8	38						
5	14.4	16.8	2.4	2.7	113						
6	16.8	20.0	3.2	3.4	106	7/1/88	3.2	20.0	3.4	106	82
7	20.0	24.0	4.0	4.0	100	7/5/88	5.0	25.0	5.0	100	85
8	24.0	25.0 T.D.	1.0	1.0	100						
Total		25.0	25.0	21.3	85			25.0	21.3		85

[a]Average per shift = 6.3 ft.

CORING DATA SUMMARY TABLES (cont)

TEST NAME: DIFFUSION
HOLE NAME: DH-3

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Drilled	Footage Core Recovered	Core Recovered (%)	Date	Day Footage[a]	Footage to Date	Daily Recovery (ft)	Daily Recovery (%)	Recovery to Date (%)
1	0.0	3.0	3.0	2.8	90	7/8/88	3.0	3.0	2.8	90	90
2	3.0	6.5	3.5	2.2	62						
3	6.5	10.8	4.3	3.6	83	7/11/88	12.8	15.8	10.8	84	86
4	10.8	15.8	5.0	5.0	100						
5	15.8	20.8	5.0	5.0	100						
6	20.8	25.8	5.0	4.0	80	7/12/88	14.2	30.0	13.2	93	89
7	25.8	30.0	4.2	4.2	100						
Total		30.0	30.0	26.8	89			30.0	26.8	--	89

[a]Average per shift = 10.0 ft.

This page intentionally left blank.

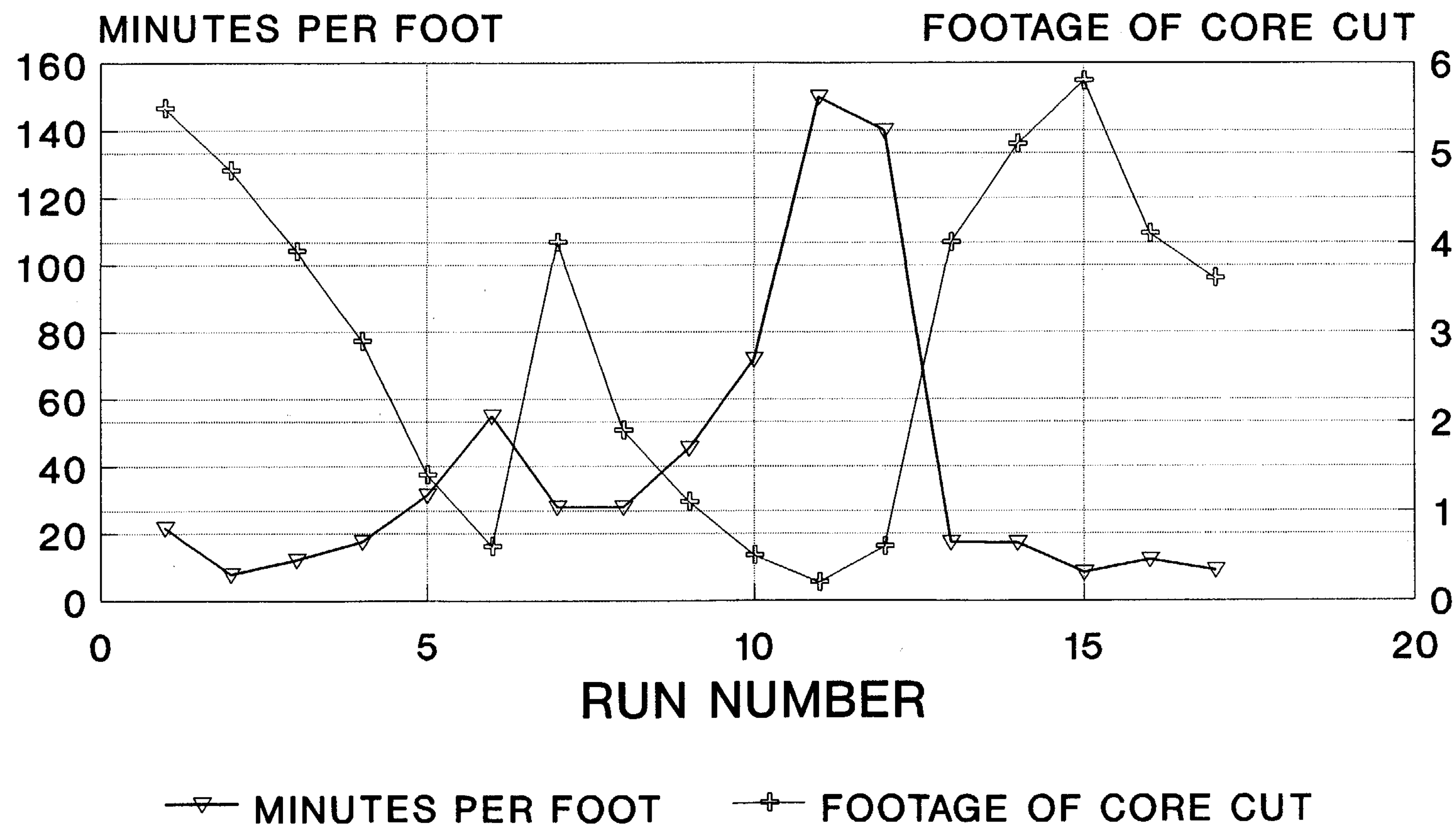
APPENDIX B (cont)

SUPPORING DATA

2. Penetration Rate Graphs and Tables

This page intentionally left blank.

PENETRATION RATES
AC-1



AS CORING TIME PER FOOT INCREASES
ACHIEVABLE CORE LENGTH DECREASES.

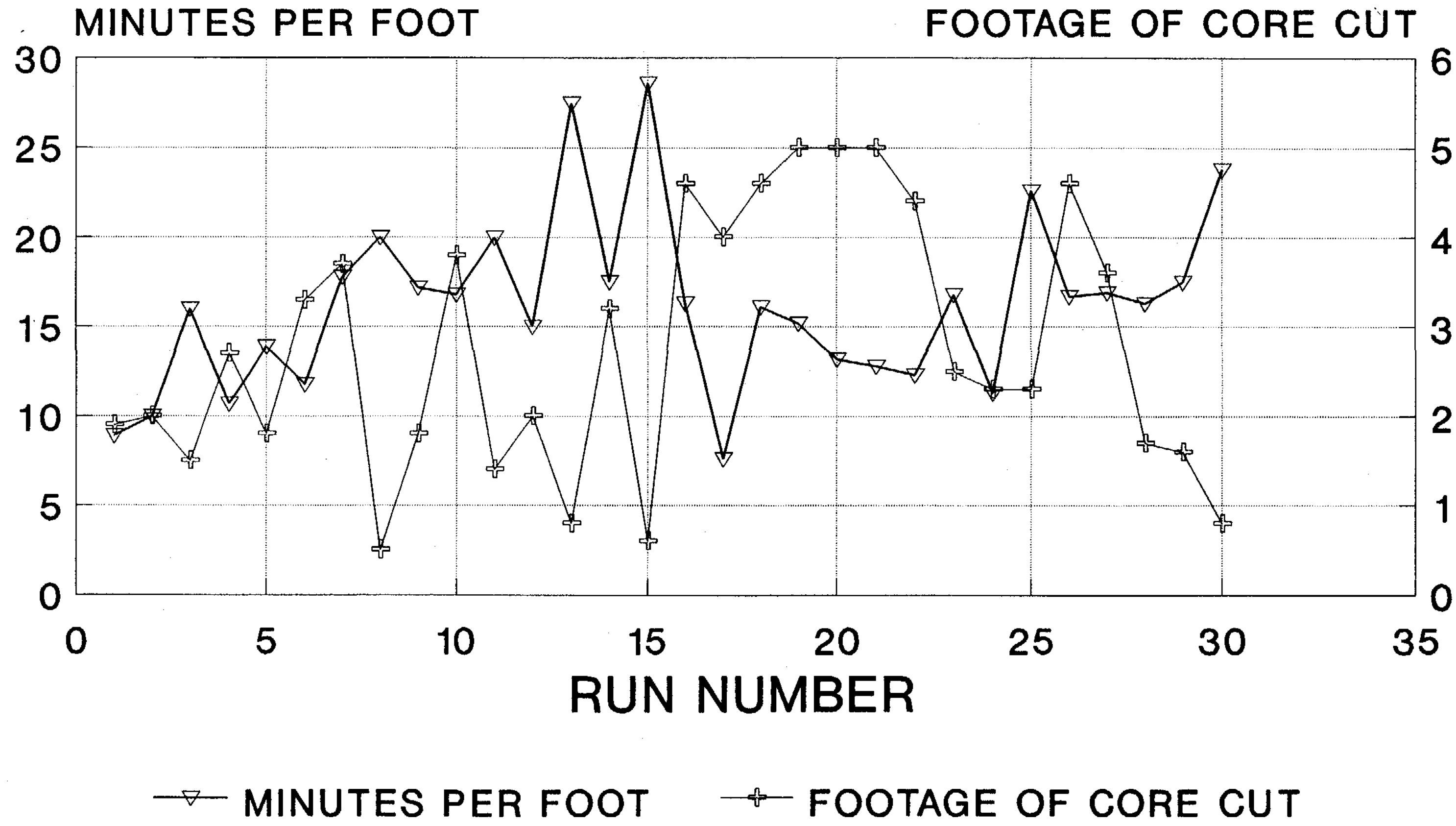
PENETRATION RATES TABLES

TEST NAME: AIR CORING
HOLE NAME: AC-1

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Cut	Footage Core Recovered	Time to Core (min)	Minutes per Foot	Comments
1	0.0	5.5	5.5	4.2	119	21.6	New bit Longyear
2	5.5	10.3	4.8	4.8	37	7.7	#L30728 - 3.895"
3	10.3	14.2	3.9	3.4	47	12.1	
4	14.2	17.1	2.9	2.9	51	17.6	
5	17.1	18.5	1.4	1.4	44	31.4	
6	18.5	19.1	0.6	0.6	33	55.0	Core block
7	19.1	23.1	4.0	4.0	111	27.8	
8	23.1	25.0	1.9	1.9	53	27.9	
9	25.0	26.1	1.1	0.9	50	45.5	
10	26.1	26.6	0.5	0.5	36	72.0	
11	26.6	26.8	0.2	0.4	30	150.0	Core block
12	26.8	27.4	0.6	0.6	84	140.0	Core block
13	27.4	31.4	4.0	4.0	69	17.3	
14	31.4	36.5	5.1	5.1	36	17.1	
15	36.5	42.3	5.8	4.4	49	8.4	
16	42.3	46.4	4.1	5.3	49	12.0	
17	46.4	50.0	3.6	4.0	32	8.9	
Total		50.0 T.D.	48.4				
				96.8% Recovery			

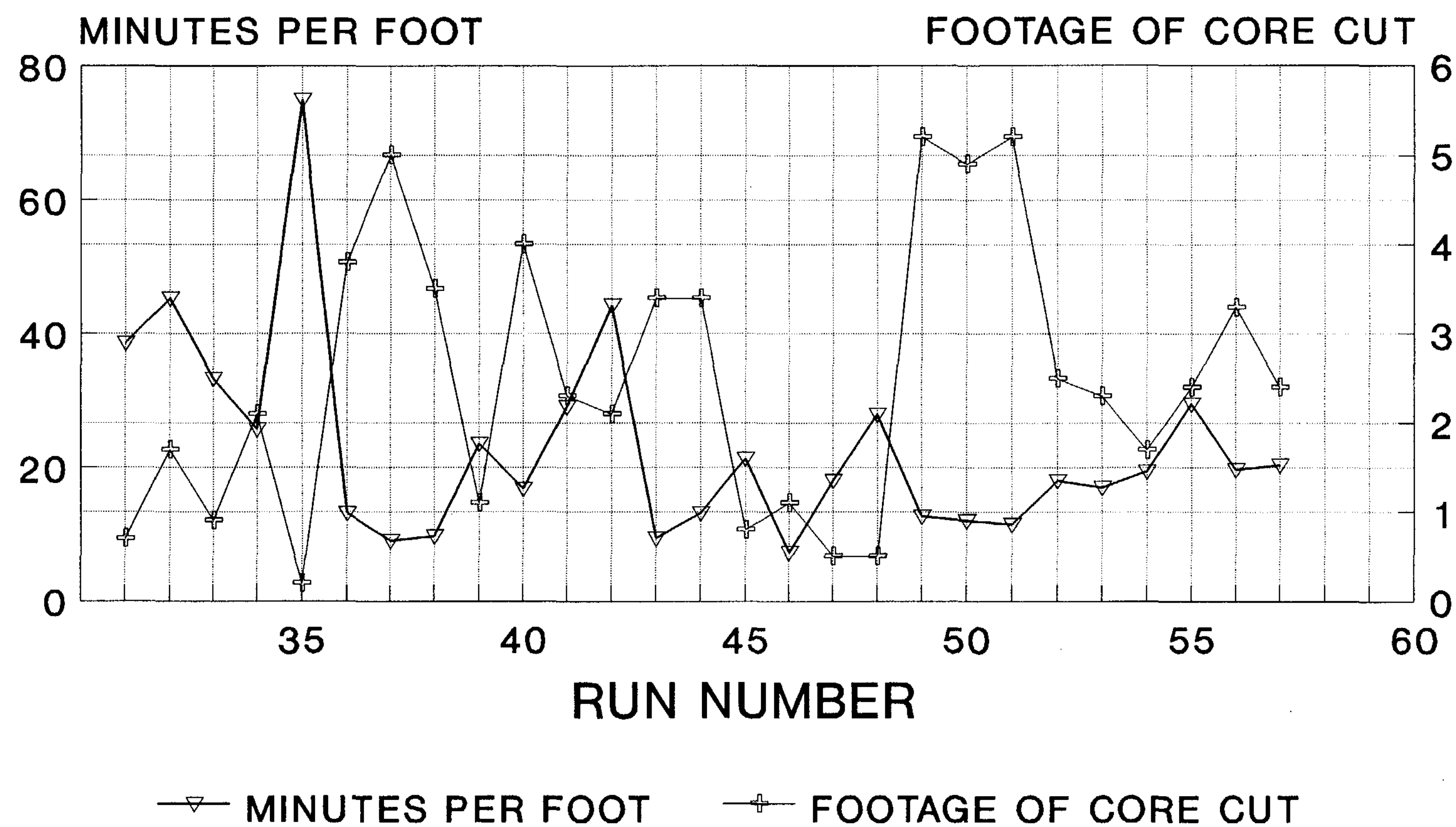
Average cut per run = 2.94 ft.
Average recovered per run = 2.85 ft.
Average time per run = 55 minutes per run.
Average minutes per foot = 19 minutes per foot.

PENETRATION RATES
AC-2 RUNS 1 THRU 30



AS CORING TIME PER FOOT INCREASES
ACHIEVABLE CORE LENGTH DECREASES.

PENETRATION RATES
AC-2 RUNS 31 THRU 57



AS CORING TIME PER FOOT INCREASES
ACHIEVABLE CORE LENGTH DECREASES.

PENETRATION RATES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Cut	Footage Core Recovered	Time to Core (min)	Minutes per Foot	Comments
1	0.0	1.9	1.9	1.9	17	8.9	New bit L33000
2	1.9	3.9	2.0	1.5	20	10.0	
3	3.9	5.4	1.5	2.0	24	16.0	
4	5.4	8.1	2.7	2.0	29	10.7	
5	8.1	9.9	1.8	1.7	25	13.9	
6	9.9	13.2	3.3	3.6	39	11.8	
7	13.2	16.9	3.7	4.0	66	17.8	
8	16.9	17.4	0.5	0.6	10	20.0	
9	17.4	19.2	1.8	1.8	31	17.2	
10	19.2	23.0	3.8	4.0	64	16.8	
11	23.0	24.4	1.4	1.4	28	20.0	
12	24.4	26.4	2.0	1.7	30	15.0	
13	26.4	27.2	0.8	0.8	22	27.5	
14	27.2	30.4	3.2	3.2	56	17.5	
15	30.4	31.0	0.6	0.7	20	28.6	
16	31.0	35.6	4.6	4.6	75	16.3	
17	35.6	39.6	4.0	4.6	35	7.6	
18	39.6	44.2	4.6	4.5	74	16.1	
19	44.2	49.2	5.0	5.0	76	15.2	
20	49.2	54.2	5.0	5.0	66	13.2	
21	54.2	59.2	5.0	5.0	64	12.8	
22	59.2	63.6	4.4	4.4	54	12.3	
23	63.6	66.1	2.5	2.5	42	16.8	
24	66.1	68.4	2.3	2.4	26	11.3	
25	68.4	70.7	2.3	2.3	52	22.6	
26	70.7	75.3	4.6	4.3	77	16.7	
27	75.3	78.9	3.6	3.1	61	16.9	
28	78.9	80.6	1.7	1.2	31	16.3	
29	80.6	82.2	1.6	1.4	28	17.5	
30	82.2	83.0	0.8	0.8	19	23.8	
31	83.0	83.7	0.7	0.7	27	38.6	
32	83.7	85.4	1.7	1.5	77	45.3	
33	85.4	86.3	0.9	1.2	30	33.3	
34	86.3	88.4	2.1	1.9	54	25.7	Start Lexan (86.31)
35	88.4	88.6	0.2	0.2	15	75.0	
36	88.6	92.4	3.8	3.8	50	13.2	New bit 4.125" L33001
37	92.4	97.4	5.0	5.0	45	9.0	

PENETRATION RATES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME AC-2

Core Run #	Start Depth (ft)	Finish Depth (ft)	Footage Core Cut	Footage Core Recovered	Time to Core (min)	Minutes per Foot	Comments
38	97.4	100.9	3.5	3.5	34	9.7	
39	100.9	102.0	1.1	1.2	26	23.6	
40	102.0	106.0	4.0	4.0	67	16.8	
41	106.0	108.3	2.3	2.3	67	29.1	
42	108.3	110.4	2.1	2.1	93	44.3	
43	110.4	113.8	3.4	3.4	32	9.4	Reran bit from AC-1 3.895" L30728
44	113.8	117.2	3.4	3.4	45	13.2	Bit seemed dull
45	117.2	118.0	0.8	0.8	17	21.3	
46	118.0	119.1	1.1	1.1	8	7.3	Ran new Christensen 3.885" bit #8S2333GR
47	119.1	119.6	0.5	0.4	9	18.0	
48	119.6	120.1	0.5	0.6	14	28.0	Bit plugged
49	120.1	125.3	5.2	3.7	66	12.7	Reran AC-1 bit sharpened L30728
50	125.3	130.2	4.9	4.9	59	12.0	
51	130.2	135.4	5.2	5.2	60	11.5	
52	135.4	137.9	2.5	2.9	45	18.0	
53	137.9	140.2	2.3	2.3	39	17.0	
54	140.2	141.9	1.7	1.7	33	19.4	
55	141.9	144.3	2.4	2.4	71	29.6	
56	144.3	147.6	3.3	2.2	65	19.7	
57	147.6	150.0	2.4	1.7	49	20.4	
Total			150.0 T.D.	146.1 97.4% Recovery			

Average cut per run = 2.63 ft.
Average recovered per run = 2.56 ft.
Average time per run = 43 minutes per run.
Average minutes per foot = 16 minutes per foot.

APPENDIX B (cont)

SUPPORING DATA

3. Drilling Variables Tables

This page intentionally left blank.

DRILLING VARIABLES TABLES

Explanatory Note

The following drilling variables were gathered in an attempt to document the many steps taken to find the best combination of drilling parameters. Drilling rpms, torque gauge readings, weight on bit, psi, and cfm of drilling air were varied to the limits, within sound drilling techniques, until the best penetration rates with smooth drilling were achieved.

Gauges on AC-1 and AC-2 were difficult to monitor. Data in parentheses in these tables have been assumed; i.e., data were written down only when known changes occurred.

DRILLING VARIABLES TABLES

TEST NAME: AIR CORING
HOLE NAME: AC-1

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
1	600	96		250	105	No vibration (vib) ballooned bag
				350	100	Ballooned bag
				200	103	
				180	105	
				200	104	
2	600			250	102	
		132		240	102	Some fugitive dust
				220		Core blocked off
3	(600)			205		Leaks at seals
				205	(102)	Vacuum (vac)
						Leaks-filters loading quickly
						Core block
4				375	100	(Ballooned)
				225	(100)	Ballooned-some leaks
				200	102	(Low)
				180	(102)	
				175	102	
				180	(102)	
	800/600					Some boot leaks
				175	102	Ballooning
5		108		275	100	Ballooning
						Cleaned bags vigorously
	900	90	450/500	175		No leaks - vac mode
						Core blocked
6		108	425	190	100	Vac - no leaks
				180	100	Slow drilling/core block
						Pulled bit - looked good
						Reran bit
7						Started pounding on DCS to help clean filter sacks
				200	105	No leaks - good vac
				250	105	" " " "
		99		190		" " " "
		99		175		" " " "
		120		160	108	More vibration than usual
		144		(0)		Blocked off - torque
		150		175	108	Soft zone - ballooned

DRILLING VARIABLES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-1

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
			375/400			Ballooned
				175		Ballooning - leaks
						Stopped to clean filter
				175		Vac - no leaks
				180	102	High torque - ballooned
		100		175		
		105		190		Leaks - ballooning
						Cleaned filter
					105	Vac
		114			105	Ballooned - soft material
	1200		302/375	(190)		
				190		Cleaned filters
						No leaks - good vac
				(?)		Core blocked - high torque
8	1500	(114)		175		Vibrations
		(114)		160	95	"
		(114)		160	98	"
		90			98	Slight leak - slight ballooning
		96			(98)	Heavy vib
		120				Heavy vib - core blocked
9		(120)		240	100	Running smooth
		48			(95)	Extreme vib - had to rpm slow
		54			(95)	" " " " " "
		48			(95)	
	1500	60	300/340		(95)	Vib lessened - allowing rpm
		(60)		175	95	Core blocking
		-				Core blocked
10		60				Vibs - forcing slow rpm
	1500	38	220/260		(95)	Heavy vibs - pulled core
						Probably core blocked
						Added stabilizer
11	1200	30	250/250		(95)	Vibs - bad torque and vibs
		30				Stabilizer was too large; it was removed
12				400		Blowing off bottom
				300		Ballooning
				250		Minor vib
				225		
				200		

DRILLING VARIABLES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-1

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
		60		190	110	
		60		175		Slowed rpm to keep vib down
				200		Pulled off bottom
				200		Vib
				175		
		36		160		Slow but smooth
	1300		210/250			
				175		Probably core block - added 1 stabilizer above bbl and 1 - 10 ft above 1st stabilizer
13		102		185	110	Good vac - no vibs
				175		Fast drilling
						Slow drilling
		60		190	100	Ballooned - no vib
	2000	(60)	300/325	190	(100)	Slight leak at boot
		60		195	100	Soft ground - leaks
						Doesn't stay in vac long
				(0)		Hole cuttings accumulating in hole - worked loose
				400!		Probable fracture
14				180		Vac
	2000	60	250/300	(180)	(100)	No vibs - balloon
		50		200		Mild vib
		42		200	100	Balloon
		42		200	105	Balloon
	2000	60	275/300	195		
				205		Vac
				200		Balloon
				140		Vac
				240		(Fracture) lots of fine cutting dust
				200		Core blocking
15				285		
				350	105	
				300	105	
				250	105	Bag leak
		66		250	105	Very fast drilling
				400!	105	Probably a fracture
		100		425	105	Some vib fracture
		66		175		Vac less vib
		60		175	105	Ballooned bag - torque fluctuating

DRILLING VARIABLES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-1

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
	2200	-	275/300	200	105	
	"		"	275	105	
	"		"	225	105	
				300	105	Boot leak
				225	105	
		60		200	105	
		60		125	105	
		60		200	105	Drilling fast
		60		200	105	
16	(60)		200	105		
		60		(200)	105	Small leak at boot - balloon
		45		200	(105)	Slowed rpm to help vib
		50		200	(105)	Slowed rpm to help vib
		(50)		200	(105)	Med vib
	2200		280/300	200	(105)	Used electric vibrator to clean filters
		(58)		225	(105)	Vac
		(58)		200	(105)	Vac
		58			(105)	Vac
				200	(105)	Vac
				200	(105)	Vac - no vibs; core full
17				300	(105)	Great vac
	2000	60	300/305	200	(105)	" "
				200	(105)	" "
	2000	60	300/305	200	(105)	Very mild vib - fast drilling
	2100	60	300/305	200	(105)	" " " " "
		60			(105)	Start to balloon
		60		200	(105)	T.D.

The DCT-90 was taken apart and inspected after completion of AC-1.

The cause of poor filter cleaning was found. The air-operated vibrators were restricted on their exhaust lines. This was remedied and the vibrators functioned very well.

The 18 filter socks were replaced with new ones because this test was started with a used machine and the old socks had been used extensively.

The inspection found one hole in a filter sock and replaced a leaking gasket.

This first hole was planned to test and modify the dust collection system. We constantly overran the cfm through the core barrel to see how much the collector would take without overloading and ballooning the bag. When the bag balloons, then the spider rubber wipers are more subject to leak, and hole cleaning can be affected.

DRILLING VARIABLES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
						New bit - L33000-4.125"-4.130" ream. Shell L33002
1	(600)			535	110	Too much air - ballooned
		120		400	"	
				375	"	Vac
				350	"	Bal
				300	"	Vac - reduced cfm to help vac
				275	"	Vac - this keeps boot from leaking
				250	"	Vac
2	(600)	120		260	100	Vac - minor leak at boot
	(600)	120		250		Vac - core blocked
3	(600)			250	100	Core blocked
4	(600)			350		Bal -tried to increase air
				260		Vac
				325		Bal - tried to increase air
				250		Vac
				275		Vac
				300	55	Vac - mine air drop
		120		275	85	Fast drilling
				400		Core jammed
5				250		Vac
	750		550/590	340		Vac
				310	118	Vac
				300		Bal minor boot leaks
				275		Vac
				240		Vac
6				300		Vac
		120		275		Vac
				260		Vac
				260		Vac
				260		Vac chatter
7				300		
	800	90	375/420	300	100	Bal - mild vibs
		100		275		Vac
		100		250		Vac
				225		

DRILLING VARIABLES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
		90		210	45	Mine air drop
				210	90	
				270	90	Vac
8	-	-	-	-	-	Core block
9	800	102	375/400	275		Vac - core block
10	750	102	500/540	260	55	Vac
				250		Vac - rpm fluctuating
	800		375/425	245		
				240	68	Vac - no leaks
		114		240		
		114		280	85	Balloon
				235	68	Vac
				235	68	
11		120		250	80	Heavy vibs - plugged (moisture in hole); shoe touching bit
12						Replaced shoe
	2200	132	430/450	300		Added stabilizer -
				275	60	Vac - no leaks - smooth
				225		
		120		225		
				225	62	
				225		
				275		Coring - fine
	2500	120	330/350	300	120	Coring fine - leak at boot
13	950	120	400/375	400		Vac - no leaks - smooth
				300		Great vac
		120		290		" "
		120		290		" "
				290		" "
		100		290	118	Great vac - vibs severe
	1000	84	350	275	125	Great vac - vibs severe - core blocked
						Added 2nd stabilizer -
14	1000	96	300/375	290	115	Great vac
		108		280		" "
				280	105	" "

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
				275		" "
				300		" "
				275		" "
				300		Ballooned
				275		Vac
				175		"
				300		"
				250		"
				250		Vib
				250		Vac - no leaks
	950	132		250		Vac - smooth - no leaks
			350	250	80	Vac - no leaks
		138		240		Vac - no leaks
				240		Vac - no leaks
15						Some chattering vibs
16						Leak at spider rubbers
17						Slight spider leak
18	1000	66	375/400	275	65	No leaks - good vac
		84		300		Opened to see if balloon
				260		Reduced to keep vac
				275		
				260	90	Mild vib - slight leak
	1000		350/390	275		Vac
				260		Vac - occasional vib
				240		Vac
				250	60	
19				320	75	Smooth - slight leak
				320		Smooth - slight leak
				260		Turned down - vac
				275		Vac - no leaks
				240	85	Ballooned - turned down - vac
				245		Vac
				230		Howling
				250		
	900	96	350/375	245		Boot leak - slightly
				250		Cleaned DCS (slight line moisture noticed)

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
				240	75	Smooth
				250		Blocked off core
20				230	70	Smooth - no leaks
				275		Leak - too much air
				250	90	Small leak
				245		Vac
	900	150	300/320	220	60	Howling
				190		Fast drilling
		132		210		Mild vib - no leak
				210	70	
21				260	95	Vac - new rubbers
		108		260		Bal - too much air
				225		Vac
		132		225		
		132		225		
				250		Bal - too much air
				225		Vac - howling
		156		125		Howling DCS not full air
		144		210		Leak - smooth
				215		Smooth
22				225		Slight howl - vac
		108		225		Not cleaning hole
		84		225	60	Mild vib
		120		205		" "
		132		225		" "
	900		340/360	225	60	" " - smooth
				275		Ballooned - turned down
				200		Vac vibs
				200	55	" "
				200		" "
				200		" "
23	900	120	350/360	225	60	Core blocked - vibs
				225	70	Fracture?
24				225		
				300		Fractures probably taking air
				275		Fractures probably taking air
	975		400/390	275	118	Slight leak - coarse cuttings
				260		

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
	900		300/330	225		Smooth - vac
				225	80	Smooth - vac
				225		
25				225	(80)	
				300		Slight leak at spider seals
				225		Vibs - vac
				220		Smooth
				200		"
		138		220		"
		114		220	60	
				250		Severe vib (fracture)
26	900	60	325/350	220	70	Vibs
		108		220	85	Fast drilling
		114		200		
		108		225	70	Leak
		132		200	70	Smooth
		120		200	70	"
				225	85	"
				200		Vib - core fall
27				200	(85)	Leak DCS filters dirty
				225		Vibs heavy
				200		Leak
28		108		225	60	Compressor down
				230		Rough - core block
29	-	-	-	-	-	Vibs core block - bad fractures
30				225	72	Very rough rock - core block
31		114		230	60	Core block - bad vibs
	900	80	300/325	230	75	Core block - moderate vibs
		60				
32		45		290		Blowing hole - vibs
		48		240		Leak
		60		225	70	Removed stabilizer
		108		225	70	Smooth
		54				Bad vibs

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
		108		240		Leak - vibs
	950	84	280/305	225		
33				225	65	Vibs
					75	
34						Started w/Lexan liners
		60		450		Vac
				300		Fractures? Vac!
				400		Vac!
		60		350		Leak - vac
		60		275		No leak - vac
		70		275	100	No leak - vibs
		65		250		No leak - vibs
		60		250		No leak - vibs
		70				
		108				Core block/Lexan collapsed
35				275	(100)	Changed bits - New L33001-4.125" Lexan collapsed
36		60		-		Smooth - vac
		72		275		Mild vibs
		66		275		
		55		275		
		86				
		60				Lexan liner collapsed
37		60		240		Smooth - vac
		60		240		" "
		96		240		" "
		96		235		" "
		96		235		" "
		96		250		" "
38		102		230		Modified Lexan with relief holes
				230		Vibs - vac
		60		250		Mild vibs
				225		" "
		96		275		" "
				225		Vibs
39		90		275		Vibs
		60				Core blocked

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
40		55		230		Vac
	950	60	320/345	225		No vibs
		60		225		
						Modified top of DCS
41				300		Large leak = too much air
		60		230		Vac
		60		225		"
		60		230		Hole plugging off
		90		275		Vibs
	2700?	60		230		"
			300/340	230		"
		78		275		Air blocked off
				175		
42		60		300		Vib
		80		275		No vib
				250		Ballooned
				250		Vib
				225		
43				225		Changed to smaller bit; (used) 3.885"/L-30728
				195		Added stabilizer
		114		175		No vibs
		120		150		Lexan collapsed (holes not open)
44		60		175		Vib
		96		175		Heavy vib
45		108		170		
		108		170		Vib heavy
		80		170		
46		120		300		Extreme vibs - blowing hole
	Very	160		200		Pulled old bit - ran Christensen
	High			195		3.895" bit plugged? - Ser. 852333GR
				145		
		120		150		
47				50		Bit plugged
				40		" "

DRILLING VARIABLES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
48				40		Bit plugged/pulled
49		50		210		Sharpened old bit and
		60		190		reran - 3.885, LYL30728
		78		180		Took out 3rd stabilizer
		80		190		Smooth
		100		180		"
	1000	78	300/305	180		Some vibs
		84		180		
		60		225		Very high vibs
		60		200		(Changed formation - very fast
		60		275		drilling)
				300		Fractures
				300		
				175		
				250		
				175		Heavy vibs - probably core block
				125		
				170		
				150		Core block
50				200		Blowing hole
				170		Smooth
				175		
		72		250		Fracture?
		82		175		No leaks
				170		Very smooth
				200		" "
				125		Blocking?
				150		"
				160		"
				100		"
				150		
				0		Blocking off
				175		
		72		175		Smooth
				170		Very quiet
				170		Very quiet
				150		Full barrel
51				175		Smooth
				175		"
	1000		400/375	300		Fractures?

DRILLING VARIABLES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
52		144		160		Smooth
	1000	144	260/300	150		Blocking off
				100		Lexan collapsed (holes blocked)
53		120		160		
		80		175		Heavy vib
		80		175		
		80		180		Core block
54		60		200		Smooth
				200		
				200		
				200		
				250		
				190		
				175		} Core block
				175		
				165		
55		60		175		Fractures may be taking air
		84				
				150		Fast drilling
				150		" "
				165		Slower drilling
				150		" "
				150		" "
				165		" "
				160		Blocking off
56	1000	72	290/310	175		Heavy vib - possible softer zone due to rubble
				200		[(noted in lithologic log (Appendix B.5.)]
				175		
				150		
				170		
				225		
				200		
				150		Soft formation
	1000		200/230	270		Fracture
				145		Smooth
				175		"
		108		250		"
				160		"
				160		"
				215		"
				300		"

DRILLING VARIABLES TABLES (cont)

TEST NAME: AIR CORING
HOLE NAME: AC-2

Run	Torque Gauge Reading	(rpm)	Wt. Gauge Reading	Air (cfm)	Air (psi)	Comments
				225		Smooth
				170		"
				200		Core blocked
57		60		200		Quiet - smooth
				175		
				250		
		84		200		Smooth
	1100		300/325	225		
				350		
				250		
		108		165		
				165		Cuttings not returning well
				175		
		60		150		Smooth
		80		200		
				220		
				250		
		60		200		Vibs
		60		190		"
				200		
				250		
				225		
				175		
		72		150		Blocking
		72		0		Blocking
				50		
		72		100		
		72		170		
				160		Vibs
				170		"

This page intentionally left blank.

APPENDIX B (cont)

SUPPORTING DATA

4. Incremental Depth Versus cfm Data

This page intentionally left blank.

INCREMENTAL DEPTH VS. CFM DATA

3.885" Bit O.D.
3.890" Reamer Shell O.D.

0' = Not tested at this interval due to length of core barrel.
5' = Not tested at this interval due to length of core barrel.

10' = 500 cfm = Open Spider
15' = 500 cfm = Open Spider
20' = 460 cfm = Open Spider
25' = 410 cfm = Open Spider

25' While Rotating = 410-415 cfm -- Open Spider

25' with DCS on = 425 cfm = Closed Spider

This sample test was performed to see how friction loss would affect the discharge (flow) of air through and back around the barrel and drill rods to the hole collar.

The dust collector may not allow more than 450 cfm to pass through filters while filtering the high percentage of fine dust generated while coring. The unit was designed to pull 610 cfm.

This page intentionally left blank.

APPENDIX B (cont)

SUPPORTING DATA

5. Lithology Logs

LITHOLOGIC LOG
AC-1

Run #	Interval (ft)	Cored (ft)	Recovered (ft)	Description
1	0.0-5.5	5.5	4.2	A rubble lens with orange matrix makes up the first foot of this run; the majority of the rest of this run is a moderately welded ash flow. Some natural fractures carry a thin dark brown coating. (complete run broken)
2	5.5-10.3	4.8	4.8	Moderately welded ash flow with abundant natural fractures. Fiamme are altered to zeolites; some small vugs are present. (1.4 ft not broken)
3	10.3-14.2	3.9	3.4	Moderately welded ash flow from 10.3 ft to 11.6 ft and rubble from 11.6 ft to 12.3 ft. From 12.3 ft on is a more densely welded ash flow containing small vugs.
4	14.2-17.1	2.9	2.9	More densely welded ash flow containing some large open vugs and fewer natural fractures. (0.7 ft broken)
5	17.1-18.5	1.4	1.4	Densely welded ash flow, a fracture parallel to the core axis runs the entire length; some dark brown coating but no displacement can be noted. A fiamme split by the fracture is altered to a green soft zeolite.
6	18.5-19.1	0.6	0.6	Same as above, contains end of fracture at 18.8 ft.
7	19.1-23.1	4.0	4.0	Densely welded and highly fractured with coatings from 21.1 ft to 23.1 ft.
8	23.1-25.0	1.9	1.9	Densely welded, natural fractures carry brown coating.
9	25.0-26.1	1.1	0.9	Densely welded, high concentration of fiamme. An open frothy vug at end of run.
10	26.1-26.6	0.5	0.5	Densely welded with large frothy vug at beginning of run.
11	26.6-26.8	0.2	0.4	Densely welded, abundant fiamme. Excess of core possibly cave.
12	26.8-27.4	0.6	0.6	Same as above.

LITHOLOGIC LOG
AC-1
(continued)

Run #	Interval (ft)	Cored (ft)	Recovered (ft)	Description
13	27.4-31.4	4.0	4.0	Densely welded, some open vugs.
14	31.4-36.5	5.1	5.1	Densely welded with open vugs containing some crystals; lithic fragments common. Fault face polished at 36.2 ft but displacement probably minor.
15	36.5-42.3	5.8	4.4	Densely welded to less densely welded, larger fiamme less flattened.
16	42.3-46.4	4.1	5.3	Dense to moderately welded tuff, no natural fracturing and fiamme large and less flattened, occasional open vug. Excellent core length for this type of rock.
17	46.4-50.0	3.6	3.6	Same as above.
T.D.50.0				Logged by M. O'Brien 3/31/88

LITHOLOGIC LOG
AC-2

Runs	Cored (ft)	Recovered (ft)	Description
57	150	146.1	Grouse Canyon ash-flow tuff, moderately welded from 0.0 ft to 120.0 ft, slightly welded from 120.0 ft to 125.0 ft, moderately welded from 125.0 ft to 150.0 ft. Contains abundant slightly flattened fiamme and occasional vuggy areas. A slight increase in vugginess occurs at approximately 54 ft. Abundant lithic fragments in a welded matrix were noted from 39 ft to 63 ft and again at 142 ft to 143 ft. An increase in pumice fragments was seen at 98 ft. Broken zones were noted at 78 ft to 81 ft and again at 144.6 ft to 145.6 ft. Logged by M. O'Brien 6/17/88

APPENDIX B (cont)

SUPPORTING DATA

6. Survey Tables

SURVEY TABLES
Explanatory Note

Straight holes and/or repeatability of hole direction is important for certain tests at Yucca Mountain. Hole direction can, to a certain extent, be controlled by the weight and rpm of the drill bit (see Appendix B.3), the placement of stabilizers, and size of the drill string components.

The data from hole deviation surveys came from Holmes & Narver, Inc. (line-of-sight as-built survey) and Fenix & Scisson, Inc. (using a Sperry-Sun single-shot tool). The data were provided in different formats by each agency, but consistent with the survey methodology. These tables present data reduced to common parameters of departure (+ right, - left) and inclination (+ up, - down) with respect to the anticipated hole path when it was spudded. There is disagreement (within the data) between the two survey methods. The nature of the single-shot technique appears to offer more opportunities for error to be introduced. However, the optical method used by Holmes & Narver, Inc., is limited to line of sight (although current work on a new tool to remove that limitation is in progress).

The as-built data are probably more reliable, but the accuracy suggested by the table is not critical to the test nor is endorsement by the authors implied. What is probably more important are the general hole deviations shown by these tests. It should be noted, however, that these attendant deviations observed at the G-Tunnel site may not necessarily be replicated in Yucca Mountain core holes. Also, the data reliability, target stand-off requirements, length and complexity of steps to data reduction, time requirements for surveying, and possible perturbation to hole stability are all potentially negative aspects for surveying ESF holes. Survey techniques and procedures need additional work before drilling ESF holes to assure that requirements can be met for tests that demand critical hole accuracies.

SUMMARY

AS-BUILT SURVEY INFORMATION FOR PROTOTYPE AIR-CORING TEST HOLES*

<u>AC-1</u>

0 + 00 (collar) to 0 + 48.30 (bottom; projected due to length of target)

Bearing S 56°-10'-54"W

Distance 48.30 ft

Vertical Inclination +0.9% or +0°-30'-36"

Difference in Elevation +0.43 ft

<u>AC-2</u>

0 + 00 (collar) to 1 + 00 (end of survey; loss of line of sight)

Bearing S 54°-06'-16" W

Distance 100 ft

Vertical Inclination +0.9% or +0°-30'-36" (same as AC-1)

Difference in Elevation +0.89 ft

---

*Information provided by Holmes & Narver, Inc., Area 12 Survey Dept.

AS-BUILT DOWN-HOLE STATIONS FOR AC-1 DRILL HOLE U12g LOWER EXTENSOMETER DRIFT*

Drill Hole Station (depth from collar in ft)	Coordinates	Departure Δ (in.)	Elevation (ft)	Inclination Δ (in.)
0+00 (collar)	N 882,779.86 E 631,938.87	--	6211.22	--
0+01.4	N 882,779.08 E 631,937.71	0	6211.24	+0.2
0+05	N 882,777.06 E 631,934.73	-0.3	6211.28	+0.7
0+10	N 882,774.30 E 631,930.56	+0.1	6211.32	+1.2
0+15	N 882,771.52 E 631,926.41	+0.1	6211.37	+1.8
0+20	N 882,768.73 E 631,922.26	-0.1	6211.41	+2.3
0+25	N 882,765.94 E 631,918.11	-0.3	6211.46	+2.9
0+30	N 882,763.15 E 631,913.96	-0.2	6211.51	+3.5
0+35	N 882,760.36 E 631,909.82	-0.4	6211.55	+4.0
0+40	N 882,757.59 E 631,905.66	-0.3	6211.59	+4.4
0+45	N 882,754.82 E 631,901.50	-0.2	6211.63	+4.9
0+46.78 (see notes)	N 882,753.83 E 631,900.02	-0.2	6211.64	+5.0
0+48.30 (bottom; see notes)	N 882,752.99 E 631,898.76	-0.3	6211.65	+5.2

*Information provided by Holmes & Narver, Inc., Area 12 Survey Dept.

Notes:
- All numbers are in feet except where noted.
- Sta. 0+01.4 was included because collar was irregular.
- These numbers have not been checked and should be considered preliminary (H&N, Inc., note).
- 0+46.78 is the last survey taken due to length of target, so 0+48.3 is a projection.
- Δ values are approximations calculated by the authors; (-) departures deviate left and (+) deviate right; (-) inclinations deviate down and (+) deviate up.

AS-BUILT DOWN-HOLE STATIONS FOR AC-2 DRILL HOLE U12g LASER DRIFT*

Drill Hole Station (depth from collar in ft)	Coordinates	Departure Δ (in.)	Elevation (ft)	Inclination Δ (in.)
0+00 (collar)	N 883,070.86 E 632,248.73	--	6205.03	--
0+05	N 883,067.92 E 632,244.69	-0.2	6205.00	-0.4
0+10	N 883,065.00 E 632,240.63	0	6204.99	-0.5
0+15	N 883,062.08 E 632,236.58	+0.1	6204.99	-0.5
0+20	N 883,059.16 E 632,232.52	+0.4	6204.99	-0.5
0+25	N 883,056.24 E 632,228.47	+0.5	6205.02	-0.1
0+30	N 883,053.31 E 632,224.41	+0.5	6205.05	+0.2
0+35	N 883,050.38 E 632,220.36	+0.5	6205.09	+0.7
0+40	N 883,047.46 E 632,216.31	+0.7	6205.12	+1.1
0+45	N 883,044.54 E 632,212.26	+0.8	6205.17	+1.7
0+50	N 883,041.61 E 632,208.21	+0.9	6205.22	+2.3
0+55	N 883,038.68 E 632,204.15	+0.9	6205.27	+2.9
0+60	N 883,035.75 E 632,200.10	+0.9	6205.33	+3.6
0+65	N 883,032.82 E 632,196.05	+0.9	6205.39	+4.3
0+70	N 883,029.89 E 632,192.00	+0.9	6205.45	+5.0
0+75	N 883,026.96 E 632,187.96	+0.9	6205.52	+5.9

AS-BUILT DOWN-HOLE STATIONS FOR AC-2 DRILL HOLE U12g LASER DRIFT* (cont)

Drill Hole Station (depth from collar in ft)	Coordinates	Departure Δ (in.)	Elevation (ft)	Inclination Δ (in.)
0+80	N 883,024.01 E 632,183.92	+0.6	6205.57	+6.5
0+85	N 883,021.08 E 632,179.87	+0.7	6205.67	+7.7
0+90	N 883,018.14 E 632,175.83	+0.6	6205.74	+8.5
0+95	N 883,015.19 E 632,171.79	+0.4	6205.83	+9.6
1+00 (see notes)	N 883,012.25 E 632,167.75	+0.4	6205.92	+10.7

*Information provided by Holmes & Narver, Inc., Area 12 Survey Dept.

Notes:
- All numbers are in feet except where noted.
- These numbers have not been checked and should be considered preliminary (H&N, Inc., note).
- 1+00 is the last survey taken due to loss of line of sight to the target.
- Δ values are approximations calculated by the authors; (-) departures deviate left and (+) deviate right; (-) inclinations deviate down and (+) deviate up.

AIR-CORING #1 (AC-1) HOLE DEVIATION DATA
FROM SINGLE-SHOT SURVEY

Station	Vertical Inclination (in.)	Vertical Inclination Cumulative Δ (in.)	Horizontal Departure (in.)	Horizontal Departure Cumulative Δ (in.)	Radial Distance of Deviation (in.)
Collar	0	0	0	0	0
25 ft	+0.9	+0.9	+7.9	+7.9	8.0
50 ft	-3.9	-3.0	-5.2	+2.7	4.0
T.D.					

Δ values are approximations calculated by the authors; (-) departures deviate left and (+) deviate right;
(-) inclinations deviate down and (+) deviate up.

AIR-CORING #2 (AC-2) HOLE DEVIATION DATA
FROM SINGLE-SHOT SURVEY

Station	Vertical Inclination (in.)	Vertical Inclination Cumulative Δ (in.)	Horizontal Departure (in.)	Horizontal Departure Cumulative Δ (in.)	Radial Distance of Deviation (in.)
Collar[a]	---	---	---	---	---
30 ft	0	0	0	0	0
60 ft	+1.6	+1.6	-2.6	-2.6	3.1
90 ft	+3.1	+4.7	-2.1	-4.7	6.6
120 ft	0	+4.7	0	-4.7	6.6
150 ft	0	+4.7	-1.6	-6.3	7.9
T.D.					

a Collar station data not used due to erosion in hole.

Δ values are approximations calculated by the authors; (-) departures deviate left and (+) deviate right;
(-) inclinations deviate down and (+) deviate up.

CROSS-HOLE #1 (XH-1) HOLE DEVIATION DATA
FROM SINGLE-SHOT SURVEY

	Vertical Inclination		Horizontal Departure		Radial Distance of Deviation (in.)
Station	**(in.)**	**Cumulative Δ (in.)**	**(in.)**	**Cumulative Δ (in.)**	
Collar[a]	---	---	---	---	---
10 ft	0	0	0	0	0
20 ft	+0.5	+0.5	0	0	0.5
30 ft	-1.0	-0.5	0	0	0.5
40 ft	0	-0.5	-0.3	-0.3	0.6
50 ft	0	-0.5	+0.3	0	0.5
60 ft	-1.4	-1.9	0	0	1.9
70 ft	0	-1.9	0	0	1.9
80 ft	0	-1.9	0	0	1.9
90 ft	+0.7	-1.2	+0.3	+0.3	1.2
100 ft	+0.3	-0.9	0	+0.3	0.9
115 ft	0	-0.9	0	+0.3	0.9
T.D.					

[a] Collar reading was unusable due to hole erosion; the station at 10 ft is used as the reference point for subsequent stations.

Δ values are approximations calculated by the authors; (-) departures deviate left and (+) deviate right;
(-) inclinations deviate down and (+) deviate up.

CROSS-HOLE #2 (XH-2) HOLE DEVIATION DATA
FROM SINGLE-SHOT SURVEY

Station	Vertical Inclination		Horizontal Departure		Radial Distance of Deviation (in.)
	(in.)	Cumulative Δ (in.)	(in.)	Cumulative Δ (in.)	
Collar[a]	0	0	0	0	0
10 ft	-2.1	-2.1	+0.3	+0.3	2.1
20 ft	+2.8	+0.7	0	+0.3	0.8
30 ft	+0.9	+1.6	0	+0.3	1.6
40 ft	-0.5	+1.1	0	+0.3	1.1
50 ft	-0.3	+0.8	-0.3	0	0.8
60 ft	+2.3	+3.1	+0.2	+0.2	3.1
70 ft	+0.2	+3.3	+0.2	+0.4	3.3
80 ft	-1.6	+1.7	-0.3	+0.1	1.7
90 ft	+1.4	+3.1	0	+0.1	3.1
100 ft	+0.2	+3.3	+0.2	+0.3	3.3
115 ft T.D.	+5.2	+8.5	-3.3	-3.0	9.0

Δ values are approximations calculated by the authors; (-) departures deviate left and (+) deviate right; (-) inclinations deviate down and (+) deviate up.

This page intentionally left blank.

APPENDIX B (cont)

SUPPORTING DATA

7. Glossary

This page intentionally left blank.

GLOSSARY

The following definitions are provided to standardize terminology as used in this report.

Collar--The mouth of a borehole.

Core--A cylindrical sample of rock or the process of cutting such a sample by use of an annular (hollow) drill bit.

Core Barrel--Tubing designed to contain the core sample produced until it can be retrieved.

Core Bit--An annular bit designed to cut a core sample of rock in boreholes. The cutting points may be serrations, diamonds, or other hard substances set in the face of the bit.

Coring--The process of obtaining cylindrical rock samples by means of annular (hollow) rock-cutting bits rotated by a drilling machine.

Demobilization--To disassemble the drill rig and accessory equipment and remove from the drill site.

Mobilization--To transport and assemble the drill rig and accessory equipment on the drill site and make ready for drilling.

Multipurpose Drill--A drill rig designed to drill core holes, rotary boreholes, and percussion boreholes. This multiple capability is achieved by incorporating in one rig the appropriate range of rotary speed, thrust, pull-back force, and torque needed to drill each type of hole.

ODEX--A rotating percussion drilling system developed by Sandvik AB and Atlas Copco in 1972. The method uses a pilot bit with an eccentric reamer, which drills a hole slightly larger than the external diameter of the casing. Casing tubes accompanying this drilling assembly are conveyed smoothly down the hole behind the eccentric reamer by the impact-hammer energy, which also is used to drill the hole.

Percussion Drilling--A method of drilling, using a hammer action and rotation of the bit, whereby the striking force produces a chipping action to bore through the rock. This method of drilling is generally powered by air and also uses air for circulation. There are two main types: (1) surface hammer and (2) down-the-hole hammer (DTH).

Prototype Testing--Activity involving the preparation and conduct of experiments, tests, and field trials to verify or validate procedures, methods, equipment, designs, and performance under simulated Yucca Mountain conditions.

Reaming Shell--A short tube designed to couple a bit to a core barrel. The outside surface of the reaming shell is provided with inset diamonds or other cutting media set to a diameter to cut a specific clearance for the core barrel. Also called "core shell," "reamer," "reamer shell."

This page intentionally left blank.

APPENDIX B (cont)

SUPPORTING DATA

8. Prototype Test Plan Draft Procedures

This page intentionally left blank.

DRAFT PROCEDURES FROM THE PROTOTYPE AIR-CORING TEST PLAN

1. Procedure for Core Drilling (Wet or Dry)
2. ODEX Drilling
3. Casing Removal with Hydraulic Jacks
4. Fishing for Stuck or Broken Tools
5. Dust Collection Procedures
6. Procedures for Handling Cores and Obtaining Other Samples
7. Running and Retrieving Inner Barrel in a Horizontal Hole
8. Operation of Multipurpose Drill
9. Problem Resolution
10. Air Volume and Air Pressure Mix
11. Drilling Log Book(s) Standardization and Maintenance
12. Procedure for Moving Equipment in Confined Spaces
13. Hole Deviation Survey
14. Hole Geophysical Survey

TECHNICAL PROCEDURES

1. Procedure for Core Drilling (Wet or Dry)

The procedure for core drilling includes the following steps.

- Prepare drill site to accommodate drill and accessory equipment.
- Build a good platform and set up drill.
- Establish the fluid circulation system.
  - If air is to be used, connect compressed air system and dust collection system. The need for a collar pipe is TBD.
  - For wet drilling, connect mud pump, drill collar hole, and set collar pipe (if required).
  - Determine the proper bit and reaming shell type and O.D.
- Start core drilling.
  - Lower bit and core barrel to bottom of hole.
  - Start fluid circulation.
    - Apply slow feed rate and rpm initially.
    - Increase rpm and feed rate (weight on bit) to achieve optimum penetration rate.
    - Maintain fluid flow (air or liquid) sufficient to flush the hole and lubricate the bit.
    - Know depth of bit at all times.
- Recover core.
  - Break core by applying steady pullback force.
  - Bring core inner barrel to surface.
  - Record, mark, and store core in core boxes.
  - Maintain core drill log and records.

2. ODEX Drilling

Procedures have been written but are not included because the ODEX capability for prototype testing is contingent upon the approval for purchase or the availability of a multipurpose drill rig.

3. Casing Removal with Hydraulic Jacks

Casing capability is contingent upon the approval for purchase of a multipurpose drill rig; therefore, the need for written procedures is undetermined.

4. Fishing for Stuck or Broken Tools

REECo underground drilling personnel are familiar with the use of standard fishing tools used for diamond core drilling equipment. The following are actions recommended to enhance the probability of successful fishing operations, if fishing operations become necessary.

- Dimensions (i.e., inside diameter, outside diameter, and length) will be recorded for all items run into the holes. This information should be kept in the driller's log book.
- Drawings of the tool string will be made, showing the placement and length of each item, and the thread nomenclature will be recorded.
- Tools for retrieving drill rods, bits, casing, and core barrels (conventional, wireline, and narrow kerf) will be placed on or near location. Both right-hand and left-hand fishing tools should be available. For standard coring, the most often used fishing tool may be a taper-tap.
- The driller should do the actual running and manipulation of fishing tools.
- The decision on which fishing tools to use and when to use them should be made collectively by REECo, the drilling consultant, and the PI.
- A correlation of fishing costs, hole necessity, and hole usability may be needed. This should be done collectively by REECo, the drilling consultant, and the PI. The PI's requirements should be accommodated wherever possible.

5. Dust Collection Procedures

To site and connect the dust collection system, the following steps are followed:

- place in a convenient location, i.e.,
    - out of traffic area,
    - near a power source,
    - near enough for hose to reach from rig during drilling operations, and
    - where the cuttings can be emptied, handled, and monitored.
- Connect the system.
    - Connect hose from boot and diverter head (if used) to the dust collection unit.
    - Connect vacuum power source (if used).

The dust collection system is tested before drilling by turning on flushing air and inspecting the seals, hoses, connectors, and dust collection box to see whether any leaks are present. If there are no leaks, proceed to drill; if leaks are observed, shut off air and fix or change seals, connectors, or boot.

Drilling proceeds after determining how often the dust collection system needs to be emptied and after developing a dumping schedule according to the size and type of hole, following the steps listed below.

- Turn off air before the dust collection system is opened.
- Bag, label, and number the cuttings to meet PI needs.
- Clean system thoroughly and close unit.
- Turn air on, check for leaks, and resume drilling.

Possible problems are listed below.

Problem: Collar boot may not seal off irregular surface of rock around hole collar with the result that air and dust will leak into the atmosphere.

Solution: Either replace the boot, position it better, or do some preparatory work on the rock surface.

Problem: Pack-off rubber/wiper leaks.

Solution: Replace pack-off rubbers, check for proper size, and check drill rod for the irregularities causing the problem.

Problem: Dust collection system does not filter properly.

Solution: Run system through cleaning cycle and replace filters if they have holes, tears, etc.

Problem: Dust collection filter plugs with moisture.

Solution: A small amount of moisture can be evaporated by the system itself by circulating air only through filters. If moisture is persistent, the PI (and industrial hygiene personnel, where pertinent) will determine whether

- occasional filter plugging is acceptable,
- sufficient moisture is present to eliminate blowing dust, thereby disconnecting the dry filters and connecting a wet cuttings collector,
- water should be injected for hole cleaning, or
- hole should be left and used as is.

6. Procedures for Handling Cores and Obtaining Other Samples

Each PI may have a procedure that is more encompassing than this generic procedure. In most cases, the use of Lexan liners is desirable. The Lexan liner is made of clear polycarbonate, and the version to be used is threaded top and bottom. The wall thickness of the threaded liner requires the use of a triple-tube-type core bit.

The following procedures are used for handling core samples.

- Assemble the liner connectors, steel ferrules, inner tube shoe, and liner to the latching assembly.
- Core as usual.
- Retrieve as usual.
- After retrieving the core, unscrew connectors, ferrules, and shoe. Immediately screw on the threaded end caps.
- Place entire Lexan tube containing the core in the core box.
- Core will be transported by REECo personnel to the storage facility designated by the PI.

Other samples are obtained in one of three ways. (1) The periodic clearing of the dust control system will provide cuttings, dust, and similar types of samples that the PI may want labeled for depth and hole number. (2) If the ODEX system is used, it will produce a considerable amount of coarse cuttings that may be suitable for certain laboratory testing. They will need to be taken at regular intervals and labeled, handled, and stored per request from the PI. (3) Other samples may be obtained as requested by the PI.

7. Running and Retrieving Inner Barrel in a Horizontal Hole

The inner barrel can be run and retrieved with either air or liquid as a pumping medium and the use of a wireline pulling system in conjunction with a stripper/pack-off assembly. Inner barrel retrieval is a common procedure, and a qualified underground driller will be experienced in this procedure.

Possible problems are listed below.

Problem: Inner barrel does not reach position, i.e., is not locked in place.

Solution: Retrieve with wireline and replace rubbers.

Problem: Inner barrel cannot be retrieved from core barrel.

Solution: Check retrieving tools for damage, pull string and core barrel, and fix problem.

8. Operation of Multipurpose Drill

The need for this written procedure is contingent upon the acceptance, approval, and acquisition of recommended equipment.

9. Problem Resolution

Several problems may occur in addition to those already described.

Problem: Hole caving may preclude completion with the planned size of hole.

Solution: Consult with PI to see if shorter hole is acceptable. See if PI wants to case hole and go to smaller hole size. See if PI wants to ODEX-ream hole while intermittently coring to horizontal total depth.

Problem: Dry hole becomes wet (Teasdale and Pemberton, 1984).

Solution: Dry out dust collection filters and try again. Connect wet cuttings catcher (without filter). Inject water if needed (with PI authorization); determine the amount of water injected and the amount of water lost in hole.

Problem: Determine whether to fish for lost or stuck drill tools.

Solution: Check with PI (and drilling superintendent) to ascertain the necessity of finishing this hole. Predict time required to fish and the probability of finishing planned hole. If necessary, move to another usable location.

Problem: Hole deviation.

Solution: Utilize proper equipment (e.g., stabilizers, reaming shells, drill rods, bit weight, and rotation speed) and well-trained crew (The Robbins Company, 1984). If hole deviation is visually apparent, this should be brought to the attention of the PI for determination of need for corrective action. If redirection is important, initiate normal hole directional drilling procedures.

Problem: Crew changes or end of shift may occur at critical times, i.e., while circulating system cannot be left unattended.

Solution: This may not be a problem but will be addressed and coordinated with the test manager and GTUF manager. Overtime is very costly, and the cost must be borne by the PI's test budget.

Problem: Casing breakage.

Solution: This is potentially a problem only if ODEXing is used. Specific solutions to this problem have been determined and will be itemized if and when the ODEX system is implemented.

10. Air Volume and Air Pressure Mix

Core drilling presents no problems if the available GTUF air supply is used. Standard mine air is sufficient.

If the DTH and ODEX methods are accepted and to be used, then procedures will be written to show the desired cuttings velocity, amount of cfm to achieve this velocity, and the proper psi needed for each tool to achieve best performance.

11. <u>Drilling Log Book(s) Standardization and Maintenance</u>

Certain information must be carefully recorded to ensure that an adequate and accurate evaluation of equipment performance can be completed. Because NTS contractors (e.g., REECo and F&S) will be involved, the specific type of information and responsibility for recording it will need to be coordinated with the participants. In some aspects, information will be duplicated as a cross check. The format and level of detail may vary with respect to standard forms used at the NTS. If the standard forms used at the NTS (e.g., drillers' logs) do not include space for all the desired information, the documentation will be supplemented where necessary by manually recording it in standard laboratory notebooks and/or other forms provided.

The following types of information will be recorded:

- Drilling:
  - location;
  - hole number or designation;
  - total depth;
  - size (diameter);
  - elevation;
  - instruments, casings, etc., left in hole;
  - depths of specific hole parameters (e.g., casing, fracture zones, fish, lost circulation, and changes of hole size;
  - changes of moisture content;
  - sketch drawings of all down-hole equipment before going into hole;
  - serial numbers and descriptions (if available);
  - rotary head rpm;
  - weight on bit (if available);
  - rig hydraulic system pressure during normal drilling (i.e., routine operations);
  - others TBD (pending acquisition of forms to be used).
- Time:
  - work structure (i.e., overall activities),
  - bit changes,
  - circulation losses, and
  - penetration rates (units and intervals TBD).

- Core:
  - run number,
  - starting footage,
  - ending footage,
  - footage recovered,
  - percent recovered, and
  - generalized description of core condition.
- Compressor:

  cfm x psi being used and pressure at compressor while drilling and while cleaning hole.
- Circulation:
  - type, amount used, and amount lost.
- Dust control system:
  - model used, problems, and frequency of service intervals.
- Problem areas (TBD).
- Participants/observers:
  - name and affiliation.

12. Procedure for Moving Equipment in Confined Spaces

Core-drilling equipment, including the drill rigs, will be moved or relocated underground using a mucking machine or similar equipment consistent with standard G-tunnel operational procedures. Very short rig moves may be handled with the drill rig winch where conditions permit. The multipurpose drill, if available, is self-propelling.

13. Hole Deviation Survey

Hole deviation surveys will be conducted at the discretion of the PI. The survey will use "single-shot" readings on stations as the hole progresses. The frequency of the stations is to be determined by the PI or his designated representative. The need for a surface collar continuous-readout survey when the hole reaches total depth is a possibility if the hole deviates excessively. The judgment of excessive hole deviation and the resulting need for a continuous survey will be at the discretion of the PI or the PI's designated representative present during the drilling.

14. Hole Geophysical Survey

It is probable that most PIs will want some combination of types of geophysical logs run in the drill holes associated with their test. The specific suite of logs to be run on a hole will be contingent upon the project use of the hole, the needs of the PI, the presence or absence of casing in the hole, hole conditions, and similar site-specific or test-specific parameters. For that reason, the need for geophysical logging will be at the discretion of the PI requesting support for the test.

This page intentionally left blank.

APPENDIX B (cont)

SUPPORTING DATA

9. Dust Collection Graphs and Table

This page intentionally left blank.

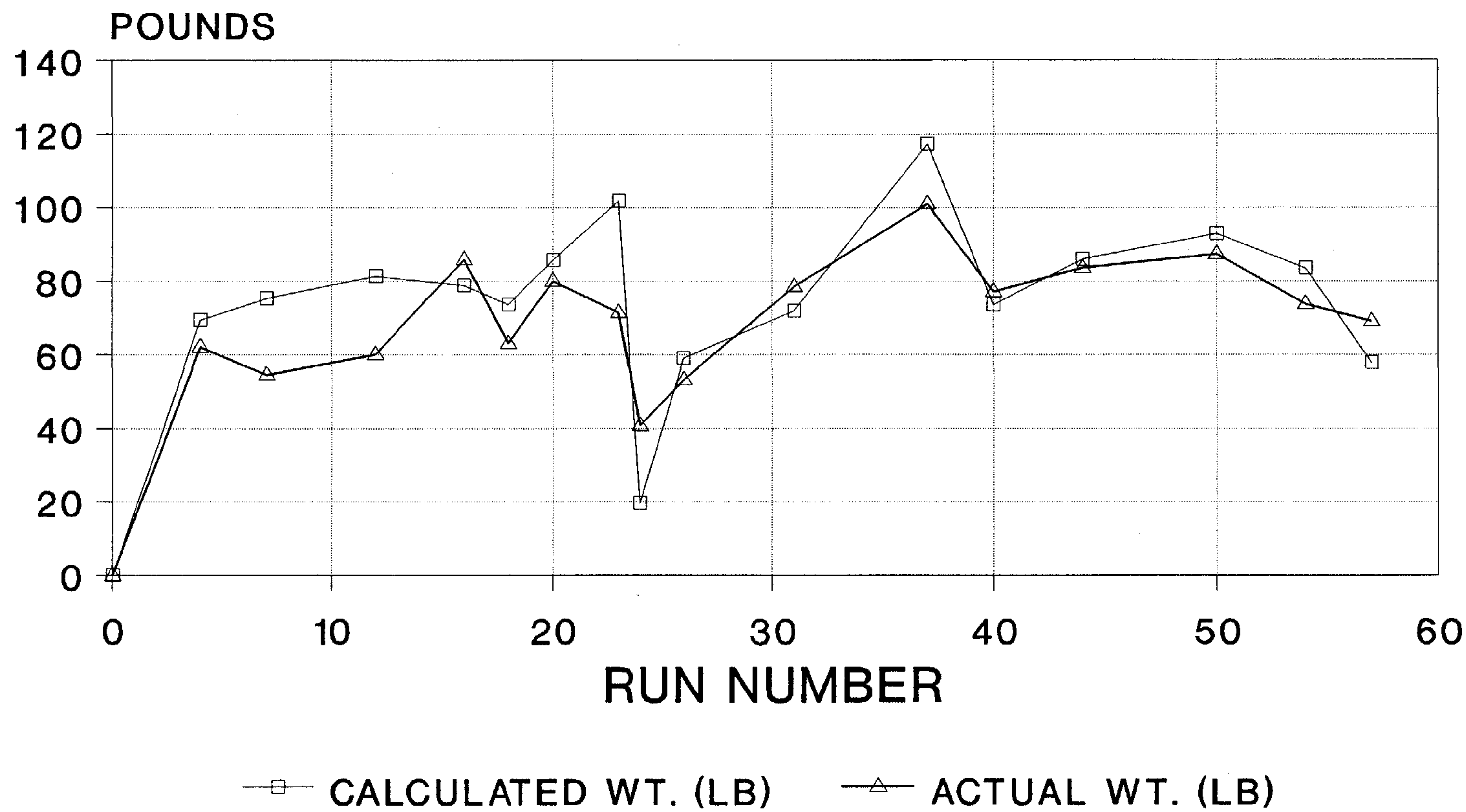
DUST COLLECTION DATA

Explanatory Note

The following table and graphs present data to evaluate dust generation by the bit kerf for comparison with the dust captured in the DCS. This allows a simple dust "budget" to be derived for hole AC-2. However, the calculated kerf dust data should be considered cautiously because slight changes in the elements of the calculation can greatly affect the results. Parameters of particular importance are natural bulk density, moisture, and fracture volumes. Based on a preliminary analysis of four random samples, 50% of the dust-sized particles averaged less than 10 μ in size (very fine silt); of these, the majority was between 0.5 and 4 μ in size.

DUST COLLECTION FOR AC-2

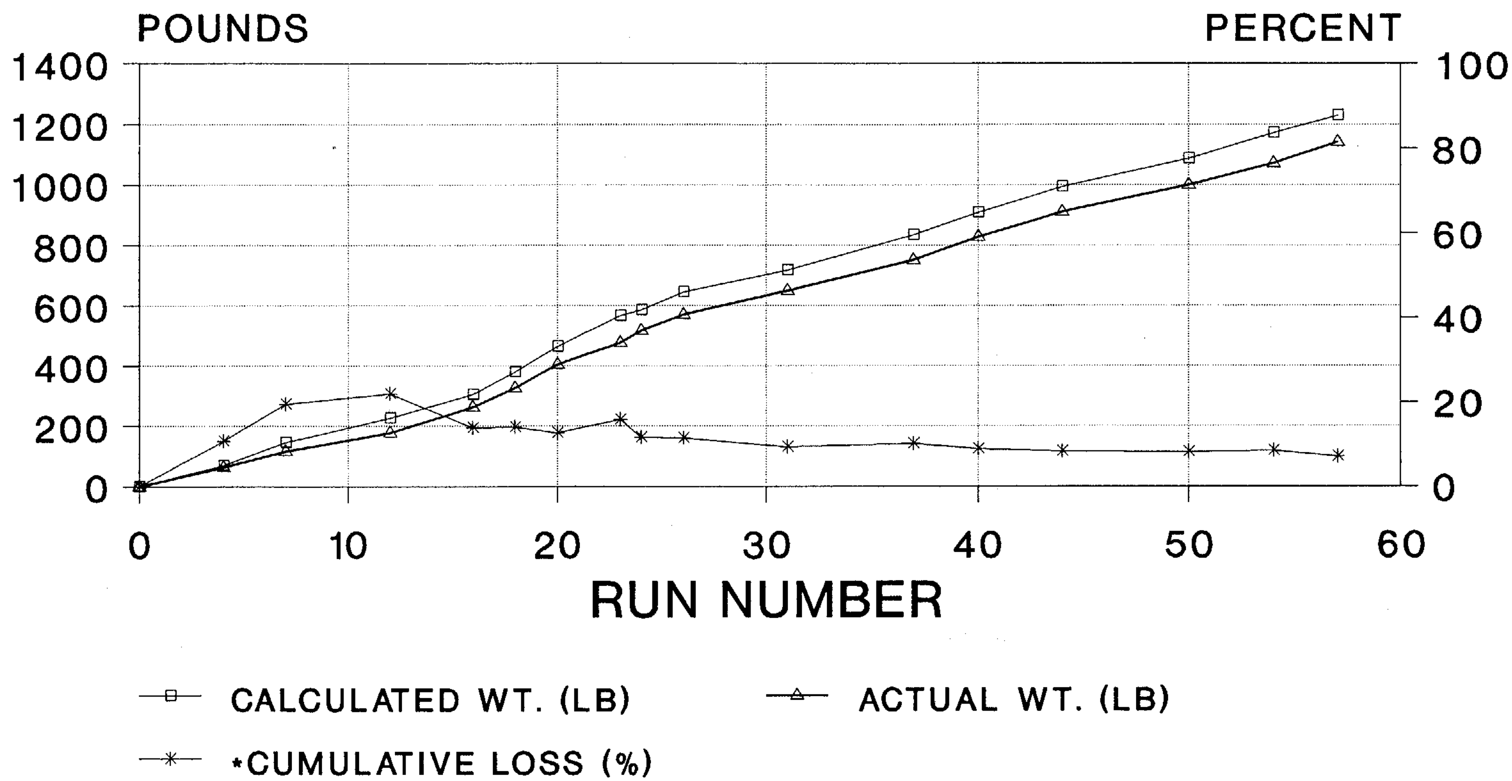
Bit-Kerf Dust Generation



Data points indicate weight of dust in
DCT bags and run interval when changed.

DUST BUDGET FOR AC-2

Bit-Kerf Dust Generation



*Expressed as a percentage of the calculated weight of dust expected to be generated (total loss=7.1% or 86.9 lb).

DUST COLLECTION DATA FOR AC-2

Runs	Footage	Calculated Weight (lb)	Cumulative Calculated Weight (lb)	Actual Weight (lb)	Cumulative Actual Weight (lb)	Net Loss (-) or Gain (+)	Cumulative Change (lb)	Cumulative Dust Loss % of Calculated
1-4	0-8.1	69.4	69.4	62.0	62.0	-7.4	-7.4	10.7
5-7	8.1-16.9	75.4	144.8	54.5	116.5	-20.9	-28.3	19.5
8-12	16.9-26.4	81.4	226.2	60.1	176.6	-21.3	-49.6	21.9
13-16	26.4-35.6	78.8	305.0	85.9	262.5	+7.1	-42.5	13.9
17-18	35.6-44.2	73.7	378.7	63.0	325.5	-10.7	-53.2	14.0
19-20	44.2-54.2	85.7	464.4	80.0	405.5	-5.7	-58.9	12.7
21-23	54.2-66.1	101.9	566.3	71.5	477.0	-30.4	-89.3	15.8
24	66.1-68.4	19.7	586.0	40.8	517.8	+21.1	-68.2	11.6
25-26	68.4-75.3	59.1	645.1	53.2	571.0	-5.9	-74.1	11.5
27-31	75.3-83.7	72.0	717.1	78.5	649.5	+6.5	-67.6	9.4
32-37	83.7-97.4	117.3	834.4	101.0	750.5	-16.3	-83.9	10.1
38-40	97.4-106.0	73.7	908.1	77.1	827.6	+3.4	-80.5	8.9
41-44	106.0-117.2	86.0	994.1	83.7	911.3	-2.3	-82.8	8.3
45-50	117.2-130.2	92.9	1087.0	87.4	998.7	-5.5	-88.3	8.1
51-54	130.2-141.9	83.6	1170.6	73.8	1072.5	-9.8	-98.1	8.4
55-57	141.9-150.0	57.9	1228.5	69.1	1141.6	+11.2	-86.9	7.1
Totals	150	1228.5		1141.6		86.9		

APPENDIX C

QUALITY ASSURANCE

The quality assurance level of this document is QA Level III.

The data presented in this report can be found in the following notebook: TWS-ESS-1-4/89-43.

REFERENCES

Best, D. A., G. M. Cordell, and J. A. Haston, 1985, "Underground Test Facility: Shaft and Tunnel Laboratory for Horizontal Well Technology," SPE 14333, report prepared by the Alberta Oil Sands Technology & Research Authority for presentation at the 60th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers held in Las Vegas, Nevada, September 22-25, 1985. NNA.910109.0343

Bish, D. L., and D. T. Vaniman, 1985, "Mineralogic Summary of Yucca Mountain, Nevada," LA-10543-MS, Los Alamos National Laboratory, Los Alamos, New Mexico. NNA.870407.0330

Byers, F. M., Jr., 1985, "Petrochemical Variation of Topopah Spring Tuff Matrix with Depth (Stratigraphic Level), Drill Hole USW G-4, Yucca Mountain, Nevada," LA-10561-MS, Los Alamos National Laboratory, Los Alamos, New Mexico. HQS.880517.1103

Carroll, R. D., and M. J. Cunningham, 1980, "Geophysical Investigations in Deep Horizontal Holes Drilled Ahead of Tunneling," International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, Vol. 17. NNA.940418.0007

Connolly, J. R., and K. Keil, 1985, "Field, Petrologic, and Geochemical Relations of the Grouse Canyon Member of the Belted Range Tuff in the GTUF Rock Mechanics Test Area, U12g Tunnel, Nevada Test Site," Contractor Report SAND84-7206, Sandia National Laboratories, Albuquerque, New Mexico. NNA.900711.0095

Connolly, J. R., W. L. Mansker, R. Hicks, C. C. Allen, J. Husler, K. Keil, and A. R. Lappin, 1983, "Petrology and Geochemistry of the Grouse Canyon Member of the Belted Range Tuff, Rock-Mechanics Drift, U12g Tunnel, Nevada Test Site," SAND81-1970, Sandia National Laboratories, Albuquerque, New Mexico. NNA.900702.0024

Langkopf, B. S., and P. R. Gnirk, 1986, "Nevada Nuclear Waste Storage Investigations Project: Rock-Mass Classification of Candidate Repository Units at Yucca Mountain, Nye County, Nevada," SAND82-2034, Sandia National Laboratories, Albuquerque, New Mexico. HQS.880517.1662

Larkin, K. P., and J. L. Speake, 1976, "Horizontal Monitoring Holes, Los Alamos, New Mexico," Report NVO-410-36, prepared by Reynolds Electrical & Engineering Co., Inc., for U.S. Energy Research and Development Administration, Nevada Operations Office, Las Vegas, Nevada. NNA.910109.0344

Maldonado, F., and S. L. Koether, 1983, "Stratigraphy, Structure, and Some Petrographic Features of Tertiary Volcanic Rocks at the USW G-2 Drill Hole, Yucca Mountain, Nye County, Nevada," Open-File Report 83-732, U.S. Geological Survey, Denver, Colorado. HQS.880517.1329

Montazer, P., 1985a, "Rationale for Air Drilling/Coring in the Exploratory Shaft and Test Chambers" (6 page draft) and "Preliminary Outline of Design Needs for Prototype Air-Coring Tests in G-Tunnel" (5 page draft) with letter (available from authors) from P. Montazer, USGS/Nuclear Hydrology Program to P. Aamodt, Los Alamos National Laboratory, providing input for planning the Prototype Air-Coring Test. NNA.940418.0008-NNA.940418.0009 NNA.940418.0010-NNA.940418.0011

Montazer, P., 1985b, letter (available from authors) from P. Montazer, USGS/Nuclear Hydrology Program to P. Aamodt, Los Alamos National Laboratory. NNA.940418.0012-NNA.940418.0013

Montazer, P., 1986, letter (available from authors) from P. Montazer, USGS/Nuclear Hydrology Program to M. Blanchard, Department of Energy/Waste Management Project Office. NNA.940418.0014

Montazer, P., and W. Wilson, 1984, "Conceptual Hydrologic Model in the Unsaturated Zone, Yucca Mountain, Nevada," Water-Resources Investigations Report 84-4345, U.S. Geological Survey, Lakewood, Colorado. HQS.880517.1675

NNWSI Project Detailed Test Plan for Experimental Procedure: Evaluation of Potential Dust-Relating Health Hazards Associated with Driling, NNWSI WBS Element 1.2.6.9.4.6.1.B. NNA.940517.0227

Norris, A. E., F. M. Byers, Jr., and T. J. Merson, 1986, "Fran Ridge Horizontal Coring Summary Report Hole UE-25h#1, Yucca Mountain Area, Nye County, Nevada," LA-10859-MS, Los Alamos National Laboratory, Los Alamos, New Mexico. HQS.880517.1359

Odum, J. K., August 1988, letter (available from authors) from Jack K. Odum, Branch of Geologic Risk Assessment, U.S. Geological Survey, to J. M. Ray, Los Alamos National Laboratory. NNA.940418.0006

Purtymun, W. D., M. L. Wheeler, and M. A. Rogers, 1978, "Geologic Description of Cores from Holes P-3 MH-1 through P-3 MH-5, Area G, Technical Area 54," LA-7308-MS, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

Ray, J. M., 1985, "Short Hole Prototype Horizontal Air-Coring in G-Tunnel," TWS-ESS-1-12/85-1, Draft Proposal, Los Alamos National Laboratory, Los Alamos, New Mexico. NNA.900427.0141

Ray, J. M., and J. C. Newsom, 1987a, "Prototype Test Plan 6.1, Prototype Air-Coring, WBS 1.2.6.9.4.6.1.A," (attachment to design criteria letters) submitted to the Department of Energy/Waste Management Project Office (TWS-ESS-1-7/87-11). NNA.870922.0059

Ray, J. M., and J. C. Newsom, 1987b, "ESF Drilling Equipment Options: Recommendations and Rationale," unpublished draft document prepared for the Department of Energy/Waste Management Project Office by Los Alamos National Laboratory to assist DOE in planning and logistics for Yucca Mountain Exploratory Shaft Facility drilling requirements. NNA.910109.0349

Ray, J. M., and J. C. Newsom, 1987c, "Prototype Tests Drilling Requirements," in Cost Estimates for Prototype Test Drilling Activities (Aamodt, P., Letter, TWS-ESS-1-8/87-35, 1987, to R. Bullock, Appendix A-I & II). NNA.940418.0015

Ray, J. M., and J. C. Newsom, 1987d, Appendix A of the "Prototype Test Plans, Revision 1," prepared by Los Alamos National Laboratory for the Department of Energy/Waste Management Project Office (TWS-ESS-1-8/87-36). NNA.870827.0017

Ray, J. M., and J. C. Newsom, 1988, "ESF Drilling Requirements," solicited compilation update of test-related ESF drilling requirements referenced as Appendix C in the Subsystem Design Requirements Document prepared by Los Alamos National Laboratory for the Department of Energy/Waste Management Project Office (reference TWS-ESS-1/LV-05/88-01). NNA.880505.0008

Robison, J. H., 1984, "Ground-Water Level Data and Preliminary Potentiometric-Surface Maps, Yucca Mountain and Vicinity, Nye County, Nevada," Water-Resources Investigations Report 84-4197, U.S. Geological Survey, Lakewood, Colorado. HQS.880517.1404

Scott, R. B., and J. Bonk, 1984, "Preliminary Geologic Map of Yucca Mountain, Nye County, Nevada, with Geologic Sections," Open-File Report 84-494, U.S. Geological Survey, Denver, Colorado. HQS.880517.1443

Scott, R. B., and M. Castellanos, 1984, "Stratigraphic and Structural Relations of Volcanic Rocks in Drill Holes USW GU-3 and USW G-3, Yucca Mountain, Nye County, Nevada," Open-File Report 84-491, U.S. Geological Survey, Denver, Colorado. HQS.880517.1444

Teasdale, W. E., and R. R. Pemberton, 1984, "Wireline-Rotary Air-coring of the Bandelier Tuff, Los Alamos, New Mexico," Water-Resources Investigations Report 84-4176, U.S. Geological Survey, Denver, Colorado. NNA.900103.0193

The Robbins Company, 1984, "Small Diameter Horizontal Hole Drilling - State of Technology," Contractor Report SAND84-7103, Sandia National Laboratories, Albuquerque, New Mexico. NNA.900810.0485

Vaniman, D., D. Bish, D. Broxton, F. Byers, G. Heiken, B. Carlos, E. Semarge, F. Caporuscio, and R. Gooley, 1984, "Variations in Authigenic Mineralogy and Sorptive Zeolite Abundance at Yucca Mountain, Nevada, Based on Studies of Drill Cores USW GU-3 and G-3," LA-9707-MS, Los Alamos National Laboratory, Los Alamos, New Mexico. NNA.870519.0043

Zimmerman, R. M., M. L. Blanford, J. F. Holland, R. L. Schuch, and W. H. Barrett, 1986, "Nevada Nuclear Waste Storage Investigations Project: Final Report G-Tunnel Small Diameter Heater Experiments," SAND84-2621, Sandia National Laboratories, Albuquerque, New Mexico. HQS.880517.2365

*U.S. GOVERNMENT PRINTING OFFICE 1994-0-673-029/7059