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Nevada Nuclear Waste Storage Investigations Project

Design of a Machine to Bore and Line a Long Horizontal Hole in Tuff

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Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789

Printed September 1987

"Prepared by Nevada Nuclear Waste Storage Investigations (NNWSI) Project participants as part of the Civilian Radioactive Waste Management Program (CRWM). The NNWSI Project is managed by the Waste Management Project Office (WMPO) of the U. S. Department of Energy, Nevada Operations Office (DOE/NV). NNWSI Project work is sponsored by the Office of Geologic Repositories (OGR) of the DOE Office of Civilian Radioactive Waste Management (OCRWM)."

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A08
Microfiche copy: A01

Distribution
Category UC-70

SAND86-7004
Unlimited Release
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DESIGN OF A MACHINE TO BORE AND LINE A LONG HORIZONTAL HOLE IN TUFF

by

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Under Sandia Contract 47-2295

Sandia Contract Monitor
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ABSTRACT

This report describes an engineering design for equipment capable of simultaneously drilling and lining deep horizontal bore holes. The ultimate use of the equipment is to bore up to 600 ft. long, 3 ft. diameter emplacement holes for a nuclear waste repository. The specific system designed is referred to as a Developmental Prototype Boring Machine (DPBM) which will be used to demonstrate the drilling/lining capability in field development tests.

The system utilizes an in-hole electric drive and a vacuum chip removal and handling system. The drilling unit is capable of active directional control and uses laser-type alignment equipment. The system combines the features of a small steerable tunnel boring machine, combined with a horizontally-oriented raise drill, thereby utilizing current technology. All elements of the system are compact and mobile as required for a shaft entry, underground mining environment.

CONTENTS

FIGURES

TABLES

APPENDICES

1.0 INTRODUCTION

The work described in this report was performed for Sandia National Laboratories (SNL) as part of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project. Sandia is one of the principal organizations participating in the project, managed by the U.S. Department of Energy's Nevada Operations Office. The project is part of the Department of Energy's program to safely dispose of the radioactive waste from nuclear power plants.

The Department of Energy has determined that the safest and most feasible method currently known for the disposal of such wastes is to emplace them in mined geologic repositories. The NNWSI Project is conducting detailed studies of an area on and near the Nevada Test Site (NTS) in southern Nevada to determine the feasibility of developing a repository in tuff.

One promising method of storing radioactive containers is using long (up to 600 ft.) horizontal boreholes. The boreholes could be drilled into the rib (side) of an underground haulage way. The specifications for the hole, including those for accuracy, the use of a noncontaminating drilling fluid, and for simultaneous lining, require an extension of current drilling technology. Sandia report SAND84-7209, prepared by The Robbins Company under contract 47-2295 Phase I, presented a trade study and a conceptual design of a drilling system to meet the requirements.

This report, covering the effort authorized under Amendment 4 of contract 47-2295, documents the detailed design of the Developmental Prototype Boring Machine (DPBM). A complete set of shop drawings for the DPBM was the principal deliverable item and was transmitted to Sandia under separate cover in October 1985.

In addition to the design documentation, this report includes an operating scenario for testing the DPBM at a specific site in the G-Tunnel complex at the NTS. A layout of the site was made showing recommended additional excavation, placement of units of the system, and additional test support equipment required. An estimated drilling schedule and manpower requirements for a test operation are provided.

The remainder of this report contains three sections and numerous supporting appendices. Section 2 describes the technical basis (background, objectives, and approach) for the study, summarizes the DPBM design and operating scenario for testing, and provides the conclusions and recommendations drawn in this study. Sections 3 and 4 provide, respectively, detailed technical descriptions of the DPBM system and an operating scenario for testing the system.

2.0 SUMMARY

The design effort of the DPBM was accomplished in a two-phase project. Phase I of Contract 47-2295 completed an engineering trade study of design options and produced a conceptual system design. A separate Phase I report, SAND84-7209, detailed this effort. This report covers the Phase II effort, detail design of the DPBM.

2.1 Background, Phase I Concept Design

In Phase 1, a matrix trade-off study evaluated a number of conceptual design options. The highest rated concept was a system featuring a non-rotating drill string with a pull-in liner. A major factor in the selection of this system is its operational independence from the liner. The design allows variable liner thickness, permits the option of a smooth I.D. protruding fittings, and minimizes the structural requirements of the liner. Further, the design allows drilling the hole with or without a liner.

Figure 1 illustrates the Phase I system concept for the simultaneous drilling/lining of horizontal emplacement holes. Principal features include:

a. A drilling unit with an eccentric cutterhead. This feature allows the drill to be removed from the hole, through a permanently emplaced steel liner. The drill can also be withdrawn from a partially completed hole in the event repairs are required and can be reinserted through the liner to continue operations.

b. An in-hole gear train and electric motor.

c. A nonrotating drill string that provides thrust for the cutterhead and liner installation.

d. A manually controlled laser guidance system.

e. A vacuum muck removal subsystem.

One of the optional designs studied in Phase I, incorporated the lining as a non-rotating "drill string," providing both the cutterhead and pipe jacking forces. This configuration was of interest because it greatly simplified the drill design by eliminating all of the drill pipe components and their handling mechanisms.

The concept was not selected, however, because it incorporated the lining as an essential structural component of the drill system. At the close of Phase I (June 1985), the hole lining was still viewed as an option, and if

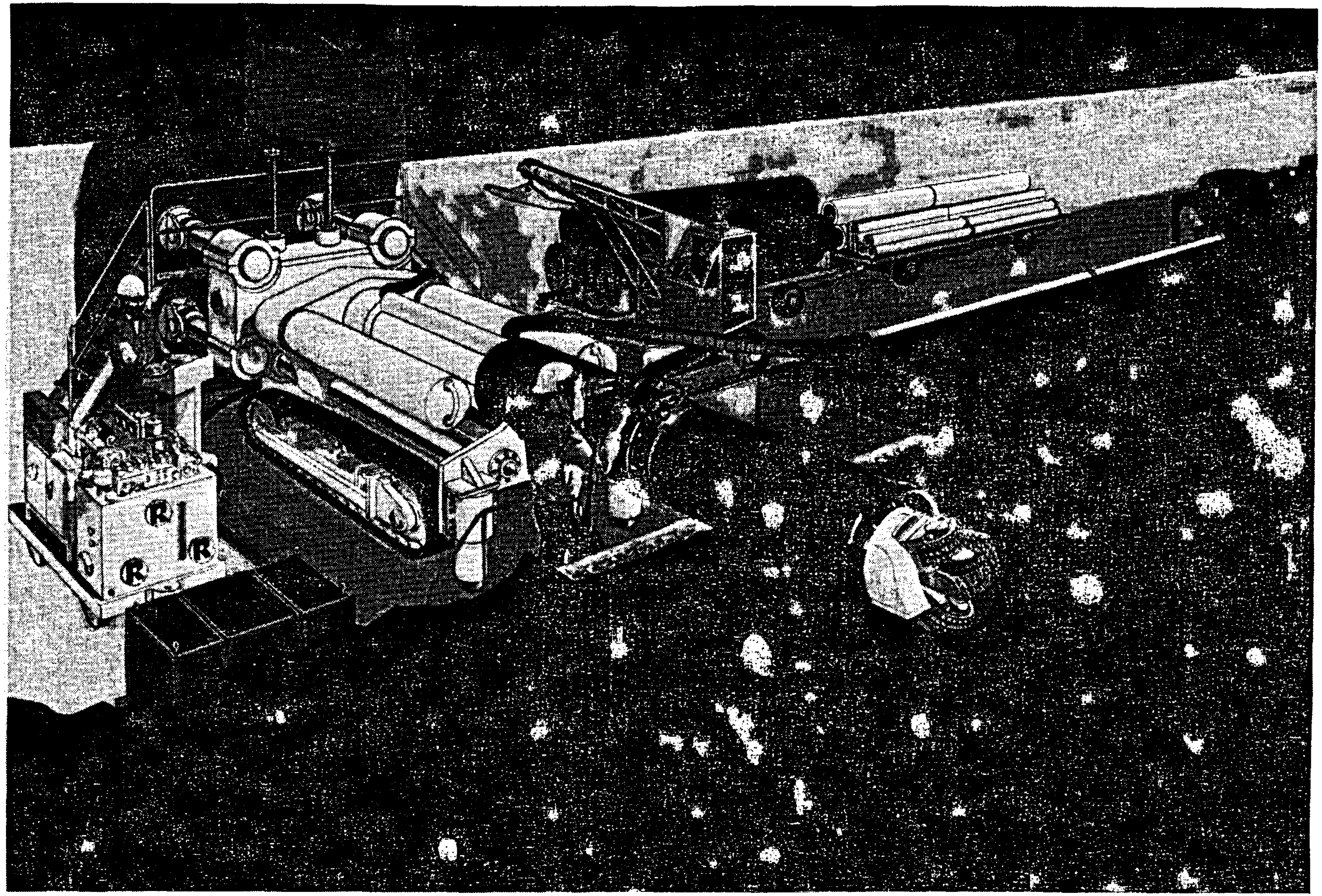

FIGURE 1 - Phase I, Horizontal Drill Concept Design

used, might only be thin shell to prevent water or raveling material from contacting canisters.

When Phase II was initiated, a minimum 3/8 inch thick liner was specified. This added specification re-opened the case for an integrated drill-string and liner. Therefore, before proceeding to detail design of the Phase I selected unit, a critical review of the concept was conducted. This resulted in substantial changes in the concept selected for detail design. Results of this review are discussed in Section 2.3.

2.2 Phase II Objectives and Requirements

The principal objective of Phase II was to produce detailed fabrication drawings and specifications for a DPBM. The DPBM was to be a functional version of the horizontal boring machine conceptually designed under Phase I of the contract but suitable for development and demonstration testing.

The DPBM was to be designed with a minimum of sophisticated parts and equipment, without jeopardizing the overall operation or performance of the system. The major performance requirements are those of the Phase I contract, modified by Amendments 4, 6, 7, and 8. These requirements are combined and summarized as follows:

a. The machine shall be capable of boring and simultaneously lining the required hole with a steel liner. The liner will be 35.0 in. inside diameter with a wall thickness of .375 in. The borehole inside diameter shall not exceed 37.0 in.

b. The maximum hole depth to be considered for design purposes shall be 600 ft.

c. The method of drilling shall not result in contamination of the borehole or adjacent rock due to drilling fluids.

d. The unit shall be as compact as reasonable and operate from a mine drift and cut out 30 ft. long by 11 ft. high by 20 ft. wide. Further, it shall break down into components 4.5 x 4.5 x 15 ft. for lowering into a shaft.

e. The drill system shall be transportable from one drilling location to another. Set-up and knockdown shall be minimized.

f. The unit shall comply with all applicable mining codes and standards.

g. The hole deviation from a straight line shall not exceed 6.0 in. in 100 ft. The total deviation of a 600 ft. hole shall not exceed 12 in.

h. The drill derrick structure shall provide the adjustment capability to permit holes to be drilled at an angle of 1.5^{o} above or below the horizontal.

i. The unit shall make use of standard components, such as drill pipes, bits, etc., where feasible.

j. The centerline of the bore above the haulage way floor shall be 72 in.

k. Following completion of the bore, or to perform machine repairs or to replace cutters, the inhole drill shall be capable of being withdrawn through the liner and shall be capable of reinsertion.

l. Instrumentation, console, and controls shall provide for recording equipment and measurements for a permanent performance record for subsequent evaluation.

m. Steel liner sections shall be welded to provide a continuous, watertight liner.

n. The DPBM system shall be capable of operating in an underground environment and drilling rock having the following characteristics:

<u>UNDERGROUND ENVIRONMENT</u>	<u>REPOSITORY</u>	<u>G-TUNNEL</u>
Ambient Rock Temp.	35°C	24°C
Air Temperature	20 - 35°C	20 - 30°
Relative Humidity	to 100%	to 100%
Altitude above Sea Level	3400 ft.	6300 ft.

<u>ROCK PROPERTIES</u>

Repository:

- densely welded, devitrified tuff;
- fracture spacing approximately seven per ft.;
- density 2.2 gms/cm^3;
- unconfined compressive strength 16,000 to 33,000 psi;
- rock may contain vugs (voids);
- uniaxial strain to failure approximately .41 to .97%; and
- rock may be saturated.

G-Tunnel:

- densely welded tuff;
- fracture spacing at least 12 per ft.;
- rock contains pumice inclusions and vugs, abrasive;

- unconfined compressive strength of 12,000 to 15,000 psi; and
- rock may be saturated.

A second objective, in addition to designing the drilling system, was to develop an operating scenario for initial tests at a specific location in the G-Tunnel complex of the Nevada Test Site. The scenario includes equipment layout, utility requirements, schedule, manpower requirements, and a step-by-step procedure for setup and operation of the DPBM. The intention is to drill two holes in a welded tuff formation between two existing drifts approximately 250 ft. apart.

2.3 Project Approach

Before initiating the Phase II effort detail design, a project review was conducted with three objectives:

a. Review and assure validity of the Phase I conclusions;

b. Assess current repository and project requirements; and

c. Simplify the drilling system, with goals of increasing reliability and reducing costs.

The review concluded that an option to drill the repository hole with or without lining was no longer necessary. From a further understanding of the geology involved and an emphasis on long-term retrievability, simultaneous drill/line appears to be the most viable option. Also, two other parameters had changes: (1) the proposed operational drift height was lowered by 1.0 ft.; and (2) preliminary testing of the DPBM would occur at a higher elevation. With the above requirement modifications and the effort to simplify the DPBM system, the following changes were made to the Phase I concept design:

a. Significant simplification of the drill and derrick units resulted by using the required liner to transmit thrust and torque reaction. This change eliminated the independent drill string, stabilizers, and related handling equipment.

b. The muck tube function and design was revised to include removal and reinsertion of the in-hole drill unit.

c. The drill electric drive motor is air cooled, rather than water cooled. This eliminated the need for a closed loop water supply in-hole.

d. The method of steering on the Phase I design pivoted the rear of the drill assembly about a fulcrum located near the cutterhead. This was changed to a direct wedging arrangement using shoes at the forward end of the drill assembly. A ball joint was provided at the rear of the drill to permit the pivoting movement. The change eliminated a complex yoke and universal joint.

e. The method of isolating the cutterhead load from the liner insertion thrust was redesigned. The modified system isolated stabilizer shoe friction, as well as liner friction from the cutterhead thrust. As overload protection for the cutterhead, instrumentation was included to warn the operator if "bottoming out" of the cutterhead isolation system had occurred.

f. The laser beam position was moved from a perimeter location to the bore centerline. This position eliminated the requirement for roll correction.

g. The in-hole hydraulic power pack was changed to a self-contained unit behind the motor, rather than being a power takeoff of the gearbox. This arrangement can provide hydraulic pressure without cutterhead rotation. This feature allows cutterhead indexing and positive functioning of the stabilizer/steering shoes for withdrawal and reinsertion of the drill unit.

h. The tricone bit on the cutterhead and its associated air supply has been replaced by an improved cutter arrangement. This simplified the umbilical connection down-hole and replaced a low reliability component.

i. The derrick system was rotated 90° on its carrier to permit side loading of the muck tube and liner. This makes installation of the liner physically simpler and reduces the head room requirement above the derrick.

j. The vacuum system components were rearranged to provide smaller individual skid mounted elements. Total capacity was unchanged, but two drop box units in tandem are used. The filter unit was separated from the pump unit, each mounted on separate skids.

2.4 Brief Description of the DPBM System

Artist sketches of the drill and derrick are shown in Figure 2 and the muck handling system is shown in Figure 3. These sketches show major components of the system and how they might be arranged in the haulageway of a nuclear waste repository.

The immediately following paragraphs are summary descriptions of the principal components. Further details are located in Section 3 and Appendix 1 is a complete indentured parts list. Appendix 2 contains the assembly drawings of the principal system components.

2.4.1 In-Hole Assembly, Ref. Drawing D35911

The drill unit operates from within a 36 in. outside diameter shield. When the drill is removed after completing the hole, the shield is left behind and forms part of the continuous liner. The drill unit is anchored

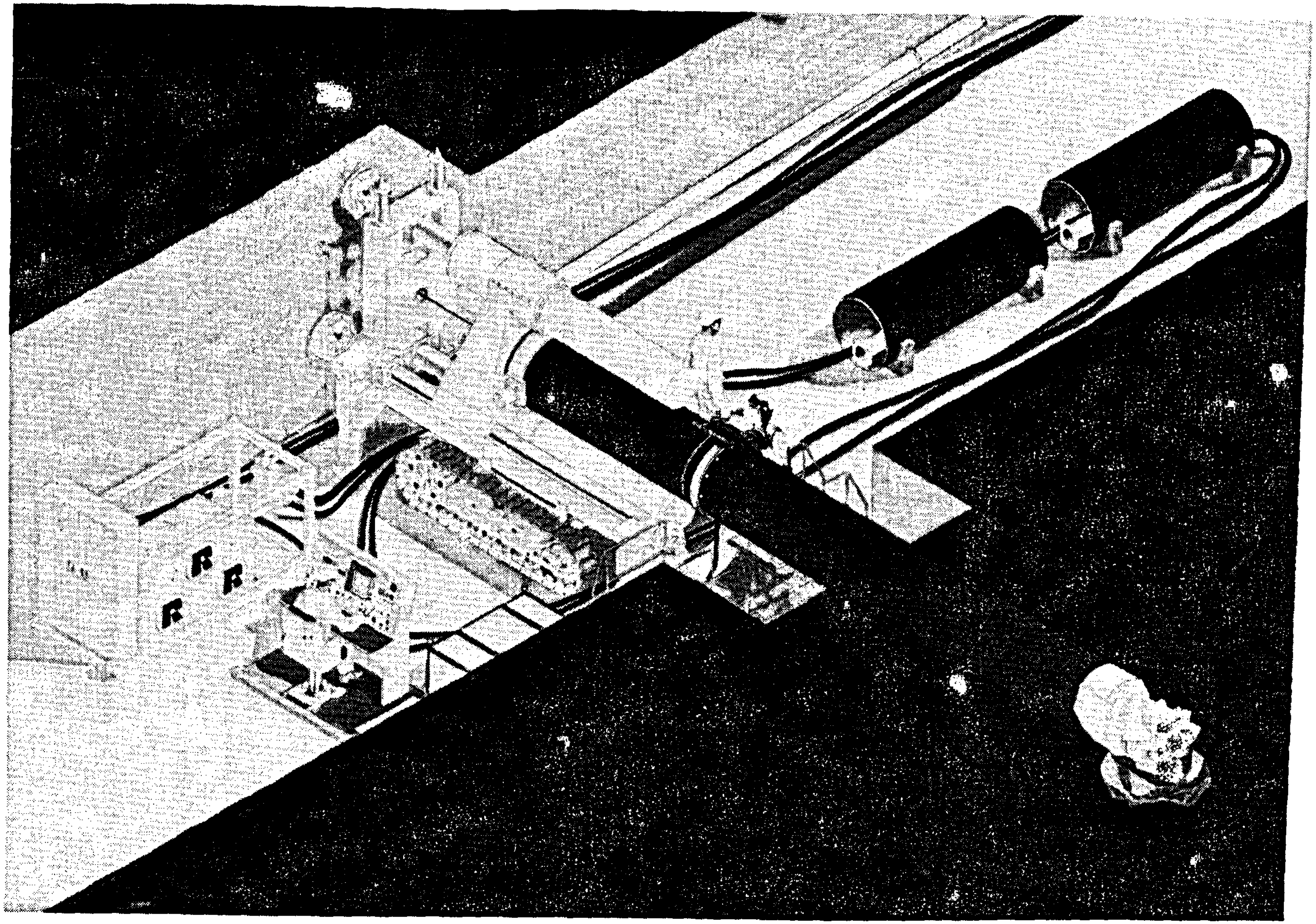

FIGURE 2 - Phase II, DPBM Drill and Derrick

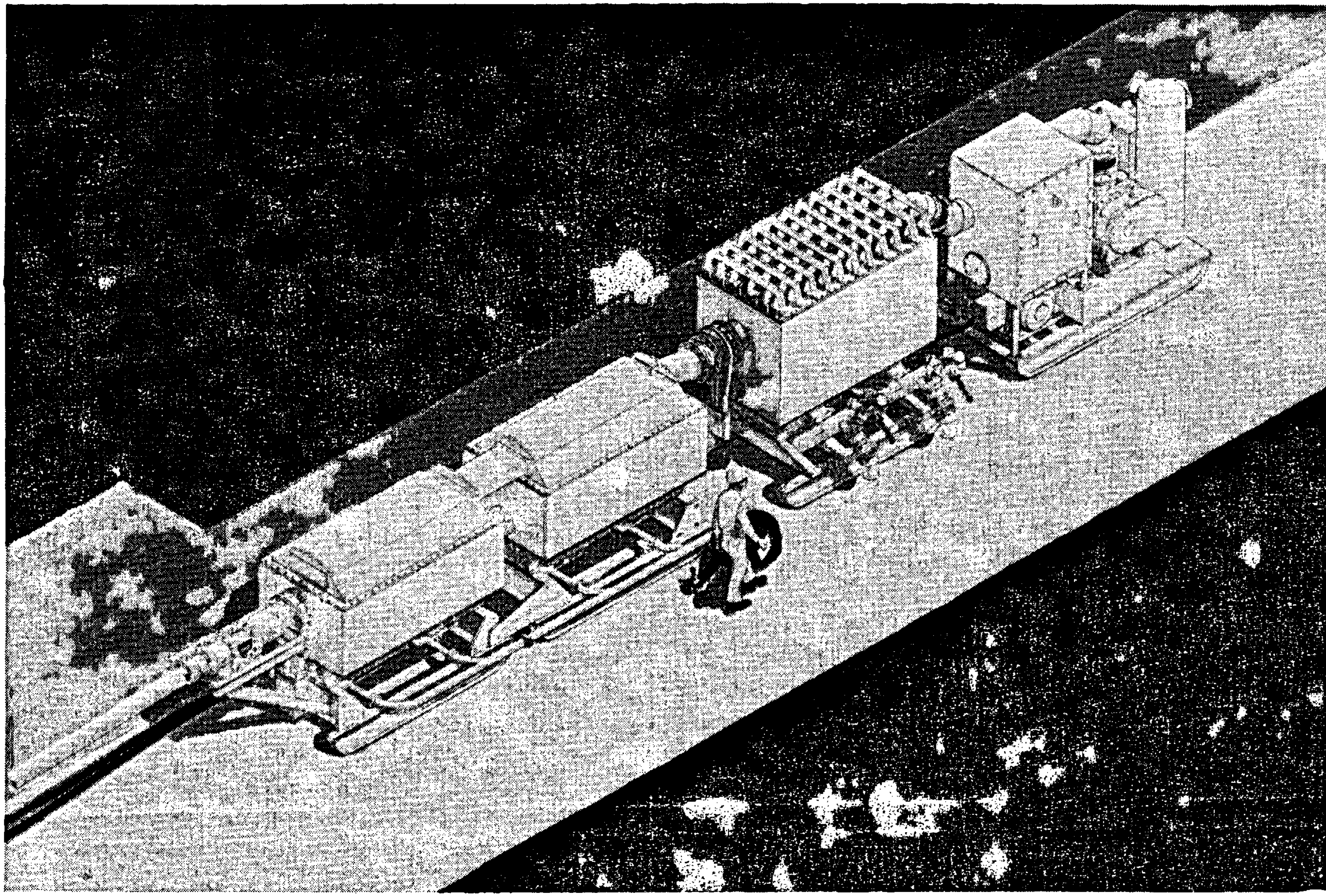

FIGURE 3 - Phase II, DPBM Muck Handling System

into the shield during the boring operation by a hydraulically operated locking device.

The cutterhead and its drive system can be pivoted about a torque reacting ball joint by means of four hydraulic cylinders. The pivoting action allows for directional corrections as well as for positioning the cutterhead for withdrawal. While boring, the cutterhead rotates about a point not its geometric center. This eccentric rotation permits the 34 in. diameter cutterhead to bore a 37 in. diameter hole. When the cutterhead is to be withdrawn from the liner (or inserted) it is indexed and moved to the center of the shield. Since the maximum diameter of the drill unit in this position is only 34 in., the drill clears the inside of the shield and liner.

The cutterhead is fitted with three tungsten carbide insert cutters on the head. The two inside cutters are cantilever-mounted and the outside, or gage cutter, is a three-row, saddle-mounted unit. This arrangement provides dynamic balance of the head while boring. Radial forces are stabilized by hydraulically loading the upper steering shoe against the bore.

Cutterhead rotation is provided by a 125 hp, air-cooled electric motor driving through a planetary gearbox. Cutterhead thrust, as well as lining insertion thrust, is provided by hydraulic cylinders mounted on the derrick. To prevent damage by overloading, cutterhead thrust is limited by a passive hydraulic cushion integral with the drive unit. Instrumentation is provided to control and monitor the thrust which is applied to the cutterhead.

The muck port into the vacuum tube is located immediately behind the cutterhead in the 4 to 5 o'clock position. Cuttings are propelled into the port by a single fixed blade mounted adjacent to the gage cutter on the cutterhead.

In-hole hydraulic power for steering, engaging the drill into the shield, etc., is supplied by a separate hydraulic pack. This 5 HP pack is mounted on a trailing unit immediately behind the ball joint. The functioning of cylinders is controlled by solenoid valves. This arrangement permits an umbilical connection with only electrical power and signal cables.

2.4.2 Mobile Derrick, Ref. Drawing D35920

The derrick unit provides the thrust and torque reaction for the drill. It is mounted on a hydraulically driven crawler unit. The in-hole drill components can also be mounted on the derrick for transportation to the borehole locations.

When in operation, four corner-mounted leveling jacks lift the crawler assembly off the floor. These are also used to set the derrick at the correct angular position and height before boring is started. The main thrust is reacted into the rear wall by three jacks attached to the rear of the derrick. Torque reaction is provided by the floor jacks and two jacks which are in contact with the repository roof.

The thrust is provided by two hydraulic cylinders, mounted vertically above below the bore centerline. The thrust is transmitted into the liner by a jacking collar attached to the cylinders. The torque is reacted by gripping the liner wall at two places on the horizontal centerline with hydraulically loaded calipers. The jacking collar slides on a pair of horizontal guide tubes which carry the torque reaction and dead weight loads.

The thrust cylinder stroke is 9.5 ft., which permits clearance for bolting up the muck pipe sections as new liner segments are added.

Attached to the rear of the jacking collar is a 90° muck tube elbow. A telescopic section attached to the elbow connects to the muck tube inside the liner.

When removing the drill from the bored hole by pulling on the muck tube, long stroke mechanical jacks normally nested in the guide tubes are extended to contact the forward tunnel wall and provide load reaction.

The hydraulic supply for the derrick and crawler functions is provided by an independent skid-mounted power unit.

2.4.3 Mucking System, Ref. Drawing D35632

The mucking system, located downstream of the derrick, consists of a transfer pipe, two drop box units, a filter unit, and the vacuum pump unit. The first drop box is connected to the derrick muck pipe elbow by means of a rigid transfer pipe. Ball joints at each end of the pipe and a telescopic unit attached to the front end of the drop box permit the required articulation as the derrick is stroked. The holding capacity of the collection boxes is compatible with the muck quantity produced by one 8 ft. drilling stroke.

The two sequential drop box units separate most particles by deceleration and deflection. A vibrating, coarse mesh filter traps finer particles.

Dust particles are carried to the primary filter unit. This unit contains a number of fabric cartridges which are periodically purged by backflushing with a charge of compressed air. The dust collected is discharged by an inclined, enclosed screw feeder.

The cleaned air then flows to the vacuum pump unit. A secondary polishing or standby safety filter is located on the vacuum unit. The vacuum pump (a lobe-type blower) discharges into a plenum chamber and then via a silencer to atmosphere. The system removes harmful respirable dust particles.

During the time pipe and lining sections are added, the muck collected in the drop boxes is expelled by a pneumatic discharge system.

2.4.4 Liner, Ref. Drawing D36514

The liner is a 36 in. outside diameter steel pipe with a wall thickness of .375 in. The segment length is 8 ft. Pipe is standard commercial tolerance except that ends are sized for alignment and beveled for the welding operation.

2.4.5 Hydraulic Power Unit, Ref. Drawing D35925

This unit combines the hydraulic power supply and the main electric motor control cabinet. A single 75 HP electric motor drives a dual pump system that can supply both high flows at low pressure or low flows at high pressure, as the operating sequence demands.

2.4.6 Welding System

An automatic orbital-type welder will be used to join the liner sections. The welding head is located on a circular track clamped adjacent to the pipe joint. The welding action is controlled by a variable duration pulse system which controls the puddle flow, depending on the arc location. A short test program to set the welding machine operating parameters is required. The test program could also be used to evaluate the best type liner alignment fixture to use.

2.4.7 Control Station Assembly, Ref. Drawing D35928

The main operating controls for the drill, derrick and mucking system are located on the console. Read outs and warning lights on the console continuously monitor the important operating parameters. The controls are interlocked so that the mucking system must be operating before boring begins, and continues to operate after boring ceases to avoid clogging the system. Taps are provided to allow addition of a data recording system.

2.4.8 Laser Guidance System

The laser beam is provided by a unit mounted rigidly to the tunnel wall behind the machine. A clearance hole in the derrick main frame provides a window. The laser is set up at the time of collaring-in the machine and must not be disturbed until the hole is complete. The laser is beamed through the bore centerline to a photo-diode array target located just aft of the ball joint. Steering control is manual in response to a display screen located at the control console.

2.4.9 Muck Tube Assembly, Ref. Drawing D36136

In addition to conveying muck out of the hole, the muck tube is used to pull or push the drill unit in and out of the liner. The tube sections, 8 ft. long to match the liner segments, are joined together with a rigid four-bolt flange. The joints are sealed by a spigot-mounted O-ring. Hangers are attached to the tube to support the electric power and control cables.

2.5 Operational Scenario

A contract change redirected the operational scenario effort from a generic situation to the specific site of initial field trials. A welded tuff formation is exposed at the far end of the G-Tunnel complex at the Nevada Test Site. The site was examined and is well suited for the tests for the following reasons:

a. The rock is a welded tuff, a little lower in compressive strength and with a lower rock quality than is expected in the repository. Rock samples have been analyzed.

b. The location permits drilling from one drift to another. This adds an emergency recovery feature to the test. The in-hole unit could be extracted by mining from the break-through end. The area has room to drill at least two 250 ft. long holes.

c. The use of the area will not interfere with existing test plans.

d. Utilities, power and labor support are close at hand.

The elevation, however, is over 6,300 ft. This substantially reduces the effectiveness of the vacuum muck removal system. However, since the vacuum unit was originally designed for a 600 ft. borehole and the experimental holes will be only 250 ft., the same system can be used.

Preliminary layouts of the site were made. Locations requiring additional excavation were identified, and special tooling requirements were established. A tentative study of operating procedures and manpower requirements was completed. The results are useful for reference and as a guide only. The exact schedule and test requirements will not be known until a definitive test plan is established. The information provided in Section 4.0 of this report can be used as baseline data for scheduling and costing an overall test program.

2.6 Conclusions and Recommendations

The following conclusions and recommendations are not listed in any order that indicates relative significance:

a. The DPBM system described in this report will provide a vehicle for demonstrating a production Horizontal Boring Machine. The principal differences between the DPBM unit and a production unit involve mobility, set-up/tear down, pipe handling, wear life and muck handling behind the system. All basic principles are intended to be equivalent to a production unit and all technology is considered available at this time.

b. A re-evaluation of the operating mode determined that reliability of the boring operation could be increased and cost decreased by using the hole liner as an integral part of the drilling operation. Analyses showed that a maximum of 1.5 million lb. of thrust might be required to insert the lining, and that a .375 in. thick wall of API 5LX-52 pipe is sufficient to ensure against buckling failure.

c. Two areas have been identified as requiring additional development before DPBM trials:

   (1) <u>Liner Welding</u>. No automated, off-the-shelf equipment was found for welding the liner sections at an acceptable speed. Equipment which could be adapted was found, but exact setup, travel speed, bead alloys and number of passes for the weld operation must be established by a small testing program.

   (2) <u>Filter Cart</u>. When physical size limitations for system components were reduced, a standard "bag house" set-up was precluded. Standard filter elements can be used, but the exact method of mounting the elements and installing the cleaning cycle equipment will have to be established before fabricating the filter cart.

d. The design effort to minimize the effects of abrasive wear in the muck pipe, elbows, and drop boxes, etc., was not completed during this project phase. Abrasive wear should be carefully observed during DPBM tests to locate critical points and to determine how to increase the life of the affected components.

e. Physical barriers for noise reduction should be considered for the vacuum muck system. The logical location of the muck system components for the trials of the DPBM is in the access haulage way. Without additional sound barriers, the noise will likely be annoying if not disruptive.

f. The information provided in the operating scenario will be useful in scheduling, staffing and costing a definitive test program. However, because the detailed scope of the test trials was not established at the time this report was written, individual function times should be reviewed before use.

g. A recommended course of action is to build the DPBM, and at the same time create a definitive test plan. The purpose of the tests should be multipurpose and include:

(1) demonstration of the ability of the drill to perform its function in a repository environment;

(2) generation of parametric operating data to further refine a production situation; manpower, cost and schedule; and

(3) design evaluation of the drill and an analysis of its reliability, availability and downtime.

These actions would provide the confidence level needed to make decisions on the layout of the repository so far as the emplacement hole drilling for the horizontal emplacement option is concerned.

3.0 TECHNICAL DESCRIPTION OF DPBM DESIGN

3.1 Review and Evaluation

Before proceeding with detailed design and drawing of the conceptual unit, several critical reviews were held to determine whether or not the approach of the conceptual design study was valid. The conceptual approach for simultaneous boring and lining a long, accurate, horizontal hole was achieved by combining a small, steerable tunnel boring machine with the large thrusting capability of a horizontally-oriented raise drill. The use of an in-hole motor eliminated the rotating drill string and permitted an active steering capability.

A vacuum pneumatic muck removal system was selected through a process of elimination. Liquid drilling fluids were undesirable from the rock contamination stand point, and also presented logistic problems in basically dry repository formations. Mechanical muck removal systems were difficult to fit into the limited space available and lacked reliability in a long, 37 in. diameter hole. A pneumatic pressurized system would fail if leakage into the rock occurred. In contrast, a vacuum system provides cooling air in-hole, locates the mechanical systems outside of the hole and keeps the bore relatively free of dust, making a laser guidance system feasible.

The major performance assumptions of the Phase I conceptual study were deemed valid and again selected. However, when canister retrievability became essential to the repository, the originally optional hole casing, or liner, became a requirement. The major change in concept, therefore, was to reconsider using the liner as the nonrotating drill string during boring. The advantages of this approach include:

a. The load bearing capacity of the in-hole drill-to-shield engagement can be significantly reduced. The thrust load path of the drill string design was down the string, through the attachment mechanism to the shield. Since the liner was being pulled into the hole, this connection had to sustain both the frictional load of the entire liner as well as provide cutterhead thrust. If the thrust is applied directly to the liner at the derrick, only the cutterhead load passes from the shield, through the engagement mechanism to the in-hole drive unit and cutterhead. Since frictional forces on the liner could be as much as ten times the cutterhead thrust, load capacity may be correspondingly reduced, and reliability increased.

b. The elimination of the drill string is a direct cost saving and also reduces handling time.

c. The elimination of the drill string leaves sufficient room inside the liner for personnel access to the in-hole assembly. In the event of a failure, persons could go in the hole to investigate.

d. The torsional stiffness of the liner is very high. This virtually eliminates cumulative wind-up problems of the drill.

e. During drilling, the liner welds are in compression rather than in tension, which is structurally safer.

f. The maximum stress in the liner is adjacent to the derrick rather than at the in-hole unit. Any structural failure is likely to occur out of or near the end of the hole, rather than deep in the bore.

An analysis was conducted to estimate the maximum thrust which could be required to insert the liner to a depth of 600 ft. Appendix 3 states the assumptions and shows the computations. A total of 1.5 million lbs. of thrust will overcome the combination of cutterhead thrust and pipe jacking forces.

In the thrust-liner operating mode, the liner will be in compression, and the wall thickness must be adequate to resist shell buckling. An analytical study was conducted to determine the minimum shell (liner) thickness and material which would provide structural integrity. Appendix 4 contains the analysis and shows that an API 5LX-52 pipe with a wall thickness of .375 or greater is adequate. Optionally, pipe fabricated from A-36 steel at .5 in. minimum wall thickness is acceptable.

The only potential disadvantage of the liner-thrust operating mode is that the liner becomes an integral part of the boring process. Since the lining requirement is not likely to be rescinded, the associated equipment cost savings and reliability increases warranted revising the conceptual drill design. Detail design of the revised concept, therefore, proceeded. A description of the components is contained in the following paragraphs.

Table 1 contains the final system specifications for the DPBM as designed during Phase II.

3.2 In-Hole Assembly, Ref. Drawing D35911

3.2.1 Cutterhead Assembly, Ref. Drawing D36120

The cutterhead arrangement is designed to fit through the liner for retrieval of the drill and also to meet the minimum out-of-balance force allowance.

Three each, multi-row carbide insert cutters are used as shown in Figure 4. Two are the cantilevered conical type, each having five rows of inserts (kerf cutters). The row spacing on each cutter is different to achieve balance and single tracking. The cutter shafts are cast as an integral part of the pedestal mount for strength reasons, and the pedestals are bolted to the machined cutterhead. Bolting allows the

TABLE 1

CONDENSED SYSTEM SPECIFICATIONS

Emplacement Hole	
Bored Diameter	37 in. (new cutters)
Bore Length	to 600 ft.
Bore Angle	Horizontal $\pm$ 1.5^{o}
Liner	
Diameter	36 in. O.D.
Length	8 ft.
Thickness	.38 - .75 in.
Material Options	.38 in. wall - API 5LX52 (52 ksi yield) .50 in. wall - API 5L (35 ksi yield)
Drill Unit	
Cutters	3 multi-row tungsten carbide insert, 2 cantilevered conical (5 row) and 1 saddle mounted (3 row)
Instantaneous Penetration Rate	2 in./min. (10 ft./hr.)
Cutterhead Total Thrust	150,000 lbs.
Cutterhead Torque	20,000 lb.ft.
Cutterhead RPM	30.3
Gear Reducer	Two stage planetary, compound first stage; overall ratio 57.80
Drive Motor	125 HP; 1,800 RPM; 460 V; 3 Phase; 60 Hz.
Diameter of Shield (Shoes Retracted)	36 in.
Length (less power unit)	14 ft. 3 in.
Weight (less power unit)	18,500 lbs.

TABLE 1, continued

In-Hole Power Unit	
Motor	5 HP; 1,800 RPM; 460 V; 3 Phase; 60 Hz.
Pump	Dual output (1.5/.38 gpm) Radial Piston
Fluid	Petroleum base
Pressure (maximum)	4,500 psi. (Maximum relief)
Length	8 ft.
Weight	950 lbs.
Derrick	
Maximum Thrust	1,500,000 lbs.
Maximum Pullback Force (Limited by relief valve)	100,000 lbs.
Thrust Feed Rate	0 - 4 in./min.
Rapid Traverse	44 in./min. (extend) 89 in./min. (retract)
Crawler Speed	0 - 2 mph (175 ft./min.)
Length	17 ft. 10 in.
Height (with crawler)	9 ft. 6 in.
Width (with crawler)	6 ft. 10 in.
Weight (with crawler)	41,900 lbs.
Derrick Power Unit	
Motor	75 HP; 1,200 RPM; 460 V; 3 Phase; 60 Hz.
Pumps	Variable Displacement, 72 gpm Variable Displacement, 11.5 gpm
Fluid	Petroleum Base
Pressure	4,500 psi (Maximum relief)

TABLE 1, concluded

Length	10 ft. 0 in.
Width	4 ft. 3 in.
Height	6 ft. 6 in.
Weight	5,000 lbs.

Vacuum Mucking System

Maximum Capacity	5.5 tons per hr.
Maximum Length	600 ft. (In-hole)
Muck Pipe Inside Diameter	7 in. (In-hole)
Maximum Vacuum	18 in. Hg.
Vacuum Pump Capacity	2,400 scfm
Motor	150 HP; 1,800 RPM; 460 V; 3 Phase; 60 Hz.
Drop Box Discharge Pressure	20 psi.

*Note: Vacuum system performance is dependent on altitude.

Laser

Power	5 mw.
Spot Diameter (600 ft.)	.6 in.
Manufacturer	Spectraphysics

Utility Supplies

Electricity	460 V; 350 KVA; 3 Phase; 60 Hz.
Air	90 psi.; 150 scfm

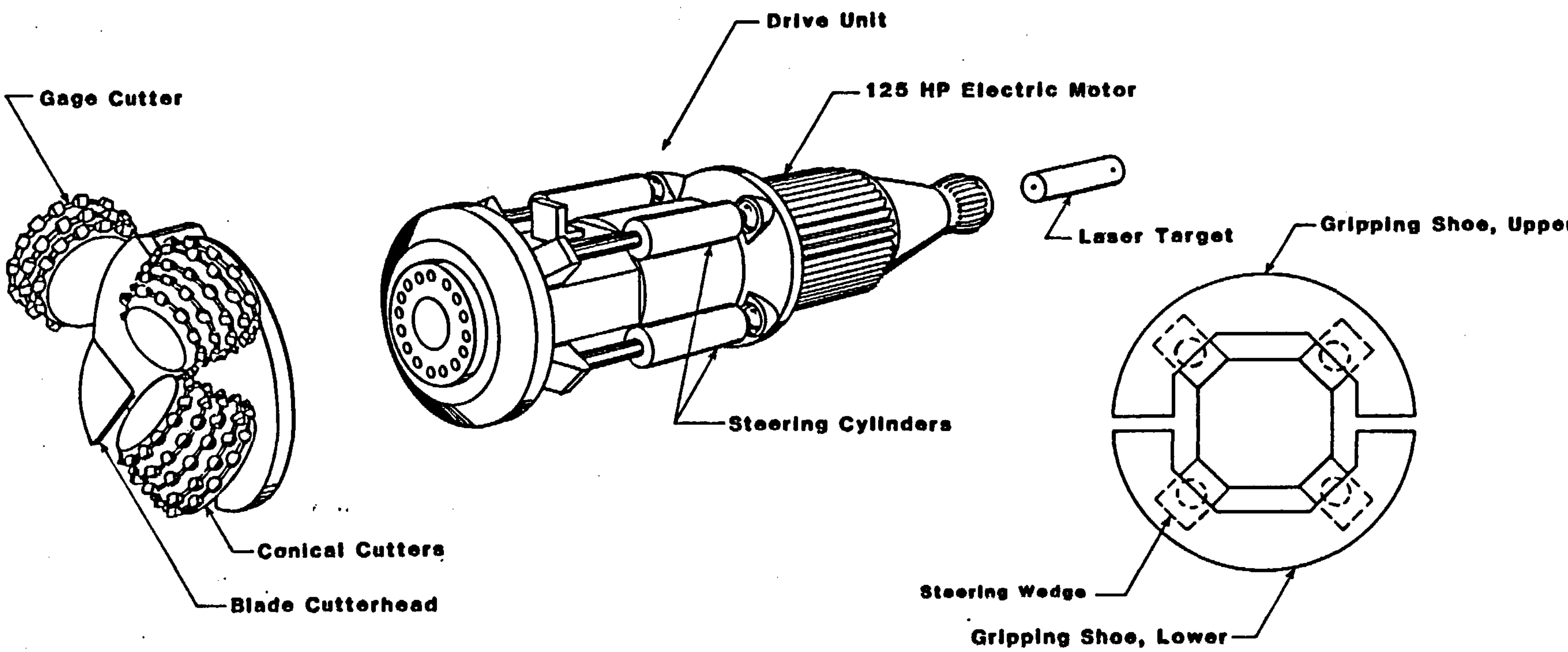

FIGURE 4 - Steerable Cutterhead Drive Assembly

cutters to be in close proximity to each other and does not compromise assembly or removal of the cutters. The outer (gage) cutter, has three rows of inserts and is saddle mounted on a welded-in-place pedestal. Figure 5 shows a similar five-kerf cutter.

The cutterhead is basically a thick plate structure onto which the cutters are mounted. It is then bolted to the flanged end of the gearbox output shaft. A spiraled, fixed blade is welded to the cutterhead to sweep rock chips rearward, toward the vacuum inlet.

3.2.2 Drive Assembly, Ref. Drawing D36121-1

The drive assembly provides cutterhead rotation and also carries the cutter thrust and lateral loading.

The main drive is a sealed 125 HP, 1,800 RPM electric air-cooled motor. The motor casing is designed to carry the full thrust and torque between the cutterhead and the steering system ball joint. A motor overtemperature indicator is provided at the console.

A double reduction planetary gearbox provides the required output torque and speed. The gearbox output shaft, to which the cutterhead is bolted directly, is supported by a triple bearing arrangement. Axial loads are reacted by a tapered roller thrust bearing. Moment loads are reacted by a forward mounted cylindrical roller bearing and by a rear mounted tapered roller bearing which also serves to preload the thrust bearing. A dual seal arrangement at the rear of the cutterhead mounting flange prevents oil leakage and ingress of dirt. Gearbox oil temperature is continuously monitored at the console.

The entire drive shaft and bearing assembly can float a distance of .75 in. relative to the gearbox outer housing. The assembly is normally thrust forward by pumping hydraulic fluid into the annular cavity behind the rear bearing housing. When thrust is applied to the cutterhead, the fluid pressure in the cavity rises, and is controlled by a pilot-operated check valve.

Because the thrust capability of the derrick unit is beyond the structural capability of the drill unit, a hydraulic isolation and monitoring system is used. Advance rate of the drill is controlled at the derrick and is limited to maintain limit load forces. If the load on the hydraulic isolation ring, located at the rear of the bearing housing, exceeds the limit (designed to be 3,500 psi), or should the system lose fluid, the drive assembly moves toward the rear. A proximity switch located in the gearbox cutter housing detects the "bottoming out." An interlock system shuts down the drilling unit and illuminates a warning light on the operator's console.

To permit removal of the drill through the liner, the cutterhead must be indexed to a specific position. A proximity switch is used to detect the location and trigger an indicating lamp at the console.

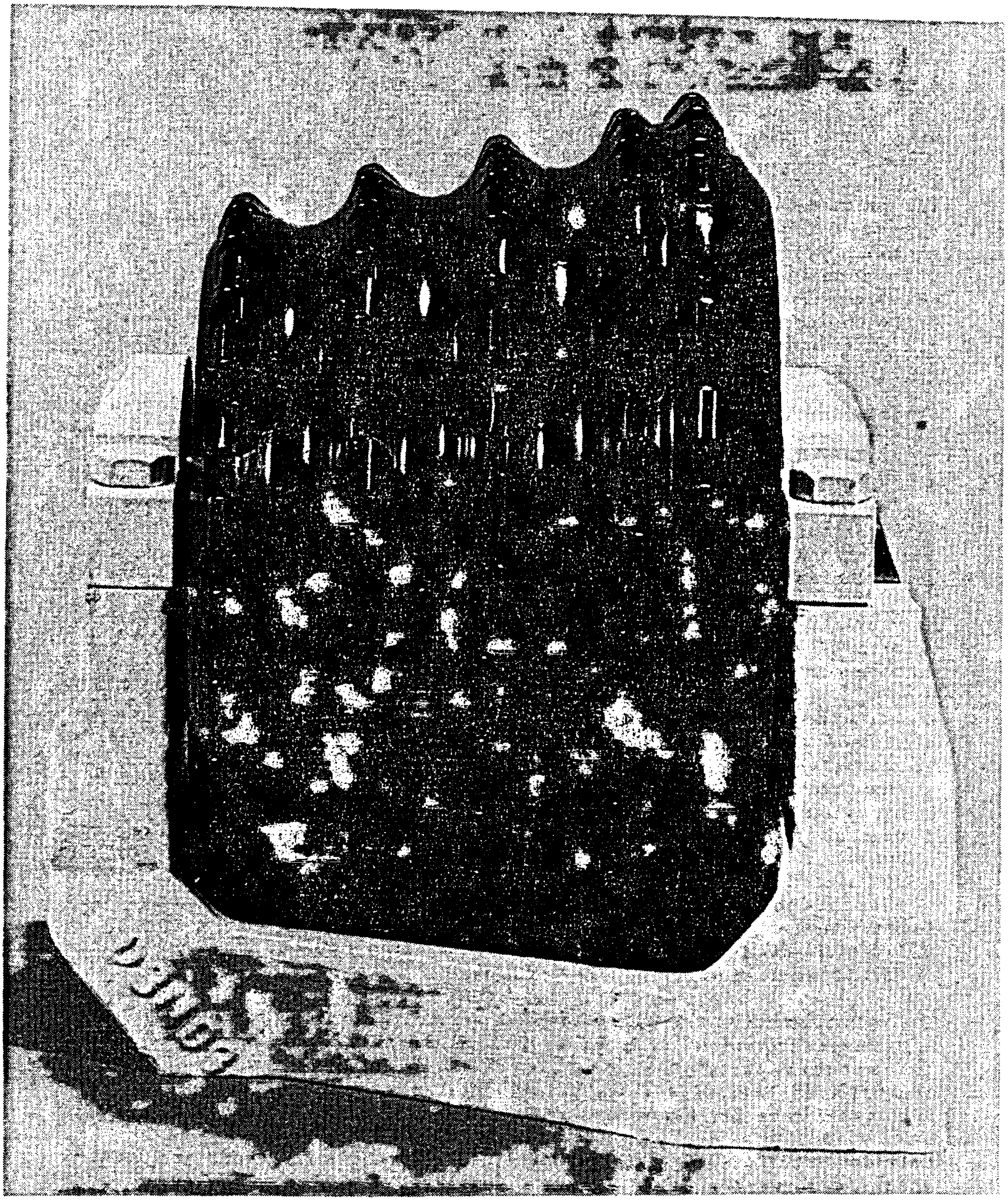

FIGURE 5 - Five Row Cutter Carbide Insert Cutter

3.2.3 Steering and Muck Pickup, Ref. Drawing D36105

Steering is achieved by radial movement of the cylinder actuated steering wedges against the gripping(stabilizer) shoes, as shown in Figure 6.

The basic method of making directional corrections is to move the head in the direction of the desired motion. This causes the cutterhead to slightly overcut in the direction it was moved and to undercut on the diametrically opposite side. The undercutting forms a ramp in the bore which the shield is obliged to follow. Thus, if the bore is descending below the true path, the cutterhead is raised slightly and the shield is forced upward by the resultant ramp. Sideways deviations are corrected in a similar way.

Steering corrections are necessarily limited because of the rigidity of the attached liner. Deviations must be detected as they occur, and steering corrections must be as small as possible. Normally, the gage of the bore at the floor line should be exactly in line with the bottom of the liner. As the cutters wear, the gage will tend to rise above the liner bottom, and the bore will tend to rise. This can be counteracted by lowering the cutterhead to compensate for such cutter wear. The steering deviation is monitored by the laser and in-hole target. As the steering corrections must be very small, and the angular change of the drill unit very slight, (about the same order as the resolution of the laser inclinometer), linear transducers are incorporated in the steering cylinders to more accurately monitor steering movement.

Apart from controlling direction, the steering cylinders (Figure 4) are also used to stabilize the drill in the bore. There are two shoes or grippers, one upper and one lower. The lower one remains in contact with the bottom of the shield at all times, while the upper one is pressed by hydraulic action of the upper cylinders against the roof of the bore. The degree of pressure can be adjusted from and monitored at the control console. The pressure should be adjusted so that the cutterhead is just stabilized, i.e., does not bounce around in the bore. If the pressure on the gripper shoe is above this level, the frictional sliding forces between the gripper shoe, the liner and bore could be come excessive. The friction loading on the gripper shoe is reacted by a shear block located on the upper side of the gearbox housing.

The entire drive train and cutterhead can pivot about a splined ball joint arrangement, which is an integral part of the shield engagement mechanism. The outer part of the joint is fixed relative to the shield. The longitudinal crowned splines permit angular movement of the drive train but resist rotational movement about the drive train axis.

Cylinder actuated wedges (Figure 4) in a quadrant arrangement are located at the forward end of the gearbox housing. The shoe wedge arrangement permits radial movement of the cutterhead from cylinders which are mounted parallel to the axis of the drill. The steering cylinders are interconnected hydraulically in a manner that, during a steering motion,

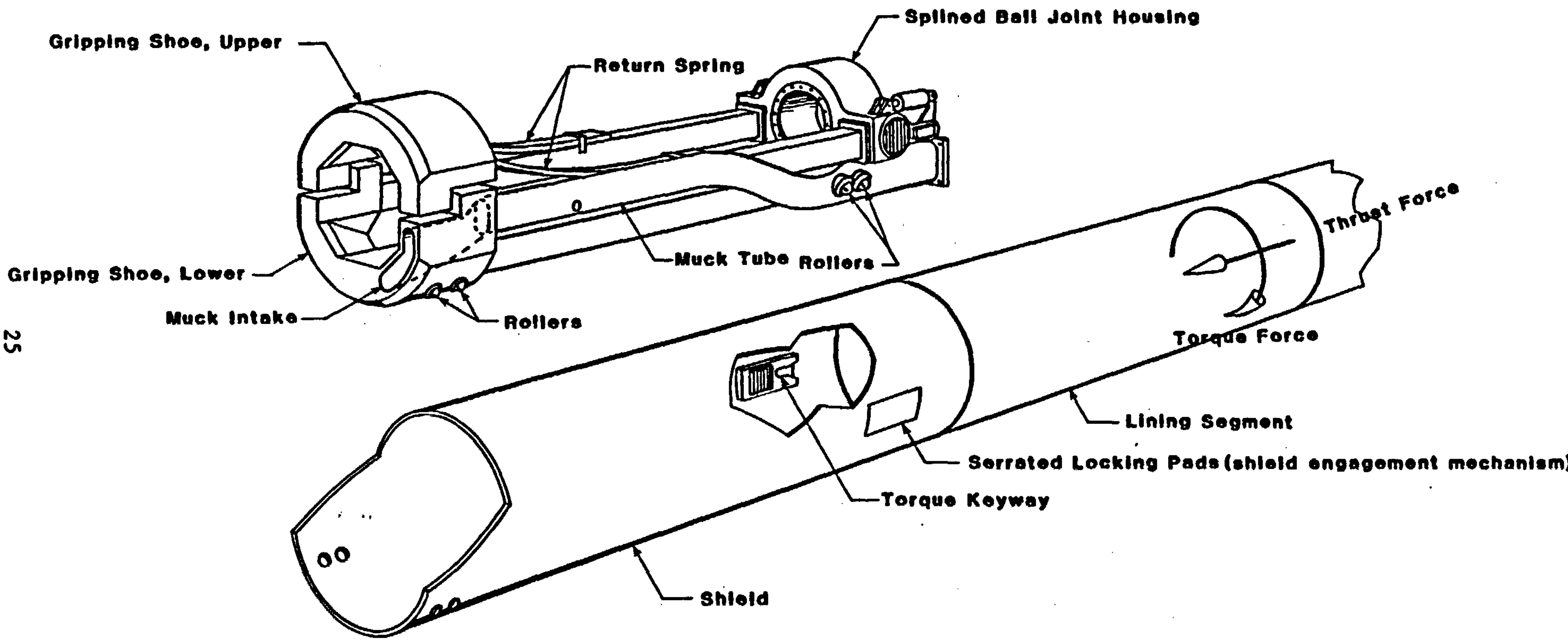

FIGURE 6 - Steering and Shield Assemblies

one cylinder extends as much as its opposite partner retracts, thus maintaining the upper shoe in its stabilizing location.

After the location is set, the lower cylinders are hydraulically locked into position to assure that there will be no movement of the head relative to the bottom of the bore. The upper steering cylinders are not locked in position but apply a controlled pressure for stabilizing purposes as described previously.

To retract the entire drill, the head must be lowered to clear the top of the liner, after it has been indexed as (rotated) to the removal position. Both sets of steering cylinders are retracted to pull the upper shoe clear of the liner. A leaf spring attached to the upper shoe forces the shoe down in case of hang up.

The muck tube passing through the drill also forms part of the steering assembly structure. The muck entry port is cast into the lower steering shoe at the 5 o'clock position as shown in Figure 6. The entry is curved in the natural direction that muck will be struck by the cutterhead blade. A specially cast muck tube, extending from the rear of the bottom shoe to the invert level beneath the shield engagement mechanism, carries the muck through the machine. Because of the necessary curvature of the tube and consequent high-muck impact, a hard-wearing weld overlay will be applied on the inside at critical locations to resist abrasion.

3.2.4 Shield Engagement System, Ref. Drawing D36106

During boring operations, the drill unit must be locked into the shield by a mechanism which will transmit both cutterhead thrust and torque reaction loads. Because of the drill removal features, the shield side of this mechanism must protrude into the shield bore as little as possible. The attachment consists of two engaging plates which have short buttress-like serrations (Figure 6). The serrated plates can spread the thrust loads over several "threads" to provide the shear area required for safe operation. The two sets of plates are hydraulically activated and are located 180° apart on the horizontal centerline.

Proximity switches on the mechanism provide indications at the control console that the plates are properly engaged before boring is started.

3.2.5 Shield Weldment, Ref. Drawing D36130

The shield is basically a heavy wall length of pipe (Figure 6), cut away at the top of the front section to provide clearance for the stabilizer shoe. A pair of serrated engagement plates, as described in paragraph 3.2.4, are welded in at the rear end. The rear edge of the shield has a beveled weld preparation groove for the attachment of the first liner segment. The shield is an expendable portion of the drill and becomes a permanent part of the hole liner.

3.2.6 Laser Guidance System, Ref. Drawing D36106

The remote laser target is mounted inside the steering ball joint (Figure 4) and is, therefore, an integral part of the shield engagement assembly. Because it is on the centerline of the bore, any roll of the drill does not significantly alter the x and y axis readout.

The unit measures x and y (horizontal and vertical) axis displacement and yaw angle (commonly known as "lead") by optical means, and incorporates inclinometers to measure roll and pitch (commonly known as "look-up"). The unit, which will be supplied by Zed Instruments Ltd. (U.K.), is a specially designed, very compact version of a standard TBM alignment system.

A display at the control station provides digital readouts of the various offsets. In this application, the important data are the x and y axis deviations. The roll should be negligible, and the yaw and pitch angles are relative to the cutterhead drive axis, not the actual bore angle at any particular point. If a deviation is noticed on x or y axis, an immediate small correction should be applied. In practice, deviations are corrected within a few millimeters of offset.

The effect of steering corrections may not be immediately apparent to the operator because of the effect of the rigid liner, and to assist in steering, a permanent record of deviation change is necessary as boring proceeds. This is provided by a printer unit which is a standard Zed accessory.

3.2.7 In-Hole Power Unit, Ref. Drawing D36135

Hydraulic power for the drill is provided by a self-contained, electric drive unit, as shown in Figure 7. The unit is located immediately behind the drill in the first liner section behind the drill shield. It is mounted on rollers so that it can be pulled back through the liner should repairs be required during the boring operation.

The power unit's principal components are a 5 HP electric, 460 V AC motor, a dual output 1.5/.38 gpm hydraulic pump, and solenoid valves for control of the drilling functions. These valves are remotely activated from the control console. The console also monitors oil reservoir level and temperature.

In operation, the power unit, along with a section of muck pipe, would be subassembled adjacent to the drill derrick. The hydraulic connections are made to the drill unit. After the drill shield has been collared in a full derrick stroke, the liner with power unit is loaded into the derrick and the liner section is welded to the drill shield.

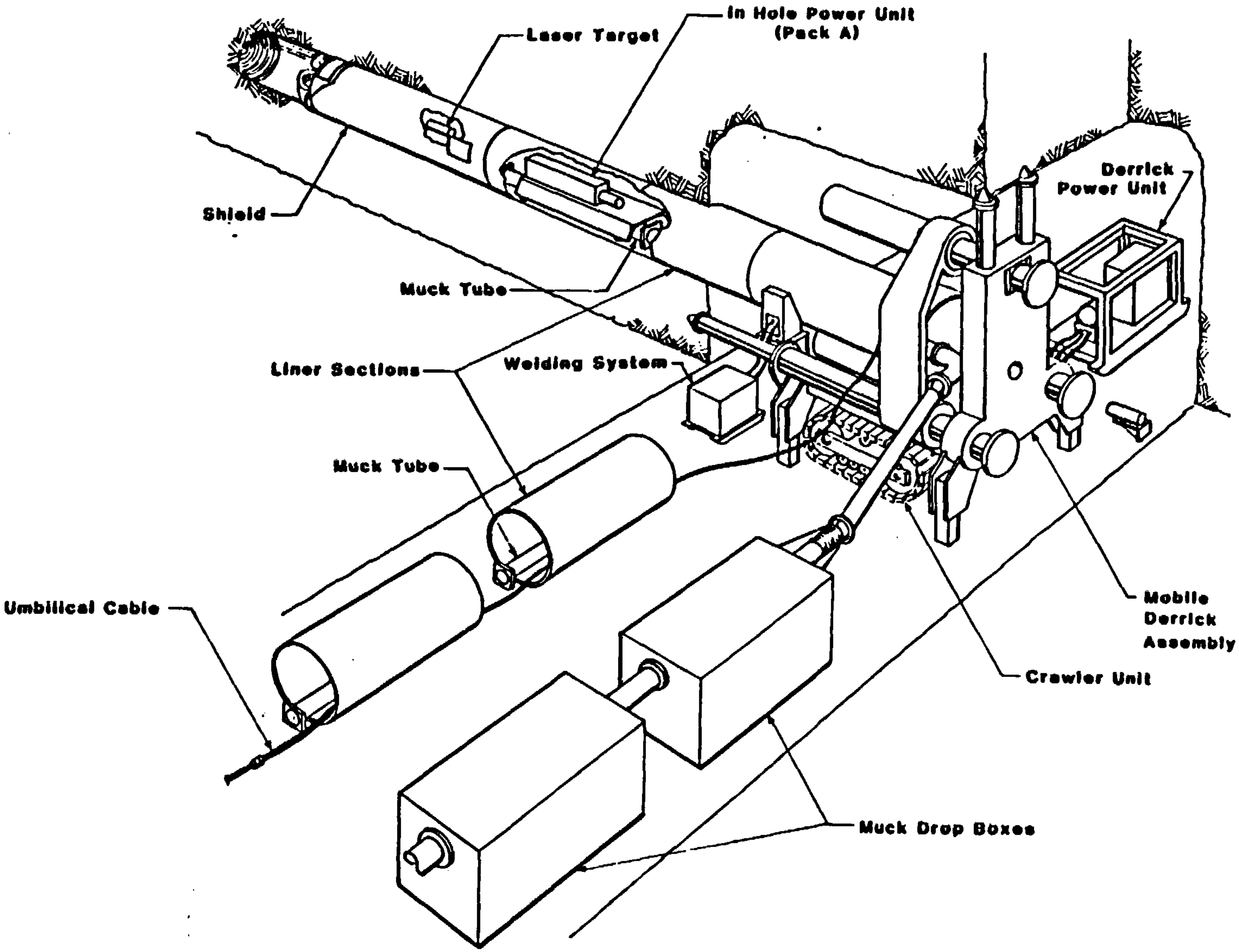

FIGURE 7 - DPBM Operating Components

3.3 Mobile Derrick Assembly, Ref. Drawing D35920

3.3.1 Crawler Unit, Ref. Drawing D35985-1

A crawler unit (Figure 8) with a high load carrying capacity was chosen as the means of locomotion of the derrick for maneuver-ability in confined spaces. Its low travel speeds are perfectly acceptable in a development prototype machine. As the design of the repository and its mode of construction finalized, rubber-tired or a rail-mounted system could be considered. The derrick unit is mounted on the crawler frame by a bolted arrangement, so it could be removed easily for shipping purposes.

The design uses standard commercially available components as far as possible, including tracks, idlers and tensioners. The drive is provided by piston-type hydraulic motors and planetary reducers. A spring-loaded brake in each drive will hold the unit in case of hydraulic failure on an incline.

The hydraulic supply for crawler movement (Figure 7) is provided by an external hydraulic power unit (Pack "B"). The DPBM design of the power unit is skid mounted, although a production unit would probably be equipped with wheels.

The crawler is used for mobilization of the DPBM only. The dead weight of the crawler and the derrick are removed from the tracks during the boring operation by means of leveling jacks attached to the derrick frame.

3.3.2 Derrick, Ref. Drawing D35921-1

The derrick configuration, as shown in Figure 8, is similar to a horizontally oriented raise drill, without a rotary drive. Two large thrust cylinders are attached by a crosshead which slides along two rigidly mounted guide tubes. The tubes carry the dead weight of the crosshead components and transmit the torque reaction from the liner to the derrick chassis. The tubes are mounted rigidly to the rear main frame and supported at the forward end by a headframe. The thrust cylinders are located one above the other on the vertical centerline.

Thrust is applied directly to the liner by a jacking thrust collar. Because of potential misalignment, the collar is attached to the crosshead via an elastomeric joint, which ensures that any eccentric loading is minimized. The surface which mates with the liner is at a 15^{o} angle to match the liner weld preparation. In addition to thrust, the collar must also transmit the drilling torque reaction. Sliding gimbal joints at thetop and bottom of the collar are used to prevent rotation yet permit alignment in the plane of the collar.

The liner is gripped by two pairs of opposed hydraulic clamping cylinders, on each side of the horizontal centerline, which apply a pinching action directly to the liner wall, similar to a caliper brake. Narrow slots in the collar are provided to allow the electrical cables to exit from the

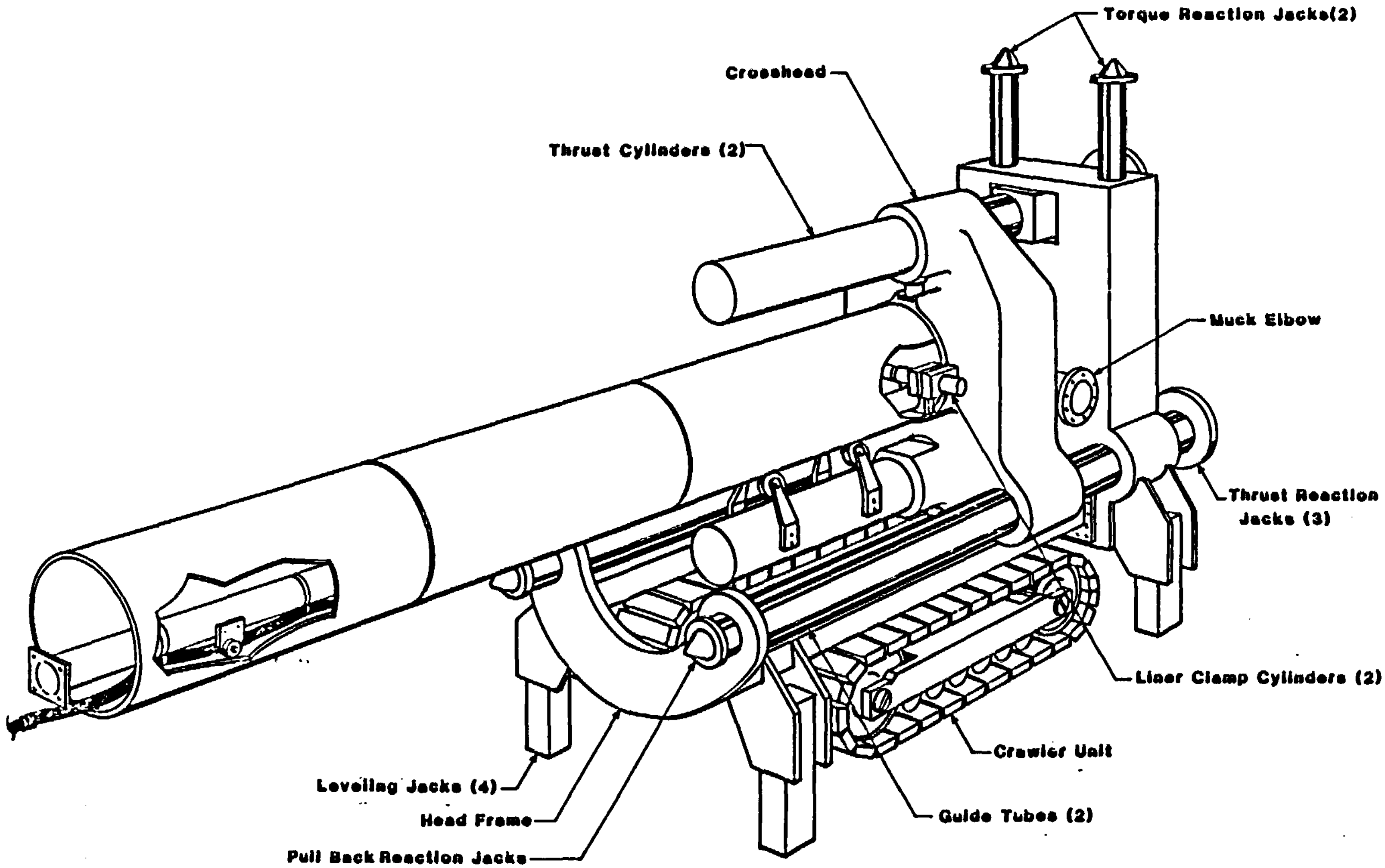

FIGURE 8 - Mobile Derrick Assembly

liner without passing entirely through the crosshead. This permits loading of the liner into the derrick with the cable prestrung to avoid disconnecting and reconnecting the cables for each addition.

Four motorized leveling screw jacks on each corner of the derrick frame are used to relieve the load from the crawler and to orient the derrick at the required boring angle.

The thrust loads are transmitted to the rear wall of the tunnel by three thrust reaction jacks mounted on the main frame of the derrick. The jacks are located in a triangular arrangement. The upper, center jack is a mechanical screw jack, and the two lower jacks are hydraulically operated. Torque reaction is provided by the floor jacks and two vertical screw jacks located on each side of the main frame which are extended to contact the roof.

A muck elbow is required in the mucking system at the derrick to route the air and muck flow toward the separation units. The elbow is located immediately behind the crosshead and is attached to the in-hole muck pipe by means of a hydraulically pressurized telescopic joint. This joint serves two functions: (1) it precludes the requirement to bolt up the joint, which would have to be broken as each section of pipe is added, and (2) it permits relative movement of muck tube and liner which can occur as a result of compression of the liner under high loading.

When the drill must be withdrawn from the hole, the telescopic joint is removed, and a fixed retrieval tool is substituted. This has a bolted flange to match the muck pipe, and provides the means for pulling the pipe.

To react the pull on the derrick during drill withdrawal, screw-type reaction jacks, normally nested in the derrick guide tubes, can be extended to contact the front wall. These may also be extended during normal boring operations to prevent the derrick from creeping out of alignment when the thrust loads are relaxed.

To facilitate handling of liners, two sets of rollers are mounted on the lower thrust cylinder. The liner is inserted between the cylinders by a hoist and is lowered onto the rollers. The rollers assure the alignment of the liner and enable it to be moved axially, relative to the crosshead during the process of bolting up the muck tube and welding to the previous liner.

For strength and ease of manufacture, the main structure of the crosshead, which is a fairly complex shape, is a steel casting. Aluminum bronze bushings are used as the sliding medium on the guide tubes for strength and durability. The guide tubes are hard chrome plated to provide a wear-resistant, smooth surface.

3.4 Mucking System, Ref. Drawing D35632

The major components of the mucking system are shown in Figure 7. Since some elements fulfill dual roles, additional component descriptions are found in the descriptions of the in-hole assembly and the derrick.

Two sets of computations for air flow, pressure drops, etc., were made. Calculations were made for 600 ft. of borehole and an elevation of 1,200 ft. (original assumed repository elevation), and for 250 ft. of borehole and an elevation of 6,300 ft. This latter requirement is for the DPBM tests at the G-Tunnel complex of NTS.

These computations are located in Appendix 5.

The complete mucking system includes the following major components:

a. In-hole muck tube (Ref. Dwg. D36136)
b. Derrick telescopic joint (Ref. Dwg. D36509)
c. Derrick elbow (Ref. Dwg. D36510)
d. Transfer pipe with ball joints (Ref. Dwg. B36543-1)
e. Telescopic joint (Ref. Dwg. D36528)
f. Primary drop box (Ref. Dwg. D35620-1)
g. Secondary drop box (Ref. Dwg. D35620-1)
h. Filter unit (Ref. Dwg. D36545-1)
i. Vacuum pump unit (Ref. Dwg. D36546-1) and
j. Control station (Ref. Dwg. D36158)

3.4.1 Muck Tube, Ref. Drawing D36136

The muck tube serves the dual purpose of conveying the muck and being used to withdraw or reinsert the drill. When the system is actually operating, the rate of abrasive wear must be observed. Excess wear could eventually compromise the strength of the pipe. Observations of wear locations and rates must be made during initial testing to permit design upgrading of a production system.

The muck tube sections are connected by four-bolt flanges and joints are sealed by a spigot-mounted O-ring. Hangers to support the electric power, control and instrumentation cables are attached to the muck tube assembly.

A pair of rollers, permanently attached to the mid-point of each pipe section, is used to hold the muck tube string clear of the liner. This reduces friction force when the string is moved in or out of the hole. The rollers also facilitate moving the tube inside the liner as new sections are installed during boring.

For test purposes, the piping material is mild steel. As dictated by test results, a longer wearing design may be required. The options include a harder, high-wearing material, hard facing, or replaceable inner liner sections.

3.4.2 Derrick Telescopic Joint and Elbows, Ref. Drawing D36509

Just before the derrick-mounted muck elbow, (a horizontal right-angle bend), the pipe is telescoped within a larger pipe section (9.625 in. ID with .75 in. wall). The telescopic joint facilitates installation of new sections of muck pipe and provides compensation for relative movement between the muck tube and liner under high-thrust loads.

The telescopic joint section is flange mounted to the derrick-mounted elbow. The elbow is a flanged 9.625 in. diameter round tubing, bent to a 39 in. radius. The elbow is followed by a transition piece to an 8 in. diameter at the first ball joint.

3.4.3 Transfer Pipe Connection, Ref. Drawing B36543-1

The transfer pipe is the principal connecting link between the derrick muck elbow and the first drop box. Ball joints are located at each end to permit angular movement as the derrick strokes forward. The pipe is 40 ft. long, 8 in. Schedule 80 pipe. A telescopic joint mounted on the front end of the drop box is incorporated to accommodate the shortening motion resulting from the angular movement of the transfer pipe as the derrick strokes.

3.4.4 Drop Boxes, Ref. Drawing D35620-1

Two virtually identical drop boxes connected in series are utilized. This provides adequate collection volume for one liner length of advance (8 ft.) and provides a two-stage deceleration of the air flow. The heaviest particles will tend to drop out in the first box, lighter particles in the second.

Air and muck enter the first of the two drop boxes through an 8 in. pipe. Inside the box the pipe enlarges to a 12 in. diameter expansion pipe. The expansion pipe is slotted along the bottom length, permitting the rock particles to drop out as the air flow decelerates. A portion of the air in the first drop box is free to pass through a 75 mesh screen at the top of the box and into a clean air manifold.

The main stream, less the volume which passed into the clean air manifold from the primary box, passes to the secondary drop box. A similar slotted deceleration pipe is used to further reduce air velocity and drop out particles. One added feature of the secondary box is a deflector plate bolted onto the end of the pipe. This is designed in the manner of a stuffing box to reduce abrasive wear.

The air from the secondary box also passes through a 75 mesh screen and into the clean air manifold. An air vibrator on the screen, actuated by pressure drop, shakes the screen to keep it relatively free of lodged particles.

The two boxes are designed to work in tandem and when the primary box fills to the point that airflow is impeded, air velocity will increase and all particles will be carried to the secondary box.

Each drop box has two hoppers. The muck is ejected from the hoppers by an externally supplied low-pressure (20 psi) pneumatic discharge system. Hoppers are discharged only while the vacuum system is turned off. During operation of the discharge system, the drop boxes are subjected to internal air pressure. Isolation valves are required at each end of the drop box assembly to prevent air from escaping back up the muck pipe or into the filter unit, which is not designed to withstand internal pressure. In normal operation, electrical interlocks are employed to prevent applying discharge pressure until the isolation valves are closed. Pressure relief valves are included on both drop boxes and the filter unit for safety.

The discharge from the four hoppers of the drop boxes is manifolded into a single discharge pipe. This pipe could be directed to a haulage vehicle.

3.4.5 Filter Unit, Ref. Drawing D36545-1

The function of the filter unit is to separate airborne dust before entry to the vacuum pump (blower) and subsequent discharge into the haulage way. The filtering device consists of eight commercially available cylindrical fabric cartridges, each 2 ft. long and 1 ft. in diameter. They are suspended below a dividing plate on a rack system for easy removal.

Air enters below the dividing plate, passes through the filter from the outside, and emerges above the plate. Air velocities through the fabric are generally .5 to .3 ft. per minute. Ample capacity (up to 6,000 cfm) is provided by the eight filter elements.

A nozzle, located above each filter outlet, periodically blasts compressed air to dislodge the dust cake from the filter. This backflushing action causes the majority of the dust to fall into the hopper arrangement located below.

The cycling of the purging system is controlled by an adjustable electric timer. A switch sensing the differential pressure across the filter pack signals a warning light on the operator's console if the cartridges become clogged.

The hoppers are designed to be emptied about once per shift by an inclined screw feeder unit enclosed in a tube. The dust can only be removed when the vacuum system is shut down. An airtight valve at the feeder outlet seals the vacuum during boring operations.

3.4.6 Vacuum Pump Unit, Ref. Drawing D36546-1

The vacuum pump is a rotary lobe, axial-flow, positive displacement pump, driven by a 150 HP electric motor with belt drive. The pump produces a dry vacuum of 12 in. of mercury at 2,400 cfm, at 1,400 rpm. Immediately ahead of the blower and located in the same skid is a secondary filter unit. This serves the dual purpose of polishing the already filtered air and acts as a safety filter in case a cartridge in the primary unit ruptures. This final system protects the blowers and assures that discharge air is respirable. Actually, the primary filter unit alone is probably efficient enough to assure that the discharged air is of respirable quality.

The secondary filter employs the same type of cartridges as in the primary unit, but a purging system is not used. Since little dust should be collected, removal is effected manually, after opening a cover plate.

A water injection unit, which is located just ahead of the pump intake, can be used if necessary to decrease the internal leakage of the pump and thus increase the working vacuum. The vacuum pump unit discharges into a plenum chamber and then to atmosphere via an air silencer unit.

3.5 Liner, Ref. Drawing D36514

The liner is an 8 ft. long pipe section (reference Figure 7). As a structure, it must withstand the maximum thrust and torque reaction loads without buckling or compression failure. An analysis (Attachment 4) showed that either a .38 in. thick wall in 52 ksi material or .5 in. wall in 35 ksi material would be suitable.

The ends of each pipe section are bevelled to permit a full penetration weld. Because a shallow angle is desirable at the jacking collar to avoid excessive wedge loads while providing sufficient opening at the joint for root penetration, the bevels at each end are at different angles. Tentatively, a 45° angle is shown in front and 15° at the rear, or thrust end, of the liner pipe. The selection of the exact angles should be determined in conjunction with the automatic welding machine manufacturer.

The manufacturing tolerances on the straightness of pipe, ovality, and squareness of the ends must be held to tolerances tighter than generally held on commercial tubing. Alternately, weld preparation on the pipe ends could include sizing or counterboring. Each liner section joint must be carefully aligned to avoid hang up of the liner in the bore or hang up of system units on misalignment ridges inside the liner.

3.6 Derrick Power Unit, Ref. Drawing D35925

The power unit (Pack B shown in Figure 7) provides the hydraulic supply for the derrick and crawler functions. A double-ended electric motor drives two variable displacement pumps. The largest pump has 72 gpm capacity and, at maximum stroke, will supply low-pressure fluid for rapidly traversing the derrick and for driving the crawler. The pump has a horsepower limit control which, when sensing increased pressure, will automatically reduce the output volume.

The smaller pump has a maximum capacity of 11.5 gpm at 4,000 psi and is pressure compensated. This is used primarily as the thrust feed supply and also to operate the various jacking functions. The feed rate is controlled by a variable flow control located on the operator's console. Suction strainers, high pressure and return filters are incorporated to ensure system cleanliness. The reservoir capacity is 300 gallons of petroleum-based hydraulic fluid. Connections to the derrick unit are made by removable hoses equipped with sealing quick disconnects at both ends.

The power unit also houses the motor control center, various starters, overload relays and circuit breakers. It also includes a programmable controller which directs the interlock logic.

3.7 Welding System, Ref. Drawing A36516

An automatic orbital welding machine (reference Figure 7) is used to join the liner sections. The welding head moves along a circular track clamped to one of the liner sections adjacent to the joint. The flow characteristics of the weld puddle are affected by gravity and depend on the instantaneous location on the pipe circumference. A variable-pulse system is used to control the fluidity of the puddle. The quickest system uses the MIG (Metal Inert Gas) process. Automatic MIG processes which have the capability of laying 5 lbs. per hour are presently developed and can be used for this system.

A short development program to evaluate the exact heats, speeds and passes will be required before the boring test.

As each new section of liner is added, alignment with the previous section must be exact. Ideally, an external alignment fixture would be used, as it does not interfere with the muck tube and cables inside the liners. A backing plate, to prevent weld intrusion and increase the MIG welding speed, is recommended.

3.8 Control Station Assembly, Ref. Drawing D35915

The control console is a skid-mounted unit complete with a seat for the operator. All drill functions, and the major functions of the derrick and mucking system, are controlled from the console. Gages and indicator lights are used to monitor various parameters. The remote laser readout screen occupies a central position and monitors bore deviation.

The panel is divided into three clearly defined areas, as shown in Figure 9, grouping separately the drill, derrick and vacuum pump systems to avoid confusion during operation (refer to Drawing D35928). Each area is described in the following paragraphs.

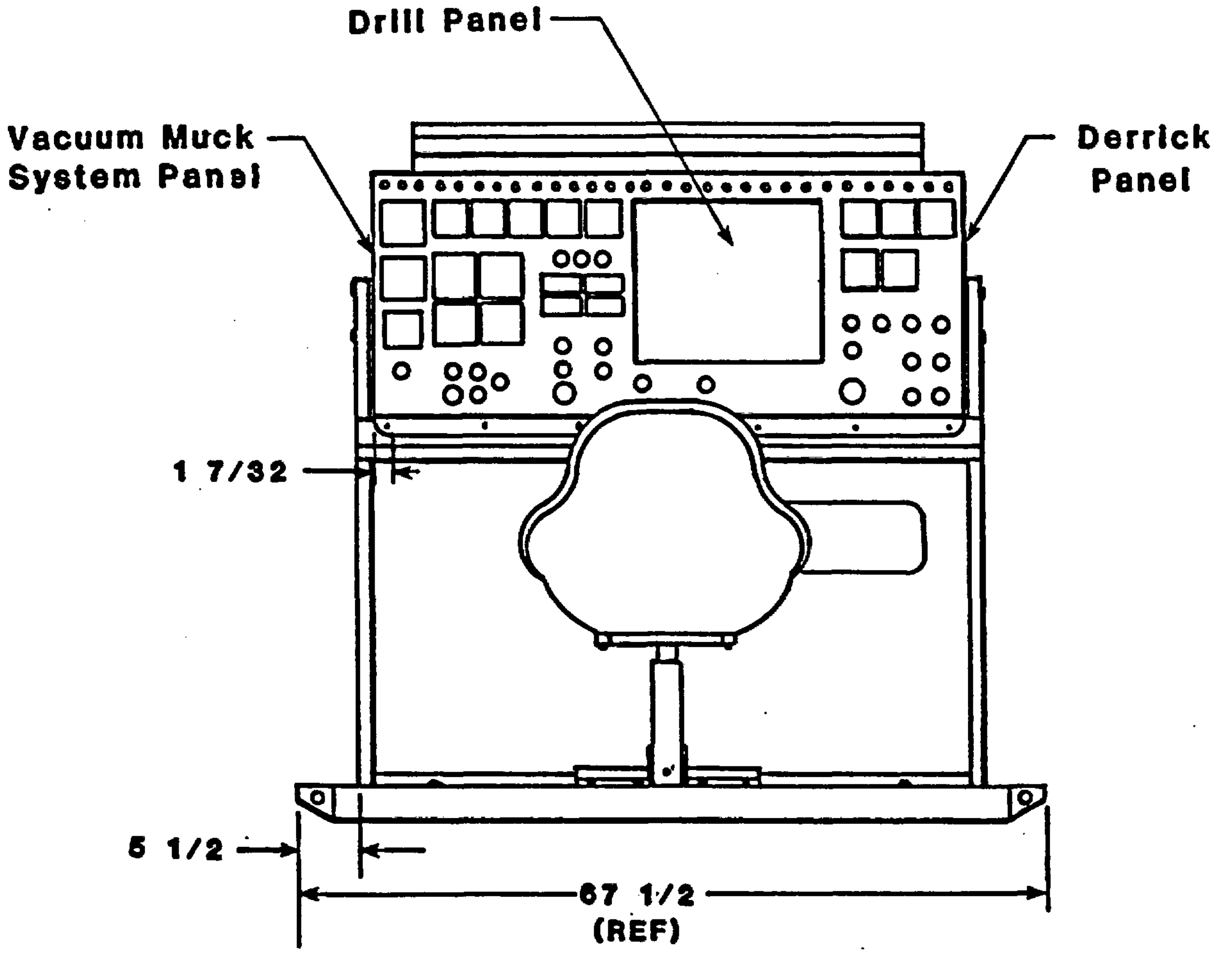

FIGURE 9 - DPBM Control Station Assembly

3.8.1 Drill Panel, Ref. Drawing D35928

The DPBM control panel contains readouts and instrumentation designed for R&D purposes. It is more complete than usual drilling panels. The following controls are incorporated:

a. Drill Motor. Besides on-off controls, jog control is provided to index the head for withdrawal.

b. In-Hole Hydraulic System Motor. On-off controls.

c. Steering. A single four-quadrant joystick controls the movement of the head up/down and right/left. Note that the mode select switch (e) must be in the "steer" position.

d. Cylinder Setting. Four switches permit individual setting of the four steering cylinders. These are used in initially setting up the cutterhead location and also in lowering it before withdrawal. The mode select switch (e) must be in the "set" position.

e. Mode Switch. This can be set to "steer" or "set" to operate those functions described previously. It is set to "bore" after the head is correctly located. In this mode, the pressure to the upper cylinders is controlled to provide the minimum force at the upper shoe for adequate stabilization.

f. Cutterhead Thrust Monitor. In the "set" position, the cutterhead is pushed forward. In the "release" position, the head can be pushed back by an external load. (The thrust control system is single acting.) The set mode must be used when boring. The "release" mode is used when reinserting the drill after mid-bore withdrawal. It enables the drill unit to be pushed as far forward as possible to engage the shield properly, without the cutterhead actually contacting the face.

g. Stabilizer Pressure. This operates a remote pressure control valve to set the stabilizer loading.

h. Shield Engagement. A single switch is provided to control both of the two engagement mechanisms.

The following gages and indicators are incorporated in the control panel:

i. Steering Cylinder Pressures. Each cylinder can be monitored individually. Note that in the bore mode, the two upper cylinders are connected and show the stabilizing pressure.

j. Steering Cylinder Positions. The stroke of each cylinder is displayed on a digital meter. This provides an accurate indication of cutterhead movement, with greater resolution than obtainable by the inclino-meter.

k. Drive and Pump Motor Amps. Meters are provided.

l. <u>Gearbox Temperature.</u> A continuous readout is provided.

m. <u>Cutterhead Thrust.</u> This measures the pressure of the fluid trapped in the control annulus.

n. <u>Warning Lights.</u> Red light warnings are provided for high drive motor temperature, low hydraulic fluid level and high temperature and failure of the cutterhead thrust control system (head moving back).

o. <u>Interlock Lights.</u> Amber lights indicate the correct functioning of the following systems. Failure of any of the following parts will cause shutdown of the drive motor and derrick feed: vacuum pump, stabilizer pressure, liner clamp (on derrick), or shield engagement.

p. <u>Indicator Lights.</u> Green lights are provided to indicate that the cutterhead index location is correct and that the upper steering shoe is retracted to permit withdrawal.

q. <u>Laser Target Screen and Controls.</u> A selector switch is incorporated so that the following parameters can be monitored: x and y deviation from the desired bore, roll, and look-up and lead (pitch and yaw). A set of thumbwheels is provided for initially zeroing the system to account for misalignments of mounting.

3.8.2 Derrick Panel, Ref. Drawing D35928

The following controls are incorporated on the derrick panel:

a. <u>Emergency Stop.</u> Shuts down all system pumps and electric motors.

b. <u>Reset.</u> Required for re-starting.

c. <u>Hydraulic Pump Motor.</u> Derrick power unit on/off.

d. <u>Thrust Cylinder Extend and Retract.</u> Two settings: High pressure, low speed or low pressure, high speed.

e. <u>Boring Feed Rate.</u> This is a hydraulic flow control valve controlling high pressure flow to the thrust cylinders.

f. <u>Control Power Switch.</u>

g. <u>Warning Siren Button.</u> To signal startup.

The following gages and indicators are incorporated on the derrick panel:

h. <u>Pump Motor Amps.</u>

i. <u>Pump Output Pressures.</u>

j. Thrust Pressure. Indicates thrust loading into liner in boring mode.

k. Pullback Pressure. Indicates pull on muck pipe when withdrawing drill.

l. Hydraulic Oil Level.

3.8.3 Vacuum Muck System Panel, Ref. Drawing D35928

The only control function is the vacuum pump motor start/stop switch. The system is interlocked such that the drill motor cannot be started until the vacuum pump has been running for a few seconds. This avoids choking the muck inlet at the drill. Similarly, the pump cannot be switched off until after the drill has been turned off, to avoid leaving material in the muck piping.

The following gages and indicators are incorporated on the vacuum pump panel:

a. Pump Motor Amps.

b. Vacuum at the Drill. (in Hg)

c. Vacuum at Pump Drill. (in Hg)

d. Vacuum Fault Light. This combines three fault indications from the vacuum system: (1) high pump inlet vacuum, indicating an overload situation or blocked pipeline; (2) low vacuum, indicating system leakage; and (3) high differential pressure at the primary filter unit, indicating clogged filters. Note that individual indications are displayed on the vacuum unit console (subsection 3.9).

e. Temperature Fault Light. This combines two fault indications. One is high outlet air temperature, indicating a fault at the pump. The other is high pump gearbox temperature. Individual indication is displayed at the vacuum unit console.

f. Isolation Valve Indicators. A green light indicates that the isolation valves on the drop boxes are open, and the system may be started.

3.9 Vacuum System Control Console, Ref. Drawing D37173

This unit, shown in Figure 10, provides local control of the vacuum pump for checking and troubleshooting purposes. An emergency stop button is also incorporated. The drop box isolation valve control switch also is located here.

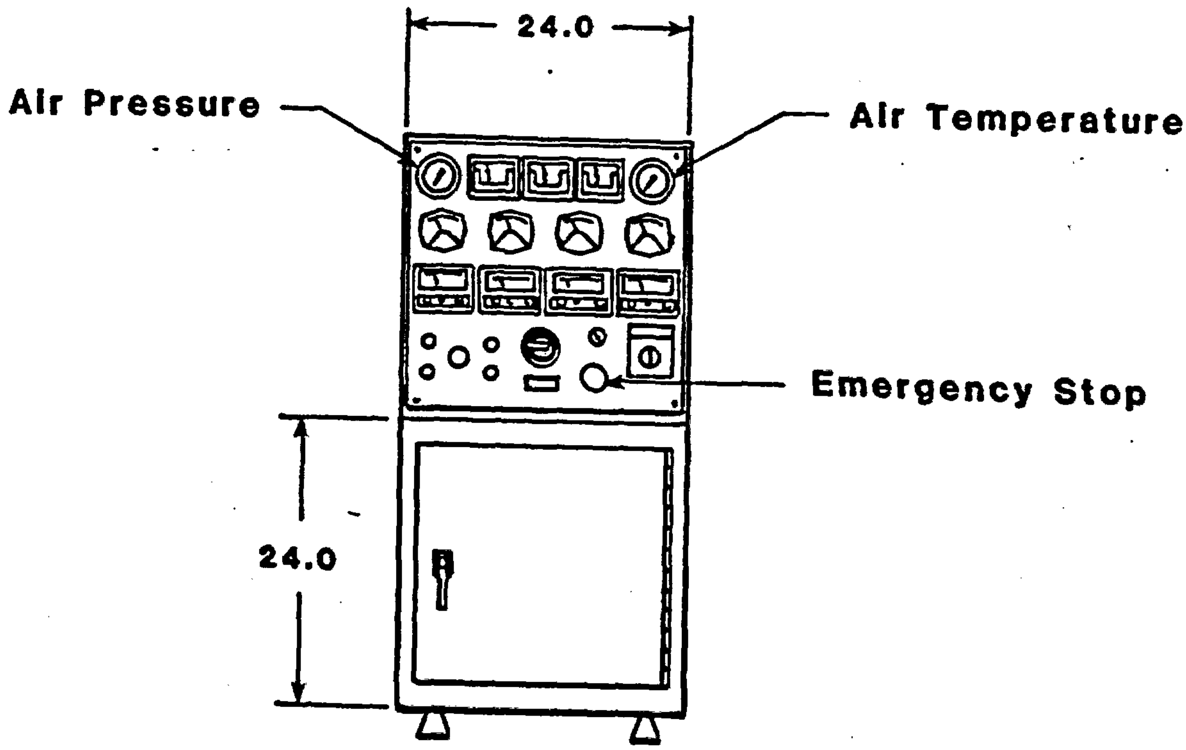

FIGURE 10 - Vacuum Pump Skid Control Console

The following gages and indicators are provided. Some are duplicated at the main control station assembly so that monitoring is possible from either location.

a. Vacuum Pump Amps. The current is monitored per phase, and a selector switch is provided.

b. Inlet Air Temperature.

c. Muck Inlet Vacuum at the Drill.

d. Secondary Filter Pressure Drop.

e. Outlet Air Pressure.

f. Air Outlet Temperature.

g. Gearbox Oil Temperature.

h. Pressure drop across the Primary Filter.

i. Pump Inlet Vacuum.

j. Air Inlet Velocity. This provides an indication of air flow, and is included for experimental data. It normally would not be included in a production unit. Probably air outlet pressure and air inlet temperature also would be excluded.

k. Isolation Valve Position Indicators. Note that if the system is started with the valves shut, excess inlet vacuum will immediately shut it down again.

If certain monitored parameters (f, g, h and i) exceed selected safety values, the system is automatically shut down. Latching indicator lights incorporated in the meter relays provide fault location after shutdown.

4.0 DPBM OPERATION

Upon completion of assembly and shop check out, the DPBM could be acceptance tested at a local quarry. Functional reliability could be assessed by drilling several short holes. Following acceptance tests, the DPBM could be reconditioned as necessary and shipped by truck to the Nevada Test Site (NTS). At NTS, the DPBM would be tested for operational performance to determine the design adequacy of the system, and to obtain performance characteristics data for welded tuff.

This section describes DPBM operation, mobilization and test requirements for boring two 250 ft. horizontal holes at a specific site in an underground facility known as G-Tunnel. An estimate of the time for individual operations is provided. These data will provide the background for the preparation of a definitive test plan. This description reflects the state of development of the DPBM at the time that the engineering design work was completed. Therefore, there are some site-specific requirements of the system and of the specific NTS test location which are identified but which need further definition.

4.1 NTS Site Description

The physical and geological data presented in the following paragraphs was obtained by a site visit, physical measurements, rock samples from the site, core and bore examination and drawings and logs provided by NTS personnel. A plan view of the selected site, the far end of G-Tunnel, is shown in Figure 11. The location of the two proposed DPBM test bores is indicated. The objective is to bore approximately 250 ft., up an incline of about 3.3° from the "laser drift" to the "rock mechanics drift." Following this course should keep the bores within a 30 ft. thick formation of welded tuff.

4.1.1 Physical Features

The elevation of the main haulage way of G-Tunnel averages about 6,300 ft. above sea level. The tunnel is equipped for rail transport, which ends approximately 6,140 ft. from the portal. The tunnel railhead is about 240 ft. from the laser drift, and 510 ft. from the rock mechanics drift.

The laser drift is approximately 75 ft. long. The first 30 ft. is a 15° incline, with the remainder level. The cross-sectional dimensions of the first 40 ft. are 11 ft. wide by 14 ft. high, with the remainder 10 ft. wide by 10 ft. high.

The rock mechanics drift is approximately 130 ft. long on a 14° incline. The cross-sectional opening is 10 ft. wide by 12 ft. high.

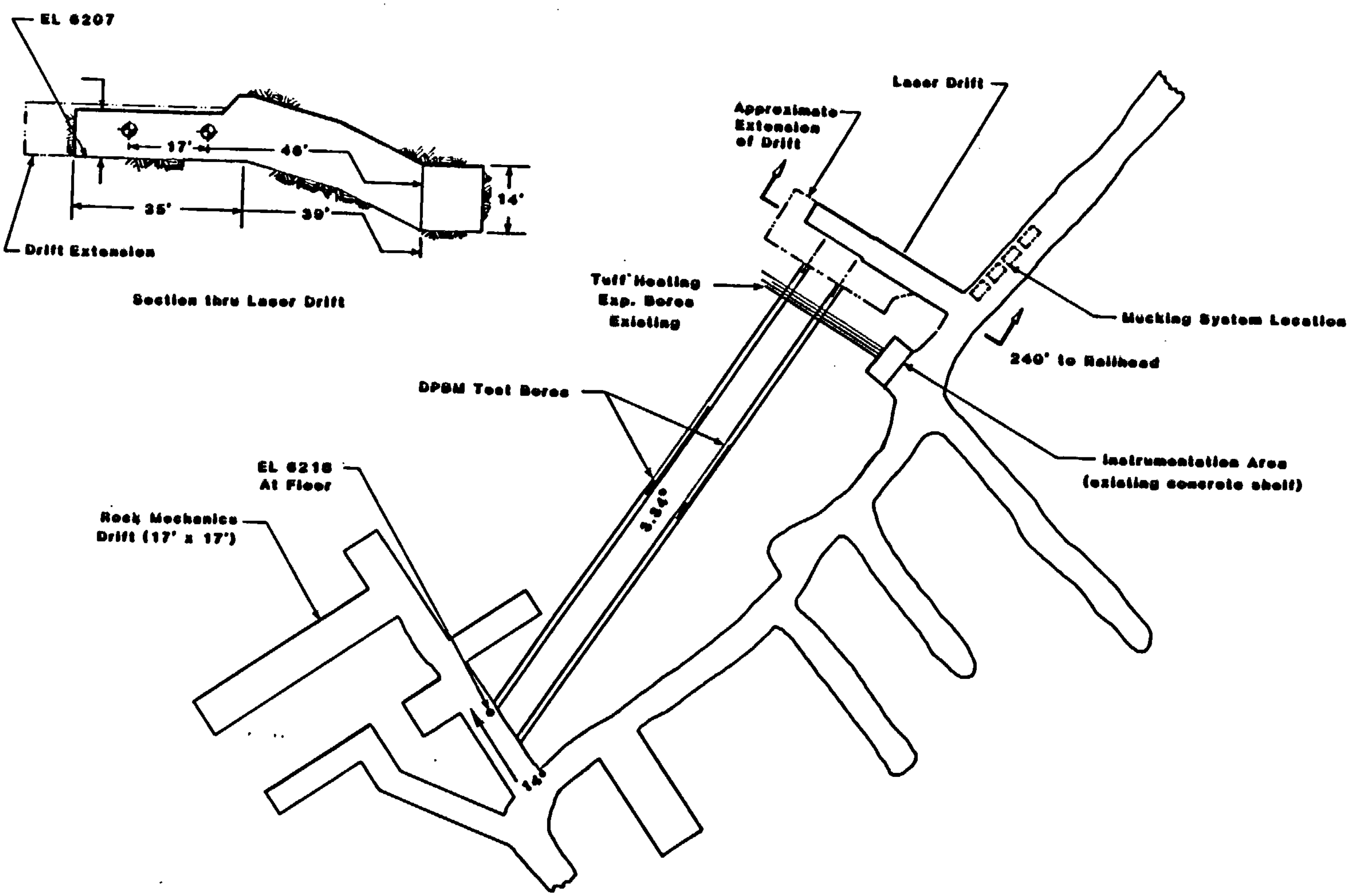

FIGURE 11 - NTS Site Test Location

4.1.2 Geology

The formation consists of densely welded tuff, containing a fracture frequency of 12 per foot minimum. The rock is abrasive and contains pumice inclusions and vugs. Unconfined compressive strengths vary from 12,000 to 15,000 psi. The rock may be saturated.

4.1.3 Utilities Available

Electric power in the tunnel is 4160 VAC, three phase. A 90 psi air supply is available in the main drive for the muck box unloading system. Lighting and ventilation are not installed in the laser drift. The rock mechanics drift presently has both ventilation and lighting. Water is not generally available in the tunnel, but is not required by the DPBM system.

4.1.4 Environment

Ambient temperature is in the range of 60 to 80^{o}F with humidity to 80%. Activity may reduce the air quality level to necessitate personnel using dust masks during some phases of testing. During the collaring in operation and at break through, the ventilation system will not likely keep up with the dust generated. Also dumping the drop boxes could produce substantial dust. Filtration intake boxes for motor cooling air may be required.

4.2 Site Preparation

The test arrangement for the first bore is shown in Figure 12. The additional excavation required for DPBM set up in the laser drift is indicated.

The test arrangement for the second bore is shown in Figure 13. The changes to the site shown are due to the relocation of the derrick from the first to the second site.

The required modifications to the site due to the physical and operational features of the DPBM are further discussed in the following paragraphs.

4.2.1 Excavation

The requirement for increased chamber size is shown in Figures 12 and 13. Additional excavation will be required in the laser drift as shown in Figure 15, to accommodate the length of the derrick unit with an 8 ft. liner segment in place. In addition, an alcove will be required in the "main drift" for housing the mucking system. A barrier will be required to suppress the noise generated by the vacuum system blowers. This would be an additional modification to the arrangement shown in Figures 11 and 12.

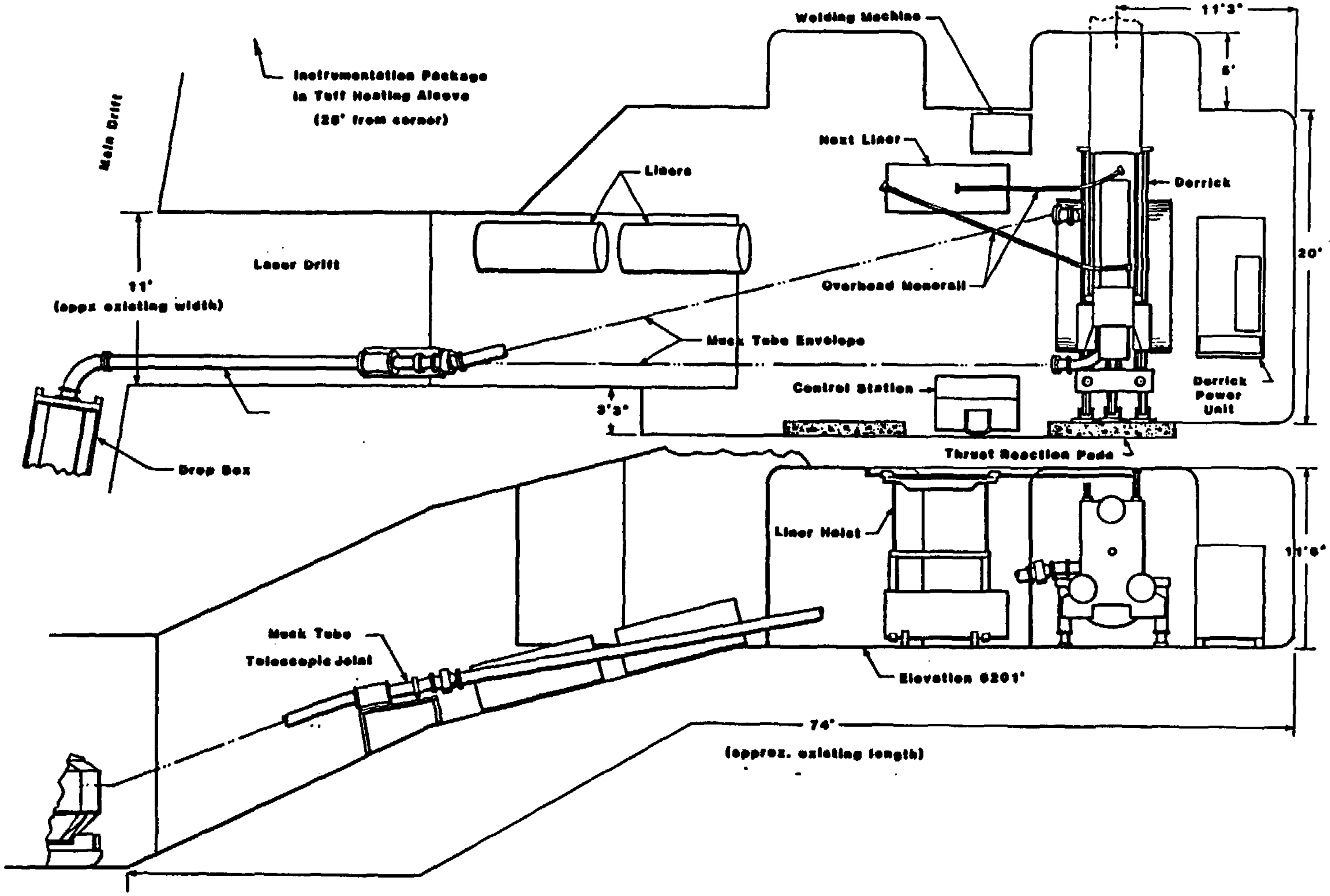

FIGURE 12 - NTS Test Site Arrangement, Bore No. 1

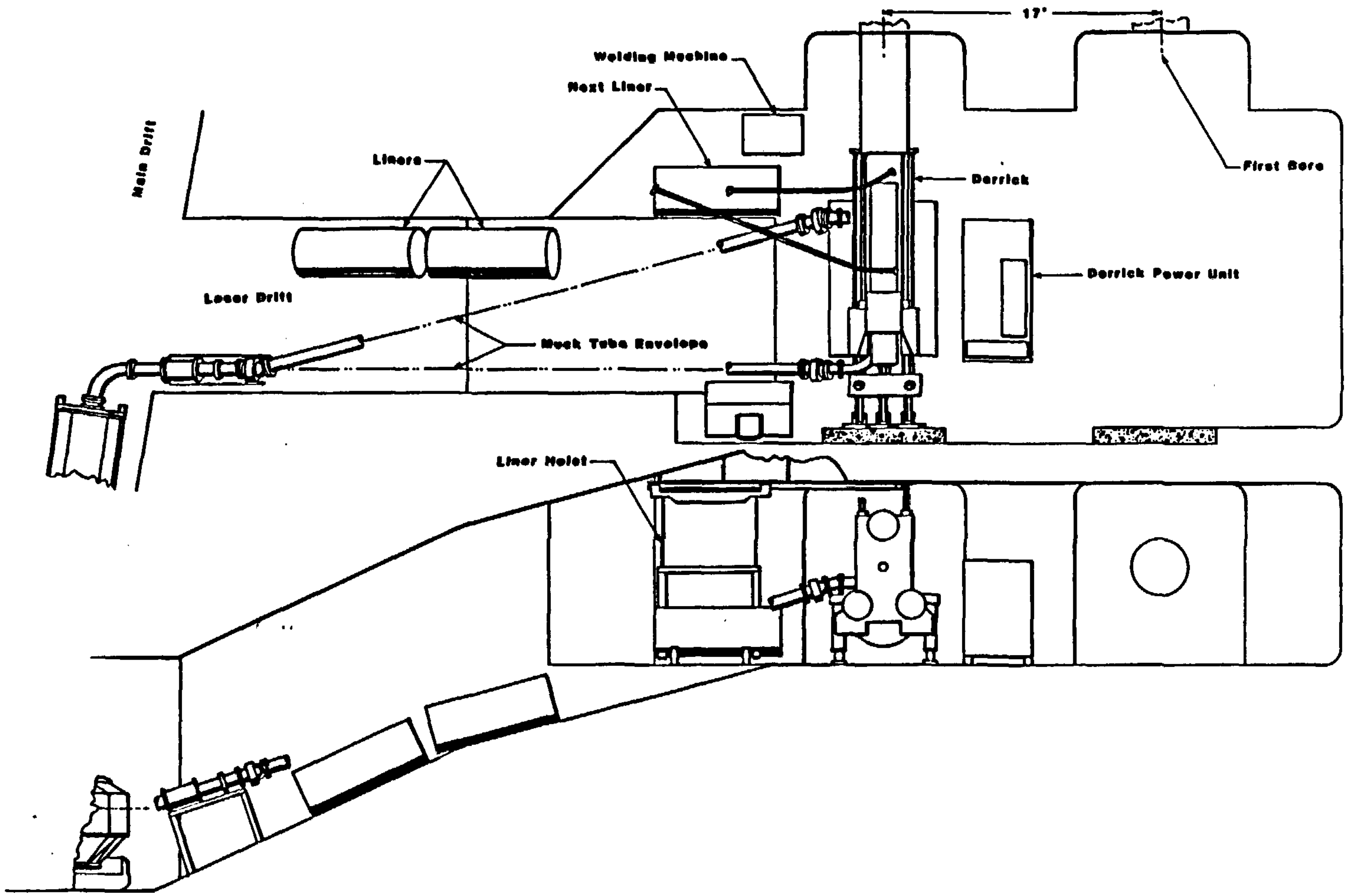

FIGURE 13 - NTS Test Site Arrangement, Bore No. 2

4.2.2 Utilities Required

The DPBM will require 400 kva of electrical power at 460 VAC; three phase. Transformers will be required to reduce the 4160 VAC mine supply.

Compressed air for the mucking system ancillary requirements such as the pneumatic discharge system (20 psi), filter purging, dust conveyor motors and isolation valve activation will be required. The existing 90 psi air supply should be adequate.

Lighting and ventilation will be required for the laser drift similar to that existing in the rock mechanics drift.

4.2.3 Special Provisions

Other modifications and additional items necessary for the operation of the DPBM are identified in the following paragraphs.

4.2.3.1 DPBM Handling Equipment

The following items will be required to handle the components of the DPBM:

a. Liner Handler. A liner handler will be required to lift and position the liner sections into the derrick chassis. This could be accomplished by means of an overhead monorail or special handling fixture. The best approach will be determined after further investigation of detail conditions in the laser drift.

b. Drill and Shield Handling Fixture. A means of handling the drill unit under two conditions is required. First, the drill unit must be installed with its shield and the entire assembly loaded into the derrick. Upon completion of the hole, or in the event of removal for repair, the fixture must be capable of handling the drill unit alone. The fixture to perform these functions has not been designed.

c. Derrick Handling Fixture. The Mobile Derrick could be lifted as an assembly by pick points designed into the main chassis for loading and transport by railway into the tunnel. However, there are two sections of the tunnel with restricted headroom (7 ft. 10 in.) which must be considered in designing the transport car. The other alternative is to disassemble the crawler from the main chassis and reassemble the unit at the tunnel railhead. Once the derrick is assembled in the main drift, near the entrance to the laser drift, the derrick mounted crawler should provide adequate mobility.

d. Power Unit Handling Fixture. A fixture will be needed to lift and position the Power Unit into the first liner section. Also, upon withdrawal of the drill, this fixture must hoist the Power Unit clear of the derrick as the final section of muck pipe is removed.

4.2.3.2 Mucking Equipment Revisions

Since the laser drift is neither long enough nor large enough in cross section, the mucking system drop boxes, filter car and blower should be located around the corner in the main drift. The preferred location would be in an alcove, excavated near the laser drift intersection. This permits the building of a noise reduction barrier without blocking the main drift. However, an extra elbow is required to duct the muck around the bend.

To accommodate the arc described by the muck transfer pipe as the derrick strokes, a telescopic joint is required. The present design houses the telescopic joint in the first drop box.

With the required positioning in the G-Tunnel complex, the joint must be accommodated in the transfer pipe. The design of pipe lengths and elbows must be accomplished and a revised telescoping joint fabricated and installed.

4.2.3.3 Load Bearing Pads

Concrete pads are required on the floor and rear wall to withstand the dead weight of the equipment and the thrust reaction loads respectively. A concrete pad, approximately 5 ft. diameter and at least 6 in. thick, should be constructed at the point of bore entry in the front wall. This will ensure a sound starting point for the drill and provide a flat bolting surface for the selected method of collaring (using a "top hat" section as described in the following section).

4.2.3.4 Collaring Fixture

A method of holding the cutterhead steady at the start of boring is necessary until the stabilizing shoes are inside the bore. Three options were considered. Briefly, (1) a collar, precast into a face pad; (2) a freestanding steel frame, stabilized at the floor and roof; and (3) a "top hat"-like steel collar, bolted to a minimal face pad were investigated. The "top hat" collar was chosen primarily because of its low cost, small size and ease of installation. The collar will be bolted to the concrete face pad through the use of rock bolts. The unit will be designed to separate in half to permit removal.

4.3 System Mobilization

The DPBM system will be transported from Seattle to NTS and offloaded near the mouth of G-Tunnel. The tunnel railway will move the components back to the specific test site. From the railhead, the components and specialty items will be moved to the laser drift by a large front end loader. The derrick will move under its own power.

The following paragraphs describe the mobilization, installation and special features of the test arrangement.

4.3.1 Transport and Handling of the DPBM

The transport of the DPBM follows the completion of the acceptance test activity in Seattle. Each component is prepared for shipment by truck for delivery to the NTS U12G Tunnel Complex portal. Components can be provided with pick points for lifting by crane for offloading onto the tunnel railway flatcars. Some items such as liner segments can be sling-lifted or handled by forklift. Items such as handling fixtures, cabling, collaring fixture and slings can be palletized for handling by forklift.

The equipment can be transported by tunnel rail to within 240 ft. of the laser drift. The use of the DPBM handling equipment described in paragraph 4.2.3.1 will facilitate placement of the system for testing.

4.3.2 DPBM Test Arrangement

The test setup for the two bores is shown in Figure 11 (Bore No. 1) and Figure 12 (Bore No. 2). The first bore is located approximately 63 ft. from the laser drift entry. A 5 ft. recess needs to be excavated into the face to permit room for the derrick with the In-Hole Assembly mounted preparatory to drilling.

Four motorized floor screw jacks on each corner of the derrick frame are used to relieve the load from the crawler and to orient the derrick at the required boring angle. The operator's console should be located such that the operator can observe the derrick and drill during the collaring process.

Sufficient clearance must be permitted in the laser drift for translation of the muck transfer pipe as the derrick pushes the liner into the bore and retracts. The transfer pipe is the connecting link between the derrick muck elbow and the elbow leading to first drop box. Ball joints located at each end of the transfer pipe are required to permit its angular rotation as the derrick strokes forward. The telescopic joint must be located in the transfer pipe or at the downstream ball joint.

The Power Unit is located next to the derrick on the opposite side from the mucking system. It provides the high pressure hydraulic oil supply for the derrick and crawler functions. The power unit also houses the motor control center, various starters, overload relays and circuit breakers. A programmable controller which directs the interlock logic is also located on the Power Unit.

The automatic welding machine is located in front of the derrick where it can join a newly added liner segment to the installed section.

The second bore is to be located 17 ft. toward the laser drift entry from the first bore, with the same general arrangement of equipment. The primary exception being the shortening of the connecting pipe between the transfer pipe and the elbow leading to the first drop box.

4.3.3 Instrumentation and Data

Although the extent of instrumentation is generally dictated by the requirements of a definitive test plan, the DPBM equipment was set up for R&D data collection. The instrumentation and real time readouts incorporated are as described in Paragraphs 3.8 and 3.9 and reflect past experience in tunneling equipment development. In addition, the console is designed to permit the installation of recording devices.

4.3.3.1 Console Monitoring

All drill functions, and the major functions of the derrick and mucking system, are controlled from the control console. Gages and indicator lights are used to monitor various parameters. The remote laser readout screen occupies a central position and monitors bore deviation from true center.

The panel is divided into three clearly defined areas, grouping separately the drill, derrick and vacuum pump systems to avoid confusion during operation.

A vacuum pump console located at the blower cart provides local control of the vacuum pump for checking and troubleshooting purposes. An emergency stop button is also incorporated. The drop box isolation valve control switch also is located here.

4.3.3.2 Data Recording

A permanent record of gage and indicator readings can be obtained by tapping off of the control console to electronic recording equipment. The selection of data to be recorded will be accomplished when preparing the definitive test plan.

4.4 Boring Operation

The operation of the DPBM follows a sequence of events from the setting-up of the machine to the withdrawal of the drill upon completion of the finished bore. The following paragraphs describe the steps involved in the drilling. They provide the basis for generating the performance estimates and for developing the operation schedule.

4.4.1 Setting Up

After making the electrical and hydraulic connections between the various components, preparations for start-up of drilling can be made.

4.4.1.1 Derrick Positioning

By maneuvering the derrick (shown in Figure 7) with the crawler tracks, it can be aligned in the plane of the intended bore. The derrick is backed up toward the rear wall within reach of the thrust reaction jacks.

The laser unit can now be accurately positioned so that it lines up with the derrick centerline in plan view and is set to the exact inclination angle required. Two temporary targets defining the centerline of the derrick are installed, one at the rear of the machine and one at the end of the headframe bolted to the guide tubes.

The following steps describe the procedure involved in positioning the derrick:

a. Align the derrick in the vertical plane using the four leveling floor jacks so that the laser spot strikes the front and rear target bullseyes.

b. Extend the thrust reaction jacks to contact the rear wall. Lock the jacks into position.

c. Extend the torque reaction jacks to contact the roof. Lock the jacks into position.

d. Check laser alignment and readjust jacks. Note that if the inclination angle is within tolerance, the laser unit can be slightly readjusted.

e. Extend the pull-back reaction jacks to contact the front wall.

4.4.1.2 In-Hole Assembly Placement

With the derrick lined up and secured in position, the In-Hole Assembly can be hoisted into place using the Drill and Shield Handling Fixture described in Paragraph 4.2.3.1 (b).

The assembly will sit on rollers located on the lower thrust cylinder. The unit is rolled back to contact the thrust collar, and the liner clamp cylinders are pressurized, gripping the liner.

4.4.1.3 In-Hole Assembly Positioning

In order to start the drilling process, the In-Hole Assembly must be connected to the In-Hole Power Unit. During collaring in of the shield, this power unit is to be positioned adjacent to the derrick and installed inside the first liner section. The following steps describe the procedure involved:

a. Complete hydraulic connections between the power unit and the In-Hole Assembly.

b. Complete electric connections between the power unit and the control console.

c. Pressurize the shield engagement mechanism to the lock position.

d. Raise the cutterhead to the boring position. Note: Stabilizer shoe is not extended at this time.

e. Stroke the thrust cylinders until the cutterhead contacts the face.

4.4.2 Collaring-In

The collaring process is performed in basically a two-step procedure as shown in Figure 14.

The temporary "top hat" collar is attached as shown in Step 1. This unit is split in the vertical plane so that it can be removed once the drill is collared in. When bolted together, it forms a 37 in. inside diameter heavy-wall steel tube. The shield is placed so that it is supported by the top hat collar.

The following steps describe the procedure involved:

a. Extend the upper (stabilizing) shoe to contact the upper inner wall of the collaring fixture by placing the control console mode selection switch to the "bore" position.

b. Extend the muck system telescopic connection at the crosshead to mate with the end of the muck pipe in the In-Hole Assembly.

c. Switch vacuum system on. (Although it will not capture all the muck particles until the head is completely collared in, it will help to control the dust generated by the cutting action.)

d. Switch cutterhead drive on. Begin boring at a very low feed rate.

In Step 2 of Figure 14, the stabilizer shoe is shown inside the freshly cut bore and the drill collar has been removed to permit the full stroke of the derrick.

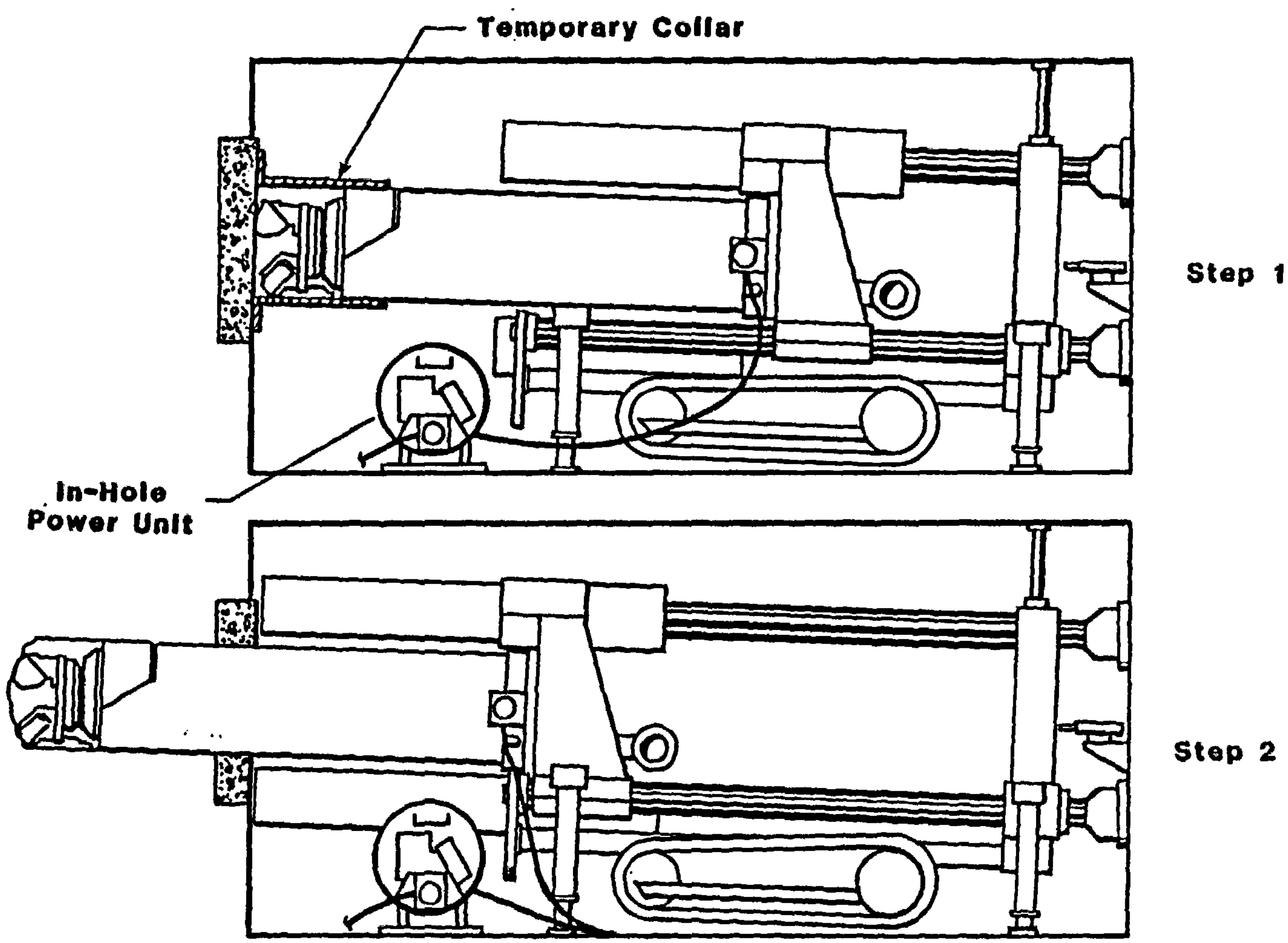

FIGURE 14 - Collaring-In

As a standard operating procedure, the laser target readout should be monitored on a continuous basis during the boring operation. After the full stroke is reached, the liner clamps are released and the thrust cylinders completely retracted.

4.4.3 Liner and Muck Pipe Installation

The installation of a liner and muck pipe segment is illustrated in two steps as shown in Figure 15.

The following are the procedures for Step 1:

a. Hoist the first liner (with the In-Hole Power Unit and a length of muck pipe nested inside) into place on the derrick roller assemblies.

b. Bolt the liner muck pipe to the In-Hole Assembly muck pipe rear unit.

c. Feed the electric cables out of the slot in the jacking collar (cables should be prestrung through at least three liners).

d. Pressurize liner clamps preparatory to boring.

The following are the procedures for Step 2:

a. Install welding machine track and head.

b. Weld the liner-to-shield joint.

c. Extend telescopic muck joint to mate with new muck pipe.

d. Restart boring operation. Complete full stroke of the derrick thrust cylinders.

The above boring and retraction of the thrust cylinders is repeated.

The second liner to be added contains a muck pipe with a large covered access hole to be used for mechanically dislodging any material which may later clog the muck passage through the In-Hole Assembly. The rear end of the In-Hole Power Unit is attached to the muck pipe in the second liner by a removable link.

Three liners should be prestrung with the electric cabling to reduce disconnection and reconnection efforts. The cabling is fabricated in 50 ft. lengths, and represents a compromise between minimizing the number of connections and causing difficult bundling and stringing problems.

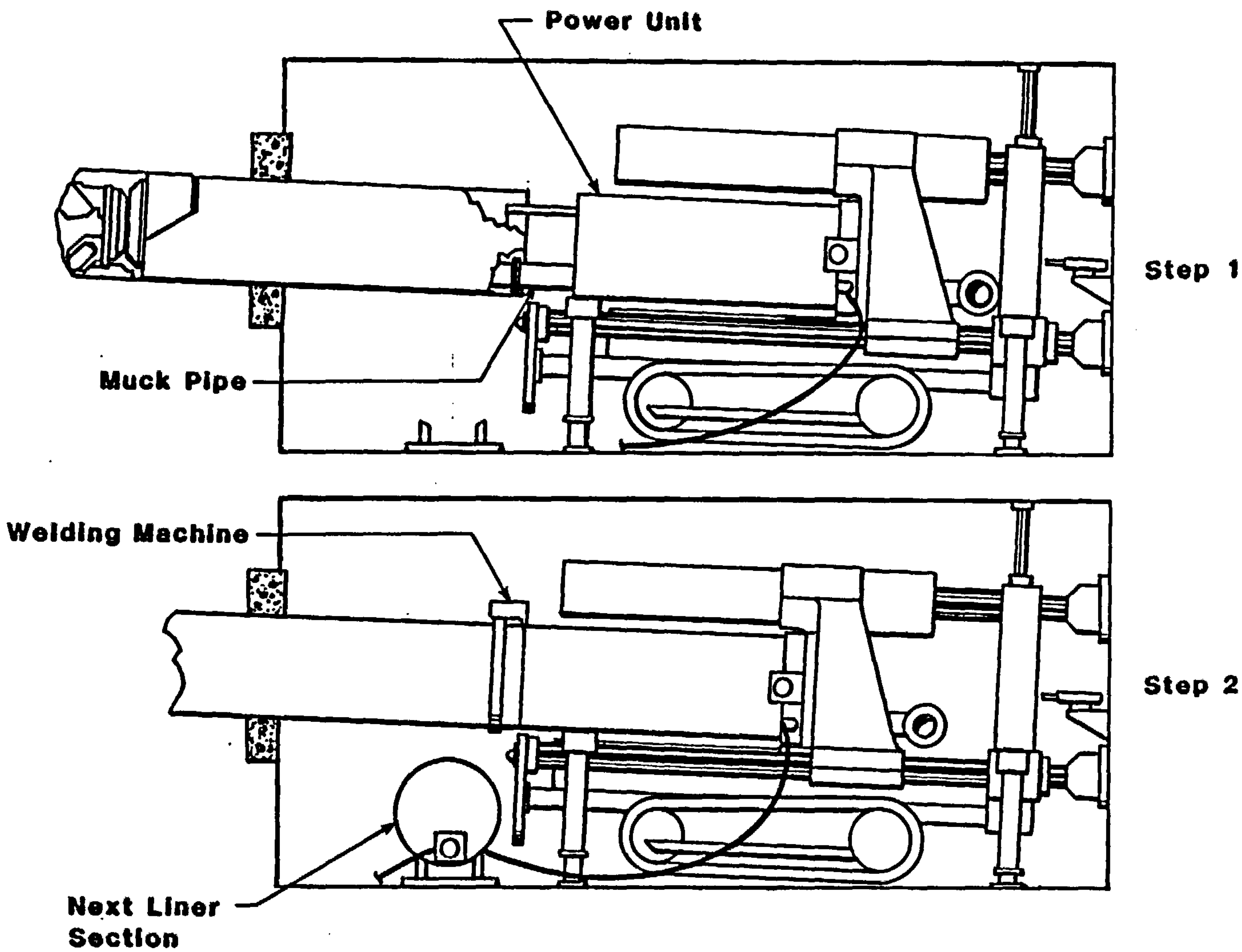

FIGURE 15 - Liner Installation

Figure 7 depicts the operating cycle with the third liner shown in place and ready for boring.

4.4.4 Drill Withdrawal

Drill withdrawal is required when the hole is completed or during drilling operations should problems develop with the in-hole components. The following steps describe the procedure involved:

a. Remove the telescopic muck joint at the derrick.

b. Install the muck pipe retrieval tool preparatory to pulling back muck pipe sections.

c. Stroke the derrick forward to connect the bolted retrieval tool to muck pipe rear flange.

d. Jog the drill motor until indicator lights on the console show that the drill head is correctly indexed for withdrawal.

e. Retract the steering cylinders to allow the upper stabilizing shoe to lower and clear the roof of the shield.

f. Release the shield engagement mechanism.

g. Retract the derrick to withdraw the drill.

h. At the completion of each retraction stroke of the derrick, remove the withdrawn section of muck pipe.

i. Extend the derrick and bolt the retrieval tool to the next section of muck pipe.

The above steps (g) through (i) are repeated until the In-Hole Power Unit is withdrawn from the liner.

The power unit is removed by performing the following steps:

a. Lift the In-Hole Power Unit using the fixture described in Paragraph 4.2.3.1 (d) sufficiently to disconnect the electrical and hydraulic connections. Detach the removable extraction link.

b. Hoist the power unit clear of the derrick and store.

c. Remove the first section of muck pipe.

d. Withdraw the (drill) In-Hole Assembly using the fixture described in Paragraph 4.2.3.1 (b).

4.4.5 Drill Reinsertion

Reinsertion is necessary if the drill has been removed for repair before completion of the hole.

With the retrieval tool still in place at the derrick, following the drill removal operation, the steps for reinsertion follow:

a. Hoist the In-Hole Assembly into alignment with the bore using the fixture described in Paragraph 4.2.3.1 (b).

b. Extend the derrick thrust cylinders, thereby pushing the drill into the bore.

c. Upon full extension of the thrust cylinders, retract the crosshead to the rear starting position.

d. Insert the first section of muck pipe and bolt it to the exit flange of the drill muck pipe.

e. Hoist the In-Hole Power Unit into position over the muck pipe.

f. Complete the hydraulic and electrical connections between the In-Hole Assembly drill and the In-Hole Power Unit.

g. Extend the thrust cylinders to insert the power unit into the bore.

h. Retract the thrust cylinders and install the second piece of muck pipe containing the access hole.

i. Install the connecting link between the second muck pipe and the power unit.

j. Extend the thrust cylinders to insert the second muck pipe into the bore.

The above steps (h) through (j) are repeated adding sections of muck pipe. The electric cabling is strung along the hangers attached to the pipe.

When the drill is almost in contact with the face, (determined by a count of the muck pipes inserted and the location of the crosshead), the thrust monitor selector on the control console must be in the "release" position. This permits the shield engagement mechanism to operate without the cutterhead being hard against the face. The following steps describe the procedure necessary to restart boring:

a. Activate the shield engagement switch. Positive engagement of the locking device is indicated by lights on the control console.

b. Position the cutterhead in accord with the last recorded position on the guidance system screen (before withdrawal) by use of the steering cylinders. If a gage cutter change has been made, a correction will be necessary to compensate for the difference in gage diameter.

c. Select "bore" mode at the console.

d. Start the vacuum system.

e. Switch on the cutterhead drive.

f. Switch the thrust monitor to "set" at the console. This will cause the cutterhead to advance relative to the shield.

Boring can now be restarted. Begin boring at a very low feed rate.

4.4.6 In-Hole Power Unit Withdrawal

Withdrawing only the power unit is not a routine procedure, but can be considered as an alternative to removal of the entire drill. Also, an emergency situation might exist where the hydraulic unit fails, preventing the drill from being extracted. This requires a man to go up the bore, disconnect the hydraulic lines to the drill and the drive link to the muck pipe, and attach a rope or small diameter push/pull rod. No ancillary equipment for withdrawal and reinsertion has been designed under the present contract. The power unit has been designed with wheels for removal and clearance are provided for it to pass over the muck pipe flanges and cable hangers.

4.4.7 Test Set Up/Borehole No. 2

Following completion of the first bore, the equipment must be moved to begin operation on the second bore. The derrick can be maneuvered on its tracks. As the move distance is only 17 ft., the power unit does not need to be moved simultaneously. Hose connections of sufficient length are provided.

The other equipment items are repositioned as shown in Figure 13.

4.5 Test Schedule Elements

The following estimates of overall boring operation times have been made by summing the times of a number of individual tasks. Some tasks are independent of the length of bore (e.g. collaring) while some are dependent on length (e.g. 8 ft. boring cycle). The analysis is for a 250 ft. length. Figure 16 shows the schedule of the major steps analyzed in Paragraph 4.5.1. To estimate the overall time required for any other bore length, recomputing the length-dependent items will provide corresponding schedules.

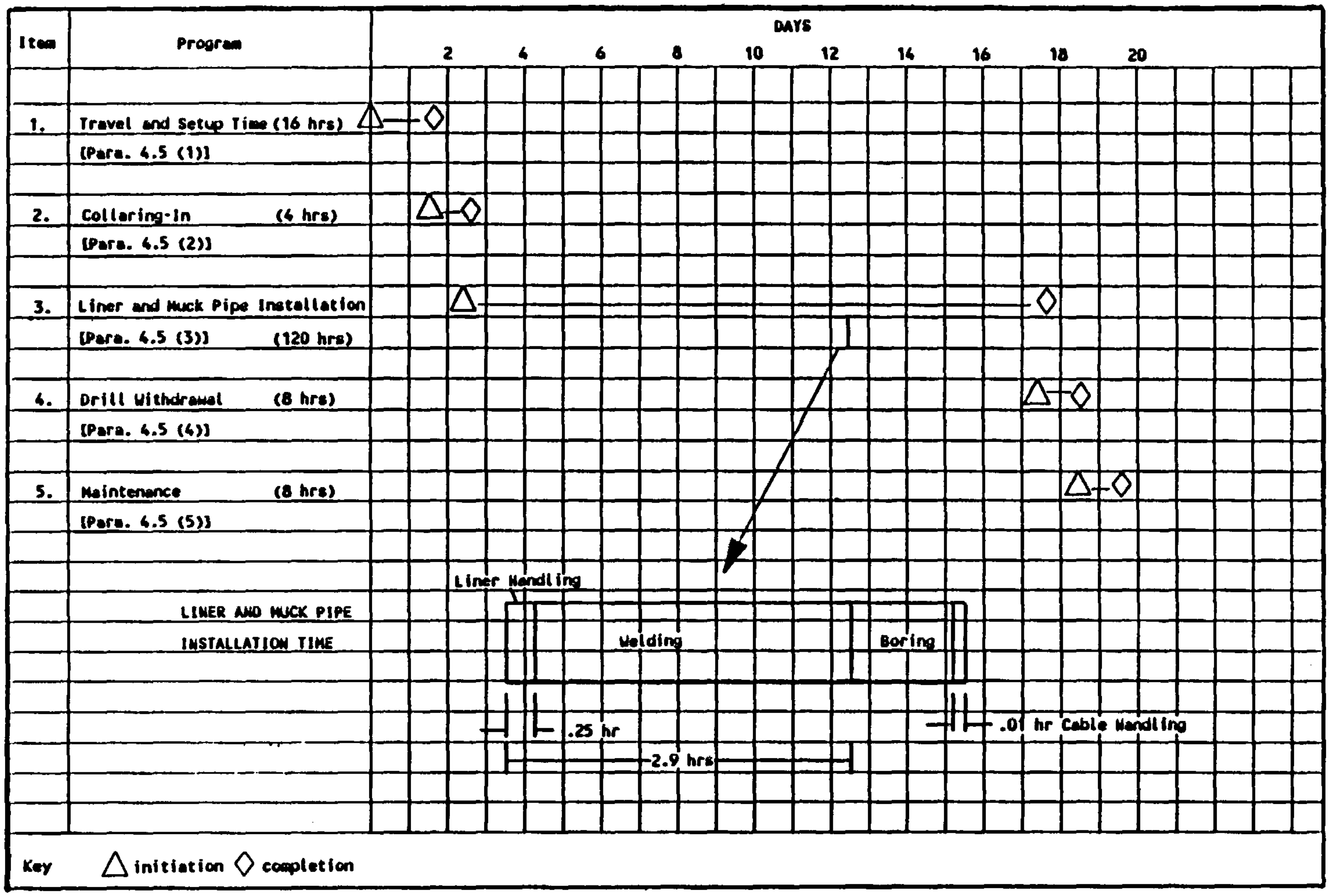

FIGURE 16 - Boring Operation Durations

The time estimates for individual tasks were assessments by experienced personnel from Robbins and specific vendors. There is a good deal of historical data from similar tasks. The schedule shown in Figure 16 does not account for the delays due to data collection, repairs or unanticipated geological conditions. It also does not account for pre-planned development test activity. The operational durations presented are intended to guide the writing of a definitive test plan. They are not indicative of a test hole schedule.

a. Travel time between Bore No. 1 and Bore No. 2. Though the distance is only 17 ft., the activity involved in equipment movement, realignment of the derrick and muck system adjustments is estimated to take 16 hours.

16 hrs.

b. Collaring-In. Total stroke during collaring is 9 ft. 6 in. Boring rate is slow to reduce forces plus time is needed to remove the temporary collar.

4 hrs.

c. Liner and Muck Pipe Installation.

(1) Handling. (Transport of liner to derrick, join muck pipe, feed cable, butt up liner before welding.)

.25 hr./liner

(2) Welding of Liner.

Installation of alignment jig	0.1 hr.
Tacking	0.2 hr.
Weld time (based on automatic machine data)	1.75 hrs.
Inspection	0.6 hr.
Subtotal	2.9 hr./line

(3) Bore 8 ft. 1 hr.

(4) Cable handling 0.3 hr. every 3 liners 0.1 hr./liner

TOTAL CYCLE TIME PER 8 FT. SEGMENT 4.0 hr./liner

For the completed 250 ft. hole, 30 liners in addition to the sacrificial drill shield are required.

TOTAL BORING AND LINER INSTALLATION TIME 120 hrs.

d. Drill Withdrawal

(1) Removal of the telescopic muck joint, installation of the retrieval tool, indexing and lowering of the cutterhead.

.25 hr.

(2) Muck pipe removal including derrick traverse, unbolting two flanges, pipe removal, retraverse and bolting up of the retrieval tool, and cable disconnection. .25 hr. per pipe times 30 pipes

Total 7.5 hrs.

(3) Removal of drill unit .25 hr.

TOTAL WITHDRAWAL TIME 8 hrs.

e. Maintenance activities including clean up, replacement of consumable components (cutters, filters, etc.) greasing and functional checking.

8 hrs.

TOTAL EMPLACEMENT BORING CYCLE SUMMARY

a.	Travel Time	16
b.	Collaring-In	4
c.	Lining/Boring	120
d.	Drill Withdrawal	8
e.	Maintenance	8
		156 hrs.

On a single-shift basis, an uninterrupted drilling sequence for a 250 ft. hole will consume 20 days. In the definitive test plan, all times for test, data collection, physical examination, etc. should be added to these time durations.

Note that this estimate assumes that emptying the muck system drop boxes and cleaning the vacuum unit, and the time required for cable threading, takes place during the liner welding operation. The supply of new liners and muck pipes to the ready area can be made at any time. Again, note that the times presented are intended only to guide the writing of a definitive test plan.

4.6 Personnel Requirements

A four-man drilling crew plus supervisor will be required. While the machine is boring, one will be operating the drill, another will monitor the vacuum system and supervise muck haulage, and a third will be involved in organizing the movement of liners, muck pipes and electric cabling. The fourth will be general labor. All four will be needed for the liner installation operation and for set up of the welding machine. While one person is operating the welding machine, the others will be involved in emptying the drop box and filter units, and performing any necessary equipment maintenance.

In addition, the services of an independent welding inspector will be required for the checking of every liner joint.

Electrical and mechanical repair personnel should be available in case of breakdown.

REFERENCES

The Robbins Company, Final Report, Repository Drilled Hole Methods Study, SAND83-7085, (Albuquerque: Sandia National Laboratories, November, 1984).

The Robbins Company, Small Diameter Horizontal Hole Drilling: State of Technology, SAND84-7103, (Albuquerque: Sandia National Laboratories, November, 1984).

The Robbins Company, Feasibility Studies and Conceptual Design for Placing Steel Liner in Long, Horizontal Boreholes for a Prospective Nuclear Waste Repository in Tuff, SAND84-7209 (Albuquerque: Sandia National Laboratories, July, 1985).

APPENDIX A

to

DESIGN OF A MACHINE TO BORE AND LINE
A LONG HORIZONTAL HOLE IN TUFF

INDENTURED DRAWING LIST

SANDIA DPBM - MASTER DRAWING LIST			SHEET 1 OF 28
ASSEMBLY TITLE: SITE INSTALLATION/GENERAL ARRANGEMENT DRAWING NO: D35910			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D35910		SITE INSTALLATION	10.25.85
D35911		IN-HOLE ASSEMBLY	10.25.85
D35920		MOBILE DERRICK ASSEMBLY	10.25.85
D35632		MUCKING SYSTEM ASSEMBLY	10.25.85
D35927		CONTROL STATION ASSEMBLY	10.25.85
B36514		LINER	10.25.85
D36136		MUCK TUBE	10.25.85
A36515		LASER	10.25.85
A36516		WELDING SYSTEM	10.25.85
D35914		HYDRAULIC SYSTEM ASSEMBLY	10.25.85
D35915		ELECTRICAL SYSTEM ASSEMBLY	10.25.85
		GENERAL SPECIFICATIONS	
A36160		LOCKWIRE INSTALLATION	10.25.85
A36165		RADIOGRAPHIC INSPECTION	10.25.85
A36166		CARBURIZATION SPECIFICATION	10.25.85
A35950		ULTRASONIC TESTING	10.25.85
A35952		MAGNETIC PARTICLE INSPECTION	10.25.85
A36544		WELDING SPECIFICATION	10.25.85
A36572		FASTENER TORQUES	10.25.85
A36162		HARDFACING PROCEDURE	10.25.85
A37355		HEAT TREATMENT SPECIFICATION	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 2 OF 28
ASSEMBLY TITLE: IN-HOLE ASSEMBLY DRAWING NO: D35911			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D35911		IN-HOLE ASSEMBLY	10.25.85
D36121		DRIVE ASSEMBLY	10.25.85
D35947		OUTER HOUSING	10.25.85
D35949		RING CARRIER	10.25.85
D35950		SEAL RING	10.25.85
D35952		BEARING CARRIER	10.25.85
D36072		CUTTERHEAD SHAFT	10.25.85
D35940		FINAL REDUCTION PLANET HUB	10.25.85
D35939		1ST REDUCTION PLANET HUB	10.25.85
D35948		END CAP	10.25.85
D36061		MOTOR COUPLING	10.25.85
D36057		COUPLING 1ST REDUCTION	10.25.85
D35943		JUNCTION BOX	10.25.85
D35941		ELECTRIC MOTOR - 125 HP	10.25.85
D35909		SUN PINION OUTPUT	10.25.85
D35908		PLANET - 1ST REDUCTION	10.25.85
D36056		COUPLING - 2ND REDUCTION	10.25.85
D35906		SUN PINION - 2ND REDUCTION	10.25.85
D35907		PLANET - 2ND REDUCTION	10.25.85
D36060		SPLINED ADAPTER	10.25.85
D36164		SPLINED COUPLING	10.25.85
D36508		SPLINED COUPLING	10.25.85
B35946		BEARING LIST	10.25.85
A35945		CYLINDRICAL ROLLER BEARING	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 3 OF 28
ASSEMBLY TITLE: IN-HOLE ASSEMBLY (CON'T) DRAWING NO: D35911			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
B36161		REDUCTION RING GEAR	10.25.85
B36069		FRONT RETAINER	10.25.85
B36149		SENSOR HOUSING	10.25.85
B36086		RETAINER	10.25.85
B36087		RETAINER	10.25.85
B36088		RETAINER	10.25.85
B36150		SEAL RING	10.25.85
A36059		SEAL GUARD	10.25.85
A36058		SPACER	10.25.85
A36068		PIN	10.25.85
A35962		PLANET PIN	10.25.85
A35961		PLANET PIN	10.25.85
A35958		BEARING SPACER	10.25.85
A35957		THRUST BEARING	10.25.85
A35956		BEARING SPACER	10.25.85
A35959		THRUST SPACER	10.25.85
A36090		THRUST WASHER	10.25.85
A35960		SPACER RING	10.25.85
A36159		SEAL SET	10.25.85
A36575		SENSOR BOSS	10.25.85
A36071		INSTALLATION INSTRUCTIONS	10.25.85
A36070		SEAL WEAR RING	10.25.85
A36144		SEAL PROTECTOR	10.25.85
A36163		THERMOCOUPLE	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST

ASSEMBLY TITLE: IN-HOLE ASSEMBLY (CON'T)

DRAWING NO: D35911

DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
B36167		BEARING SHIM	10.25.85
A36160		LOCKWIRE INSTRUCTIONS	10.25.85
D36105		STEERING & MUCK SYSTEM ASSEMLY	10.25.85
D36055		GRIPPING SHOE - UPPER	10.25.85
D36054		GRIPPING SHOE - LOWER	10.25.85
D35944		MUCK TUBE	10.25.85
D35942		WEDGE - TOP	10.25.85
D35942		WEDGE - BOTTOM	10.25.85
D35951		CYLINDER - TOP	10.25.85
D35951		CYLINDER - BOTTOM	10.25.85
D35953		SHEAR LUG	10.25.85
D36065		BEAM	10.25.85
B36129		CYLINDER RETAINER	10.25.85
B36115		FLANGE MALE	10.25.85
A36507		LINEAR TRANSDUCER SENSOR	10.25.85
A36124		SPRING	10.25.85
A36092		RETAINER	10.25.85
A36094		SPHERICAL SEAT	10.25.85
A36123		SPRING HOLDER	10.25.85
A36125		SPRING RETAINER	10.25.85
A36126		SPRING HOLDER	10.25.85
A36524		ANGLE FOR MUCK TUBE	10.25.85
A36522		ROLLER BALL	10.25.85
A36743		KEY	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST SHEET 5 OF 28

ASSEMBLY TITLE: IN-HOLE ASSEMBLY (CON'T)

DRAWING NO: D35911

DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
B36523		SPHERICAL NUT	10.25.85
B36525		CYLINDER THRUST SOCKET	10.25.85
A36160		LOCKWIRE INSTRUCTIONS	10.25.85
D36106		SHIELD ENGAGEMENT SYSTEM	10.25.85
D35977		THRUST BALL HOUSING	10.25.85
D36064		LOCKING LUG	10.25.85
D36185		COUPLING	10.25.85
D35955		SPLIT CLAMP	10.25.85
D35954		CROWN COUPLING	10.25.85
B36095		WEDGE	10.25.85
B36117		CYLINDER	10.25.85
B35930		ZED LASER TARGET	10.25.85
A36091		LINK	10.25.85
A36093		BARREL NUT	10.25.85
A36096		PIN	10.25.85
A36094		SPHERICAL SEAT	10.25.85
A36103		RETAINER - BALL	10.25.85
A36522		ROLLER BALL	10.25.85
A36127		TRUNNION	10.25.85
A36128		THREADED ROD	10.25.85
A36160		LOCKWIRE INSTRUCTIONS	10.25.85
A36720		SENSOR MOUNT BRACKET	10.25.85
D36130		SHIELD WELDMENT	10.25.85
D36062		LOCKPLATE	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 6 OF 28
ASSEMBLY TITLE: IN-HOLE ASSEMBLY (CON'T) DRAWING NO: D35911			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D36120		CUTTERHEAD ASSEMBLY	10.25.85
D36112		CUTTERHEAD MACHINING	10.25.85
D36118		CUTTERHEAD WELDMENT	10.25.85
A36568		CUTTER ASSEMBLY NO. 1	10.25.85
A36569		CUTTER ASSEMBLY NO. 2	10.25.85
A36570		GAGE CUTTER ASSEMBLY	10.25.85
D36664		DRIVE PLATE-POWER UNIT	10.25.85
D36136		MUCK TUBE ASSEMBLY (SEE SHT. 15)	10.25.85
D36662		MUCK TUBE - DRIVER ASSEMBLY	10.25.85
D36136		MUCK TUBE ASSEMBLY	10.25.85
B36114		FLANGE - FEMALE	10.25.85
B36115		FLANGE - MALE	10.25.85
A36109		WHEEL BRACKET	10.25.85
A36108		WHEEL	10.25.85
B36137		CABLE SUPPORT BRACKET	10.25.85
A37333		STOP	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 7 OF 28
ASSEMBLY TITLE: MOBILE DERRICK ASSEMBLY DRAWING NO: D35920			

DRAWING NO. (1 2 3 4 5 6)	REV	TITLE	RELEASE DATE
D35920		MOBILE DERRICK ASSEMBLY	10.25.85
D35985		CRAWLER FRAME ASSEMBLY	10.25.85
D35978		CRAWLER FRAME WELDMENT	10.25.85
D35979		TRACK FRAME WELDMENT	10.25.85
B35980		SIDE RAIL	10.25.85
A35981		BAR	10.25.85
A35982		WEAR STRIP	10.25.85
D35983		LOCATING TOOL (REF)	10.25.85
D35984		HUB DETAIL	10.25.85
D35986		CYL. TRACK ADJUSTER	10.25.85
D35987		CYLINDER BASE	10.25.85
D35988		CYLINDER BODY	10.25.85
D35989		PISTON	10.25.85
D35990		SPRING ASSEMBLY	10.25.85
A35991		SHAFT	10.25.85
A35992		SPRING RETAINER	10.25.85
A35993		SPRING RETAINER	10.25.85
A35994		COMPRESSION SPRING	10.25.85
A35995		COMPRESSION SPRING	10.25.85
D35996		SPROCKET	10.25.85
D35997		TRACK IDLER ASSEMBLY	10.25.85
A35998		STEEL BALL	10.25.85
D35999		TRACK ROLLER ASSEMBLY	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 8 OF 28
ASSEMBLY TITLE:		MOBILE DERRICK ASSEMBLY (CON'T)	
DRAWING NO: D35920			

DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D36000		UPPER IDLER ASSEMBLY	10.25.85
D36001		TRACK, CHAIN, COMPONENTS	10.25.85
A36002		TRACK SHOE	10.25.85
A36003		SEAL - OIL	10.25.85
A36004		SEAL - PISTON	10.25.85
D36005		TORQUE HUB	10.25.85
A36006		FAILSAFE BRAKE	10.25.85
A36007		HYDRAULIC MOTOR	10.25.85
D35921		DERRICK ASSEMBLY	10.25.85
D36009		THRUST CYLINDER - UPPER	10.25.85
A36008		SEAL KIT	10.25.85
D36010		THRUST REACTION JACK	10.25.85
A36011		SEAL KIT	10.25.85
D36014		EXPANSION PIN	10.25.85
B36012		TAPER PLUG	10.25.85
B36013		TAPER PLUG	10.25.85
D36015		EXPANSION PIN	10.25.85
D36022		LEVELING JACK ASSEMBLY	10.25.85
A36016		WORM GEAR	10.25.85
A36017		COUPLING	10.25.85
A36018		HYDRAULIC MOTOR	10.25.85
D36023		JACK BODY L.H.	10.25.85
D36089		JACK BODH R.H.	10.25.85
D36024		JACK LEG	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST SHEET 9 OF 28

ASSEMBLY TITLE: MOBILE DERRICK ASSEMBLY (CON'T)

DRAWING NO: D35920

DRAWING NO. (1 2 3 4 5 6)	REV	TITLE	RELEASE DATE
B36025		PLATE	10.25.85
D36026		TORQUE REACTION JACK ASSEMBLY	10.25.85
B36027		ROD	10.25.85
B36028		LOCKNUT	10.25.85
B36029		SLEEVE	10.25.85
D36037		PULLBACK REACTION JACK	10.25.85
B36036		SLEEVE	10.25.85
D36034		ROD	10.25.85
D36035		TUBE	10.25.85
D36046		THRUST REACTION PAD ASSEMBLY	10.25.85
D36041		THRUST PAD	10.25.85
B36042		RETAINER PLATE	10.25.85
B36043		PIN	10.25.85
D36044		ROD EYE	10.25.85
A36045		RUBBER CUSHION	10.25.85
D36040		FRAME ASSEMBLY	10.25.85
D36019		COLUMN ASSEMBLY	10.25.85
D36020		COLUMN	10.25.85
D36021		COUPLING HALF	10.25.85
D36033		HEAD FRAME ASSEMBLY	10.25.85
D36032		HEAD FRAME	10.25.85
D36031		COUPLING HALF	10.25.85
D36038		MAIN FRAME	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 10 OF 28
ASSEMBLY TITLE: MOBILE DERRICK ASSEMBLY (CON'T)			
DRAWING NO: D35920			
DRAWING NO. 1 2 3 4 5 6	**REV**	**TITLE**	**RELEASE DATE**
D36031		COUPLING HALF	10.25.85
D36039		BEAM	10.25.85
B36047		THREADED SHAFT	10.25.85
D36075		CROSSHEAD	10.25.85
D36074		CROSSHEAD PRE-MACHINING	10.25.85
D36076		CYLINDER RETAINER	10.25.85
D36077		COLUMN RETAINER	10.25.85
D36078		SEAL RETAINER - SPLIT	10.25.85
D36079		BUSHING SPLIT	10.25.85
B36080		THRUST WASHER ASSEMBLY	10.25.85
D36081		THRUST RING	10.25.85
D36082		PIVOT MOUNT	10.25.85
D36083		PIVOT BLOCK	10.25.85
D36084		CYLINDER MOUNT - INNER	10.25.85
D36085		CYLINDER MOUNT - OUTER	10.25.85
D36741		THRUST CYLINDER - LOWER	10.25.85
B36511		LINER CLAMP CYLINDER	10.25.85
B36030		BARREL NUT	10.25.85
B36512		GRIPPER PAD - INNER	10.25.85
B36513		GRIPPER PAD - OUTER	10.25.85
D36510		DERRICK MUCK ELBOW	10.25.85
D36509		TELESCOPIC MUCK JOINT ASSEMBLY	10.25.85
D36143		TELESCOPIC TUBE	10.25.85
D36142		CYLINDER MOUNT TUBE	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 11 OF 28
ASSEMBLY TITLE: MOBILE DERRICK ASSEMBLY (CON'T)			
DRAWING NO: D35920			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
B36148		CYLINDER	10.25.85
B36145		PACKING RETAINER	10.25.85
B36146		PACKING SPACER	10.25.85
B36147		PACKING	10.25.85
D36733		LINER SUPPORT BRACKET	10.25.85
B36574		PIN - SUPPORT BRACKET	10.25.85
D36053		DRILL RETRIEVAL ADAPTER	10.25.85
A36742		TURNBUCKLE	10.25.85

COMPILED BY: Peter B. Dowden	DATE: 10.25.85	NO. A35926	REV -

SANDIA DPBM - MASTER DRAWING LIST			SHEET 12 OF 23
ASSEMBLY TITLE: MUCKING SYSTEM ASSEMBLY DRAWING NO: D35632			

DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D35632		MUCKING SYSTEM - GENERAL ARRANGEMENT	10.25.85
D35620		DROP BOX ASSEMBLY	10.25.85
D36555		SKID - DROP BOX	10.25.85
D36566		EJECTOR DISCHARGE PIPE	10.25.85
D35607		EJECTOR VALVE ASSEMBLY	10.25.85
D35595		VALVE BODY	10.25.85
D35619		BODY BLOCK	10.25.85
B35618		BULB VALVE - EJECTOR VALVE	10.25.85
B35603		CAP - EJECTOR VALVE	10.25.85
A35612		GASKET - EJECTOR VALVE	10.25.85
A35601		SPRING CAP - EJECTOR VALVE	10.25.85
A35604		LOCKNUT - EJECTOR VALVE	10.25.85
B35602		FORK END - EJECTOR VALVE	10.25.85
B35611		SPINDLE - EJECTOR VALVE	10.25.85
B35609		SPRING - EJECTOR VALVE	10.25.85
B35606		LINK - EJECTOR VALVE	10.25.85
B35605		LEVER - EJECTOR VALVE	10.25.85
B35608		PIN - EJECTOR VALVE	10.25.85
B36565		GASKET - DROP BOX HOPPER/VALVE	10.25.85
D35625		HOPPER - DROP BOX	10.25.85
D35638		GASKET - DROP BOX	10.25.85
D35629		DROP BOX BODY	10.25.85
D35630		SLOTTED EXPANSION TUBE	10.25.85
D36533		GASKET	10.25.85

COMPILED BY: Peter B. Dowden	DATE: 10.25.85	NO. A35926	REV -

ASSEMBLY TITLE: MUCKING SYSTEM ASSEMBLY (CON'T)

DRAWING NO: D35632

DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
B35610		DOOR - DROP BOX	10.25.85
B36564		DOOR GASKET - DROP BOX	10.25.85
D36562		SCREEN ASSEMBLY	10.25.85
D35616		TOP SECTION - DROP BOX	10.25.85
D36545		PRIMARY FILTER UNIT ASSEMBLY	10.25.85
D37172		45 DEGREE ELBOW	10.25.85
D36554		SKID - FILTER UNIT	10.25.85
B36541		SCREW CONVEYOR	10.25.85
D37231		MOUNTING SUPPORT	10.25.85
D36532		TRANSITION (45°)	10.25.85
D35593		HOPPER	10.25.85
D35631		FILTER BOX	10.25.85
D36548		COVER - TOP	10.25.85
D35637		GASKET	10.25.85
D37166		END COVER	10.25.85
D36556		END COVER GASKET	10.25.85
B35597		GASKET	10.25.85
B35598		GASKET	10.25.85
B37164		GASKET - MARLIN VALVE	10.25.85
D37224		TRANSITION - SCREW CONVEYOR TO VALVE	10.25.85
D37225		TRANSITION - VALVE TO BAG	10.25.85
A37239		VALVE - CLARKSON 6"	10.25.85
D35627		FILTER COMPONENTS	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 14 OF 28
ASSEMBLY TITLE: MUCKING SYSTEM ASSEMBLY (CON'T)			
DRAWING NO: D35632			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D36546		VACUUM PUMP UNIT	10.25.85
D36560		SKID-VACUUM PUMP ASSEMBLY	10.25.85
B36539		SILENCER - VACUUM PUMP	10.25.85
D35640		BELT GUARD - PUMP DRIVE	10.25.85
B35628		ELECTRIC MOTOR 200HP	10.25.85
B37258		VACUUM PUMP	10.25.85
A37168		EXPANSION JOINT	10.25.85
A37169		EXPANSION JOINT	10.25.85
D36540		DUCT ELBOW	10.25.85
D35633		FILTER BOX - SECONDARY	10.25.85
D35634		COVER	10.25.85
D35635		GASKET	10.25.85
D35636		COVER	10.25.85
D37240		GASKET	10.25.85
B36542		GASKET	10.25.85
D35627		FILTER PACK	10.25.85
D35639		PEDESTAL - FILTER BOX	10.25.85
D35639		PEDESTAL - FILTER BOX	10.25.85
B36538		GASKET	10.25.85
D37173		VACUUM SYSTEM CONTROL CONSOLE	10.25.85
A36168		D.C. MILLIAMMETER (TEMP)	10.25.85
A37255		D.C. MILLIAMMETER (VACUUM)	10.25.85
A37255		D.C. MILLIAMMETER (TEMP)	10.25.85
A37255		D.C. MILLIAMMETER (VACUUM)	10.25.85

COMPILED BY: Peter B. Dowden	DATE: 10.25.85	NO. A35926	REV -

SANDIA DPBM - MASTER DRAWING LIST			SHEET 15 OF 28
ASSEMBLY TITLE: MUCKING SYSTEM ASSEMBLY (CON'T)			
DRAWING NO: D35632			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
A36505		D.C. MILLIAMMETER(VACUUM)	10.25.85
A37259		AIR VELOCITY METER	10.25.85
A37259		PHASE SELECTOR SWITCH	10.25.85
D36528		EXPANSION JOINT TRANSFER PIPE	10.25.85
D36534		BODY	10.25.85
D36535		PISTON	10.25.85
B36536		FLANGE - ROD WIPER	10.25.85
B37345		PACKING RETAINER	10.25.85
B37346		PACKING	10.25.85
D35599		RAIL - EXPANSION JOINT	10.25.85
B37165		THREADED PISTON STOP	10.25.85
A37170		KGA PNEUMATIC SOLENOID VALVE	10.25.85
B37338		SEAL - GUARD RETAINER	10.25.85
D36537		SUPPORT FRAME	10.25.85
D36533		TRANSITION ASSEMBLY	10.25.85
A37170		PNEUMATIC SOLENOID VALVE	10.25.85
A37171		EXPANSION JOINT	10.25.85
D36531		TRANSITION - DROP BOX	10.25.85
D35624		DROP BOX CONNECTION VACUUM PIPE	10.25.85
D35614		DROP BOX CONNECTION MUCK PIPE	10.25.85
D35596		MUCK PIPE- DROP BOX CONNECTOR	10.25.85
B35594		SPLIT RING - DROP BOX CONNECTOR	10.25.85
B35615		SLIDING FLANGE RING	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 16 OF 28
ASSEMBLY TITLE: MUCKING SYSTEM ASSEMBLY (CON'T)			
DRAWING NO: D35632			
DRAWING NO. (1 2 3 4 5 6)	REV	TITLE	RELEASE DATE
D35623		BALL JOINT ASSEMBLY	10.25.85
D35621		BALL JOINT SOCKET	10.25.85
D35622		BALL JOINT RETAINER	10.25.85
D37223		BALL JOINT	10.25.85
D36533		GASKET	10.25.85
B35617		END STOP - DROP BOX	10.25.85
B35613		VACUUM DUCT STOP	10.25.85
B36530		DROP BOX SKID HINGE	10.25.85
B36530		DROP BOX SKID HINGE	10.25.85
B36543		TRANSFER PIPE	10.25.85
B37175		WATER INJECTION - EJECTOR DISCHARGE	10.25.85
B37174		FLEXIBLE HOSE ASSEMBLY	10.25.85
B36538		GASKET	10.25.85
B36561		GASKET	10.25.85
A35600		DISCHARGE PIPE INTERCONNECTORS	10.25.85
A37168		12.0 EXPANSION JOINT	10.25.85
B37254		COMPOUND GAUGE ASSEMBLY	10.25.85
A37260		VACUUM SENSOR	10.25.85
A37260		DIFF. VACUUM SENSOR	10.25.85
B37252		TRANS. PIPE - AIR INJECTION ASSY.	10.25.85
B37253		WATER INJECTION - VAC. P. INLET	10.25.85
D37173		TEMPERATURE SENSOR	10.25.85
A37259		VELOCITY SENSOR	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 17 OF 28
ASSEMBLY TITLE: MUCKING SYSTEM ASSEMBLY (CON'T) DRAWING NO: D35632			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
A37260		DIFF. VACUUM SENSOR	10.25.85
A37260		TEMPERATURE SENSOR	10.25.85
D37173		PRESSURE SENSOR	10.25.85
A37260		TEMPERATURE SENSOR	10.25.85
B37257		MASTER AIR VALVE ASSY. DROP BOX	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 18 OF 28
ASSEMBLY TITLE: CONTROL STATION ASSEMBLY			
DRAWING NO: D35927			

DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D35927		CONTROL STATION ASSEMBLY	10.25.85
D36158		CONTROL CONSOLE STAND	10.25.85
D36621		OPERATOR'S PLATFORM	10.25.85
D36620		LAMP HOOD	10.25.85
A36617		OPERATOR'S SEAT	10.25.85
A36619		PEDESTAL - OPERATOR'S SEAT	10.25.85
A36618		LIGHT FIXTURE	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 19 OF 28
ASSEMBLY TITLE: MUCK TUBE - DRIVER DRAWING NO: D36662			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D36662		MUCK TUBE - DRIVER	10.25.85
B36114		FLANGE - FEMALE	10.25.85
B36115		FLANGE - MALE	10.25.85
A36109		WHEEL BRACKET	10.25.85
A36108		WHEEL	10.25.85
B36137		CABLE SUPPORT BRACKET	10.25.85
D36664		DRIVE PLATE	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 20 OF 28
ASSEMBLY TITLE: MUCK TUBE ASSEMBLY DRAWING NO: D36136			
DRAWING NO. (1 2 3 4 5 6)	REV	TITLE	RELEASE DATE
D36136		MUCK TUBE ASSEMBLY	10.25.85
B36114		FLANGE - FEMALE	10.25.85
B36115		FLANGE - MALE	10.25.85
A36109		WHEEL BRACKET	10.25.85
A36108		WHEEL	10.25.85
B36137		CABLE SUPPORT BRACKET	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

ASSEMBLY TITLE: HYDRAULIC SYSTEM ASSEMBLY

DRAWING NO: D35914

DRAWING NO. (1 2 3 4 5 6)	REV	TITLE	RELEASE DATE
D35914		HYDRAULIC SYSTEM ASSEMBLY	10.25.85
D35924		IN-HOLE DRILL INSTALLATION	10.25.85
D36135		POWER UNIT ASSEMBLY - IN-HOLE	10.25.85
D36073		HYDRAULIC RESERVOIR	10.25.85
B36131		MANIFOLD BLOCK	10.25.85
D36122		RETURN HEADER	10.25.85
D36104		MANIFOLD ASSEMBLY	10.25.85
A36649		DIRECTIONAL VALVE	10.25.85
A36652		COUNTERBALANCE VALVE	10.25.85
A36663		MANIFOLD	10.25.85
D36116		MANIFOLD ASSEMBLY	10.25.85
A36649		DIRECTIONAL VALVE	10.25.85
A36654		CHECK VALVE	10.25.85
A36662		MANIFOLD	10.25.85
A36651		RELIEF VALVE	10.25.85
D36156		MANIFOLD ASSEMBLY	10.25.85
D36110		MANIFOLD	10.25.85
A36650		RELIEF VALVE	10.25.85
A36648		DIRECTIONAL VALVE	10.25.85
A36655		RELIEF VALVE	10.25.85
A36653		CHECK VALVE	10.25.85
D36132		MANIFOLD - BULKHEAD	10.25.85
B36151		PUMP/MOTOR ADAPTER	10.25.85
B36152		COUPLING	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 22 OF 28
ASSEMBLY TITLE: HYDRAULIC SYSTEM ASSEMBLY (CON'T)			
DRAWING NO: D35914			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
B36153		COVER PLATE	10.25.85
B36154		GASKET	10.25.85
B36140		LEVEL SWITCH ADAPTER	10.25.85
B36141		LEVEL GAGE	10.25.85
A36728		ELECTRIC MOTOR, 5 H.P., 1800 RPM	10.25.85
A36623		RADIAL PISTON PUMP	10.25.85
A36658		SUCTION STRAINER	10.25.85
A36659		RETURN FILTER	10.25.85
A36660		AIR BREATHER	10.25.85
A36668		SAMPLE VALVE	10.25.85
A36609		THERMOMETER	10.25.85
A36661		THERMO SWITCH	10.25.85
A36610		LEVEL SWITCH	10.25.85
A36723		SUCTION FITTING	10.25.85
A36670		MINI-CHECK COUPLING	10.25.85
A36612		PRESSURE TRANSDUCER	10.25.85
A36657		QUICK DISCONNECT	10.25.85
A36155		MALE CONNECTOR - MODIFIED	10.25.85
A36611		PRESSURE SWITCH	10.25.85
A36656		QUICK DISCONNECT	10.25.85
A36108		WHEEL	10.25.85
A36670		MINI-CHECK COUPLING	10.25.85
D35925		INSTALLATION DERRICK POWER UNIT	10.25.85
D35976		POWER UNIT FRAME	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 23 OF 28
ASSEMBLY TITLE: HYDRAULIC SYSTEM ASSEMBLY (CON'T) DRAWING NO: D35914			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
B35964		BOLT RING - INTERNAL	10.25.85
B35968		BOLT RING	10.25.85
B35970		BOLT RING	10.25.85
D35974		BAFFEL PLATE	10.25.85
D36724		MANIFOLD ASSEMBLY	10.25.85
A36584		RELIEF VALVE	10.25.85
A36585		RELIEF VALVE	10.25.85
A36586		PRESSURE REDUCING VALVE	10.25.85
A36589		CHECK VALVE	10.25.85
A36590		CHECK VALVE	10.25.85
D35975		MANIFOLD - PUMP CONTROL	10.25.85
D36051		HOUSING - COUPLING	10.25.85
D36052		HOUSING - COUPLING	10.25.85
D36050		COVER - HOUSING	10.25.85
D36063		MANIFOLD SUPPORT BRACKET	10.25.85
D36067		SUCTION ADAPTOR FLANGE	10.25.85
B35965		COVER PLATE	10.25.85
B35966		GASKET	10.25.85
B35967		TAP BAR	10.25.85
B35969		FILTER BRACKET	10.25.85
B35971		GASKET	10.25.85
B35972		COVER PLATE	10.25.85
B35973		FILTER BRACKET	10.25.85
B36140		LEVEL SWITCH ADAPTER	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST SHEET 24 OF 28

ASSEMBLY TITLE: HYDRAULIC SYSTEM ASSEMBLY (CON'T)

DRAWING NO: D35914

DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
B36101		COUPLING	10.25.85
B36102		COUPLING	10.25.85
B36141		LEVEL GAGE	10.25.85
A36729		ELECTRIC MOTOR - 75 H.P., 1200 RPM	10.25.85
A36576		PISTON PUMP "REXROTH" A7V250LV	10.25.85
A36577		VAR. VOL. PUMP "REXROTH" A7V40DR	10.25.85
A36604		SUCTION STRAINER	10.25.85
A36606		H.P. FILTER	10.25.85
A36605		H.P. FILTER	10.25.85
A37161		QUICK DISCONNECT	10.25.85
A36607		RETURN FILTER	10.25.85
A37163		QUICK DISCONNECT	10.25.85
A36610		LEVEL SWITCH	10.25.85
A36609		THERMOMETER	10.25.85
A36608		AIR BREATHER	10.25.85
A36612		PRESSURE TRANSDUCER	10.25.85
A36598		NEEDLE VALVE	10.25.85
A36599		BALL VALVE	10.25.85
A36597		FLOW CONTROL VALVE	10.25.85
A36593		CHECK VALVE	10.25.85
A36670		MINI-CHECK COUPLING	10.25.85
A36669		MAGNETIC PIPE PLUG	10.25.85
A36601		PRESSURE GAGE (0-3000 PSI)	10.25.85
A36602		PRESSURE GAGE (0-6000 PSI)	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST — SHEET 25 OF 28

ASSEMBLY TITLE: HYDRAULIC SYSTEM ASSEMBLY (CON'T)

DRAWING NO: D35914

DRAWING NO. (1 2 3 4 5 6)	REV	TITLE	RELEASE DATE
A36603		GAGE SNUBBER	10.25.85
A36517		SUCTION HOSE FITTING	10.25.85
A36518		90 DEGREE ELBOW FLANGE	10.25.85
A36519		4-BOLT FLANGE - REDUCING	10.25.85
A36727		NAMEPLATE	10.25.85
A37155		QUICK DISCONNECT	10.25.85
A37157		QUICK DISCONNECT	10.25.85
A37159		QUICK DISCONNECT	10.25.85
A36155		MALE CONNECTOR - MODIFIED	10.25.85
D35923		HYDRAULIC INSTALLATION DERRICK	10.25.85
D36730		MANIFOLD ASSEMBLY	10.25.85
A36581		DIRECTIONAL VALVE	10.25.85
A36582		DIRECTIONAL VALVE	10.25.85
A36591		CHECK VALVE	10.25.85
A36616		MANIFOLD	10.25.85
D36731		MANIFOLD ASSEMBLY	10.25.85
A36583		DIRECTIONAL VALVE	10.25.85
A36587		PRESSURE REDUCING VALVE	10.25.85
A36615		MANIFOLD	10.25.85
A36613		MANIFOLD	10.25.85
D36134		MANIFOLD ASSEMBLY	10.25.85
D36133		MANIFOLD	10.25.85
A37214		PRESSURE CONTROL VALVE	10.25.85
A36578		DIRECTIONAL VALVE	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 26 OF 28
ASSEMBLY TITLE: HYDRAULIC SYSTEM ASSEMBLY (CON'T) DRAWING NO: D35914			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
A36579		DIRECTIONAL VALVE	10.25.85
D36734		MANIFOLD - TANK RETURN	10.25.85
D36735		MANIFOLD - DRAIN RETURN	10.25.85
D36736		BULKHEAD MANIFOLD - CRAWLER	10.25.85
D36738		MOUNTING BRACKET - MANIFOLD	10.25.85
D36737		BULKHEAD PLATE	10.25.85
A36583		DIRECTIONAL VALVE	10.25.85
A36588		PRESSURE REDUCING VALVE	10.25.85
A36592		CHECK VALVE	10.25.85
A36595		FLOW CONTROL VALVE	10.25.85
A36600		PRESSURE GAGE	10.25.85
A36602		PRESSURE GAGE	10.25.85
A36603		GAGE SNUBBER	10.25.85
A36611		PRESSURE SWITCH	10.25.85
A36612		PRESSURE TRANSDUCER	10.25.85
A36614		SUB-PLATE	10.25.85
A36155		MALE CONNECTOR - MODIFIED	10.25.85
A36670		MINI-CHECK COUPLING	10.25.85
A37155		QUICK DISCONNECT - NIPPLE	10.25.85
A37157		QUICK DISCONNECT - NIPPLE	10.25.85
A37159		QUICK DISCONNECT - NIPPLE	10.25.85
A37161		QUICK DISCONNECT - NIPPLE	10.25.85
A37163		QUICK DISCONNECT - NIPPLE	10.25.85
D35922		HYDRAULIC INSTALLATION - CRAWLER	10.25.85

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST — SHEET 27 OF 28

ASSEMBLY TITLE: HYDRAULIC SYSTEM ASSEMBLY (CON'T)

DRAWING NO: D35914

DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D37152		MANIFOLD BLOCK	10.25.85
B37153		ANGLE BRACKET	10.25.85
A36580		DIRECTIONAL VALVE	10.25.85
A36594		SHUTTLE VALVE	10.25.85
D36671		HYDRAULIC INSTALLATION - CONSOLE	10.25.85
D36721		MOUNTING BRACKET - VALVE	10.25.85
A36596		FLOW CONTROL VALVE	10.25.85
A36722		SUBPLATE	10.25.85
B37209		HOSE ASSEMBLY	10.25.85
A37154		QUICK DISCONNECT - COUPLER	10.25.85
B37210		HOSE ASSEMBLY	10.25.85
A37156		QUICK DISCONNECT - COUPLER	10.25.85
B37211		HOSE ASSEMBLY	10.25.85
A37158		QUICK DISCONNECT - COUPLER	10.25.85
B37212		HOSE ASSEMBLY	10.25.85
A37160		QUICK DISCONNECT - COUPLING	10.25.85
B37213		HOSE ASSEMBLY	10.25.85
A37162		QUICK DISCONNECT - COUPLING	10.25.85
D35916		HYDRAULIC SCHEMATIC - IN HOLE	10.25.85
D35919		HYDRAULIC SCHEMATIC - DERRICK	10.25.85
A36665		HOSE ASSEMBLY	
A36666		PRESSURE TESTING KIT	

COMPILED BY:	DATE:	NO.	REV
Peter B. Dowden	10.25.85	A35926	-

SANDIA DPBM - MASTER DRAWING LIST			SHEET 28 OF 28
ASSEMBLY TITLE: ELECTRICAL SYSTEM ASSEMBLY DRAWING NO: D35915			
DRAWING NO. 1 2 3 4 5 6	REV	TITLE	RELEASE DATE
D35915		ELECTRICAL SYSTEM ASSEMBLY	10.25.85
D36725		ELECTRICAL INSTALLATION - IN HOLE	10.25.85
D36667		ELECTRICAL PANEL	10.25.85
A36507		CYLINDER POSITION INDICATING SYSTEM	10.25.85
B35930		CONNECTING CABLE	10.25.85
D35626		IN-HOLE CABLING	10.25.85
D35928		CONTROL CONSOLE ASSEMBLY	10.25.85
D36138		CONTROL CONSOLE BOX	10.25.85
A36168		MILLIAMMETER	10.25.85
A36505		MILLIAMMETER	10.25.85
A36506		DIGITAL METER	10.25.85
A36169		METER RELAY	10.25.85
A36526		MILLIAMMETER	10.25.85
A36504		MILLIAMMETER	10.25.85
B35930		ZED UNIT	10.25.85
D36119		NAMEPLATE	10.25.85
D36098		ELECTRICAL CABINET ASSEMBLY	10.25.85
D36097		ELECTRICAL ENCLOSURE	10.25.85
B36527		CABLE ASSEMBLY	10.25.85
B36740		CRAWLER CONTROL	10.25.85
D36739		ENCLOSURE	10.25.85
A36732		SINGLE AXIS CONTROLLER	10.25.85
D35917		ELECTRICAL SCHEMATIC	10.25.85

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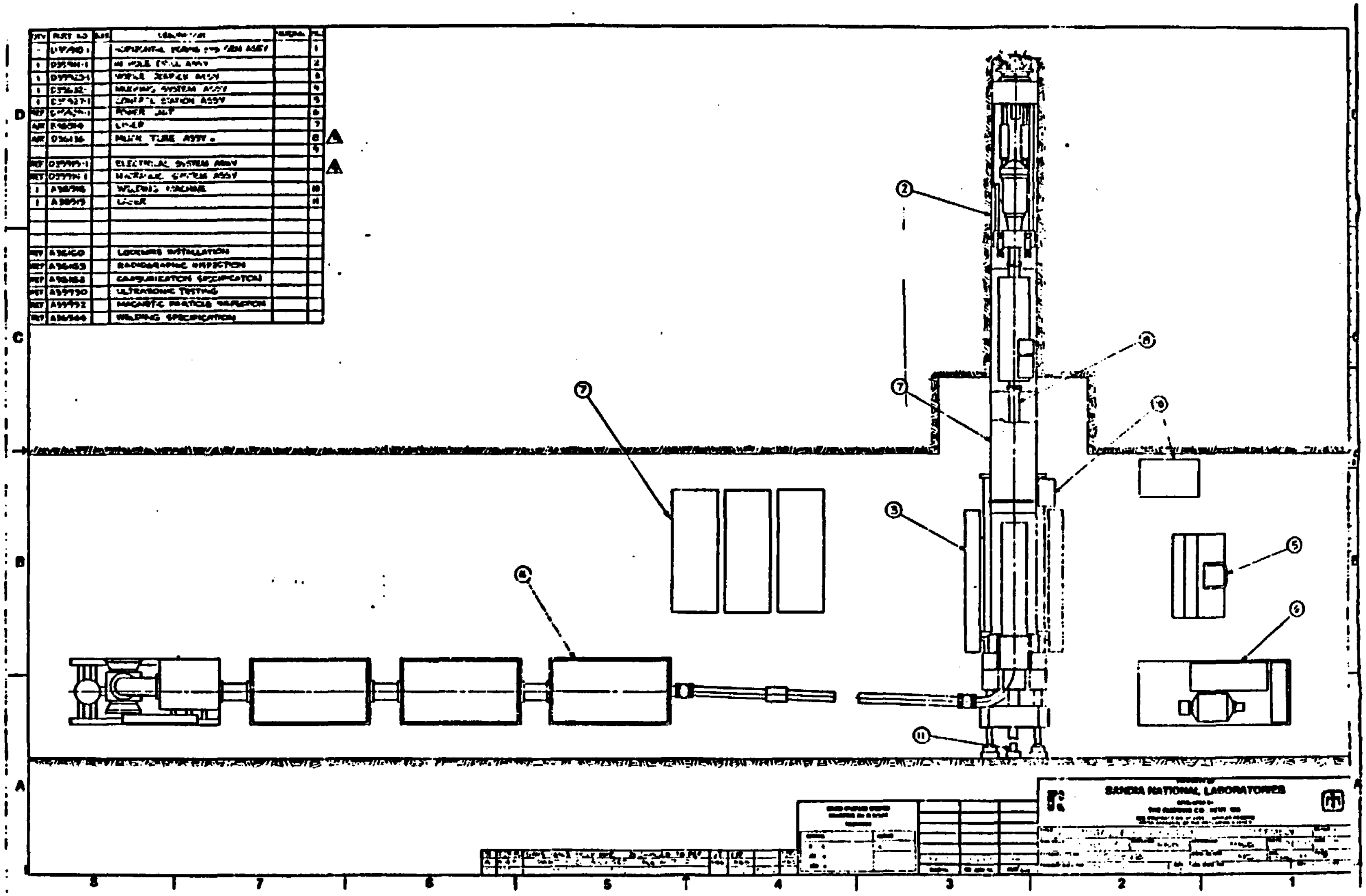
Peter B. Dowden	10.25.85	A35926	-

APPENDIX B

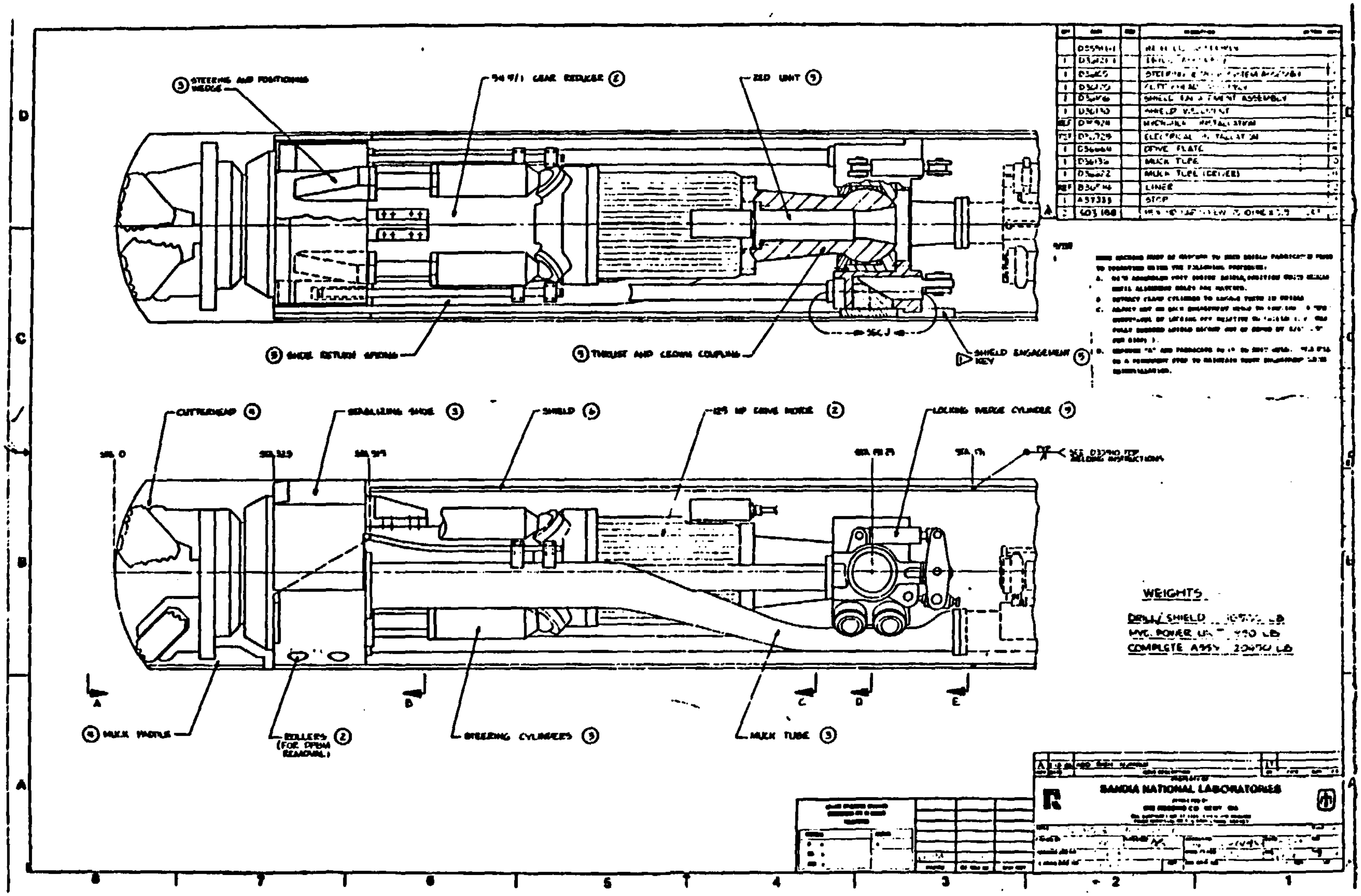
to

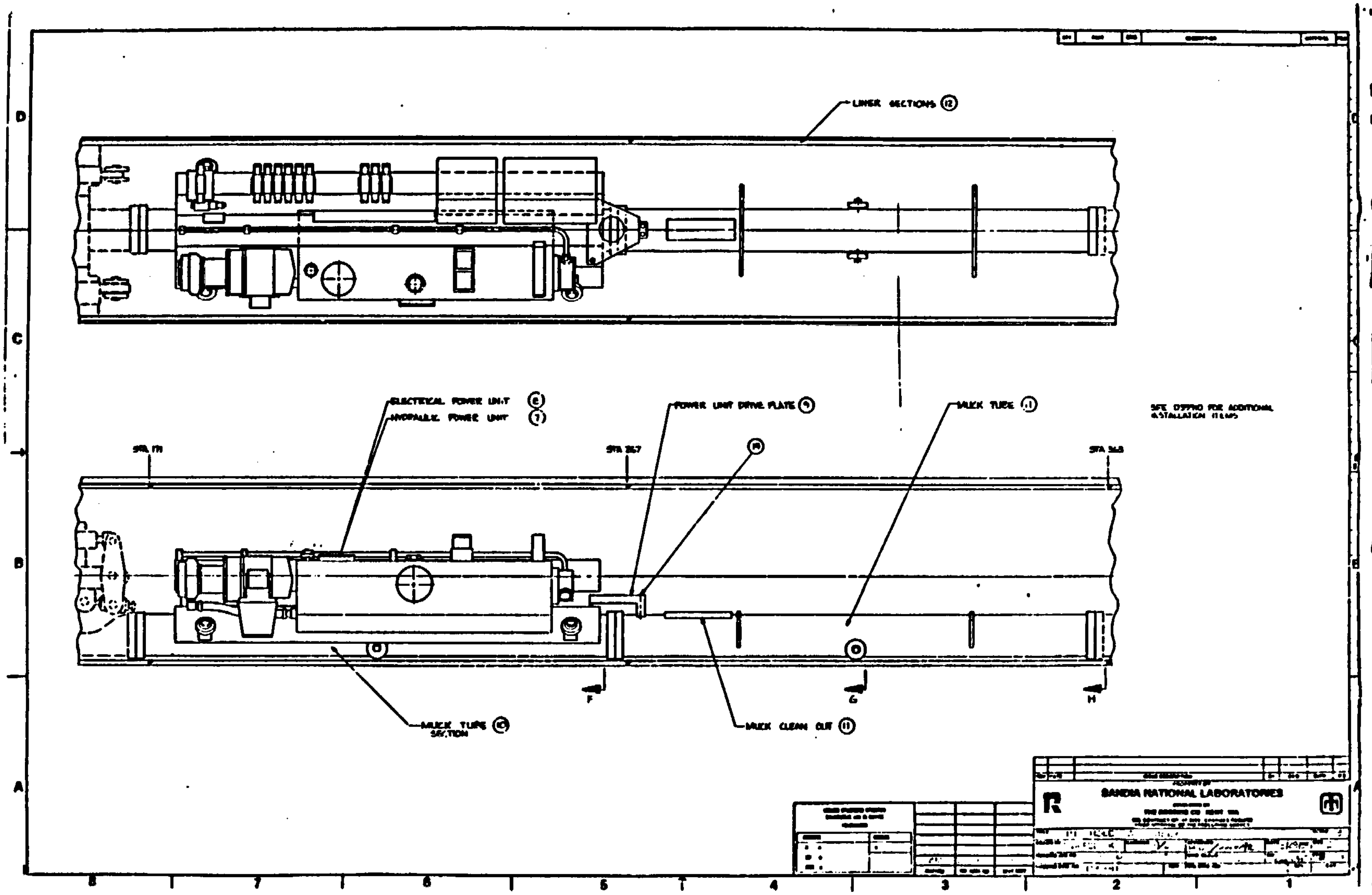
DESIGN OF A MACHINE TO BORE AND LINE
A LONG HORIZONTAL HOLE IN TUFF

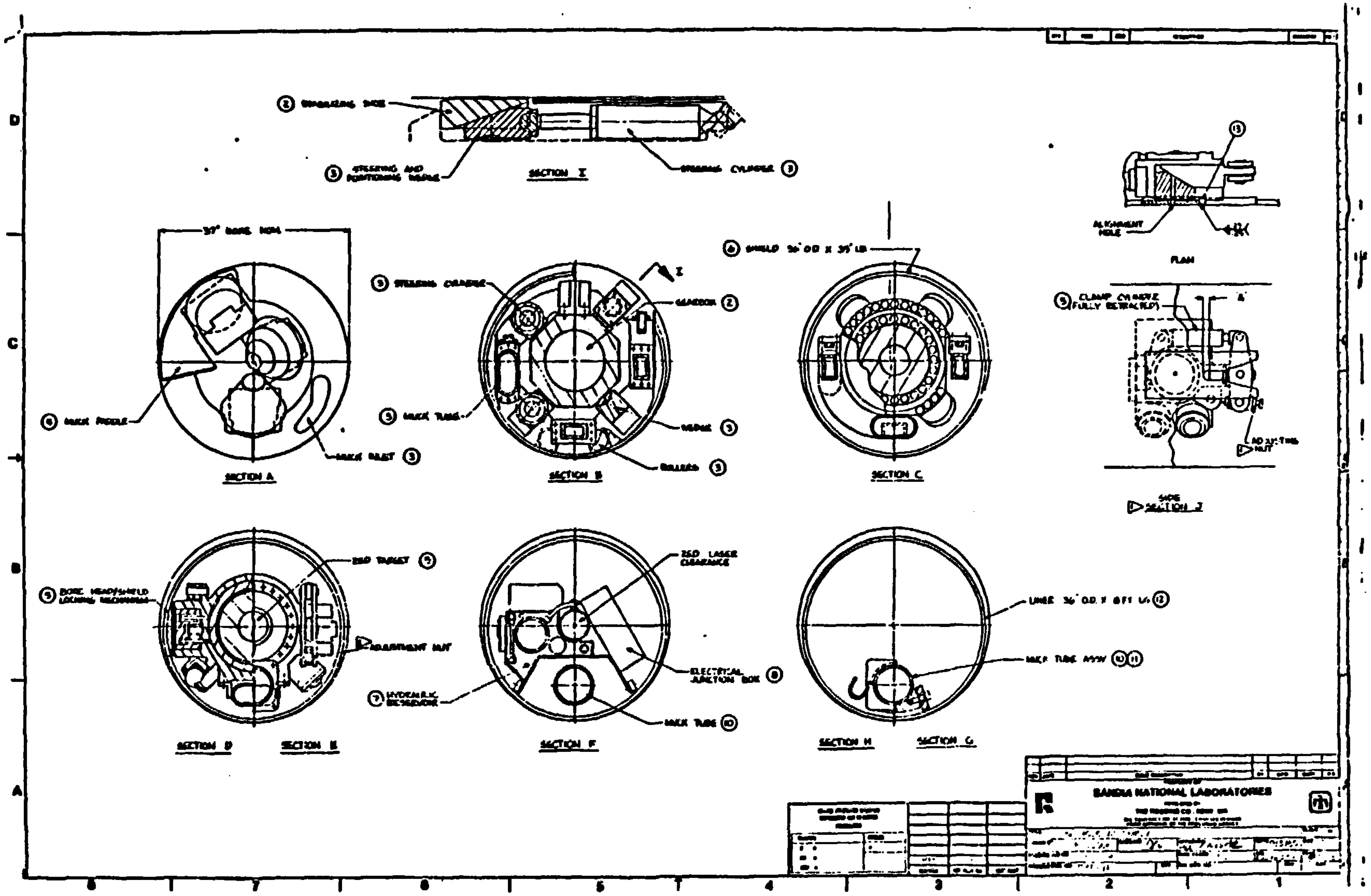
DPBM ASSEMBLY DRAWINGS



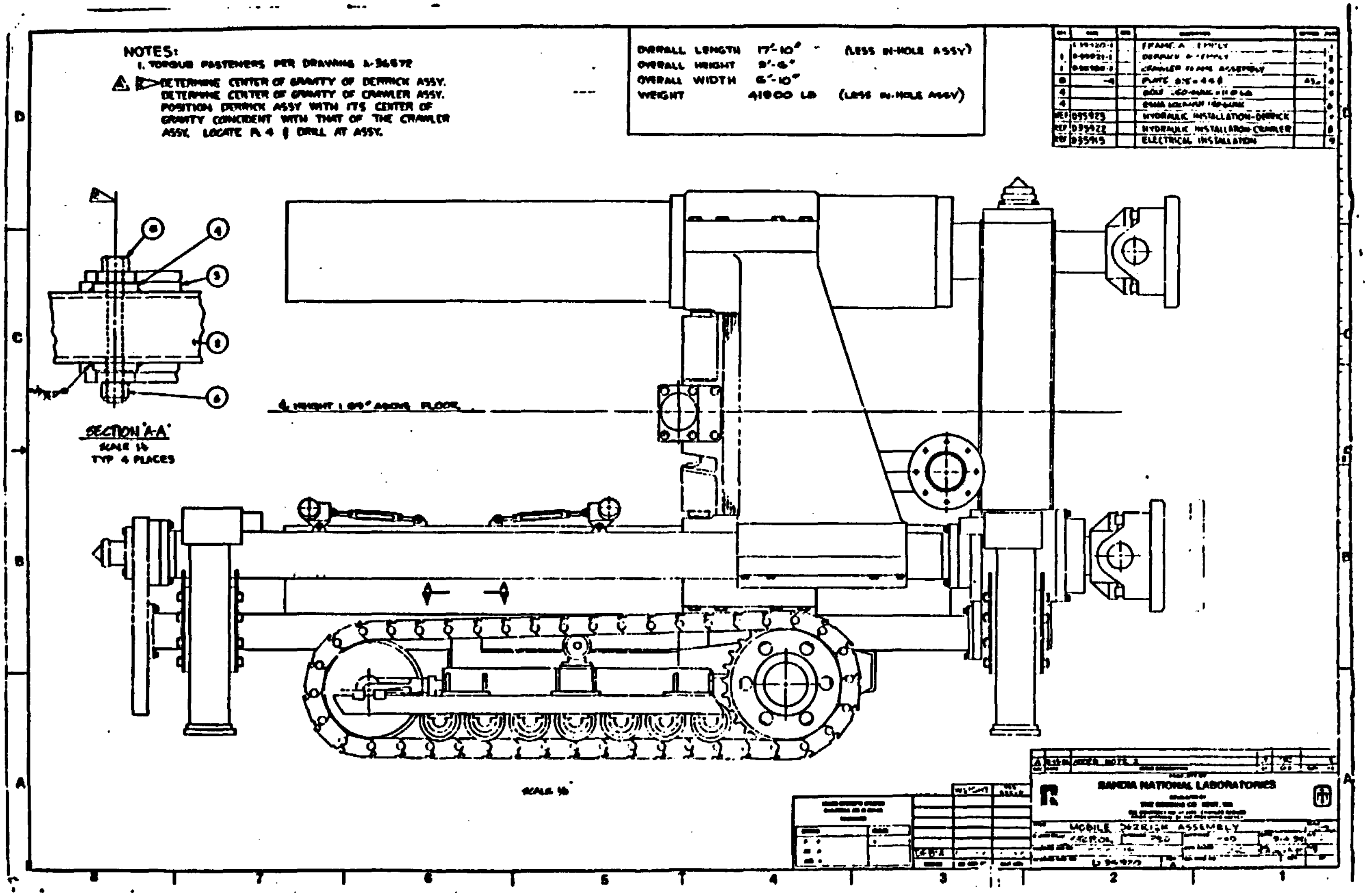
QTY	PART NO.		DESCRIPTION		NO.
-	[illegible]		[illegible] ASSY		1
1	[illegible]		IN HOLE [illegible] ASSY		2
1	[illegible]		[illegible] ASSY		3
1	[illegible]		[illegible] SYSTEM ASSY		4
1	[illegible]		CONTROL STATION ASSY		5
REF	[illegible]		POWER UNIT		6
AR	[illegible]		LINER		7
AR	[illegible]		MUCK TUBE ASSY		8
					9
REF	[illegible]		ELECTRICAL SYSTEM ASSY		
REF	[illegible]		HYDRAULIC SYSTEM ASSY		
1	[illegible]		WELDING MACHINE		10
1	[illegible]		LASER		11
REF	[illegible]		LOCKWIRE INSTALLATION		
REF	A36163		RADIOGRAPHIC INSPECTION		
REF	[illegible]		CARBURIZATION SPECIFICATION		
REF	[illegible]		ULTRASONIC TESTING		
REF	[illegible]		MAGNETIC PARTICLE INSPECTION		
REF	[illegible]		WELDING SPECIFICATION		


STEERING AND POSITIONING WEDGE
GEAR REDUCER
SHOE RETURN SPRING
SHIELD ENGAGEMENT KEY
CUTTERHEAD
STABILIZING SHOE
SHIELD
125 HP DRIVE MOTOR
LOCKING WEDGE CYLINDER
MUCK PADDLE
ROLLERS (FOR PPBM REMOVAL)
STEERING CYLINDERS
MUCK TUBE
WEIGHTS
SANDIA NATIONAL LABORATORIES


LINER SECTIONS (12)
ELECTRICAL POWER UNIT (8)
HYDRAULIC POWER UNIT (7)
POWER UNIT DRIVE PLATE (9)
MUCK TUBE (11)
STA 171
STA 267
STA 363
MUCK TUBE (10) SECTION
MUCK CLEAN OUT (11)
SANDIA NATIONAL LABORATORIES



SECTION I
STEERING CYLINDER
37" BORE NOM
SECTION A
MUCK PADDLE
MUCK INLET
STEERING CYLINDER
GEARBOX
MUCK TUBE
WEDGE
ROLLERS
SECTION B
SHIELD 36" OD X 35" ID
SECTION C
PLAN
ALIGNMENT HOLE
CLAMP CYLINDER (FULLY RETRACTED)
ADJUSTING NUT
SIDE SECTION J
BORE HEADSHIELD LOCKING MECHANISM
ADJUSTMENT NUT
SECTION D
SECTION E
RED LASER CLEARANCE
ELECTRICAL JUNCTION BOX
HYDRAULIC RESERVOIR
MUCK TUBE
SECTION F
MUCK TUBE ASSY
SECTION H
SECTION G
SANDIA NATIONAL LABORATORIES


NOTES:
1. TORQUE FASTENERS PER DRAWING A-36672
DETERMINE CENTER OF GRAVITY OF DERRICK ASSY. DETERMINE CENTER OF GRAVITY OF CRAWLER ASSY. POSITION DERRICK ASSY WITH ITS CENTER OF GRAVITY COINCIDENT WITH THAT OF THE CRAWLER ASSY. LOCATE PL 4 & DRILL AT ASSY.
OVERALL LENGTH 17'-10" (LESS IN-HOLE ASSY)
OVERALL HEIGHT 9'-6"
OVERALL WIDTH 6'-10"
WEIGHT 41000 LB (LESS IN-HOLE ASSY)
HYDRAULIC INSTALLATION-DERRICK
HYDRAULIC INSTALLATION-CRAWLER
ELECTRICAL INSTALLATION
SECTION 'A-A'
TYP 4 PLACES
SANDIA NATIONAL LABORATORIES
MOBILE DERRICK ASSEMBLY

NOTES

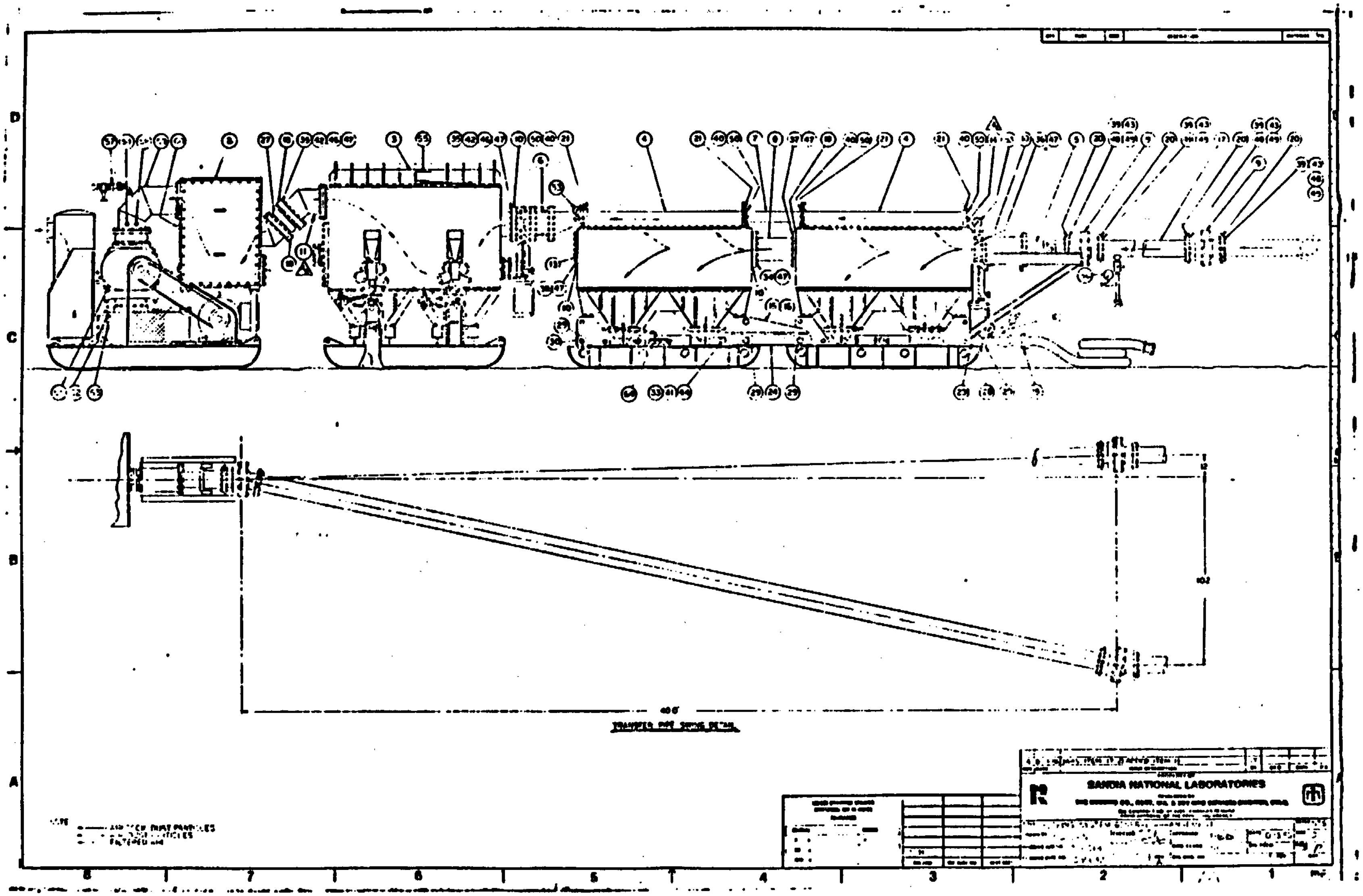
1. REFER TO DWG A36672 FOR TORQUE SETTING ON STANDARD BOLTS AND GENERAL ASSEMBLY INSTRUCTIONS
2. AT SHOP ASSEMBLY OF DROP BOXES THE ALIGNMENT OF THE CONNECTION FLANGES IS TO BE CHECKED. FULLY ASSEMBLE THE DROP BOXES AND TIGHTEN JOINTS BETWEEN MAJOR COMPONENTS WITH [illegible] RESTING ON FLAT LEVEL SURFACE. CHECK HEIGHT FROM BOTTOM SIDE OF SKIDS TO A DATUM BOLT HOLE CHOSEN ON VACUUM CONNECTION FLANGE AT END OF DROP BOX [illegible] COMPARE MEASUREMENTS FROM EACH END OF BOTH BOXES AND SHIM JOINT BETWEEN SKID UNIT AND DROP BOX [illegible] UNITS HEIGHTS CORRELATE WITHIN [illegible] MAKE UP PERMANENT SHIMS AND TACK WELD TO JOINT SURFACE OF SKID UNIT
3. MAXIMUM SAFE WORKING PRESSURE CAPACITY OF DROP BOXES AND ASSOCIATED PIPEWORK TO BE 25PSIG TEST DROP BOX UNITS AND PIPEWORK AT [illegible] 30PSIG

[illegible] PIPE LINES [illegible] PRESSURE TRANSDUCER [illegible] CONSOLE
PRESSURE PIPE [illegible] TO GAUGE IN CONSOLE
TEMPERATURE SENSOR LINKED BY PRESSURE LINE TO GAUGE ON CONSOLE
HOT WIRE SENSOR [illegible] CONSOLE

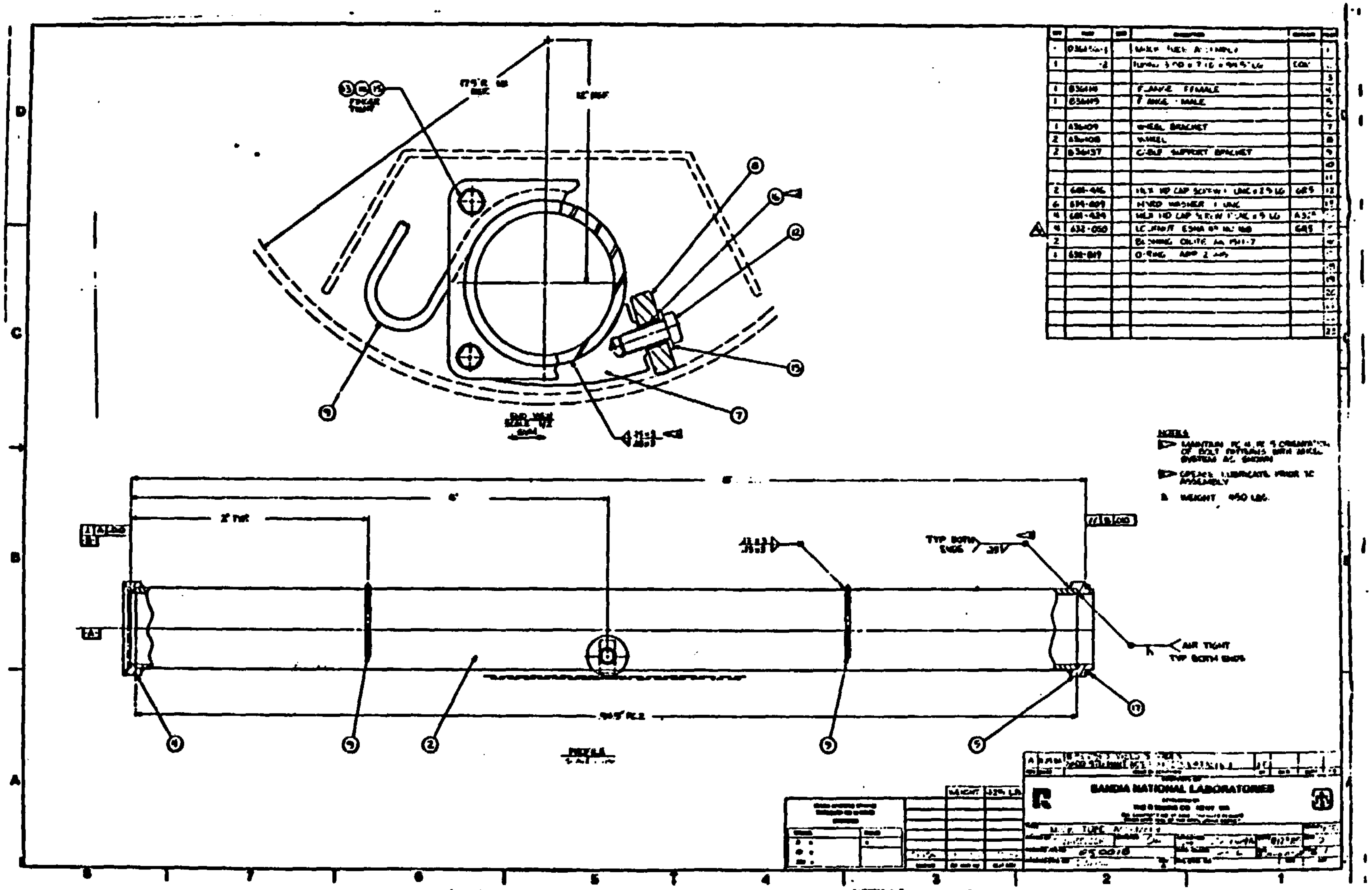
FLAG NOTED PARTS-REFER TO DWGS D37248 & D37349

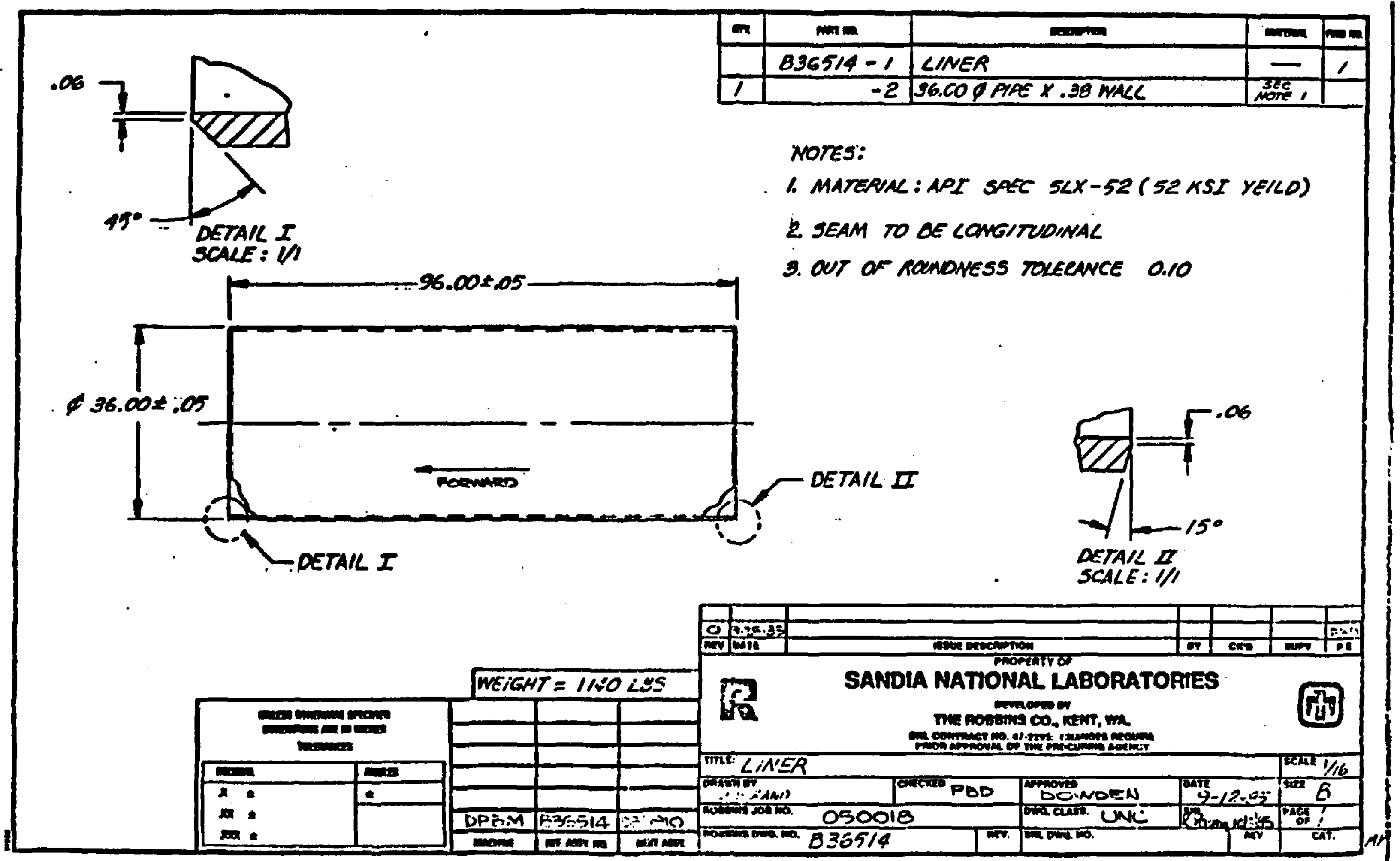
REV STATUS

SANDIA NATIONAL LABORATORIES



TRANSFER PIPE SWING DETAIL
SANDIA NATIONAL LABORATORIES


SANDIA NATIONAL LABORATORIES
AIR TIGHT
TYP BOTH ENDS


B36514 - 1 LINER — 1
1 -2 36.00 ∅ PIPE X .38 WALL SEE NOTE 1
NOTES:
1. MATERIAL: API SPEC 5LX-52 (52 KSI YEILD)
2. SEAM TO BE LONGITUDINAL
3. OUT OF ROUNDNESS TOLERANCE 0.10
.06
45°
DETAIL I
SCALE: 1/1
96.00±.05
∅ 36.00±.05
FORWARD
DETAIL II
DETAIL I
.06
15°
DETAIL II
SCALE: 1/1
WEIGHT = 1140 LBS
ISSUE DESCRIPTION
PROPERTY OF
SANDIA NATIONAL LABORATORIES
DEVELOPED BY
THE ROBBINS CO., KENT, WA.
TITLE: LINER
SCALE 1/16
CHECKED PBD
APPROVED DOWDEN
DATE 9-12-85
SIZE B
ROBBINS JOB NO. 050018
DWG. CLASS. UNC
ROBBINS DWG. NO. B36514
DPEM B36514

QTY	PART		DESCRIPTION	MATERIAL	ITEM
6	601-177		HEX HD CAPSCREW .75-10UNC x 2.0LG	GRS	81
4	601-176		HEX HD CAPSCREW .75-10UNC x 1.75LG	GRS	82
16	601-151		HEX HD CAPSCREW .62-11UNC x 1.50LG	GRS	83
12	601-103		HEX HD CAPSCREW .50-13UNC x 1.50LG	GRS	84
4	601-104		HEX HD CAPSCREW .50-13UNC x 1.75LG	GRS	85
4	601-112		HEX HD CAPSCREW .50-13UNC x 3.75LG	GRS	86
4	601-061		HEX HD CAPSCREW .38-16UNC x 3.00LG	GRS	87
36	601-027		HEX HD CAPSCREW .31-18UNC x .75LG	GRS	88
16	601-028		HEX HD CAPSCREW .31-18UNC x 1.00LG	GRS	89
4	625-003		HEX NUT .38-16 UNC		90
4	625-005		HEX NUT .50-13 UNC		91
4	635-015		LOCKWASHER .75 (MED)		92
					93
					94
A/R			2½ PIPE SCH. 80	[illegible]	95
2			2½ - 90° BUTT WELD ELBOW (SCH. 80)	STL.	96
1	653-905		2" - 90° ELBOW (SCH. 80) THRD		97
1	653-906		2½ - 90° ELBOW (SCH. 80) THRD		98
1			2" PIPE NIPPLE x 5" LG	[illegible]	99
1			2½ PIPE NIPPLE x 5.5 LG.	[illegible]	100
1	653-957		¼ PIPE PLUG		101
2	653-958		1 PIPE PLUG		102
1	653-960		2½ PIPE PLUG		103
					104
1			2½ [illegible] - ANCHOR #W6-60-40		105
1			2" [illegible] - ANCHOR #325		106
1			2" KING NIPPLE-DIXON # ST-25		107
1			2½ KING NIPPLE-DIXON # ST-30		108
2	651-073		¼ - 90° STREET ELBOW #C3409x8	[illegible]	109
1	651-557		¼ PIPE TEE #C3709x4	[illegible]	110
2	650-971		90° MALE PIPE ELBOW #C3519x6	[illegible]	111
A/R			¼ PIPE SCH. 40	STL.	112
1			¼ PIPE COUPLING 3000#	STL.	113
2			¼ PIPE COUPLING 6000#	STL.	114
1			1¼ - 45° ELBOW 6000#	STL.	115
1			2½ - 45° ELBOW 3000#	STL.	116
2			1¼ CLOSE NIPPLE (SCH. 80)	STL.	117
1			2½ CLOSE NIPPLE (SCH. 80)	STL.	118
1			1¼ [illegible] - ANCHOR #W43-20-20		119
1			2½ [illegible] - ANCHOR #W43-40-40		120
					121
					122
					123
					124
3	A36153-3		MALE CONNECTOR - MODIFIED		125
1	A36153-4		MALE CONNECTOR - MODIFIED		126
7	A36153-5		MALE CONNECTOR - MODIFIED		127
					128
					129
					130
					131
					132
					133
					134
					135
					136
					137
					138
					139
					140

QTY	PART		DESCRIPTION	MATERIAL	ITEM
1	A36598-1		NEEDLE VALVE	(¾ NPT)	41
1	A36599-1		BALL VALVE	(1¼ NPT)	42
1	A36597-1		FLOW CONTROL VALVE		43
1	A36593-1		CHECK VALVE		44
2	A36670-2		MINI-CHECK COUPLING		45
					46
3	A36669-1		MAGNETIC PIPE PLUG		47
1	A36601-1		PRESS GAGE (0-3000 PSI)		48
2	A36602-1		PRESS GAGE (0-6000 PSI)		49
3	A36603-1		GAGE SNUBBER		50
1	A36517-1		SUCTION HOSE FITTING		51
1	A36518-1		90° ELBOW FLANGE		52
1	A36519-1		4-BOLT FLANGE - REDUCING		53
1	A36737-[illegible]		NAMEPLATE		54
1	A36737-[illegible]		NAMEPLATE		55
1	A36737-[illegible]		NAMEPLATE		56
3	A37155-1		QUICK DISCONNECT-NIPPLE (¾)		57
1	A37157-1		QUICK DISCONNECT-NIPPLE (1¼)		58
1	A37159-1		QUICK DISCONNECT-NIPPLE (1)		59
A/R	653-540		H.P. HOSE (¼) - AQUIP 2781-4		60
A/R	653-541		H.P. HOSE (⅜) - AQUIP 2781-6		61
A/R	653-500		H.P. HOSE (½) - AQUIP FC250A-8		62
A/R	653-501		H.P. HOSE (¾) - AQUIP FC250A-12		63
A/R	653-502		H.P. HOSE (1) - AQUIP FC250A-16		64
A/R			H.P. HOSE (1¼) - AQUIP FC273-20		65
					66
A/R	653-524		SUCTION HOSE (2) AQUIP H2660-32		67
A/R	653-525		SUCTION HOSE (2½) - AQUIP H2660-40		68
					69
10			HOSE END (¼) AQUIP 1S1100M-4S		70
6			HOSE END (⅜) AQUIP 1S1100M6-6S		71
4			HOSE END (½) AQUIP FC9515-0808S		72
6			HOSE END (¾) AQUIP FC9515-1212S		73
2			HOSE END (1) AQUIP FC9508-1616S		74
4			HOSE END (1¼) AQUIP FC9321-2020S		75
					76
					77
					78
4	653-754		HOSE CLAMP (2) ENGA #HC200		79
4	653-755		HOSE CLAMP (2½) ENGA #HC250		80

QTY	PART		DESCRIPTION	MATERIAL	ITEM
-	D35925-1		HYDRAULIC INSTALLATION PWR UNIT		
1	D35936-1		POWER UNIT FRAME - DERRICK RESERVOIR		[illegible]
1	D36051-1		HOUSING COUPLING		[illegible]
1	D36052-1		HOUSING - COUPLING		[illegible]
2	D36050-1		COVER - HOUSING		[illegible]
2	D36050-2		COVER - HOUSING		[illegible]
1	D36063-1		MANIFOLD SUPPORT BRACKET		[illegible]
1	D36067-1		SUCTION ADAPTER FLANGE		[illegible]
1	D36724-1		MANIFOLD ASSEMBLY (D35975-1)		[illegible]
					[illegible]
					[illegible]
					[illegible]
					[illegible]
3	B35965-1		COVER PLATE (15,000)		[illegible]
3	B35966-1		GASKET (15,000)		[illegible]
2	B35967-1		TAP BAR		[illegible]
1	B35969-1		FILTER BRACKET		[illegible]
2	B35971-1		GASKET (10,000)		[illegible]
2	B35972-1		COVER PLATE (10,000)		[illegible]
1	B35973-1		FILTER BRACKET		[illegible]
1	B36100-1		LEVEL SWITCH ADAPTER		[illegible]
1	B36101-1		COUPLING - FALK (60T10)		[illegible]
1	B36102-1		COUPLING - FALK (70T10)		[illegible]
1	B36141-2		LEVEL GAGE		[illegible]
					[illegible]
					[illegible]
1	A37161-1		QUICK DISCONNECT-NIPPLE (1¼)		[illegible]
1	A37163-1		QUICK DISCONNECT-NIPPLE (1½)		[illegible]
1	A36119-1		ELECTRIC MOTOR - 75HP, 1200 RPM		[illegible]
1	A36536-1		PISTON PUMP REXROTH A1V250LV		[illegible]
1	A36533-1		VAR. VOL. PUMP REXROTH A1V40DR		[illegible]
2	A36604-1		SUCTION STRAINER		[illegible]
1	A36606-1		H.P. FILTER	[illegible]	[illegible]
1	A36605-1		HP FILTER	[illegible]	[illegible]
1	A36607-1		RETURN FILTER		[illegible]
1	A36610-1		LEVEL SWITCH		[illegible]
1	A36609-1		THERMOMETER		[illegible]
1	A36608-1		AIR BREATHER		[illegible]
2	A36612-1		PRESSURE TRANSDUCER		[illegible]

NOTES:

1. DO NOT CHANGE PLUMBING AS SHOWN ON DRAWING WITHOUT THE ROBBINS CO. ENGINEERING DEPARTMENT APPROVAL.
2. [illegible]
3. [illegible]
   (a) [illegible] "LOCTITE" [illegible]
   (b) [illegible] "LOCTITE" [illegible]
   (c) [illegible]

DRILL & TAP .25 NPT IN ELBOW FOR PC 45 AT ASSY

REV STATUS

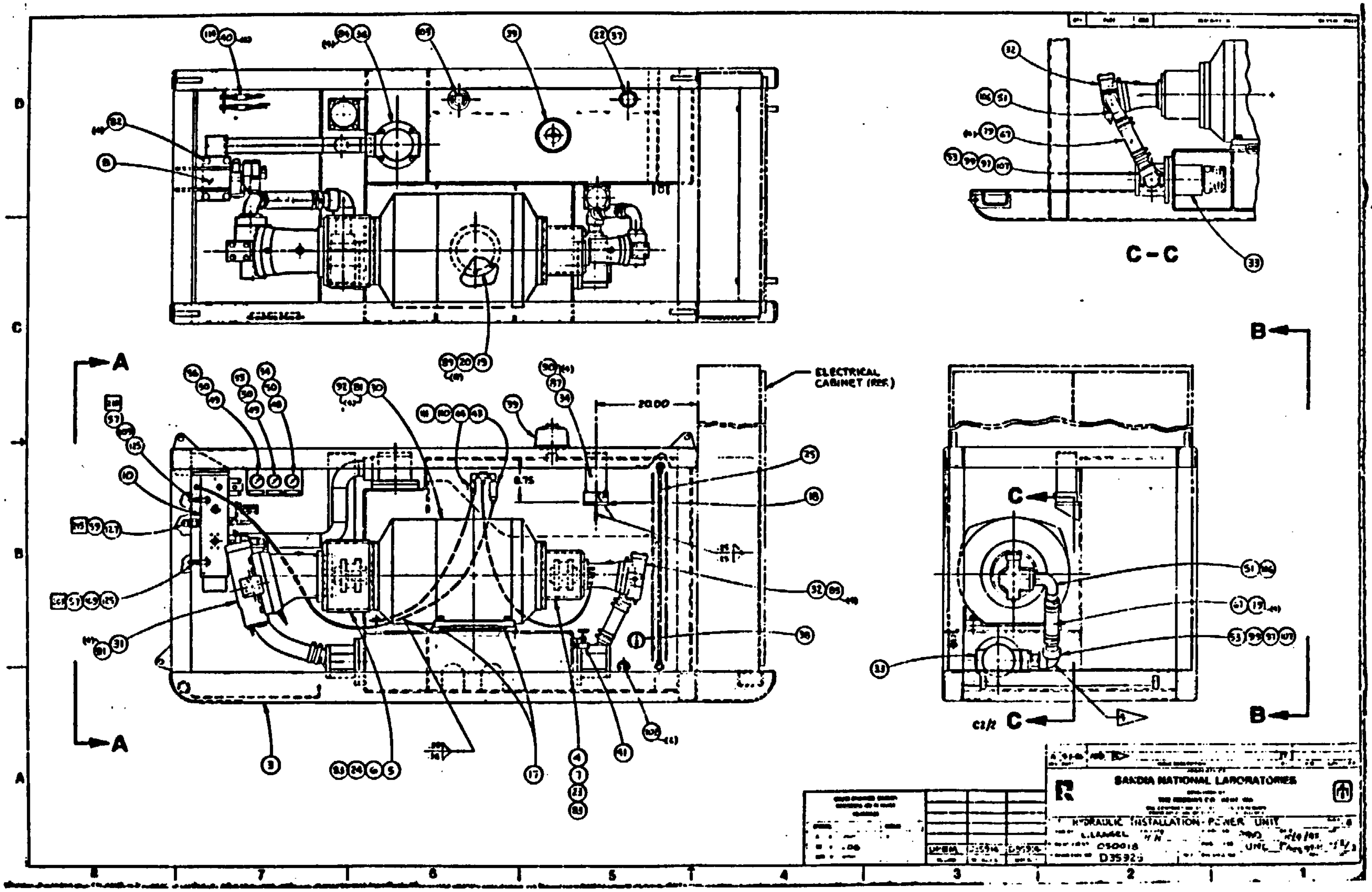
WEIGHT - 5000 LB

SANDIA NATIONAL LABORATORIES

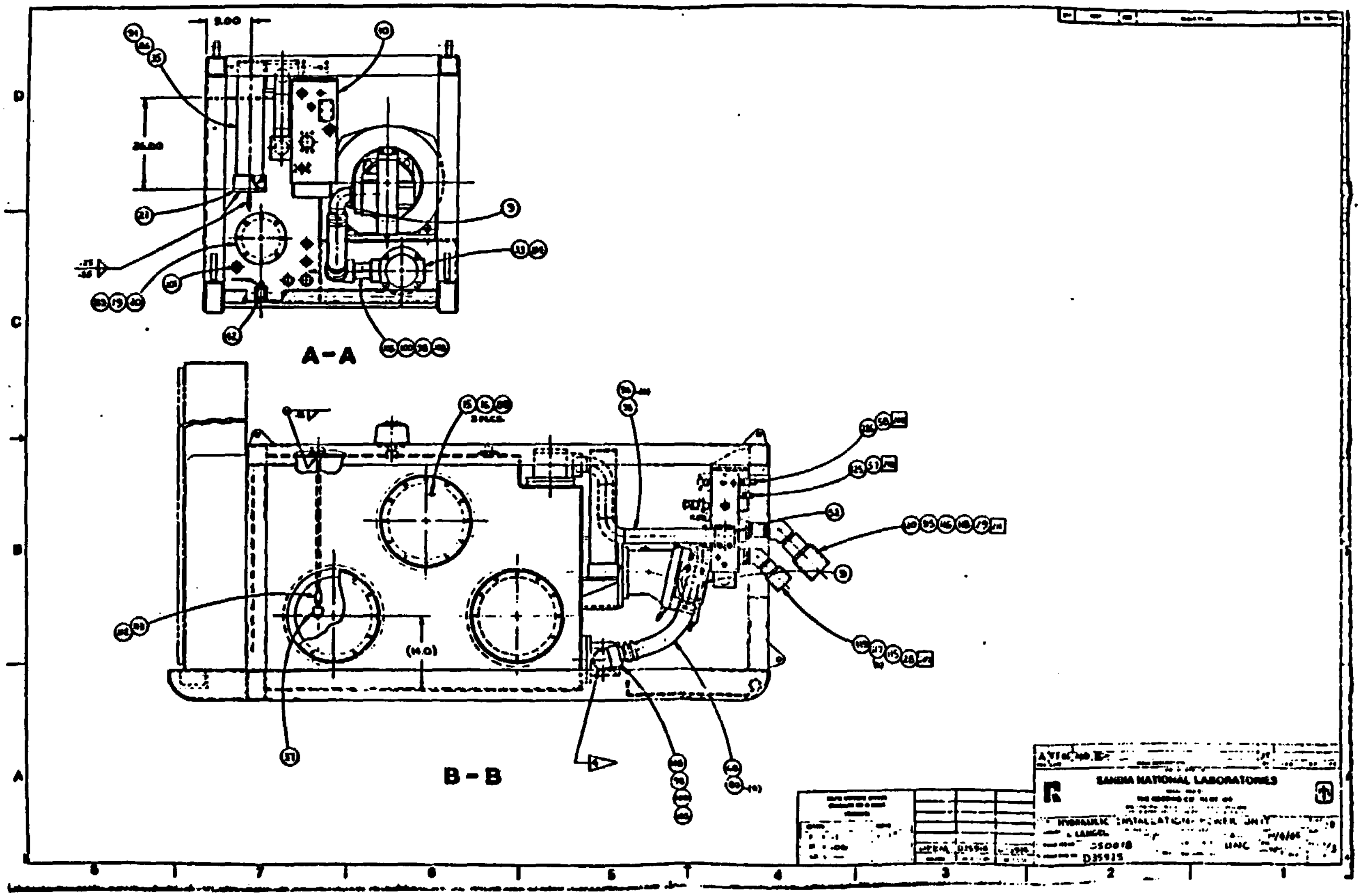
HYDRAULIC INSTALLATION - POWER UNIT

LANGEL

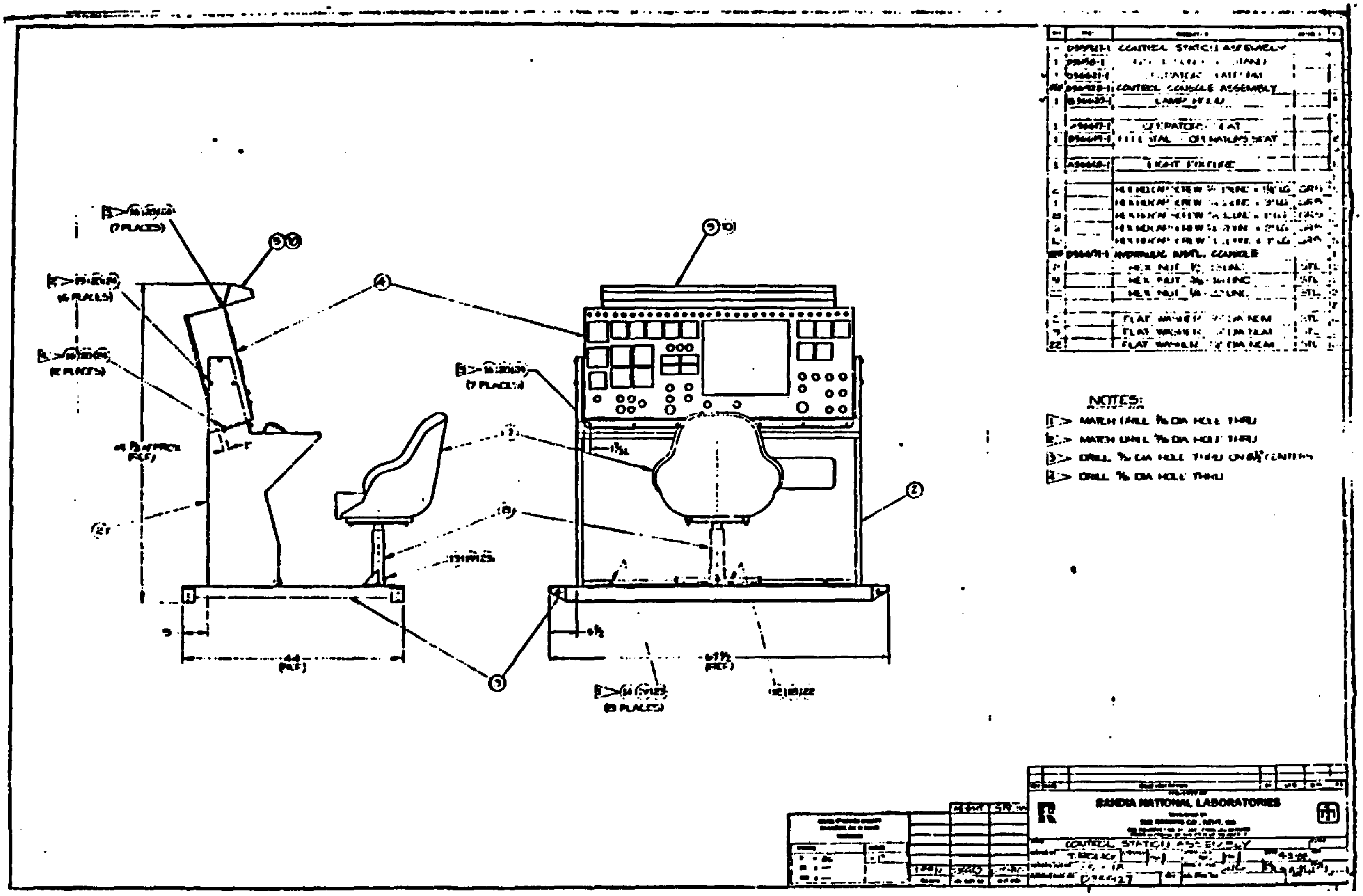
D35925



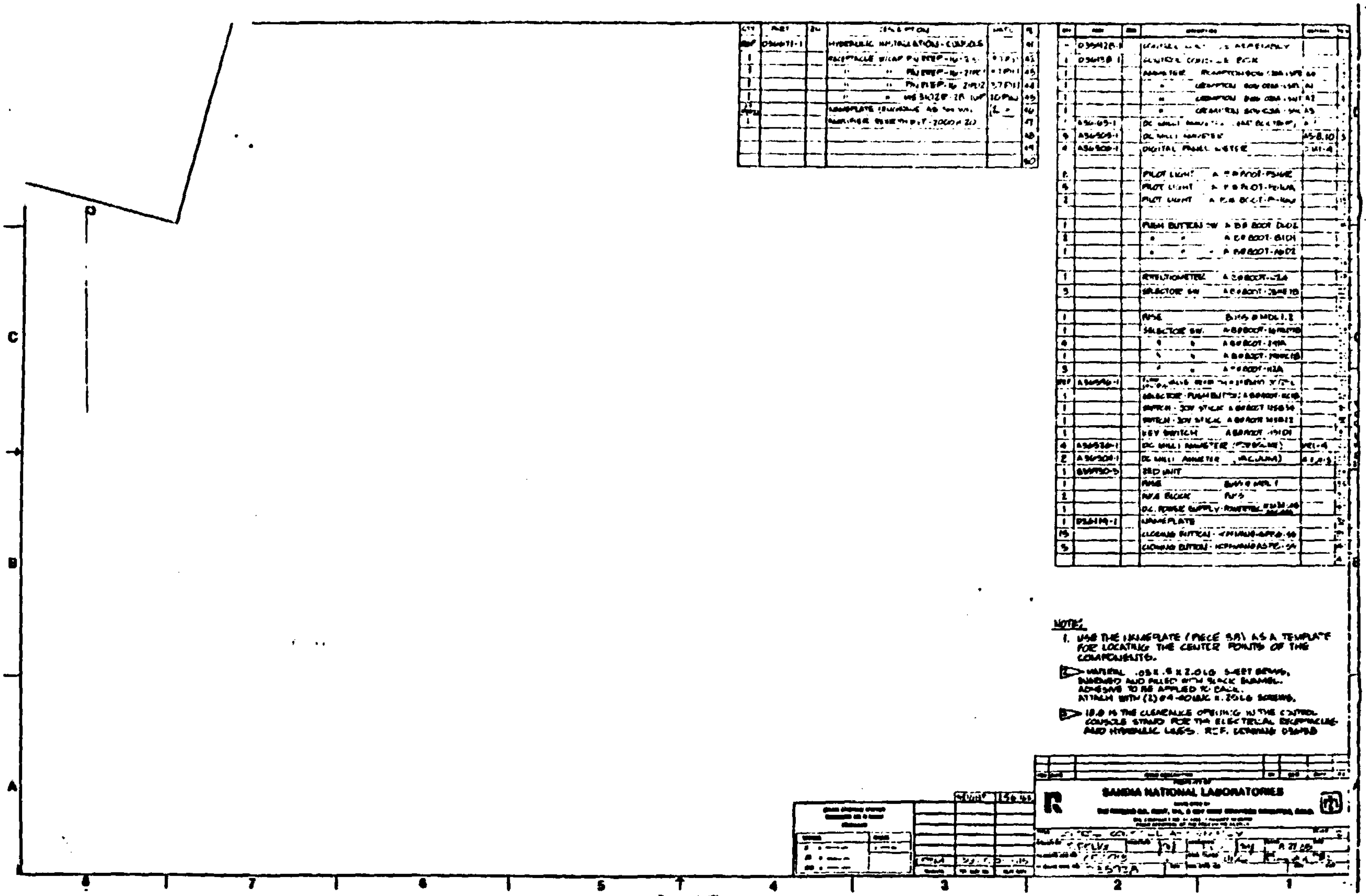
A
A
B
B
C
C
C - C
ELECTRICAL CABINET (REF.)
20.00
SANDIA NATIONAL LABORATORIES
HYDRAULIC INSTALLATION-POWER UNIT

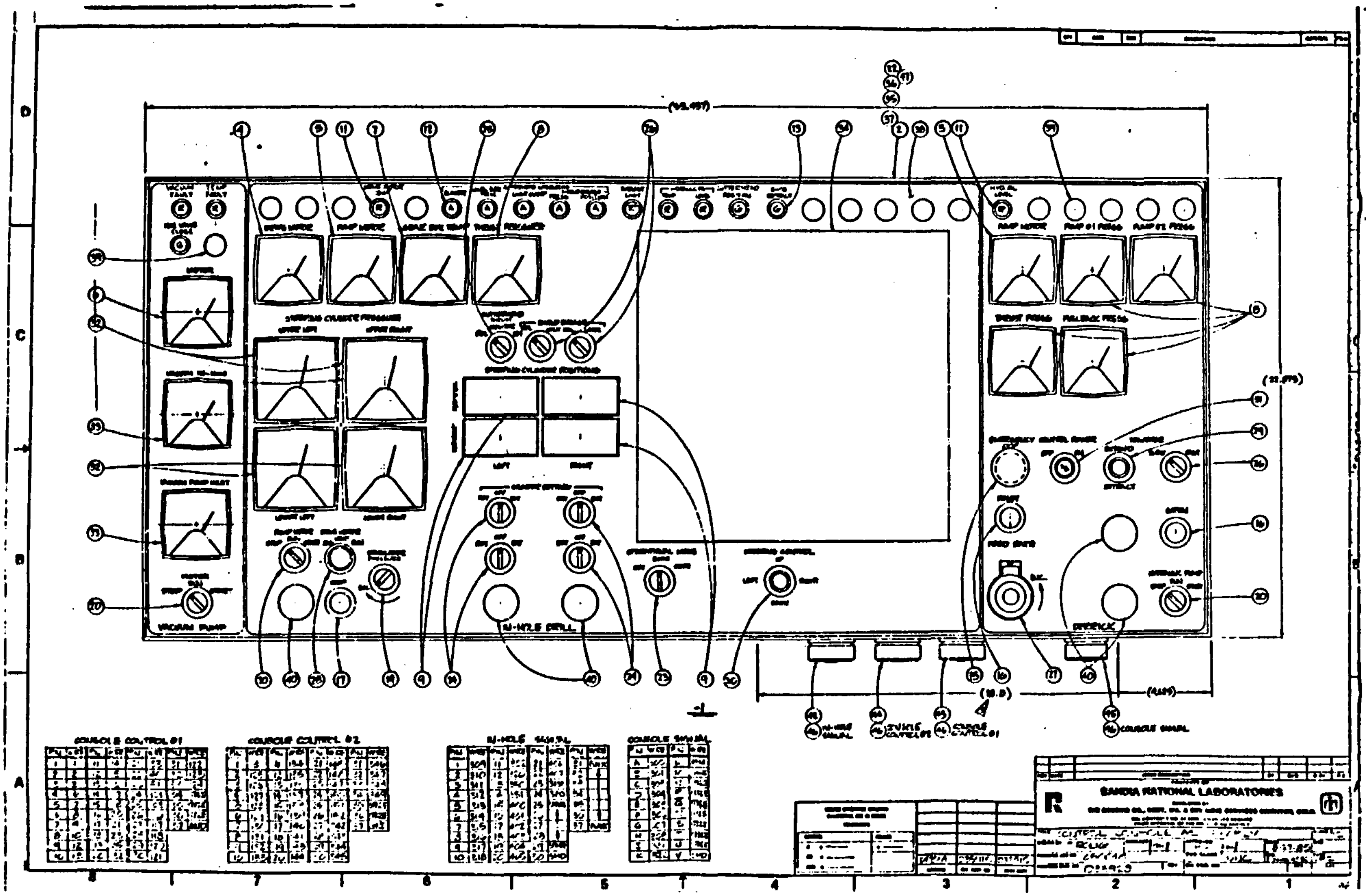


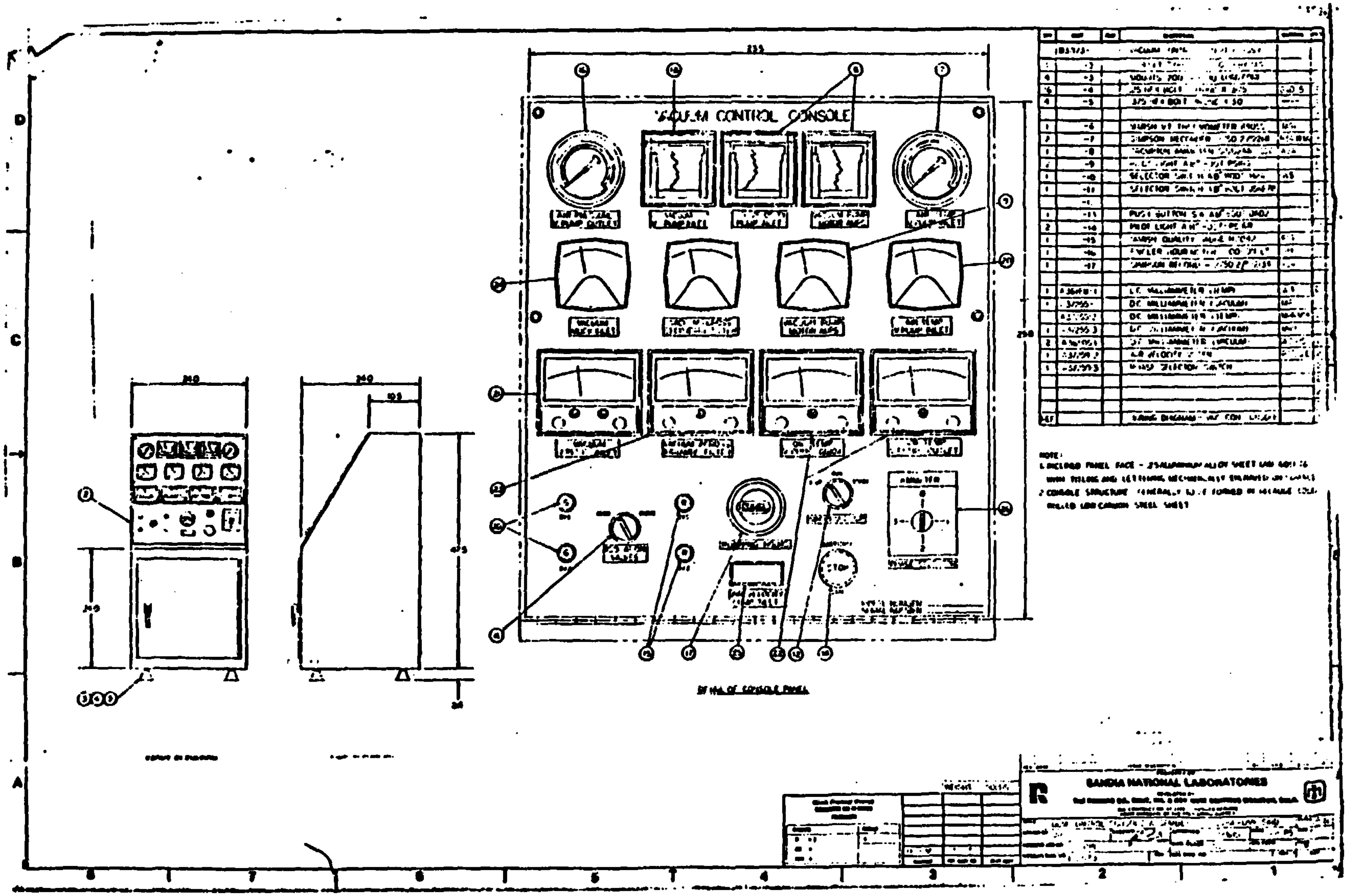
A-A
B-B
(14.0)
SANDIA NATIONAL LABORATORIES
HYDRAULIC INSTALLATION POWER UNIT
D35915



CONTROL STATION ASSEMBLY
CONTROL CONSOLE ASSEMBLY
LIGHT FIXTURE
NOTES:
SANDIA NATIONAL LABORATORIES


NOTES:
1. USE THE NAMEPLATE (PIECE 58) AS A TEMPLATE FOR LOCATING THE CENTER POINTS OF THE COMPONENTS.
ADHESIVE TO BE APPLIED TO EACH.
SANDIA NATIONAL LABORATORIES
PILOT LIGHT
PUSH BUTTON SW
SELECTOR SW
FUSE
KEY SWITCH
NAMEPLATE
DIGITAL PANEL METER
DC MILLI AMMETER
C
B
A
8
7
6
5
4
3
2
1


VACUUM PUMP
N-HOLE DRILL
SANDIA NATIONAL LABORATORIES


VACUUM CONTROL CONSOLE
STOP
DETAIL OF CONSOLE PANEL
SANDIA NATIONAL LABORATORIES

APPENDIX C

to

DESIGN OF A MACHINE TO BORE AND LINE
A LONG HORIZONTAL HOLE IN TUFF

THRUST REQUIREMENT ANALYSIS

THRUST REQUIREMENT

Total thrust requirement is the sum of the:

(a) Cutterhead force.
(b) Frictional force between liner and bore due to dead weight.
(c) Frictional force due to stabilizer loading.
(d) Rock shearing force at shield leading edge.
(e) Gradient component force.
(f) Liner binding force in deviated bore.

(a) <u>Cutterhead Force</u>

Based on a penetration of .06 inch/revolution, in 20 ksi rock, total axial cutter force requirement is 150,000 lbs.

	<u>150,000 lbs</u>

(b) <u>Dead Weight Friction</u>

Weight of drill	20,450	lbs
74 liner lengths (.50 in. wall)	112,100	
74 muck tubes	31,450	
Cabling	<u>3,600</u>	
Assuming friction coefficient of .8	<u>134,080</u>	<u>lbs</u>

(c) <u>Stabilizer Friction</u>

Force on upper and lower shoes (each) (based on stabilizing force = 3 x cutter side load)	120,000 lbs
Total force assuming friction coefficient of 0.8	<u>192,000 lbs</u>

(d) <u>Rock Shearing Force</u>

Assume the bore is undercut by .25 inch over one third of the circumference during a steering manuever. Area of rock "shoulder" = 37 x sin 60^{o} x .25 = 8 sq. in.

Assume rock resistance = unconfined compressive stress = 20 ksi

Shearing force = 20,000 x 8 = <u>160,000 lbs</u>

(e) Gradient Component

Assume worst angle of 3^o

Force = 225,000 x sin 3^o 11,800 lbs

(f) Binding in Bore

Assume a lateral deviation of the bore of 2 inches in each 100 ft. length. See Figure C-1. Assume the bore is .5 in. larger than liner outside diameter (allowing for part worn cutters) resulting in a net deviation of 1.5 in. Shape of deflected liner can be considered equivalent to a series of 50 ft. span simply supported uniformly loaded beams. See Figure 1B.

For 36 in. O.D. .50 in. wall

T = 8790 in^4

E = 30 x 10^6 lb/in^2

$$\text{Deflection} = .75 = \frac{5\ F(50 \times 12)^3}{384 \times 30 \times 10^6 \times 8790}$$

F = total force = 70,320 lb.

Total force over 600 ft. length

= 12 x 70,320 = 843,840 lb.

Sliding friction force =
(assuming friction coefficient of 0.8) 675,072 lbs

Total force required (sum of (a) - (f)) = 1,356,952 lbs

A nominal force of 1.5 x 10^6 lb. has been chosen, based on the estimates. This is in line with forces used on existing pipe jacking equipment for approximately the same size pipe.

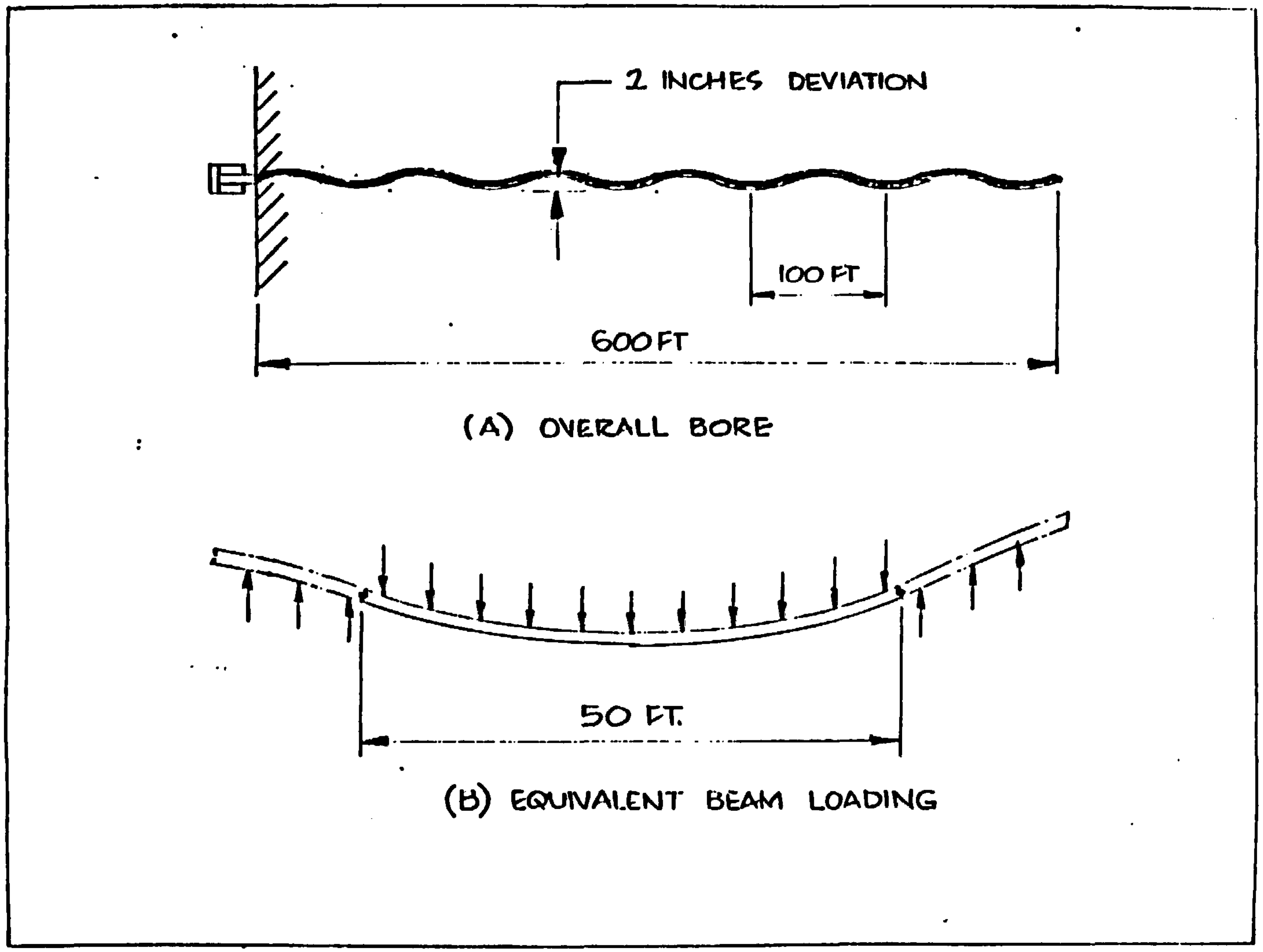


Figure C-1 Bore Deviation and Liner Forces

APPENDIX D

to

DESIGN OF A MACHINE TO BORE AND LINE
A LONG HORIZONTAL HOLE IN TUFF

LINER BUCKLING STUDY

LINER BUCKLING STUDY

The derrick is to be provided with 1.5 million lb. thrust. The majority of this thrust is required to overcome potential binding forces on the liner due to faulty ground or hole misalignment. There is also provision for cutterhead thrust and sliding friction. Even with a perfect bore, a thrust of approximately 0.5 million lbs. will be needed at a hole length of 600 ft.

Consideration must be given to the structural behavior of the liner. In the compressive mode, buckling failure must be studied. There are two types of buckling, column and local shell buckling.

a. Column Buckling

For this to occur, there must be unimpeded lateral movement. This clearly cannot happen in a confined hole. Maximum lateral movement is one inch.

b. Shell Buckling

If the liner wall is thin in relationship to its diameter, a potential exists for local crumpling of the wall. According to the technical literature, true "thin" shells are those having a radius/thickness (R/t) ratio of at least 100, and generally in the region of 200-400. If a minimum liner thickness of 0.38 in. is considered, it has a ratio of 48. The ratio for a 0.5 in. wall is 36. These low ratios provide an extra margin of safety over the buckling forces predicted by "thin" shell theory.

1. Buckling of Cylindrical Shell Under Uniform Axial Load.

Roark (fifth edition) has the following formula for the limiting stress prior to buckling:

$$\sigma = \frac{E}{\sqrt{3} \bullet \sqrt{1 - \nu^2}} \bullet \frac{t}{R}$$

Where σ = critical stress

E = Young's Modulus (30×10^6 psi)

ν = Poisson's Ratio (.27)

t = wall thickness (inch)

R = cylinder radius = 18 in.

$$\therefore \quad \frac{\bullet 6 \bullet 30 \bullet 10^{6}}{\sqrt{3} \bullet \sqrt{1 - 27^{2}}} \bullet \frac{t}{18}$$

Roark recommends multiplying by a factor of 0.4 to 0.6 to account for actual experience as opposed to theory. Tennyson (Reference 1) shows a graph showing that the factor approaches 0.6 as R/t decreases to 100. This factor is used, though it will in fact be higher at ratios less than 50.

For wall thicknesses of .38, 0.5, and .75

σ_t = .38 = 228 ksi (6.5 yield)

σ_t = 0.5 = 300 ksi (8.5 yield)

σ_t = .75 = 450 ksi (12.9 x yield)

In all cases, material will yield before buckling. Shell thickness for buckling just at yield (35 ksi) is 0.6 in.

Figure D-1 shows the buckling load plotted as a function of wall thickness, based on the calculated buckling stress over the pipe cross-section.

2. Direct Stresses

Area (.38) = 42 in^2

Area (0.5) = 55.8 in^2

Area (.75) = 83 in^2

Assuming axially applied load of 1.5 x 10^6 lbf.

σ_t = (.38) = 35714 psi

σ_t = (0.5) = 26881 psi

σ_t = (.75) = 18072 psi

Figure D-2 shows the direct stress plotted as a function of wall thickness.

36 in. O.D. STEEL PIPE

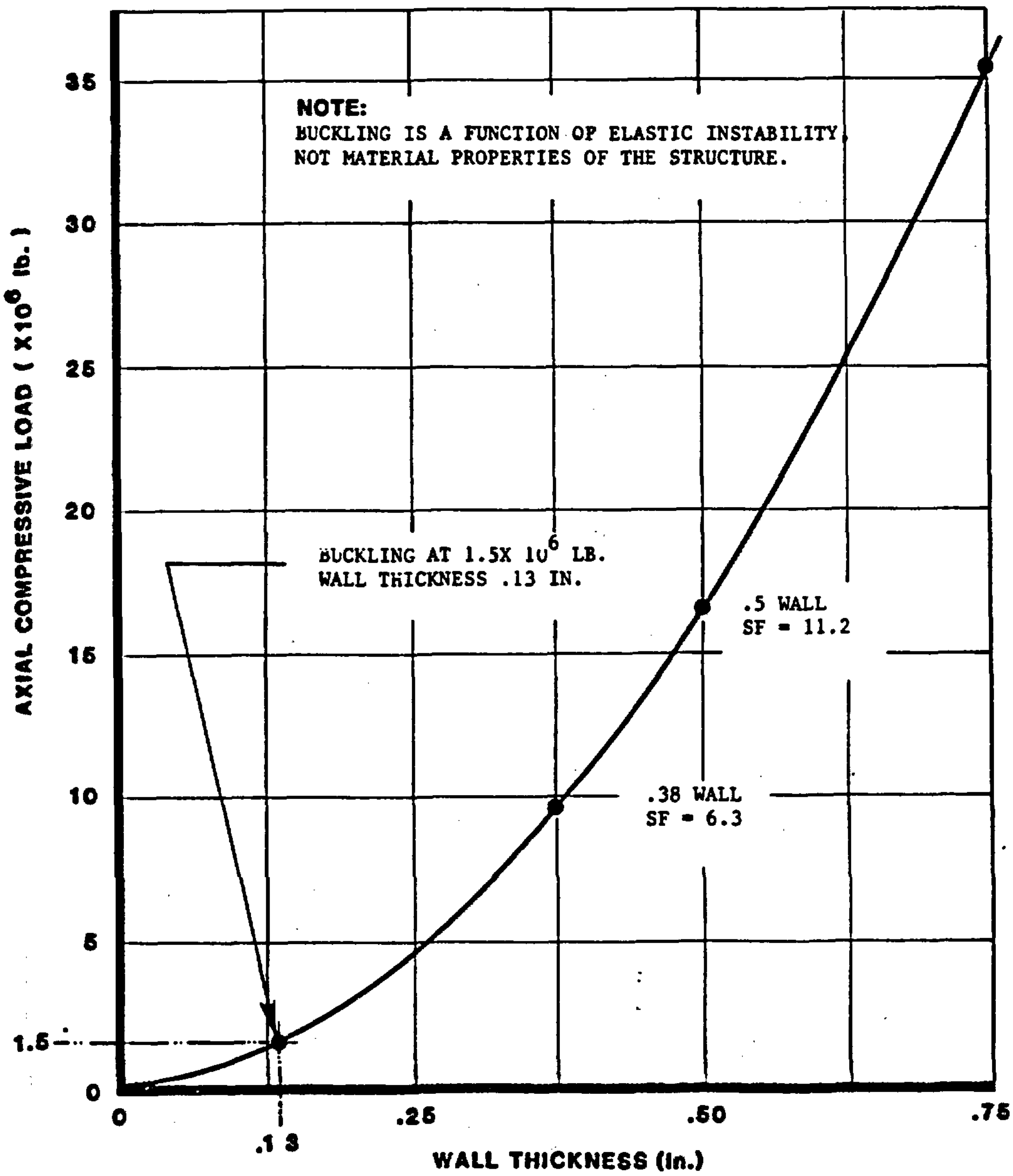


Figure D-1 Direct Stress at 1.5 x 10^6 lb. Axial Load vs. Wall Thickness

36 in. O.D. STEEL PIPE

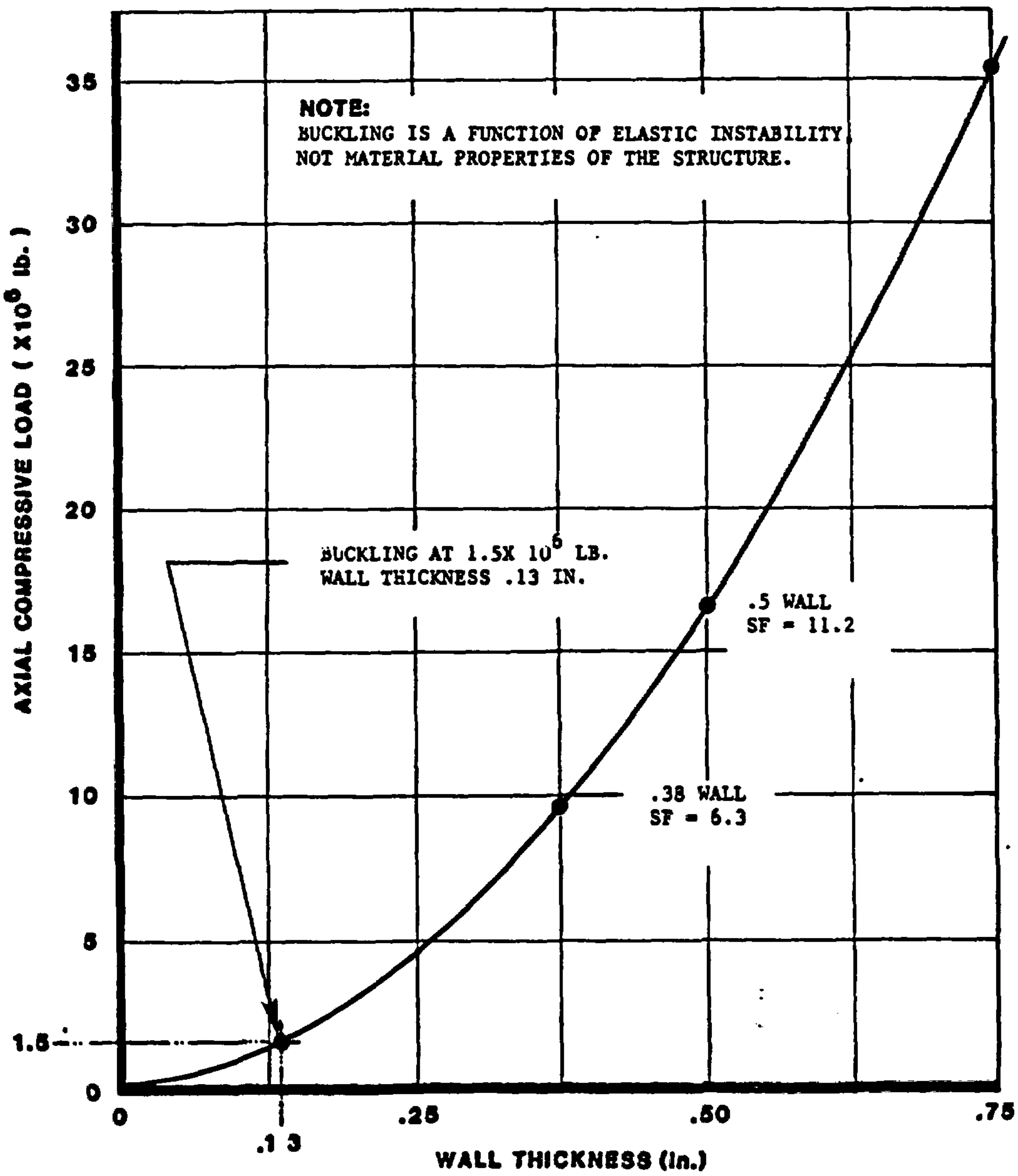


Figure D-2 Buckling Load vs. Wall Thickness

3. <u>Stress Under Eccentric Loading</u>

The thrusting collar surface will be aligned square to the line of thrust, and the liner and surfaces machined symmetrically to the liner axis within .03 in. Additionally, the collar may incorporate a flexible backing pad or be mounted on a swiveling arrangement to minimize eccentric loading.

Even if eccentric loading is applied to the extent that the yield stress is reached, structural failure is unlikely. Yielding will take place until axial deformation redistributes the stress levels as the neutral axis is allowed to shift. A state of equilibrium is generally reached due to the confinement of the hole.

The successive axial yielding together with displacement presents an indeterminate problem for the calculation of actual stresses. The purpose of this analysis is to support the selection of a wall thickness, as opposed to calculating an actual stress state. In contrast to the compressive state, the tensile situation generates a reduction in wall thickness with a corresponding higher stress level and possibly ultimate failure. A liner pull system is therefore inherently less reliable.

Shell buckling as a function of elastic behavior, not strength properties of the materials, will not occur in the eccentric mode as the stresses will not be able to approach the levels calculated in b(2). To improve the understanding of liner stress influence, it is proposed that strain gages be installed on selected liners to monitor the stress state during the NTS tests. Linear strain data, together with associated thrust load levels, should provide useful information in understanding liner behavior, together with the operating characteristics of the DPBM.

c. <u>"Dimpling" of Liner</u>

In faulted ground, the possibility of rock being wedged between the liner and the bore is unlikely as the friction between liner and rock is less than between two rock surfaces. If a wedge situation occurs, dimpling of the liner is possible. The question has been raised as to the effect of the cross sectional change on buckling. Again, column type buckling cannot occur because of the side restraint. Shell buckling stresses will not be reached, though if the dimpling is severe (greater than one quarter of the circumference) compressive yielding could occur across the entire cross section of a 0.5 in. wall. This assumes that the dimpled section provides no resistance. This amount of dimpling is so severe, however, that the available axial forces could probably not move the liner in any case. The problem would be equally severe if the liner were being pulled instead of pushed. Repair work would be required from inside the liner in order to proceed.

d. General Considerations: Pushing vs. Pulling

1. Compression loading is inherently safer structurally providing buckling is not possible. Tensile loading above yield leads to thinning of the section, stress increase and ultimately fracture. Excess compression leads to distortion, which is acceptable in this case, providing that no fracture occurs. Welds in compression are therefore superior.

2. With liner thrust (pipe jacking), the maximum loads are applied at the work station. In the event of failure, it will be easy to replace a broken section. In the original pull-in scheme, maximum loads are at the drilling machine. A failure will be in-hole and difficult to repair.

CONCLUSION

The liner configurations considered will not be subject to buckling problems because they have an R/t ratio outside the critical range. However, the direct stresses (which are the same for push or pull) are too high for a 0.38 wall liner made from mild steel (35 ksi). A higher strength liner (50-65 ksi) could be used. Extra cost will necessarily be incurred either in the use of a superior material or a thicker wall.

Reference[1] - R. C. Tennyson, "Buckling Modes of Cylindrical Shells Under Axial Compression," AIAA Journal, Vol. 7, Aug. 1969, pp. 1481-7.

APPENDIX E

to

DESIGN OF A MACHINE TO BORE AND LINE
A LONG HORIZONTAL HOLE IN TUFF

VACUUM SYSTEM COMPUTATIONS

VACUUM SYSTEM COMPUTATIONS

An analysis of the airflow through the muck handling system is complicated by the fact that the hole boring machine may be tested in at least three locations. The locations are at different elevations with variations in air temperature and relative humidity, resulting in a concomitant variation in the density of air and barometric pressure. The testing is expected to be as follows:

1. Initial testing in a rock quarry near Seattle (no analysis required.)

2. Proof of concept testing with the hole boring machine in U12G tunnel complex at the Nevada Test Site at the 6300 ft. elevation and air temperature of 75°F.

3. Hole boring in a proposed repository at 1200 ft. elevation and 80° F ambient air.

For a fixed muck throughput, pipe length has the greatest effect on power consumption by the vacuum pump. High altitudes cause a derating of the vacuum pump because of the reduced air density. Consequently, a dual set of calculations is required for the two cases. For convenience, the cases will be referred to as Test Tunnel and Repository Tunnel.

GENERAL DESCRIPTION OF THE VACUUM MUCKING SYSTEM

1.	Diameter of borehole	37 in.
2.	Area of face	7.47 sq. ft.
3.	Controlled advance rate	2 in/min.
4.	Volume solids extracted	1.25 cu.ft/min.
5.	Specific weight of rock	150 lb/cu.ft.
6.	Weight of rock drilled	187.5 lb/min.
7.	Length of borehole lining per section	8 ft.
8.	Solid volume per lining section	59.76 cu. ft.
9.	Swell factor	1.6
10.	Total drop box volume required	95.6 cu. ft.
11.	Muck production	5.6 tph
12.	Heat transfer in borehole	5300 btu/min.
13.	Temperature rise in muck	70°F
14.	Borehole lithology	welded tuff

DESIGN ASSUMPTIONS

1. The air drawn from the main haulage tunnel is free from dust and available in adequate quantity from the ventilation system. The test tunnel is 6,300 ft. above sea level with a temperature of 75°F and the repository tunnel is at 1,200 ft. altitude and 80°F.

2. The borehole is lined with a smooth steel liner.

3. The unobstructed area in the borehole is 3 sq. ft.

4. The minimum area around the muck plate for the passage of the air is approximately 0.5 sq. ft.

5. The sum of the areas normal to the airflow around the cutter is approximately 2 sq. ft.

6. The maximum length of the borehole is 600 ft.

7. The maximum length of the muck handling system in the main haulage way is approximately 100 ft.

8. The borehole is at right angles to the main tunnel.

DESCRIPTION OF THE AIRFLOW

The air required at the borehole face will be drawn into the borehole from the main tunnel by the pressure differential between the face and atmospheric pressure in the main tunnel. As the air passes over the motor and gearbox it will gain heat and volumetric flow rate, but lose density.

The air will be drawn into the face around the muck plate. The small area for entry will increase the velocity of the air to a point where dust will not be able to enter the main tunnel from the borehole.

The air velocity across the face will carry small dust particles and respirable dust back to the intake. Heavy particles, falling freely from the cutters, will be deflected towards the intake orifice.

The heavy particles resting on the invert will gradually move towards the intake orifice as the drill advances into the face. In addition, a sweep or plough blade set at an angle of 45^{o} will sweep the muck towards the intake, imparting an initial velocity and maintaining a dynamic condition that will assist the air stream in propelling the muck into the intake. Once in the muck pipe, the air velocity increases as the pressure decreases (increasing vacuum) until the muck reaches the drop boxes. In the boxes the cross-sectional area of flow is increased sharply, resulting in quickly reduced airflow velocities.

1. TEST TUNNEL

PRESSURE DROP FOR AIRFLOW INTO BOREHOLE:

Assume that particle pick up velocity is 6000 ft/min.

Area through muck hole plate is 0.2 sq. ft.

Minimum airflow must be 6000 x 0.2 = 1200 cfm.

Borehole collar elevation is 6300 ft.

Specific weight of air is 0.0588 lb/cu. ft. at 75°F.

Barometric pressure (equivalent) is 23.71 in Hg absolute.

Borehole diameter at collar restricted by thrust collar, muck pipe, and two thrust jacks. Assume unrestricted area is 6.305 - 1.354 = 4.95 sq. ft.

Velocity at entrance is 1200/4.95 = 242 ft/min. = 4.04 ft/s.

Entrance loss, V x V/4g expressed as a pressure drop is 4.04 x 4.04 x 0.0588/(4 x 32.2 x 144) = 0.00005175 psi ***

PRESSURE DROP FOR AIRFLOW IN BOREHOLE:

Maximum length of test borehole is 271 ft. less 21.5 ft. length of drill or about 250 ft.

However, this area is reduced by electric cables, cable holders on the muck pipe, and a pair of caster mounts on the mid-point of each muck pipe section for positioning the muck pipe as each section is inserted in the borehole. Assume that the reduced area is 900 sq. in., but that the wetted perimeter is unaffected.

Cross section is circular less area of muck pipe.

Hydraulic radius = Rh = A/P = 900/(138.2 x 12) = 0.543 ft.

Wall roughness of steel liner approximately 0.00015 ft. = k

Relative wall roughness = k/4Rh = 0.000069

Dynamic viscosity of air = 3.86 x 10E-7 lb. - s/sq. ft.

Reynolds No. of airflow = 4.04 x 4 x 0.543 x 0.0588/(3.86 x 10E-7 x 32.2) = 41,516

Stanton-Moody friction factor (D'Arcy-Weisbach) = 0.0221

PRESSURE DROP DUE TO WALL FRICTION:

0.0588 x 0.0221 x 250.5 x 4.04 x 4.04/(4 x 0.543 x 64.4 x 144) - 0.00026377 psi ***

ANALYSIS OF TEMPERATURE RISE AROUND THE MACHINE

Installed power -	125 hp - 93.25 kw
Equivalent heat energy -	93.25 x 3420 - 318,915 btu/hr. - 5303 btu/min.
Ambient temperature -	75°F
Table of Losses:	
To ground assume 15%	- 795 btu/min.
To watercooling 5%	- 265 btu/min.
To additional steel liner, airflow and cut rock 80%	- 4243 btu/min.
Weight of liner and thrust tube	- 81 lbs/ft.
Weight of rock removed	- 187.5 lbs/min.
Weight of air (1200 x 0.0588)	- 70.6 lbs/min.
Specific heat of steel	- 0.113
Specific heat of rock	- 0.191
Specific heat of air	- 0.237

Combined specific heats:

81	x 0.113 -	9.153	
187.5	x 0.191 -	35.8125	
70.6	x 0.237 -	16.7322	
339.1		61.6977	61.6977/339.1 - 0.1819 Sp.heat

Temperature rise - 4252/61.6977 - 68.77°F

From this, it is deduced that the steady running temperature around the machine will be in the order of 75 + 69 - 144°F.

PRESSURE DROP FOR AIRFLOW THROUGH DRILL MACHINE

The density of the air in the borehole will decrease and its volumetric flow rate increase as the temperature rises near the drill machine.

The increase in volumetric flow rate is:

T2 P1 V1/T1 P2 = 604 x 11.6489639 x 1200/(535 x 11.6486484) = 1355 cfm

where T2 = 144F; T1 = 75F; P1 = 23.71 in Hg = 11.6489639 psia

The weighted cross-sectional area of the in-hole drill machine blocking the airflow is estimated to be that of an 18 in. diameter cylinder. The cross-sectional area of free airflow is 763 sq. in. and the wetted perimeter is 170 in., giving a hydraulic radius, Rh = 0.375 ft.

Across the drill machine use average airflow and temperature to obtain (1200 + 1355)/2 = 1278 cfm and 110F.

Average velocity is 1278 x 144/763 = 241 ft/min. or 4 ft/s.

Reynolds No. = 4 x 4 x 0.375 x 0.0588/(3.97 x 10E-7 x 32.2) = 27,725

Assume a roughness of 0.0002 ft. and relative roughness becomes 0.0002/(4 x 0.375) = 0.0001.

The friction factor is 0.0244 and the pressure drop due to wall friction is 0.0588 x 0.0244 x 21.5 x 16/(64.4 x 144 x 4 x 0.375) = 0.00003548 psi ***

Velocity past muck plate = Q/A = 1355/0.5 = 2710 fpm = 45.16 ft/s

Velocity head expressed as pressure drop through muck plate = 45.16 x 45.16 x 0.0588/(64.4 x 144) = 0.01293496 psi ***

ANALYSIS OF AIRFLOW AROUND FRONT OF DRILL MACHINE

Air to intake	= 1355 cfm
Velocity past cutters	= Q/A = 1355/2 = 677.5 ft/min. = 11.29 ft/s.
Velocity head expressed as pressure drop past cutters	= 11.29 x 11.29 x 0.0588/(64.4 x 144) = 0.00080820 psi ***

The airflow is obstructed by the cutters. The flow is bounded by a complex structure and has a wetted perimeter of about 18 ft.

The cross-sectional area is about 2 sq. ft. The hydraulic radius is

therefore 0.1111 ft. and the path length is 3.5 ft. Reynolds No. - 11.29 x 0.444 x 0.0588/(3.97 x E-7 x 32.2) - 23,078
Relative wall roughness is 0.0003375; friction factor - 0.0258

PRESSURE DROP AROUND FRONT OF DRILL MACHINE

- 0.0588 x 0.258 x 3.5 x 11.29 x 11.29/(64.4 x 144 x 4 x 0.1111) - 0.00016422 psi ***

ANALYSIS OF AIRFLOW INTO INTAKE AND TRANSITION MUCK PIPE

Airflow available is 1357 cfm corrected for pressure reduction

Area of intake, Ai - 0.2 sq. ft.; Area of pipe, Ap - 0.196 sq. ft.

Intake velocity - 1357/0.2 - 6785 ft/min.

Velocity in pipe - 1357/0.196 - 6923 ft/min.

Average velocity - (6785 + 6923)/2 - 6854 ft/min. - 114 ft/s.

Wetted perimeter of intake, Pi - 2.5 ft.

Wetted perimeter of pipe, Pp - 1.55 ft.

Hydraulic radius of intake, Rhi - 0.2/2.5 - 0.08 ft.

Hydraulic radius of pipe, Rhp - 0.196/1.55 - 0.126 ft.

Average hydraulic radius - (0.08 + 0.126)/2 - 0.1032 ft.

Entrance loss, V x V/4g expressed as a pressure drop is 114 x 114 x 0.0588/(4 x 32.2 x 144) - 0.0413728 psi

Reynolds No. of airflow - 114 x 4 x 0.1032 x 0.0588/(3.97 x 10E-7 x 32.2) - 216,459

Relative wall roughness - k/4Rh - 0.00015/(4 x 0.1032) - 0.00036

Stanton-Moody friction factor - 0.0181

Pressure drop due to wall friction in 12 ft. transition pipe - 0.0588 x 0.0181 x 12 x 114 x 114/(4 x 0.1032 x 64.4 x 144) - 0.04335696 psi

Correct for density change from air to air plus muck for both entrance and wall losses;

Airflow weight rate is 1357 cfm x 0.0588 lb/cu.ft. - 79.8 lb/min.

Rock flow weight is 187.5 lb/min. (1.25 cu. ft/min.)

Total weight rate is 267.3 lb/min.
Specific weight of mixture is 267.3/1358.25 = 0.1968 lb/cu. ft.

Corrected entrance pressure drop is 0.0413728 x 0.1968/0.0588 = 0.13846601 psi

Corrected wall friction pressure drop is 0.04335696 x 0.1968/0.0588 = 0.14511309 psi

Total pressure deop at intake = 0.2835791 psi ***

ANALYSIS OF AIRFLOW IN MUCK PIPE IN BOREHOLE

Length of 7 in. I.D. pipe is 250 ft. plus elbow length (5 ft.) = 255 ft.

Expanded air volume rate is 1357 x 11.65/11.28 = 1400 cfm

Air V = Q/A = 1400/0.26725 = 5244 ft/min. = 87 ft/s.

Assume 1.5 psi drop due to wall friction. Air expands to 1400 x 11.28/(11.28 - 1.5) = 1615 cfm

Average airflow is (1400 + 1615)/2 = 1507 cfm

Average air velocity is 94 ft/s.

Reynolds No. of airflow is 94 x 7 x 0.0588/(3.97 x 10E-7 x 32.2 x 12) = 252,230

Relative wall roughness = 0.00015 x 12/7 = 0.00026

Stanton-Moody friction factor = 0.0171

New mixture specific weight is ((1615 x 0.0588) + 187.5)/1616.25 = 0.1748 lb/cu. ft.

Pressure drop due to wall friction and corrected for mixture specific weight:

=0.1748 x 0.0171 x 255 x 94 x 94 x 12/(7 x 64.4 x 144) = 1.24473911 psi *** (close enough to estimated 1.5 psi, ok)

ANALYSIS OF AIRFLOW IN MUCK PIPE IN MAIN TUNNEL

Pipe diameter is 7.625 in. inside. Flow rate is 1615 cfm

Velocity of air is 1615/0.317 = 5093 ft/min. = 85 ft/s.

Reynolds No. of airflow is 85 x 7.625 x 0.0588/(3.97 x 10E-7 x 32.2 x 12) = 248,087

Relative wall roughness = 0.00015 x 12/7.625 = 0.000236

Stanton-Moody friction factor = 0.0170

Length of pipe to drop boxes including equivalent lengths of fittings assumed to be 200 ft.

Pressure drop due to wall friction and corrected for mixture density = 0.1748 x 0.0170 x 200 x 85 x 85 x 12/(7.625 x 144) = 0.72870415 psi

Pressure drop considered significant for increasing airflow intake rate.

Airflow correction is 1615 x 10.04/9.31 = 1742 cfm

Average airflow is (1742 + 1615)/2 = 1678 cfm

Average velocity is 1678/0.317 = 5294 ft/min. = 88 ft/s.

Corrected pressure drop is 0.72870414 x 88 x 88/(85 x 85) = 0.78530796 psi ***

<u>ANALYSIS OF AIRFLOW INTO DROP BOXES</u>

Flow rate is 1742 cfm. Head loss into box is due to sudden enlargement from 8 in. pipe to 12 in. pipe. Velocity difference is (91.6 - 37.0) ft/s. and enlargement loss expressed as pressure drop is 46.33 x 0.0588/144 = 0.01891636 psi.

Correcting the specific weight of the mixture gives ((1742 x 0.0588) + 187.5)/1743.25 = 0.1663 lb/cu. ft. and the corrected enlargement pressure drop is 0.05349985 psi ***

The airflow through the muck boxes is difficult to analyze because in each box a slot 7 ft. long by 6 in. wide permits the coarser solids to drop out of the airstream. The airflow, now containing mostly dust and small particles, must come up around the exterior of the 12 in. diameter pipe, pass through the screen, and enter the discharge plenum along the top of the muck boxes.

Consider the exit losses through the slots as follows:

Expanded airflow is now 1742 x 9.31/9.26 = 1751 cfm. Slot opening is 2 x 7 x 6/12 = 7 sq. ft. Velocity leaving slot is 1751/7 = 250 ft/min. or 4.2 ft/s. The exit loss expressed as a pressure drop is 4.2 x 4.2 x 0.1663/(2 x 32.2 x 144) = 0.00031183 psi ***

Note that the specific weight of the mixture is used here. The pressure drop for wall friction in the slotted pipe is considered negligible.

ANALYSIS OF AIRFLOW THROUGH SCREEN

Expanded flow rate is approximately 1762 cfm. Surface area of screen is 24 sq. ft. For an initial trial consider an 80 mesh with 80 wires to the inch and square openings of 0.0069 in. This is an effective area of 52% or about 12 sq. ft. If the screen openings are too small, the screen will restrict the airflow. Pressure drops are unknown across the screens, so 1/2 psi will be allowed.

ANALYSIS OF AIRFLOW INTO PLENUM

Expanded airflow is 1865 cfm

Slotted intake area is 1.76 sq. ft.

Velocity is 1856/1.76 = 1055 ft/min. = 17.6 ft/s.

Assume entrance loss only, expressed as a pressure drop, giving 17.6 x 17.6 x 0.0588/(4 x 32.2 x 144) = 0.00097933 psi ***

Along the plenum the length is 14.3 ft., A = 0.75 sq. ft. and the wetted perimeter is 5 ft., giving a hydraulic radius of 0.15 ft.

V = 1865/0.75 = 2487 ft/min. = 41 ft/s.

Reynolds No. of airflow = 41 x 4 x 0.15 x 0.0588/(3.97 x 10E-7 x 32.2) = 114,380

Relative wall roughness = 0.00015/(4 x 0.15) = 0.00025

Stanton-Moody friction factor = 0.0191

Pressure drop due to wall friction (assuming a mixture specific weight of 0.08 lb/cu. ft.) is 0.08 x 0.0191 x 14.3 x 41 x 41/(4 x 0.15 x 64.4 x 144) = 0.00660127 psi ***

ANALYSIS OF AIRFLOW THROUGH FILTER

The maximum pressure drop through the two filter units is expected to be of the order of 3 in water gage or 0.11 psi ***

From the secondary filter the airflow enters the 14 in. diameter vacuum pump inlet through two feet of piping. The vacuum pump discharges through a 12 in. diameter opening into a plenum 4 ft. x 4 ft. x 20 in. before entering the 8 in. diameter intake to the silencer. The pressure drop is assumed to decreas another 0.5 psi ***

A summary of the losses in the test tunnel is tabulated.

2. REPOSITORY TUNNEL

The same procedure is followed as above but with the changes noted below:

Borehole collar elevation is 1200 ft.

Specific weight of air is 0.0706 lb/cu. ft. at 80°F.

Equivalent barometric pressure is 28.71 is Hg absolute.

Maximum length of borehole is 578.5 ft.

A summary of the losses in the repository is tabulated.

SUMMARY OF LOSSES IN TEST TUNNEL

LOCATION	PRESSURE DROP psi	SUMMATION psi
Into Borehole	0.00005175	0.00005175
In Borehole	0.00026377	0.00031552
Through Drill Machine	0.01297044	0.01328596
Into Front of Drill Machine	0.00097242	0.01425838
Into Intake	0.13846601	0.15272439
Transition Muck Pipe	0.14511309	0.29783748
Borehole Muck Pipe	1.2447391	1.54257658
Pipe in Main Tunnel	0.78530796	2.32788454
Drop Box Intake	0.0534999	2.38138444
Drop Box Slot Exit	0.00031183	2.38169627
Through Screen	0.5	2.88169627
Plenum Entry	0.00097933	2.8826756
Plenum Length	0.00660127	2.88927687
Filter Unit	0.11	2.99927687
Pump Inlet/Silencer	0.5	3.49927687
		or 7.12 in. Hg vac

Air volume rate to vacuum pump is approximately 1900 cfm. Referring to the Gardner-Denver curves for the 11CDL23 rotary blower: 1900 cfm at 8 in. Hg vac. and 975 rpm requires 45 bhp.

SUMMARY OF LOSSES IN REPOSITORY TUNNEL

LOCATION	PRESSURE DROP psi	SUMMATION psi
Into Borehole	0.00006213	0.00006213
In Borehole	0.00069830	0.00076043
Through Drill Machine	0.01557108	0.01633151
Into Front of Drill Machine	0.00116833	0.01749984
Into Intake	0.14677493	0.16427477
Transition Muck Pipe	0.15126457	0.31553934
Borehole Muck Pipe	3.31748066	3.63302000
Pipe in Main Tunnel	1.10905518	4.74207518
Drop Box Intake	0.10022235	4.84229753
Drop Box Slot Exit	0.00041819	4.84271571
Through Screen	0.5	5.34271571
Plenum Entry	0.00161855	5.34433426
Plenum Length	0.00876574	5.35310000
Filter Unit	0.11	5.46310000
Pump Inlet/Silencer	0.5	5.96310000
		or 12.13 in. Hg vac.

Air volume rate to vacuum pump is approximately 2400 cfm. Referring to the Gardner-Denver curves for the 11CDL23 rotary blower: 2400 cfm at 12 in. Hg vac. and 1300 rpm requires 85 bhp.

APPENDIX F

to

DESIGN OF MACHINE TO BORE AND LINE
A LONG HORIZONTAL HOLE IN TUFF

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