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Nevada Nuclear Waste Storage Investigations Project

Feasibility Studies and Conceptual Design for Placing Steel Liner in Long, Horizontal Boreholes for a Prospective Nuclear Waste Repository in Tuff

The Robbins Company
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FEASIBILITY STUDIES AND CONCEPTUAL DESIGN FOR PLACING STEEL LINER IN LONG, HORIZONTAL BOREHOLES FOR A PROSPECTIVE NUCLEAR WASTE REPOSITORY IN TUFF

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Under Sandia Contract: 47-2295

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ABSTRACT

Sandia National Laboratories Report SAND83-7085 analyzed vertical and horizontal methods of drilling holes for emplacement of nuclear waste canisters in a repository in tuff. While the horizontal method showed a significant cost advantage, the risk of hole blockage due to rock falls is higher. This report addresses the possibility of emplacing a steel casing simultaneously with drilling the hole. It appears that a drill could be developed that could be removed for repair from a partially complete hole and then reinstalled to complete drilling. A conceptual design featuring an eccentric cutterhead was completed. Capital and operating costs, as well as an operational schedule, were developed for the drill unit.

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1.0 INTRODUCTION

The work described in this report was performed for Sandia National Laboratories (SNL) as a part of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project. Sandia is one of the principal organizations participating in the project, which is managed by the U.S. Department of Energy's Nevada Operations Office. The project is a 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 canisters is in long (600-ft), horizontal boreholes. The boreholes could be drilled from the rib (side) of an underground haulageway. The specifications for the hole, including those for accuracy and a noncontaminating drilling fluid, would require an extension of current drilling technology. A prior study by the Robbins Company[1] determined that a laser-guided, boxhole-type drill employing vacuum mucking (cuttings removal) was practical. The drill design was a novel application and combination of basically existing components.

If the formation being drilled is not sound or will not stand for an extended period, a steel liner may be required. The emplacement of a steel casing after completion of drilling is a common practice and therefore was not addressed. A sequential drilling and lining procedure would be recommended if the formation has sufficient integrity.

This study addresses a worst-case scenario in which the formation being drilled would have a high probability of collapse before the drill could be removed or the liner installed.

2.0 SUMMARY

2.1 Objectives and Approach

2.1.1 General Requirements

The general requirements for a simultaneous drill-and-line system are identical to those of the prior study,[1] with added requirements. Items a through i are common to any repository drill, while items j through l are unique to this contract and study. The drill design shall ensure that:

a. The unit be as compact as reasonable.
b. The maximum length be no more than 20 ft.
c. The unit complies with all mining codes and standards.
d. The unit make use of standard components, drill pipe, bits, etc.
e. The unit will be readily transportable from one hole to another with minimum setup and demobilization time.
f. The hole direction be selectable from 80° to 100° from the axis of the drift and from -10° to +10° elevation with ±0.25° accuracy.
g. The hole deviation be no more than 6 in. in 100 ft with no more than 12-in. accumulated offset.
h. The unit be either a rotating drill string-type or an in-hole motor-type design.
i. The unit be capable of being lowered down an 18-ft-diameter shaft, either intact or disassembled into major components.
j. A cylindrical steel, 0.5-in.-thick carbon steel liner, containing no internal or external protrusions, be installed in the hole, simultaneously with the drilling operation.
k. The liner sections be welded to provide a single watertight liner.
l. The drill bit be capable of being pulled out, repaired or cutters replaced, and reinserted to complete the hole.
m. Further, the unit be capable of operating in an underground environment and be capable of drilling rock with properties as listed below.

Underground Environment:

Ambient Rock Temperature	35°C
Air Temperature	20° to 35°C
Relative Humidity	Up to 100%

Rock Properties:

- Densely welded devitrified tuff
- Fracture spacing approximately seven per foot in dense material

- Density 2.2 g/cm^3
- Unconfined compressive strengths 16,000 to 33,000 psi
- Rock may or may not contain vugs (voids)
- Uniaxial strain to failure approximately 0.41% to 0.97%
- Rock may be saturated

2.1.2 Approach

The approach attempted was to add a simultaneous lining feature to the basic drill designed in the previous study,[1] for an unlined, 33-in.-diameter horizontal hole. This approach avoided a start-from-scratch study and permitted incorporation of a significant amount of standard equipment. A matrix trade-off study (Figure 1), evaluated a number of design options. The highest rated approach featured:

a. An in-hole drive and electric motor.

b. A nonrotating drill string that provided thrust for both the drill head and liner installation.

c. Preinstalled power and control cable. A 50-ft-long cable section is strung through several liner lengths and is pulled into the hole with the liner.

A major factor in the selection of this option is its operational independence of the liner. The design allows a variable thickness, permits the option of a smooth inside diameter or protrusions, and minimizes the structural requirements of the liner.

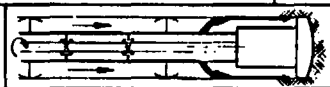
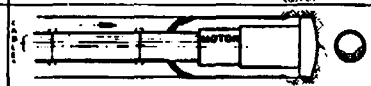
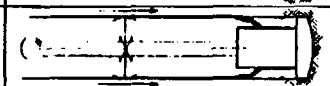
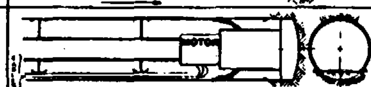
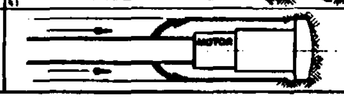
A second key feature is the eccentric cutterhead, which allows the drill to pull through an inside diameter (i.d.) smaller than its bore diameter. This feature also allows reinsertion of the drill for continuation of the drill/line operation after drill maintenance and/or cutter replacement.

Although this design study and report addresses only a simultaneous drill/line operation, the selected approach may be used in other modes as well.

a. The drill is capable of drilling without a lining as well as with one.

b. It would be possible to initiate drilling without a liner, determine that one is needed, pull out, insert liner to the bored depth, and then continue drilling while simultaneously lining.

While not a prime consideration, this versatility of operation is a bonus of the selected independent liner concept.

ESTIMATION OF IMPORTANCE				7	3	2	1	5	4	6			
SANDIA - BORE AND LINE STUDY MATRIX COMPARISON OF VARIOUS METHODS (10 : BEST)				INITIAL COST	OPERATING COST	OPERATIONAL COMPLEXITY IN DRIFT	IN-HOLE RELIABILITY	NEW TECHNOLOGY REQUIRED	INDEPENDANCE OF LINER DESIGN	SIMPLICITY OF THRUST MECHANISM	.	WEIGHTED AVE. POINTS	POSITION
CONCEPT NUMBER	DESCRIPTION OF METHOD		% RELATIVE IMPORTANCE SCORE	20 20 25	50 70 50	75 75 80	95 95 96	30 40 35	40 60 40	25 30 30			
			AVE. B	21.667	56.667	76.667	95.333	35.000	46.667	31.333			
			PERSON	J J A	J J A	J J A	J J A	J J A	J J A	J J A			
1	NON-ROTATING PIPE DRAG IN LINER PROP. SHAFT CONTROL CABLE SPOOL		AVE. A	3.33	5.33	4	6	8.333	10	6.33		2209,885	2
			SCORE	3 4 3	5 5 6	4 5 3	5 8 5	8 9 8	10 10 10	5 6 8			
			A x B	72.220	302.220	306.667	572.000	291.667	466.667	198.444			
2	NON-ROTATING PIPE DRAG IN LINER IN-HOLE MOTOR USE PIPE AS CONDUCTOR		AVE. A	3.667	5.667	4.333	5.333	3	10	9		2094,888	3
			SCORE	3 5 3	8 6 3	4 6 3	4 9 3	3 3 3	10 10 10	8 9 10			
			A x B	79.444	326.111	332.222	508.444	105.000	466.667	282.000			
3	LINER FOR PUSH & T. REACT ROTATING SHAFT MOTOR ON DERRICK CONTROL CABLE SPOOL		AVE. A	8	6	6.333	4.667	8.667	3.667	5.333		2085,307	—
			SCORE	8 8 8	7 5 6	8 8 4	6 4 4	9 8 9	2 7 2	5 7 4			
			A x B	173.333	340.000	485.53	444.884	303.333	171.111	167.111			
4	PUSH IN LINER THRUST ON NON-ROT. PIPE IN-HOLE MOTOR CABLES IN CAVITY		AVE. A	3.667	4.333	6.333	3.333	5.333	1.667	5.333		1559,857	—
			SCORE	3 4 4	3 7 3	4 8 7	4 3 3	5 6 5	1 3 1	5 7 4			
			A x B	79.444	245.556	485.556	317.746	186.667	77.778	167.111			
5	DRAG IN LINER NON-ROTATING PIPE PRE-INSTALL CABLES, ETC. INTO ± 6 LINER LENGTHS ±50'		AVE. A	8	6.333	4	7	8.333	10	7.333		2494,334	1
			SCORE	7 9 8	7 6 6	4 4 4	7 8 6	8 9 8	10 10 10	8 6 8			
			A x B	173.333	358.889	306.667	667.333	291.667	466.667	229.778			

Robbins
Seattle, Washington USA

MATRIX COMPARISON OF VARIOUS METHODS

DWN. L. LANGEL — DATE 5/1/84 — NO. C 33211 — SHT 1 OF 1

Figure 1. Matrix Comparison of Various Methods

2.2 Conclusions and Recomendations

The following conclusions and recommendations are listed in the order that the subjects are discussed in the body of the report, not in order of significance.

a. The basic requirements of a simultaneous drill-and-line system can be met. The selected system uses an in-hole drive and a conventional rotary head with rolling carbide insert cutters. The drill design is sound, incorporates new components and component combinations, but utilizes all proven concepts. For cuttings removal, a vacuum pneumatic mucking system is recommended.

b. If the nuclear waste repository uses horizontal emplacement holes, the drill concept designed under this contract has a high probability of success.

c. The use of carbide insert-type cutters on the drill bit is considered conservative. Any further studies involving hardware should consider parallel tests of disc-type cutters. The potential for an order of magnitude reduction in drill cutter costs is good.

d. A trade-off study of transporter design, namely crawler treads, tires, or rail-compatible, is needed. This must be coordinated with overall repository mine plan. A preliminary opinion, after association with the project and study of this drill application, would favor rail.

e. Semiautomated steering requiring operator response was selected over full automation. Full automation would not reduce manpower and would likely require a lengthy and costly development to achieve the necessary reliability. Automation could be a later development to be retrofitted should experience show, for example, that a single crew could operate multiple drills.

f. A complete construction cycle (drilling, lining, moving, and maintenance) for one 600-ft-long emplacement hole is 15 days.

g. Direct labor hours per 600-ft horizontal hole are 1172 hours, based on a three-man crew plus specialists. This is 33.5 hours per canister (35 canisters per hole).

h. Equipment costs per canister are estimated between $2,355 and $2,738. Of these figures, $1,571 is lining cost, assuming a 0.5-in.-thick wall, 36-in.-outside-diameter (o.d.) lining.

i. A bored haulageway would increase mobility of the drill system (crawler treads could be replaced with tires or rail and reduce the site preparation costs. A bored wall surface would not likely require concrete thrust pads or a collar starting pad.

3.0 TECHNICAL DISCUSSION

3.1 General Approach

A survey of pilot hole drilling,[2] "Small Diameter Horizontal Hole Drilling, State of Technology," SAND84-7103, revealed that attempts at long horizontal holes had been made in diameters ranging from 3 to 20 in. All attempts used standard rotary techniques and accuracy in all cases was far less than the tolerances required to meet this requirement (see 2.1.1 g). In one trial, a horizontal pilot hole was drilled and then enlarged by pulling a standard reamerhead through it.

Blind holes in the 2- to 7-ft-diameter size have been drilled commonly, both from the top down and from the bottom up. All examples found were drilled at steep angles, and by far the most common orientation was vertical.

Accuracy control for blind drilling most commonly involves pulling the bit and inserting a surveying tool. If a deviation must be corrected, a special bit is installed and a correction made. After pulling the special bit and resurveying, the standard bit is replaced and drilling continues. To attain accuracies of less than 0.25 degree, this procedure is repeated frequently, at great cost. Continuous monitoring with continuous correction is the ultimate method to attain accuracy, but no such drilling system is available on the market. Tunnel boring machines (TBMs) always use continuously monitored and steered systems. However, the smallest TBMs are in the range of 6 ft in diameter.

In the area of simultaneous lining and drilling, smaller bores in soft rock (in the 15-in.-diameter range) are made using an expanding bit employing hinged cutters on the outside of the bit. These expand and contract on command, sometimes using the drilling mud to provide a hydraulic signal.

The brief technology survey revealed no directly applicable equipment that could be used for drilling the horizontal holes of a prospective nuclear waste repository. Further, it verified that the approach taken in the previous study was correct, i.e., to incorporate the steering features of a TBM with the features of an in-the-hole rotary drill. Our work was then directed inward advancing the expandable bit concept and the means of inserting the liner simultaneously with drilling.

3.2 Liner

By direction of SNL, only steel liners, up to 1-in. wall thickness, were considered. To avoid redesign of as many drill components as possible, the conceptual study hole size was increased to 37 in.

The original repository drill study was for a bore diameter of 33 in. Allowing sufficient clearance between the machine and the smallest liner inner diameter (the reinforced leading edge of the liner) results in 36-in. o.d. of the liner. The hole size, making provision for cutter wear, was set at 37 in. diameter.

Robbins personnel and an SNL technical representative considered methods to bore and line the emplacemet hole using varous types of machines, derricks, and drill pipe. A comparison of five feasible methods was made (Figure 1). A significant factor in selecting the best approach was the requirement to have the liner design independent of the installation method. Further, in-hole reliability was deemed the most important drill system characteristic. The selected system received the highest rating because the hole is drilled in a single pass (blind) and the mechanism is protected at all times by the liner/shield.

Finally, the selected method allows the liner to be assembled in the drift from cylindrical sections that require only a circumferential weld.

3.3 Cutterhead

The added requirement that the cutterhead cut a 37-in. bore and yet retract through a 34-in.-i.d. shield necessitated a new cutterhead concept. The traditional and most obvious method is to install retractable or pivoted cutters and cutter housings. This method was considered in depth but finally was rejected because:

a. The cutter, which must retract, is the gauge (outside) cutter. This cutter position absorbs not only normal thrust but added load because of steering corrections. Experience has shown that in hard rock, gauge cutters must be rigidly attached to the cutterhead.

b. Installing the many mechanisms required in the small cutterhead diameter would be a complex design, assembly, and maintenance chore.

c. Although a complex remotely controlled mechanism for contracting and expanding the cutterhead could be made to work on a bench test, reliability in a hot, abrasive, dusty, and high-vibration environment is difficult to imagine.

Two alternative overcutting type cutterheads were conceived:

a. An eccentric cutterhead.

b. A tilting, elliptical-type cutterhead.

The elliptical cutterhead was not investigated in great detail. The eccentric head had potentially fewer moving parts than the tilting cutterhead and was therefore selected for further study. The principle behind the eccentric cutterhead design is that the maximum diameter of the cutterhead is less than the smallest inside diameter of the shield or liner. The cutterhead will rotate about a point 2 in. off center and thus cut a 4-in. oversize hole.

The bottom cutterhead support shoes extend to a fixed stop on the shield, which ensures that the centerline of the pivoting plane, made up of the four cutterhead support shoes, is on the centerline of the shield on that same plane.

When all of the cutterhead support shoes are retracted and the steering shoes are likewise retracted, the maximum dimension across these shoes and any other part of the boring machine is less than that of the cutterhead. When the drill pipe is carefully pulled back by the derrick, the cutterhead rides up over the leading edge ramp of the shield, thereby tilting the boring machine, and in this manner the machine and cutterhead are withdrawn from the liner (see D32924 in Attachment 2).

When the cutterhead is to be reinserted into the liner, the cutterhead will be rotated so that the shoe mounted to the cutterhead in line with No. 1 cutter rides on the invert of the liner. This shoe will skid over any protuberances that exist in the liner and shield and will also protect the cutter buttons from being damaged or causing damage to the liner or shield.

3.3.1 Cutters

The first design used for each, two-row carbide insert cutters, mounted such that the maximum dimension of the cutterhead was 33 in., but rotated about a point two in. from its geometric center. This would produce a bore diameter of 37 in. This head had the advantage of using standard two-row carbide cutters but necessitated an unbalanced cutter arrangement. As shown on the computer run (Attachment 1), fairly high unbalance forces are produced. These forces could be reacted only by the support shoes at the forward end of the shield.

Such out-of-balance conditions could lead to complete instability of the cutterhead in soft ground if the forces would cause the stabilizers to dig into the hole walls. In addition, main bearing life is shortened and other structural problems occur due to vibration.

A balanced three-cutter head (plus center three-cone unit) was laid out incorporating a three-row carbide insert cutter. The computer printouts for this centerhead show excellent vector balance (Attachment 1).

A three-row carbide cutter for use adjacent to the stinger (or three-cone center bit) is available (see D12401), but cutters for the outer two positions must be a modification of an existing design. A current-design two-row cutter (see D7091) can be modified by machining the cutter body for three rows of carbide inserts. This modified cutter is shown on D32937.

Disc cutters should be considered as an option for this application but were not included in this study. Carbide insert cutters are considered conservative on two counts:

a. They ensure smaller chips to enhance a vacuum mucking system.

b. Carbide cutters have a longer life. Having to replace a disc cutter in a nearly completed hole could negate the unit cost advantage of disc cutters.

The operational cost advanatage of the disc cutter, however, warrants their consideration in future studies. Compared to carbide insert cutters, discs improve the drilling rate and reduce bit costs by a minimum of 50%.

3.3.2 Muck Bucket and Muck Plate

A single bucket mounted to the cutterhead behind the gauge cutter keeps the invert clean. This bucket discharges through an opening in a segmented muck plate. This opening feeds the transition piece of the vacuum muck pipe.

The segmented muck plate is in four pieces. Each piece is attached to a centerhead support shoe. When these shoes are extended, the muck plate virtually seals the cutterhead cavity from the rest of the machine, thereby ensuring an efficient vacuuming system and excellent dust control.

When the cutterhead support shoes are retracted, these segmented muck plates retract to positions that do not interfere with the boring machine's withdrawal from or reinsertion into the liner.

3.4 Mobility

To provide a compact and highly mobile machine, all the standard mining options are available. For rapid mobilization, the drill-and-line unit should be self-propelled, as opposed to being towed or pushed into position by an auxiliary piece of equipment.

Since the entire drill weight is less than 30,000 lb., rail, tires, or crawler track, all of which are commonly used, can be considered.

a. Rail - Rail bogies offer the highest tramming speeds and in large mines offer the highest overall mobility. They are frequently the least costly to install and are by far the least costly to maintain.

b. Rubber Tires - Rubber tires are common but have the disadvantage of being unreliable through rough terrain where sharp rock and mine muck spillage are present. Tires are preferred where good roadways exist, tramming speeds can be high, and distances trammed are moderate. If access ways are bored and smooth, vehicles with tires add to mobility.

c. Crawler Treads - Crawlers provide the most versatility and are preferred in rough terrain or where distances are short. This was the option selected fo this study, but no trade-off study was made.

Minimum mobilization and demobilization time are important when assessing overall unit mobility. The weight class of this machine makes either of two general methods acceptable:

a. Thrust Pad - A conventional method for machine setup is to bolt the machine securely to a prepared concrete foundation. This ensures that all drilling forces and vibrations from thrust and torque are adequately reacted from a stable location. The concrete foundation also ensures that, once the unit has been bolted down securely and boring has commenced, no movement of the unit will occur that could damage the drill pipe or liner. The use of concrete starting foundations is a proven, successful method, simple and ideal for long holes where the machine is at the drilling site for a significant time. The concrete base cost is a small portion of the total cost of the hole. However, the time involved in setting up and removing the machine from the base once the hole is complete is significant.

b. Support Jacks - A less conservative but far quicker method has been employed for light drill rigs and is recommended in this case. The proposed horizontal boring machine employs a series of jacks that, when the machine is in position, can be extended from the machine in various directions to react against appropriate rock faces. Risk is involved, as each jack's security is dependent on its proper placement against a rock surface. To reduce the risk of the jacked-up derrick moving while boring and thereby jeopardizing the hole accuracy or the safety of the equipment, the derrick should be supported by a level concrete pad. If these foundation pads are cast to a predetermined level with respect to the tunnel rib, lining-up time for the machine can be minimized.

The jacking system is a far more secure operation if the emplacement drift is constructed using a TBM on a bored surface. If the tunnel is constructed by drill-and-blast methods, this preliminary recommendation may have to be revised.

Rapid alignment capability is a third element of mobility. The method used for securing the machine at the dril site has a direct bearing on the ability to drill holes in selectable directions. A securing method must be used that allows the machine to be rotated to and secured at the desired azimuth angle. A crawler-type machine on a concrete pad would accommodate such requirements. A dip angle would be achieved by leveling jacks built onto the crawler.

3.5 Description of the System

Figure 2 shows the conceptual design of a horizontal drill capable of simultaneous drilling and lining. The cutterhead is driven by an in-hole electric motor and fixed-ratio gearbox, directly coupled to the cutterhead assembly.

Cutterhead thrust is provided through a nonrotating drill pipe. Thrust to the drill pipe is generated by hydraulic cylinders mounted in the derrick assembly. This thrust also provides the pull to draw the liner in with the cutterhead as drilling commences.

Both thrust and the torque developed by the cutting action of the rolling-type cutters against the rock face are transferred through the drill pipe and into columns in the derrick. While the machine is boring, the derrick and crawler are braced and held securely by hydraulic cylinders. The thrust reaction jacks are positioned against the sidewall behind the derrick. The torque reaction jacks bear against the rock surface of the roof and against the tunnel floor. A preferred operation would be to have concrete pads poured for the thrust jacks and the floor jacks to bear against. In the case of a tunnel produced by drill-and-blast, these pads would be mandatory.

All power to the rig is electric. Hydraulic pressure for cylinders and jacks is provided from a separate cart-mounted power pack. Similarly, power for a vacuum muck pickup system is provided by a cart-mounted power pack, containing the blower, separator, and operational controls.

Rock chips are removed by a vacuum system, chosen primarily because it utilizes only air as a bailing fluid and eliminates potential contamination of the emplacement hole by fluids, oils, or polymers. Cuttings are picked up by the rotary motion of the head and dumped into the mouth of a separate vacuum pipe. Cuttings and air are drawn into a separation chamber or drop box. Each time a new pipe section is added to the drill, vacuum is broken and the

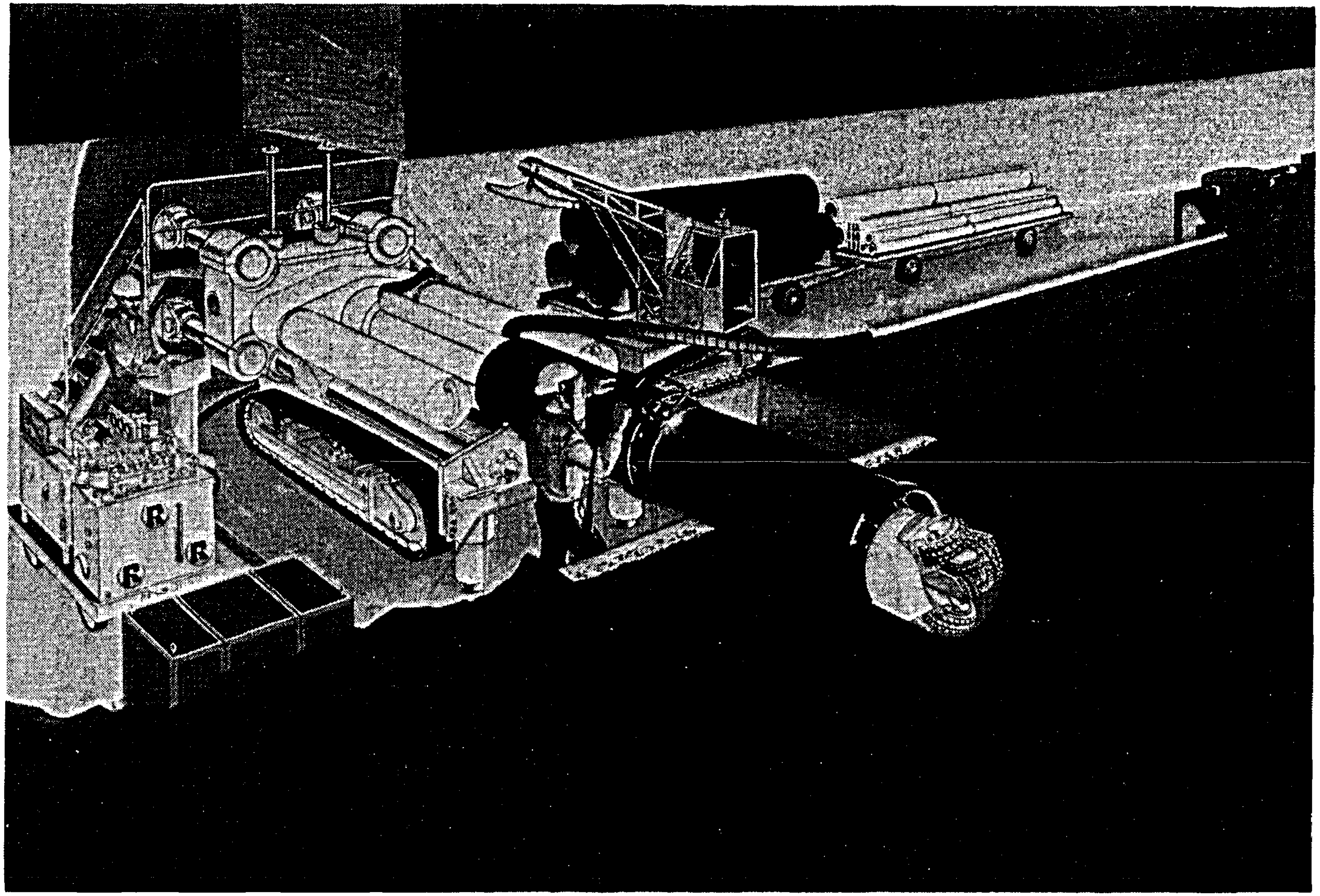


Figure 2. Simultaneous Drill-and-Line Rig

drop box is dumped. Haulage of muck from the drop box may be by any conventional system: conveyor belt, haulage vehicle, or perhaps a pressure pneumatic system.

Controls for operating and steering the machine, as well as on-off and dump controls for the vacuum system, are mounted on a separate console convenient to the derrick. Boring accuracy is monitored by a laser beam guidance system.

After the distance equal to one drill pipe length has been bored, boring and muck handling operations are stopped while lengths of liner, drill pipe, and muck pipe are installed at the derrick. The drill pipe uses threaded connections, the vacuum pipe uses victualic clamps, and the liner is welded together.

The boring machine is designed to operate in a 12-ft-high by 20-ft-wide drift that has a 5-ft-6-in. cubby cut to one side (see D32894). A 6-in. intended collar to facilitate collaring and to provide safe reaction surface for the thrust reaction jacks. The concrete pad and the collar rib provide safe reaction surfaces for the pullback reaction jacks. A mounting bracket for the laser beam source should be supplied on the floor pad. Three services are required at the rig: electricity, compressed air, and water for cooling the in-hole motor. Requirements are as follows:

a. 20 gpm of water at 400 psi.

b. 400 kVA (480 V, 50 Hz, three-phase).

The machine described employs well-proven technology; the design, however is new. Although most of the components are not standard the majority are adaptations of similar components used on existing machines.

3.6 Drill System Specifications

Condensed specifications for the drill rig and ancillary equipment are provided in Table 1. Detailed descriptions of significant components follow:

3.6.1 Cutterhead

The cutterhead consists of a flanged steel weldment with three cutter saddles attached. Each saddle carries a 12-in.-diameter, three-row, tungsten carbide button cutter.

The center of the cutterhead is machined to accept a standard 12-1/4-in.-diameter three-cone bit. This bit is flushed and cooled by compressed air.

A bucket is provided adjacent to the gauge cutter saddle to pick up muck and transfer it to the vacuum system intake point. All of the above components are depicted in Figure 3.

Table 1

Condensed Drill Specifications (Simultaneous Drilling and Lining)

Condensed Specifications	
Liner	36-in. o.d., 1/2-in. wall, 8-ft joints welded circumferentially on installation
Hole diameter	37 in.
Hole length	Capability to 700 ft
Drive motor (in hole)	ac induction motor 3-phase, 50 Hz, 480 V, 125 hp, 885 rpm Totally enclosed water-cooled with hollow shaft
Cutterhead	Balanced, eccentric flattened elliptic profile having three cutters, one three-cone bit and one mucking bucket
Cutters	12-in.-diameter with three row tungsten carbide buttons. Each row spaced 1-1/2 in. apart. 12-1/4-in.-diameter standard three-cone bit in center
Head rotation speed	33.5 rpm (fixed)
Gear reduction	Planetary-type 26.44 to 1 ratio
Torque	20,000 foot pounds
Thrust	1,500,000 lb at 4000 psi
Boring feed rate	0-4 in./min
Traverse rate (no load push)	50 in./min forward 110 in./min pullback
Drill pipe	16-in.-diameter, 96-in. length with standard splined and three-point bolt connection
Transporter	Electrohydraulic-powered crawler, Tramming speed 2 mph

Table 1 (Continued)

Condensed Drill Specifications (Simultaneous Drilling and Lining)

Condensed Specifications

Muck bailing		Vacuum system through 6 in. bore piping 250 hp roots blower, handling 1307 cfm at 20-in. vacuum gauge
Electrical power	125 hp	Cutterhead drive motor
	30 hp	Hydraulic thrust pack
	250 hp	Blower drive
	25 hp	Auxiliary available
		Total of 400 kVA connected 60 Hz, three phase, 480 V, ac
Cooling water		20 gpm at 400 psi
Compressed air		600 cmf at 80 psi
Approximate weight, derrick and cutterhead (self-propelled treads)		28,000 lb

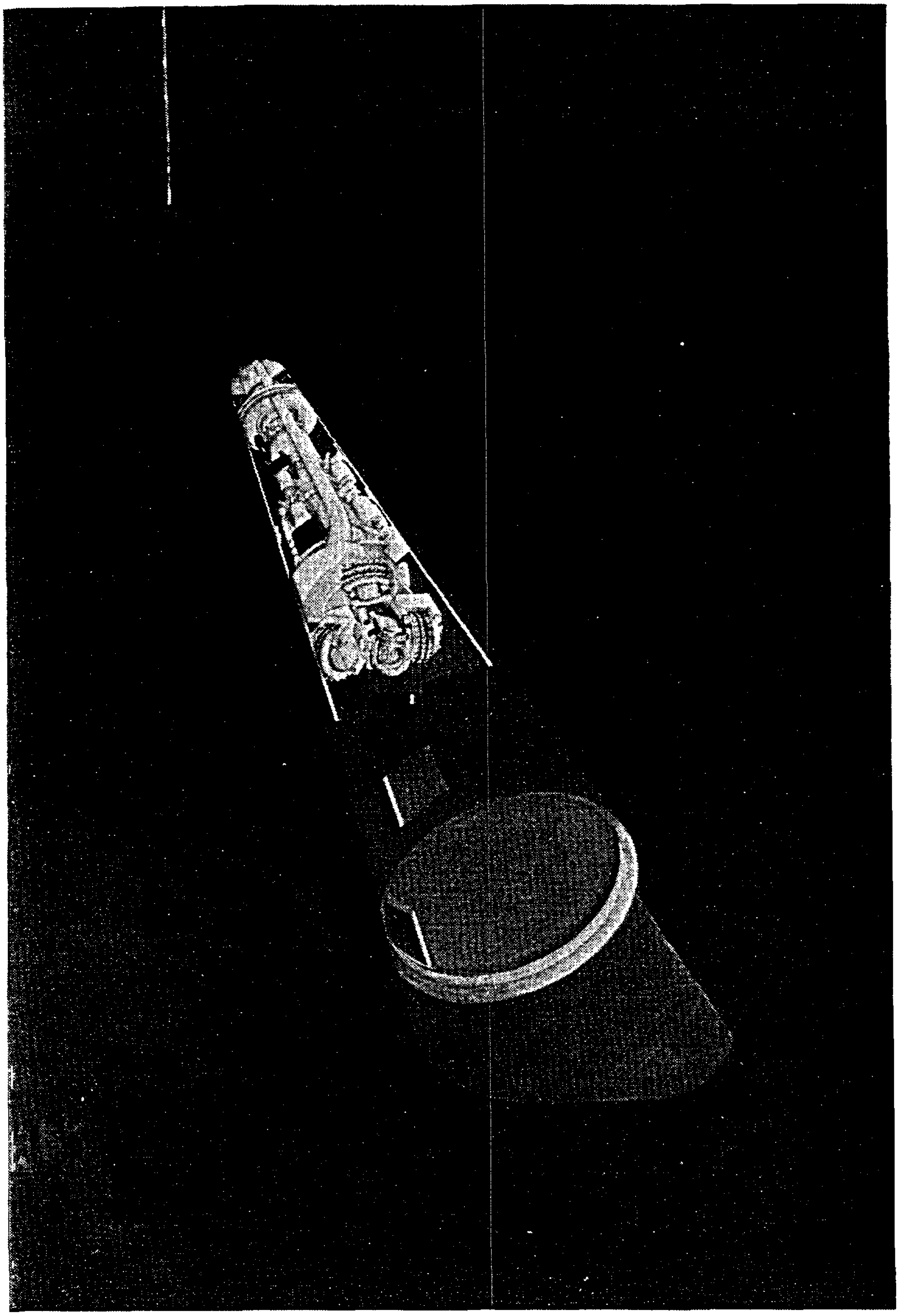


Figure 3. Retracting Cutterhead Configuration

The cutterhead is bolted to the output flange of the drive train. The cutterhead utilizes principles and components used successfully on other Robbins machines. Similar 12-in.-diameter tungsten carbide button cutters have been well proven on blind hole borers in much harder rock formations. The 12-1/4-in.-diameter tricone bit is a standard component on Robbins cutterheads for blind hole borers. The bucket is unique, but similarly styled buckets are used on Robbins full-face TBMs.

3.6.2 Muck-Handling System

A segmented, retractable, circular muck plate, with minimal tunnel clearance is mounted directly behind the cutterhead. A funnel-like chute is welded to the left side of the muck plate. This chute provides the entrance to the 4-1/2-in.-diameter vacuum pipe that leads to the back of the drive train housing. As the cutterhead rotates, the bucket scrapes up the muck, lifting it against the muck plate until the vacuum opening is reached. The angle of each bucket at this point is such that gravity aids muck discharge from the bucket into the funnel and vacuum pipe. The 4-1/2-in.-diameter muck pipe is increased to 6-in. diameter at the rear of the drive gearbox to the hole collar and from there to the muck drop box. Vacuum pipe is added in 8-ft lengths, coupled together with victualic-type clamps. Curved brackets are attached to the drill pipe stabilizers to support the individual vacuum muck pipe lengths at the drill hole springline.

Vacuum for the system is generated by a 250-hp, electric motor-driven blower mounted on the vacuum cart assembly. This vacuum mucking system is identical to the unit designed during a previous horizontal drill study.[1] A detailed description of the system and the reasoning behind component selection is contained in this reference.

The weight and volume of muck to be handled as a function of drilling rate (penetration rate) are shown in Figure 4.

3.6.3 Drive Train Assembly

The cutterhead drive is a 125-hp, 480-volt, 60-Hz, three-phase, totally enclosed, water-cooled induction motor running at 885 rpm. The drive shaft is hollow to allow for the passage of an air tube to the three-cone bit. The front end cover is flanged for bolting to a bell housing. Electric power is fed to the motor through a trailing cable.

The drive motor is a special unit designed in cooperation with the supplier. Similar larger water-cooled motors are used on other blind hole drills, and both the design and manufacturing technologies are well established.

MUCK RATE (TONS WEIGHT & BROKEN VOLUME) VS PENETRATION RATE

DENSITY : 150 LB/FT^3 SWELL FACTOR : 1.6

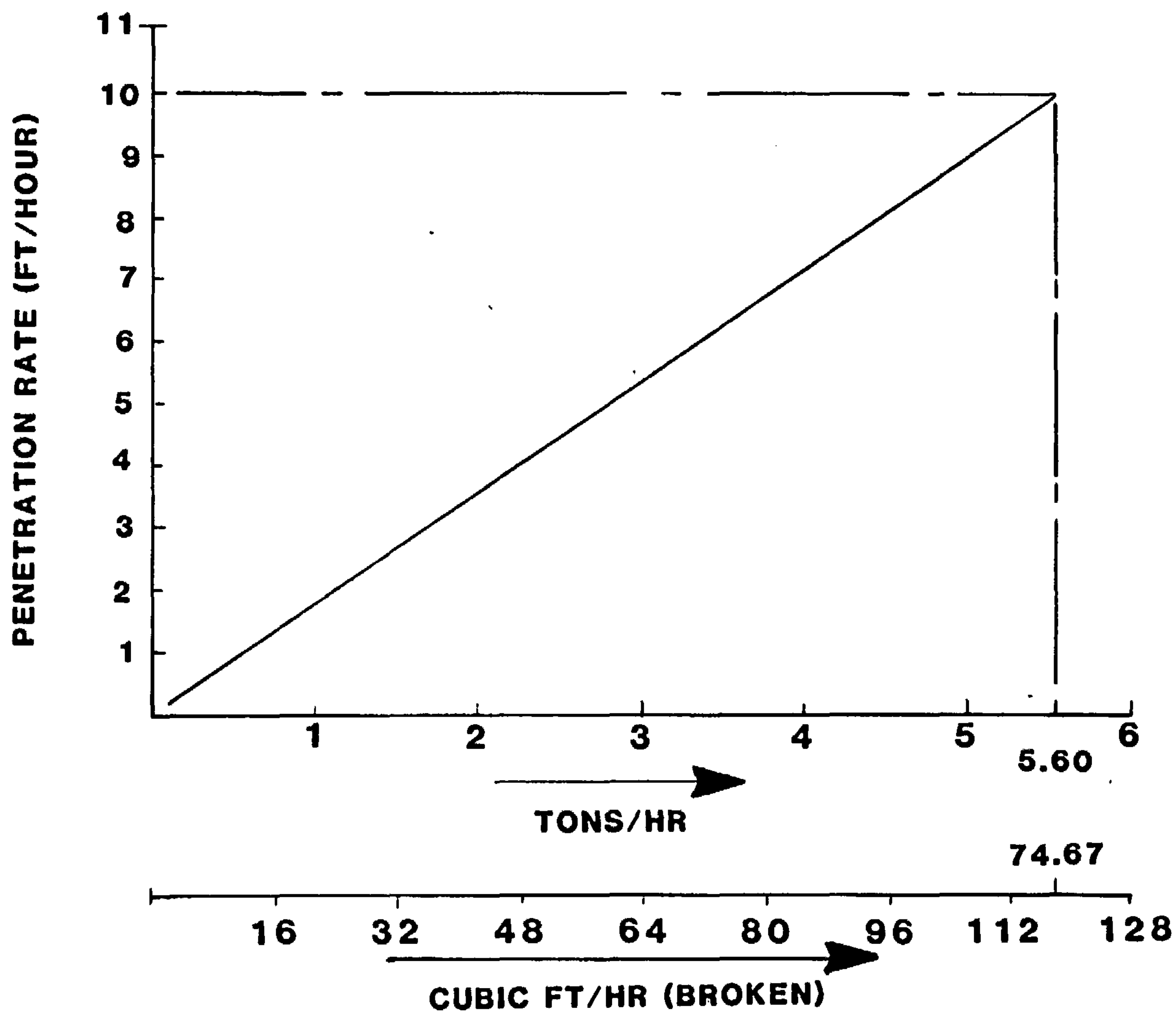


Figure 4. Horizontal Boring Machine, Muck Rate--37-in.-Diameter Hole

The bell housing is a machined casting that provides the mounts for the oil pump, oil filter, manifold block, and solenoid directional control valves, plus plumbing for the steering shoe and cutterhead support cylinders. In turn, the bell housing is flang-bolted, together with the planetary gearbox housing, to the cutterhead supports. The motor shaft is spline-coupled to the input shaft of the first stage of the planetary gear reducer. This first stage has a reduction ratio of 4.833 to 1. The hydraulic pump is driven by a simple auxiliary geared drive from the first-stage planet carrier.

The second stage of the planetary gear reducer has a ratio of 5.471 to 1 giving an overall reduction ratio of 26.44 to 1. The second-stage planet carrier output shaft is supported by a high thrust capacity, double-row tapered roller bearing, fitted to the outer housing. The output flange and subsequently the cutterhead are bolted to this shaft.

Spring-loaded lip seals and a grease labyrinth seal ensure that the gear case retains its lubricant and that dirt is excluded.

Half of a multidegree-of-freedom coupling is bolted and keyed to the rear of the motor. This coupling provides the connection between the thrust and torque reaction system and the cutterhead drive assembly. The coupling has the ability to react thrust, torque, and retraction forces even when the boring machine has been steered out of line with the drill pipe. The other half of this coupling connects to a cutterhead thrust control cylinder assembly mounted inside the liner thrust ring of the drill pipe (see D32909).

The thrust control cylinder has been included in the system to prevent the cutters from being overloaded. The maximum load that can safely be applied to the cutterhead is 21,000 lb, only 14% of the total thrust available from the derrick. This thrust control cylinder has a 3-in. stroke, and boring is done with the cylinder fully extended. A relief valve in the cylinder hydraulic circuit is set to approximately 3000 psi, thereby ensuring that the cutterhead is not overloaded. Torque reaction bypasses the thrust control cylinder and is transmitted through a sliding splined connection that keys the piston rod flange through a coupling to the drill pipe. Both the multidegree-of-freedom coupling and the splined cutterhead thrust control cylinder are new concepts.

The main bearing and seals are standard catalogue items. The 752 Robbins gear reducer employed is a standard component and is used on many TBMs. It has been proven under arduous vibration and shock loading conditions. The minor modifications and additions built into this reducer to incorporate the main bearing and the power takeoff to drive the auxiliary hydraulic pump will not detract from its performance.

3.6.4 Steering Controls and Guidance System

The outer housing, which is a machined casting, also serves as foundation for the four cutterhead supports. These supports consist of a curved shoe welded to two double acting machined wedge slides. A hydraulic cylinder moves the shoe up or down a similarly machined pair of inclined planes that are cast integral with the outer housing (see D32909).

Integral with the bell housing are similarly machined inclined-plane wedges, located at 45° on either side of the vertical centerline. A hydraulically actuated shoe, similar to the cutterhead support shoes, is attached to each wedge.

The purpose of the top supports is to stabilize the cutterhead and reduce head vibration by pressing through windows in the shield, directly against the hole wall. Together with the lower supports, the top supports provide a fulcrum plane about which the rear steering jacks, operating against the inside of the shield in various combinations, can pivot the cutterhead relative to the shield. This pivoting action provides the ability to correct drilling direction and is similar to the steering action of TBMs.

The cylinders operating the various support shoes receive filtered hydraulic oil under pressure from the multiaxial piston pump driven by a gear reducer via solenoid-actuated directional control valves. The electrical signals to the solenoids originate from the operator at the control console and through a multicored control cable attached to the boring machine.

To enable the operator to know which way to correct the drill, a ZED Instruments, Ltd., series TG 26E (modified) guidance system is incorporated. The target for this system is mounted in-hole on the right side of the outer muck plate housing, and the laser is mounted on a steel bracket at the entrance to the bored hole. When the laser beam strikes the photo-diode array target, a signal is transmitted to a monitor unit located on the operating console. Numbers, in millimeters, appear on the screen in the zone of the offset. For example, if a 4 appears on the uppper part of the screen, the drill head is 4 mm high. Additional data on the system are contained in SAND83-7085.

The cutterhead support principle is standard on Robbins TBMs.

Using four remotely controlled steering jacks operating on the wedge principle is a new application for a drill. However, similar cylinder-actuated wedges are used to operate the side cutterhead supports on TBMs according to proven principle. The success of this steering concept will be dependent upon the reliability and sensitivity of the hydraulic components, namely, the pump and the directional control valves, and the severity of steering corrections needed to keep the drill on course. The valves, pump, and laser guidance system have been selected on the basis of proven performance and reliability.

The other all-important factor that will determine the success of this system is how the operator handles the controls. To achieve the machine's designed ability to perform satisfactorily, operators must be trained.

The steering concept of pivoting the axis of the boring machine by actuating the four steering jacks about a fulcrum plane (provided by the roof jack and front supports), thereby forcing the gauge cutters on the cutterhead to overcut the bored hole in the desired direction, is well proven on Robbins hard rock TBMs. To incorporate this principle in a shield is unique. Nearly all shield machines have the forward portion of the shield rigidly attached to the cutterhead, and steering is achieved by altering the axis of the forward shield with respect to the tunnel axis. The rear portions of the shield are dragged behind the forward shield to which they are attached in telescopic fashion. Generally these shield machines are propelled forward by thrusting off tunnel lining emplaced behind the forward shield.

The drill requirement for a prospective nuclear waste repository in tuff is unique in that the liner is to be pulled into the bored hole behind the shield, simultaneously with boring. Furthermore, the hole is to be bored to a blind end, which necessitates removal of the boring machine through the liner upon completion of the hole. During boring of the hole it may be required to remove the boring machine, repair the cutterhead, reinsert the machine into the liner, pick up the shield, and continue boring.

The action of the top cutterhead supports on the rock surface forces the bottom of the shield to ride on the invert of the bored hole. This is the surface that controls the direction the shield will follow. The action of the steering shoes is to tilt the axis of the boring machine relative to the axis of the shield, thereby raising or lowering the cutterhead to cut the invert in a manner that the shield can readily follow. Because of the difference in diameters between the cutterhead (bored hole is 37-in. diameter nominally) and the liner (36-in. diameter), the cutterhead must be tilted upwards by an amount that ensures that the cut invert is in the same plane as that of the liner. As the gauge cutter wears down, the bored hole becomes smaller in diameter, and the boring machine axis must be tilted less and less to ensure that the shield follows the correct course.

Due to the clockwise rotation of the cutterhead (when viewed from the rear of the machine), the natural tendency will be for the cutterhead to overcut on the right side. This can be compensated for by canting the axis of the machine sideways in varying amounts, depending on cutter wear, to ensure that the shield follows the correct line.

The requirements of the prospective repository have created some unique drilling needs. The system designed accommodates all the requirements, using a unique combination of proven methods and components. The approach taken here was a semiautomated system that depends upon an educated response from an operator. Full automation may be a logical next step.

3.6.5 Drill Pipe

The drill pipe is constructed as a welded assembly. Its components are two hollow, cylindrical, flanged castings welded to each end of a length of standard hollow tubing. The overall length between abutment flanges is 96 in. and the o.d. is 16 in. One of the castings has male splines machined into its flange, and the other casting has female splines machined into its flange, enabling successive pipes to be mated. This forms a continuous structural tube able to react the torsional forces generated by the cutting action of the cutterhead. Provision is also made for bolting successive pipe lengths together at three fixment blocks cast 120° apart. These fixment block are also fitted with pins (bosses) to accept the hook-on interlocking stabilizers necessary to support the drill pipe in the liner and to prevent it from buckling under the high compression loads generated by pulling the liner into the bored hole during the boring operation.

The topmost stabilizer fins are also used to cover, protect, and support the cables and hoses that lead from the drilling site to the boring machine. They also have curved brackets fixed to them for supporting the muck pipe along the length of the hole.

The stabilizers for centering the drill pipe in the liner and preventing it from buckling under thrust loads are similar, except for the depth of section, to those used on 20 machines currently in operation.

3.6.6 Derrick Assembly

This assembly consists of a head frame, a mainframe, a crosshead, two thrust cylinders, and two guide columns.

The headframe is a steel member attached to the mainframe by the two columns and two long extensions of the mainframe. It provides guidance and support of the liner during installation.

The steel mainframe weldment is the foundation member that supports and locates all other members. The two members connecting the headframe to the mainframe form the attachment of the derrick to the crawler chassis.

The crosshead is a machined forging traversed between the mainframe and headframe by two thrust cylinders. It is guided by bushings that slide on the outside of the guide columns. The purpose of the crosshead is to transmit the forces from the thrust cylinders evenly to the drill pipe. The crosshead has a male spline connection and three matching bolt holes to enable the drill pipe to be attached to it. The length of travel between headframe and mainframe is adequate to accommodate the overall length of one drill pipe. The crosshead also transmits the torque reaction from the drill pipe into the guide columns.

The tubular guide columns ensure that the crosshead traverses accurately in the direction of the hole being bored. The torque reaction loads transmitted to the guide columns by the crosshead are in turn transmitted to the mainframe through solid-crown coupling fixtures. The columns have a hard chromed outer surface for long wear. The sliding bushings are aluminum bronze for the same reason.

The double-acting thrust cylinders are securely attached by their barrels to the crosshead. The eyes of the piston rods are fixed to the mainframe by expansion pins. The derrick's hydraulic system is supplied by an independent hydraulic power pack.

The derrick is fitted with four motorized mechanical screw jacks, two at the headframe and two at the mainframe. These jacks lift and level the machine to enable accurate collaring of the hole to be drilled.

Four thrust reaction jacks are mounted at the rear of the mainframe and operate parallel to the main thrust cylinders. At setup, the thrust reaction cylinders are extended until the pads attached to the piston rod ends contact the concreted wall opposite the rock face being drilled.

The hydraulic controls are designed so that the opposing forces between the thrust cylinders and the thrust reaction cylinders are always balanced. This prevents the crawler and derrick from moving laterally on the leveling jacks when drilling.

Two vertical torque reaction jacks are attached to the rear of the mainframe. These reaction jacks are extended upwards to react against the ceiling of the excavation. The pressure in these cylinders is fixed at a level sufficient to allow the full stall torque of the cutterhead to be reacted with no rotational movement of the derrick on the crawler. The vertical reaction jacks are mounted with adequate float to enable the pointed piston rod pads to be securely located against solid rock formation.

If the cutterhead becomes stuck on pullback, two additional pullback reaction jacks mounted on the front of the derrick can be securely positioned against the concreted wall being drilled.

The new derrick design is tailored to the high-thrust requirements for the installation of the liner. The concept, however, is similar to many derricks designed and built for Robbins raise drills and blindhole borers.

The crawler is a standard piece of equipment used on larger raise drills, modified to carry a different derrick.

The thrust and torque reaction jacks have been used on similar smaller drilling machines throughout the world. This would be the first time on a machine of this size. However, the principle appears sound, and if the concrete pads are cast as specified or the emplacement drift is machine bored, no problems should be experienced.

3.6.7 Pipeloading and Liner Installation

Drill pipe is added to or removed from the drill string in the derrick by a mobile jib crane. Hydraulically actuated centralizers mounted below the derrick ensure that the drill pipe is quickly and accurately located for each mating to the previously drilled pipe and the crosshead. The crane is also used for installing new liner lengths.

The stabilizer fins are attached to the drill pipe in the derrick just prior to insertion into a new liner length and before liner welding takes place. A new length of muck pipe is added to the vacuum line while the boring machine is stopped for a drill pipe change. This requires the blower to be shut down and the muck line to be broken, but only after the drilling muck has been completely flushed from the muck pipe after the machine has stopped boring. This should take only a few seconds.

To facilitate drill pipe, muck pipe, and stabilizer fin loading, all three items are transported on a mobile transporter in sufficient numbers to drill to the depth of six drill pipes.

The new 8-ft liner lengths, complete with accurately machined ends and weld preparations are similarly transported, six to a transporter. Forty-eight feet of power cable, control cable and two water hoses are bundled together and threaded through the liner sections in a manner which facilitates connecting the bundled cable and hose ends to the machine and to the various supply points.

Once these cables and hoses are in the circuit, the liner lengths can be carefully lifted and fed over the bundled cables and hoses to the derrick where installation takes place (see D39894).

The mobile jib crane can be powered by a diesel engine, compressed air (if available), or an electric motor via a trailing cable. This vehicle also provides for towing and maneuvering of the drill pipe transporters and other wheel-mounted equipment.

3.6.8 Hydraulic Power Pack

This unit consists of 30-hp electric motor-driven hydraulic pumps, an oil reservoir, directional valves for controlling all derrick functions, filters, relief valves, and various other safety devices for ensuring proper, safe, and trouble-free operation of the drill. All electrical power and safety components are housed in a closed, dustproof cabinet mounted on the power pack.

3.6.9 Control Console

All electric and hydraulic controls for operating the derrick, driving the in-hole assembly, and functioning of the vacuum system and drop box are located on the operator's console. This is a rectangular box mounted on a movable pedestal. It is coupled to the power packs and drill by multicore trailing-type control cables and small-diameter hydraulic hoses.

4.0 OPERATIONAL ANALYSIS

4.1 Operating Scenario

The operating scenario is presented here in the form of an abbreviated procedure. The description assumes that any concrete pads for floor and back are placed in advance (required if the tunnel has been constructed by drill-and-blast). The procedure also calls for a collar pad to be preinstalled at the point where drilling is to commence. This pad can be bolted in place (if the tunnel is cut) or cast in place (if the tunnel was blasted).

The shield that houses the main drill body is sacrificial; i.e., it becomes a permanent part of the liner upon completion of a hole. Therefore, a new shield section must be assembled to the drill between holes. This is part of the between-hole service in addition to the usual cutter refurbishment and maintenance.

In addition, the following procedure assumes services and muck haulage equipment are in place and ready to operate.

A site layout showing the items of equipment needed and their arrangement in the access drift is presented in drawing D32894. Further, the procedure described below is presented in a pictorial sequence in drawing D32917.

4.1.1 Mobilization

a. Maneuver the crawler and drill onto the starting pad.

b. Ensure that the laser beam is operating and is aligned. Probable mounting position is a plate on the rear tunnel wall concrete reaction pad.

c. Align the drill using the crawler and adjust the grade by using the leveling jacks.

d. Extend the torque reaction jacks and pressurize. Pressurize fore and aft reaction jacks.

e. Check out all machine motions.

f. Install the special collaring three-cone bit and stinger.

Note: The cutterhead may be equipped with two optional three-cone bits, a starting unit that includes a stinger or starting pipe, or the normal flush bit for blind drilling.

4.1.2 Collaring

a. Extend the thrust cylinders on the derrick, while the head is not rotating, until the three-cone bit just touches the face of the concrete collaring pad. Ensure that the fore and aft reaction jacks are secure.

b. Turn on the motor cooling water, the three-cone bit cooling air, and the vacuum system; then start the drill motor.

c. Feed the three-cone bit into the concrete at a slow rate until the main bit cutters begin to cut. Continue boring, gradually increasing pressure until the entire cutterhead is into the face. Bore at a rate not exceeding 3 ft/hour until the thrust cylinders are fully extended.

d. Retract the cutterhead fully and remove the three-cone bit and stinger. Install the flush three-cone bit. This is accomplished using a torquing tool as both bits are equipped with standard American Petroleum Institute threads.

e. Reinsert the cutterhead and shield fully into the hole by extending the thrust cylinders.

4.1.3 Drill Pipe Installation and Drilling

a. Loosen and remove three bolts securing the drill pipe flange to the crosshead.

b. Retract the crosshead fully into the derrick.

c. Using the crawler-mounted gantry crane, install a new length of drill pipe and bolt flanges together inside the shield.

d. Continue boring for the full stroke of the thrust cylinders.

e. Disconnect the recently installed drill pipe at the boring machine end inside the shield and retract the crosshead with the length of drill pipe attached.

f. Shut down the machine and disconnect the electrical cables and hoses at the machine.

4.1.4 Liner Installation

a. Ensure that the liner transporter, with six lengths of liner complete with cables and hoses threaded continuously through five lengths, is close at hand.

b. Thread the cables and hoses from the machine through the sixth liner and connect it to the one end of the new hose and cable lengths. Connect the feeder cable from the power pack, the control cables from the control console, and the water feed and regular hoses to the other end of the hose and cable lengths.

c. Using the mobile gantry crane, carefully lift the closest liner length and thread it over the newly connected cables. Install the liner between the shield and the end of the drill pipe in the derrick. The liner is supported and kept on line and grade by the derrick headframe.

d. Install the stablilzers onto the drill pipe in the derrick and ensure cables and hoses are secure.

e. Slide the liner partially over the drill pipe toward the crosshead to give sufficient clearance to allow the drill pipe and muck pipe connections to be made inside the shield.

f. Insert a new length of muck pipe into the new liner length and connect one end inside the shield, and the other end to the flexible muck pipe to the vacuum system. The muck pipe is supported on the stabilizer cradles.

g. Start the machine and extend the crosshead until the drill pipe flanges can be connected inside the shield.

h. Install a welding unit onto liner, push the liner into position abutting the shield, and line it up accurately.

i. Tack weld the liner into position.

j. Retract the crosshead fully.

k. Welder liner to shield. During this time:

   1. Install a new length of drill pipe into derrick and connect to the crosshead.

   2. Check attitude of boring machine and shield and direction of drilling. Make any necessary minor alignment corrections.

   3. Check power packs, mucking system, laser, and derrick and do preventive maintenance as required.

l. Once welding is completed, inspected, and found satisfactory, extend the crosshead. Make up the drill pipe connection inside liner.

m. Continue boring and begin immediately to make steering corrections, as required, to place the drill precisely on course.

n. The following must be continuously monitored by the operator to ensure proper boring of the hole.

1. Derrick thrust pressure.
2. Thrust reaction jack pressures.
3. Torque reaction jack pressures.
4. Cutterhead thrust pressure.
5. Motor amps.
6. Steering shoe cylinder pressures.
7. Cutterhead support shoe cylinder pressures.
8. Compressed air pressure to three-cone bit.
9. Water flow to motor.
10. Water flow to hydraulic power pack oil cooler.
11. Drive motor temperature.
12. Water temperature to and from drive motor.
13. Hydraulic oil temperature.
14. Vacuum on muck removal system.
15. Air flow volume in muck removal system.
16. Chip size and amount of fines from muck removal system.
17. Rate of penetration.
18. Steering control readouts on ZED system.

o. The above procedure is repeated after each length of pipe and lining is fully inserted; i.e., the thrust cylinders are fully extended.

p. Between pipe lengths, the vacuum pumps are disconnected and the rock drop box must be flushed. The box will not hold more than the volume of material bored in one stroke. Size of particles, color, texture, etc., should be observed and compared with a geological log for the hole.

4.1.5 Withdrawal of the Cutterhead

At the completion of the hole, or if for any reason a problem is encountered with the cutterhead:

a. Reduce derrick thrust pressure to zero and activate directional control valve to reduce cutterhead thrust control pressure to zero.

b. Stop the cutterhead rotating.

c. Activate directional control valves to retract the four cutterhead support shoes and the four steering control shoes.

d. Verify that the pullback reaction jacks are secure against the concrete collaring face.

e. Gradually retract the crosshead, continually observing retract pressure on thrust cylinders and pressure in the pullback reaction jacks. Unless the gauge cutter happens to stop at bottom dead center, the head will ride up over the chamfered edge of the shield as it is pulled up. This is facilitated by the universal coupling behind the drive motor. If a hangup is noted through careful observation of the retracting pressure, the motor may have to be "jogged" to move the gauge cutter upward.

f. Once the crosshead has been fully retracted, remove the muck pipe and drill pipe stabilizers, support the drill pipe with the mobile gantry crane, disconnect the drill pipe from the crosshead and adjacent drill pipe, and remove it from the derrick.

g. Extend the crosshead to mate with the drill pipe inside the exposed liner, bolt the drill pipe to the crosshead, and retract the crosshead as before.

h. Continue in this manner until the cutterhead is visible, but do not pull out beyond the liner.

i. Secure a sling around the cutterhead and support it with the mobile gantry crane. Retract the crosshead until the cutterhead and rest of boring machine can be supported by the cutterhead support shoes on the headframe.

4.1.6 Reinsertion of the Cutterhead

The reverse procedure, as described in 4.1.4, should be followed with the additional provision that the cutterhead be positioned so that the three-cone bit abutted cutter (Cutter No. 1) is pointed directly downward. This positions the skid shoe at the bottom so the drill body can ride on the invert of the liner.

4.2 Schedule and Manpower

All times and schedules are based on a three-man drilling crew. One man monitors the drill and the second operates the mobile gantry and welding rig. In addition, a third man will be needed for monitoring the vacuum system, supervising muck haulage and generally facilitating movement of equipment to and from the drill site. In addition, periodic services of a weld inspector, electrician, and hydraulics mechanic will be required.

The sequences and times provided in the following studies are considered conservative, based on only 48 ft/day of drilling and lining. An experienced and piecework-motivated crew would likely cut the drilling/welding operation time by as much as 50%.

4.2.1 Schedule Basis

The drilling schedule for a hole is made up of a number of work tasks. The major work tasks are listed below along with the reasoning for each task time. Elements are compiled to arrive at the general schedule.

a. Collaring

11 ft at 2.9 ft/hour at .8	4.8 hours	
Back out and replace center bit	0.5	
Other alignment checks, etc.	0.7	
Operation subtotal:		6 hours

b. Pipe handling

For each pipe:		
Drill pipe handling	5 min	
liner handling	5	
Muck pipe and stabilizer	5	
		15 min
For each six pipes:		
Disconnect cables, hoses	6 min	
Thread bundle through liners	6	
Reconnect cables, hoses	6	
		18 min
		3 min
Operation subtotal:		18 min/pipe

c. Welding

Setup	30 min
Root weld, three passes at 12 in./min	28
Coverweld, six passes at 20 in./min	34
Inspection	30
Lost time	28
	150 min
Operation subtotal:	2.5 hours/joint

d. Cycle summary

Drilling at 8 ft/hour	1.0 hour
Handling (from b.)	0.3
Welding (from c.)	2.5
Joining and miscellaneous	0.2
Time per 8-ft joint	4.0 hours

e. Drill removal

Remove stabilizer, muck pipe, etc.	5 min
Uncouple flange joint	5
Remove pipe and store	4
Disconnect cables, hoses, pipes, every six pipes (1 min/pipe)	1
Operation subtotal:	15 min/joint

4.2.2 Drilling Schedule

Table 2 shows the general schedule for drilling a repository hole, moving the machinery, maintenance, and setting up for the next hole; in other words, one complete cycle. It was compiled by summing the elements of Section 4.2.1 plus judgements on the nonrepetitive work tasks. The major schedule driver is the computation of 4 hours to drill one joint (8 ft). This limits advance to 48 ft/day.

A move from one site to another was allowed 16 hours. This assumes a relatively short move of less than 500 ft in the same drift. However, it also assumes the slowest transport method, crawler threads.

Table 2

Drill-and-Line Operating Cycle
(15 Days)

Description	Hours Required	Day
Collar in, drill 0-11 ft	8	1
Drill 11-27 ft (2 joints)	8	1
Drill 27-43 ft (2 joints)	8	1
Drill 43-91 ft (6 joints)	24	2
Drill 91-139 ft (6 joints)	24	3
Drill 139-187 ft (6 joints)	24	4
Drill 187-235 ft (6 joints)	24	5
Drill 235-283 ft (6 joints)	24	6
Drill 283-331 ft (6 joints)	24	7
Drill 331-379 ft (6 joints)	24	8
Drill 379-427 ft (6 joints)	24	9
Drill 427-475 ft (6 joints)	24	10
Drill 475-523 ft (6 joints)	24	11
Drill 523-571 ft (6 joints)	24	12
Drill 571-587 ft (2 joints)	8	13
Drill 587-603 ft (2 joints)	8	13
Pull out 603-347 ft (32 joints)	8	13
Pull out 347-91 ft (32 joints)	8	14
Pull out 91-0 ft (10 joints plus drill assembly)	4	14
Inspect, refurbish, uncouple	12	14
Move to new site	16	15
Maintenance, setup	8	15

4.2.3 Manpower Computation

Labor required per hole, based on Table 2 is a follows:

Labor Category	Number	Hours	Days	Total Hours
Drill operators	3	8	15	360
Liner welder	3	8	15	360
Material handling labor	3	8	15	360
Weld inspector	1	4	15	60
Electrician/mechanic	2	8	2	32
Direct labor hours/hole:				1172

Assuming that 35 canisters are emplaced per hole, 33.5 labor hours per canister are required.

4.3 Economic Analysis

The costs projected in this study are based on custom-assembled production machines. Nonrecurring engineering costs for the first machine have not been included. These costs would likely be amortized against a production order or previously paid for in a prototype project.

The equipment costs stipulated are based on equipment designed and built to commercial standards. Costs do not include the use of governmental design standards or manufacturing procedural methods.

4.3.1 Selling Price

The selling price for one horizontal boring machine system as described in this report, would be approximately $1,806,500 in 1984 dollars, FOB factory.

This price includes:

a. Drilling machine with laser guidance system.
b. Vacuum muck removal system.
c. Drill pipe, muck pipe, and stabilizers for 600 ft.
d. The initial dress of cutters.
e. Auxiliary operating equipment.
f. A semiautomated pipe welding rig.
g. Pipe handler and 10 transport cars.

This price is for a setup, fully operational drilling system. There are, however, other services and/or equipment necessary for the excavation that have not been included, such as:

a. Electrical, water, and air services from the mine surface to the drilling site.

b. Conveying of the drilling muck from the drilling site to the disposal area.

c. Service and repair equipment for the maintenance and care of the mancinery.

d. Predrilling construction requirements at the individual drill site.

e. Lining and expendable shield segment.

f. A locomotive or tractor for moving pipes and equipment carts to and from the drill site.

4.3.2 Operating Costs

This section deals only with the excavation equipment and its operating costs. Labor costs and cost of services are not included.

a. Cutters and Maintenance

Cutters and maintenance parts will depend upon many factors, including geology, climate and skill level of the operators. Best-case (favorable) and worst-case (unfavorable) scenarios are provided:

	Favorable		Unfavorable	
	$/yd^3	Total $ for 600 ft	$/yd^3	Total $ for 600 ft
Cutters	23.55	3908	31.40	5210
Maintenance	1.00	166	1.50	249

b. Liner and Expendable Shield

Shield weight =	3,168.06 lb
Cost/lb	x $3.00
Shield cost	$9,506.00
Liner weight = (592 ft of 1/2 in. pipe, 36 in. o.d.)	113,687 lb
Cost/lb	x $0.40 (based on U.S. material)
Liner cost	$45,475.00

Total cost per hole $54,981.00

c. Depreciation of Equipment

Depreciation should also be considered in computing operating costs. A 3- or 5-yr amortization schedule is common for drilling and other heavy equipment.

The single emplacement hole drilling schedule, Table 2, shows a three-shift capability of one hole completed per 15 days. This means a system might complete as many as 24 holes per year. However, even assuming adequate spare components are available, 60 days of downtime per system per year would be reasonable. Production rate is then 20 holes per year (60 holes in 3 yr or 100 holes in 5 yr).

Per-hole depreciation:

Favorable (5-yr Depreciation)	Unfavorable (3-yr Depreciation)
$\frac{\$1,806,000}{100} = \$18,060$	$\frac{\$1,806,000}{60} = \$30,100$

d. Major Overhaul and Replacement of Components

With due care and proper maintenance, the life of this equipment is indefinite; however, peridoic replacement of major components is necessary. The optimum period for major overhaul has been determined to be at 5000 hours of operation. Replacement of components and overhaul of some of the subsystems, such as the vacuum system, will occur at shorter intervals. For the purpose of this report, these costs have been calculated and included in the 5000-hour overhaul.

Based on experience with similar types of drilling equipment and the calculated life of the vacuum system components, the estimated cost of major overhall will average approximately 18.5% of the total capital cost, or $334,110.

At an average run time of 79 hours per hole, a system is estimated to require overhaul every 63 holes. Therefore, overhaul cost per hole is $5,303.

4.3.3 Cost Summary

The costs for placement of the waste containers, using the horizontal drilling system, are summarized below. These costs are only for the equipment and do not include any labor, power consumption, or auxiliary services.

Cost for one 600-ft hole (35 canisters):

	Favorable	Unfavorable
Cutters and maintenance	$ 4,074.00	$ 5,459.00
Liner and shield	54,981.00	54,981.00
Depreciation	18,060.00	30,100.00
Overhaul allowance	5,303.00	5,303.00
	$ 82,418.00	$ 95,843.00
Cost per canister	$ 2,355.00	$ 2,738.00

Comparing the favorable costs with the results of the previous study[1] shows:

Unlined hole costs	$652/canister
Lined hole costs	$2,355/canister

However, $54,981 ÷ 35 = $1,571 per canister for the lined hole is strictly lining cost. Construction cost accounts for only $784 per canister of the total. The difference in operations, despite a larger drilling crew and slower operation, only increased costs from $652 to $784 per canister.

REFERENCES

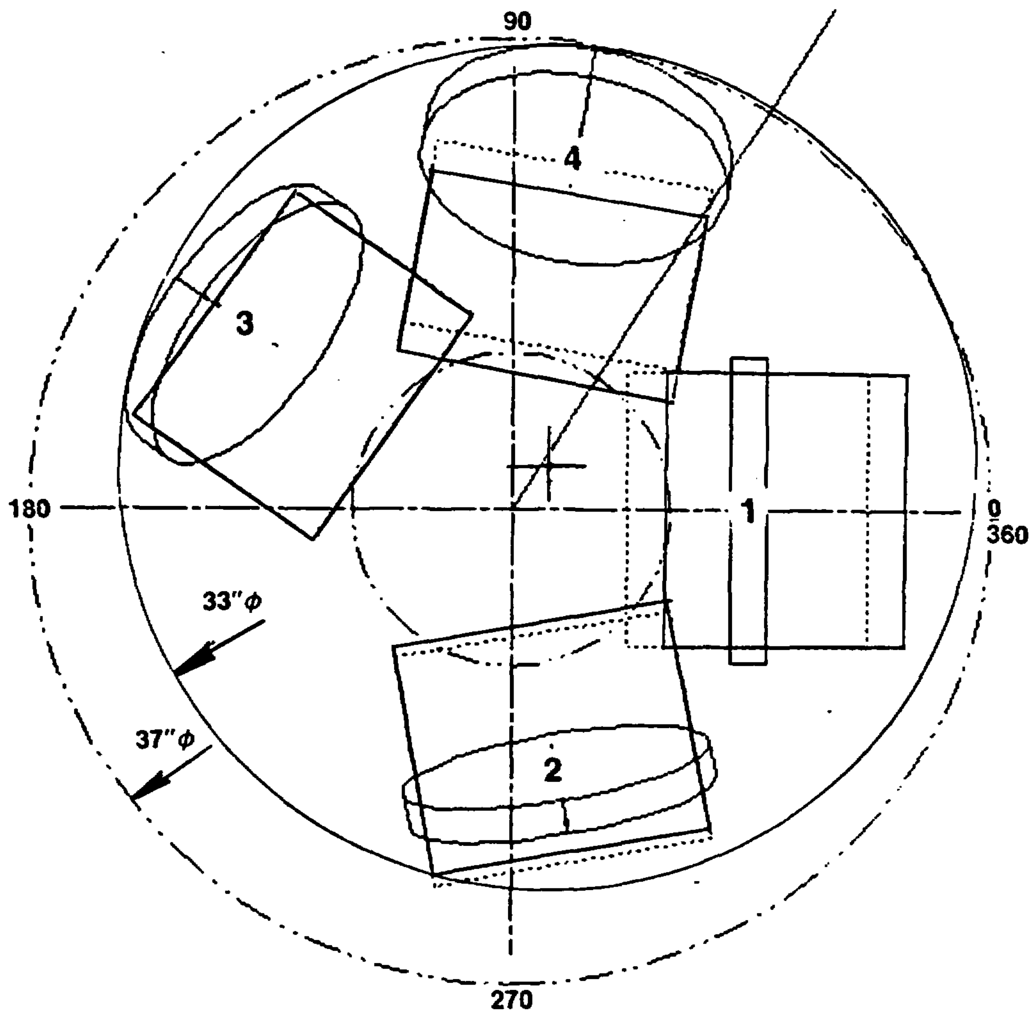
1 The Robbins Company, Final Report, Repository Drilled Hole Methods Study, SAND83-7085 (Albuquerque: Sandia National Laboratories, July 1984).

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

ATTACHMENT 1

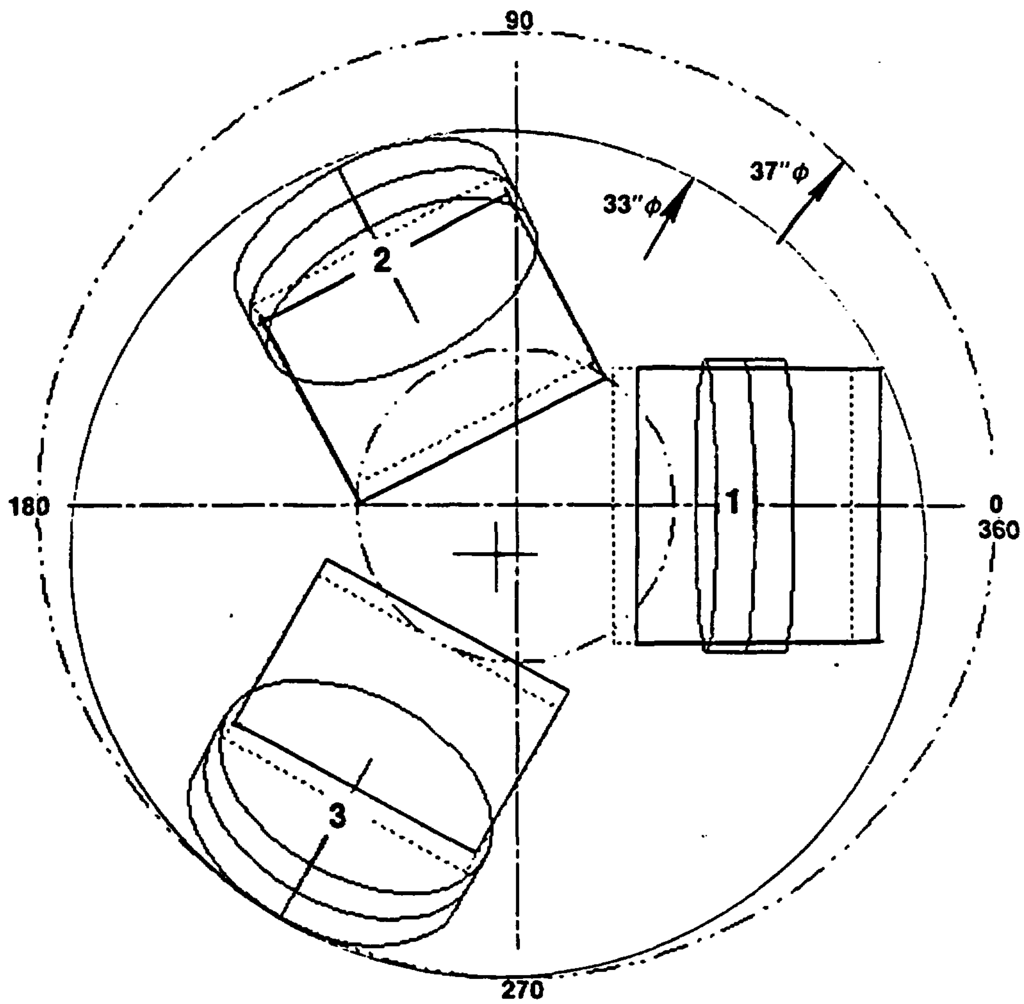
Computer Vector Balance Runs

CUT No.	HOR.COORD	VERT.COORD	CUT.L	AZIMUTH	VECTOR	X-COMPT	Y-COMPT
1	9.125	6.000	0.000	0.000	9.125	9.125	0.000
2	10.900	6.197	12.667	280.000	10.592	1.839	-10.431
3	12.588	6.778	25.333	145.000	11.045	-9.047	6.335
4	14.108	7.716	38.000	80.000	10.061	1.747	9.908
	OUT OF BALANCE VECTOR COMPONENTS=				6.8708	3.6640	5.8123



UNBALANCED ECCENTRIC CUTTERHEAD

CUT No.	HOR.COORD	VERT.COORD	CUT.L	AZIMUTH	VECTOR	X-COMPT	Y-COMPT
1	8.843	5.986	4.000	0.000	8.821	8.821	0.000
2	10.762	6.555	29.000	117.725	9.137	-4.251	8.088
3	13.807	8.569	38.000	240.525	9.290	-4.571	-8.087
	OUT OF BALANCE VECTOR COMPONENTS=				.0004	-.0002	.0004

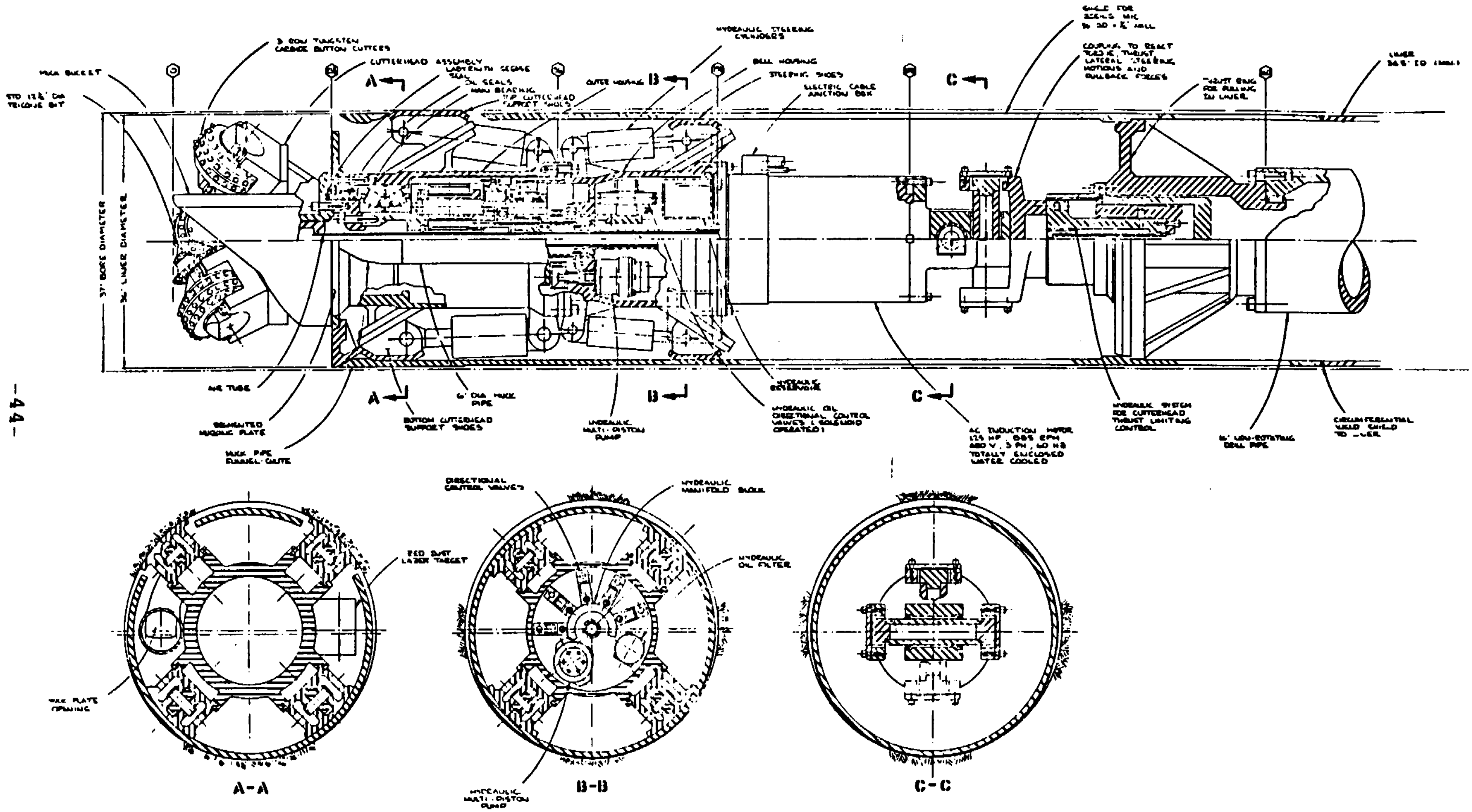


BALANCED ECCENTRIC CUTTERHEAD

ATTACHMENT 2

Drawings

D32909	In-The-Hole Assembly
D32937	Cutter Assembly - Carbide, 12" Diameter, Sheet 1 and 2
D32886	37" Diameter Horizontal Boring Machine, Sheet 1 and 2
D32925	Withdrawal of Cutterhead, Sheet 1 and 2
D32894	Site Layout
D32917	Boring Procedure, Sheet 1, 2, and 3
D7091	Cutter Assembly, Carbide 12 inch, Narrow 2 Row, Sheet 1 and 2
D12401	Cutter Assembly, Carbide 12 inch, Tri-cone Abutted, Sheet 1 and 2



D32909 In-The-Hole Assembly

-7	-6	-5	-4	-3	-2	-1	PART	DESCRIPTION	MAT'L	PC
							~~D7091-1~~	~~CUTTER ASSY-CARBIDE, 12" DIA, NARROW~~		~~1~~
					—		D7091-2			2
				—			D7091-3			3
			—				D7091-4			4
		—					D7091-5			5
	—						D7091-6			6
—							D7091-7			7
										8
										9
										10
										11
										12
										13
					1		A18044-1	CUTTER HUB - CARBIDE		14
				1			A18044-2			15
			1				A18044-3			16
		1					A18044-12			17
	1						DM1002-1			18
1							DM1330-1			19
										20
										21
										22
										23
										24
1	1	1	1	1	1		C6532	SHAFT		25
2	2	2	2	2	2		C6533	RETAINER - SHAFT		26
1	1	1	1	1	1		A12571	SPACER - BEARING		27
2	2	2	2	2	2		A16999-1	CUP - BEARING		28
2	2	2	2	2	2		A16999-2	CONE - BEARING		29
1	1	1	1	1	1		DM1173-1	SEAL SET		30
										31
2	2	2	2	2	2			O-RING PHZ-234-N674-70		32
8	8	8	8	8	8			SCREW-CAP, SOC. HD. 5/8-11 UNC X 1½ LONG	GR-8	33
4	4	4	4	4	4			PLUG - HEX. SOC. 1/8 NPT		34
										35
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										66

NOTES:

1. FOR ASSEMBLY & MAINTENANCE REFER TO A18235.

3. WEIGHT: APROX. 158 LBS (71,7 kg)
   OIL CAPICITY: APROX. 15 FL. OZ. (444 ml)

4. STEEL STAMP SERIAL Nº IN LOCATION SHOWN (SHAFT RETAINER). THE SERIAL Nº IS THE Nº WHICH APPEARS AT THE I.D. OF THE HUB WEB & AT THE EXTERNAL HUB FACE.

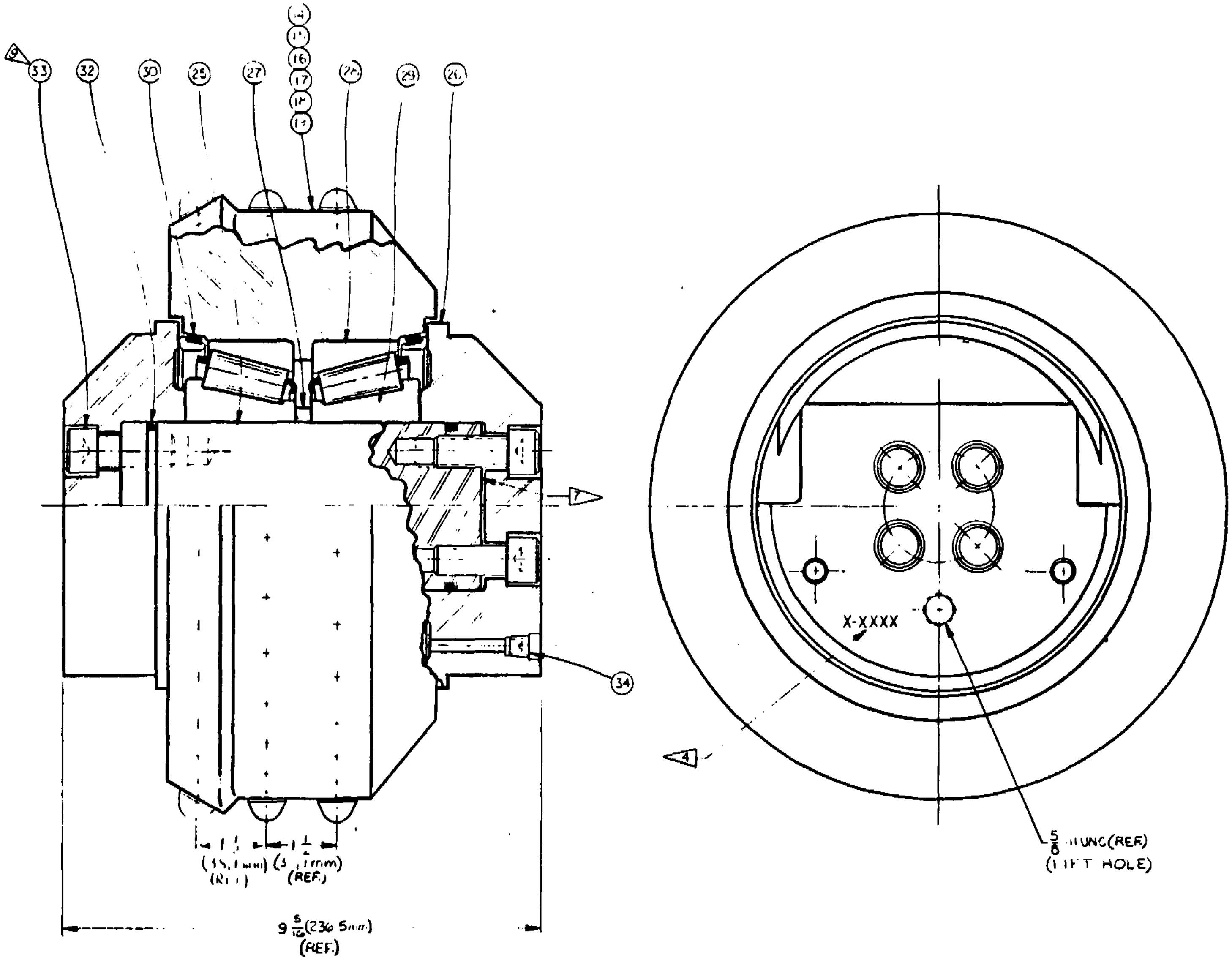
7. ASSEMBLE SHAFT WITH PART Nº AT THIS END.

9. APPLY "LOCTITE" Nº 271 TO THE THDS OF PC. 33 & TO THE MATING THDS OF PC. 25. THREADS MUST BE CLEAN & GREASE-FREE BEFORE APPLYING "LOCTITE."

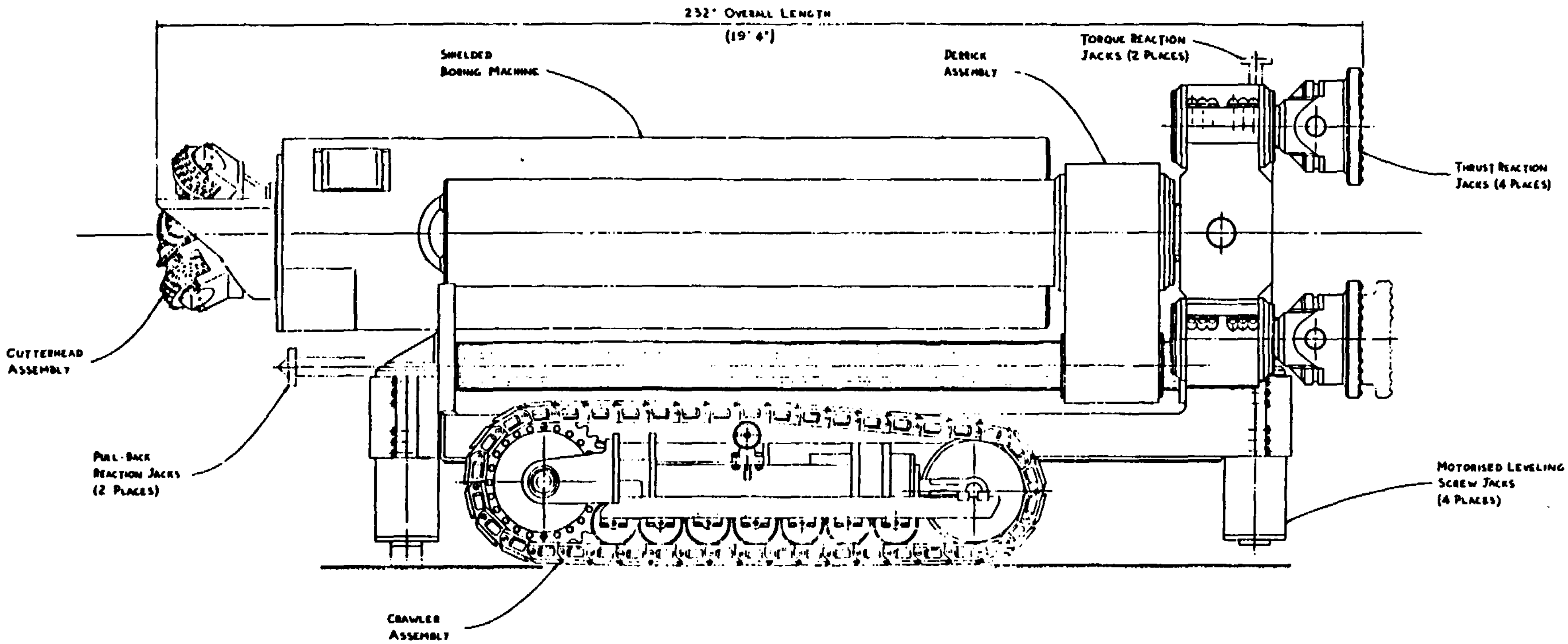
10. PAINT PER ORDER SPEC.

11. SEE DWG. C9027 FOR LIST OF CUTTER TOOLS.

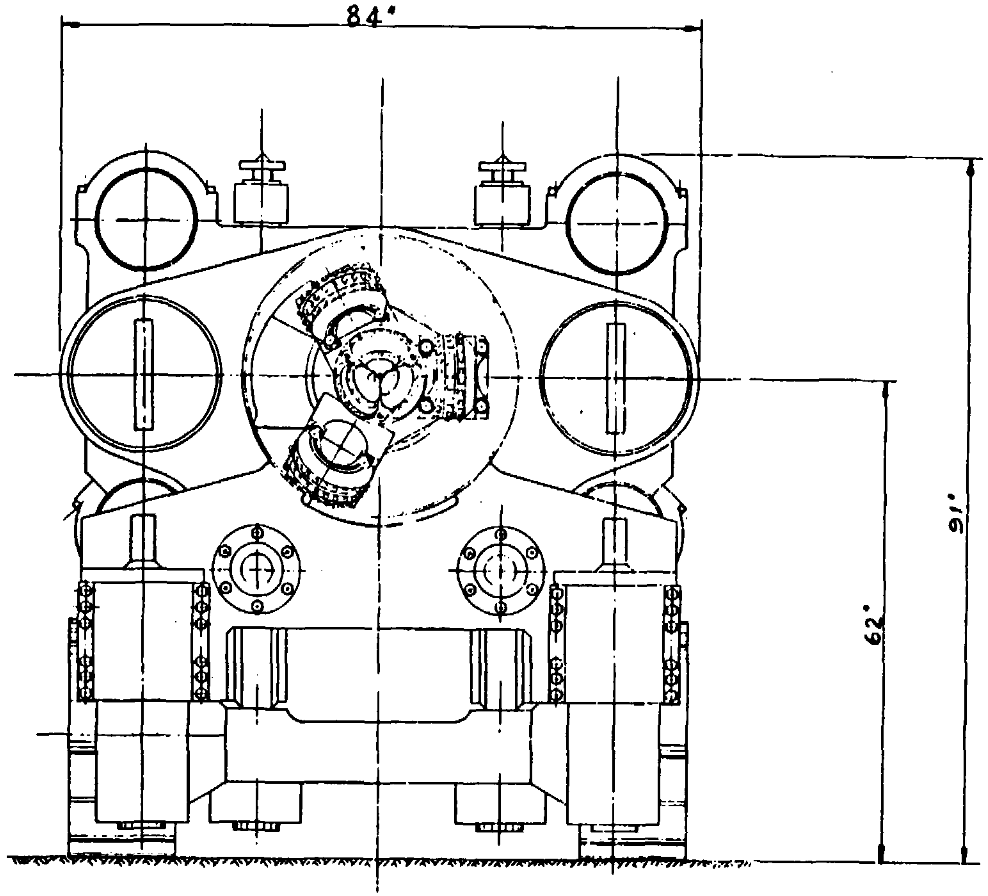
D32937 Cutter Assembly - Carbide, 12" Diameter, Sheet 1



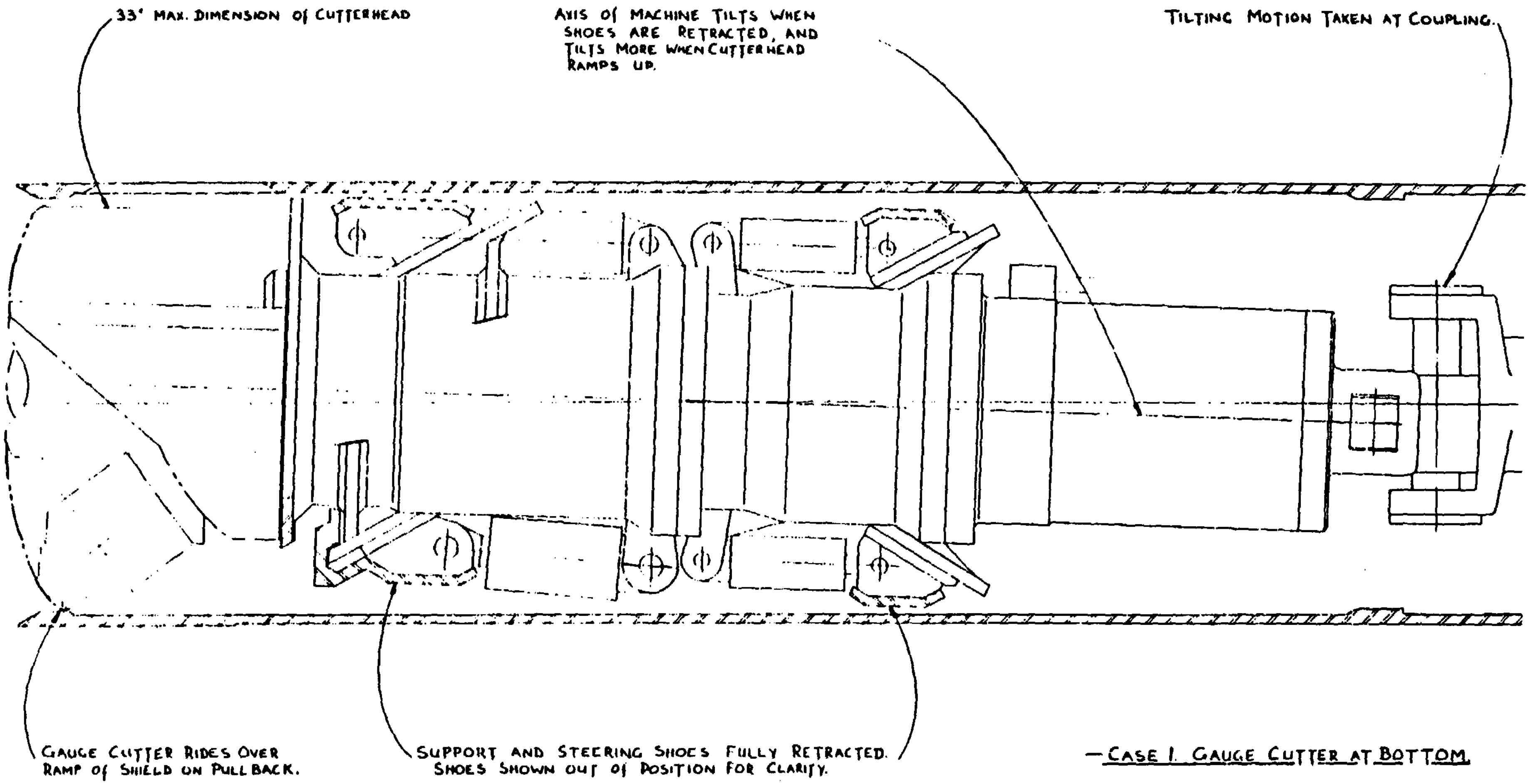
D32937 Cutter Assembly - Carbide, 12" Diameter, Sheet 2



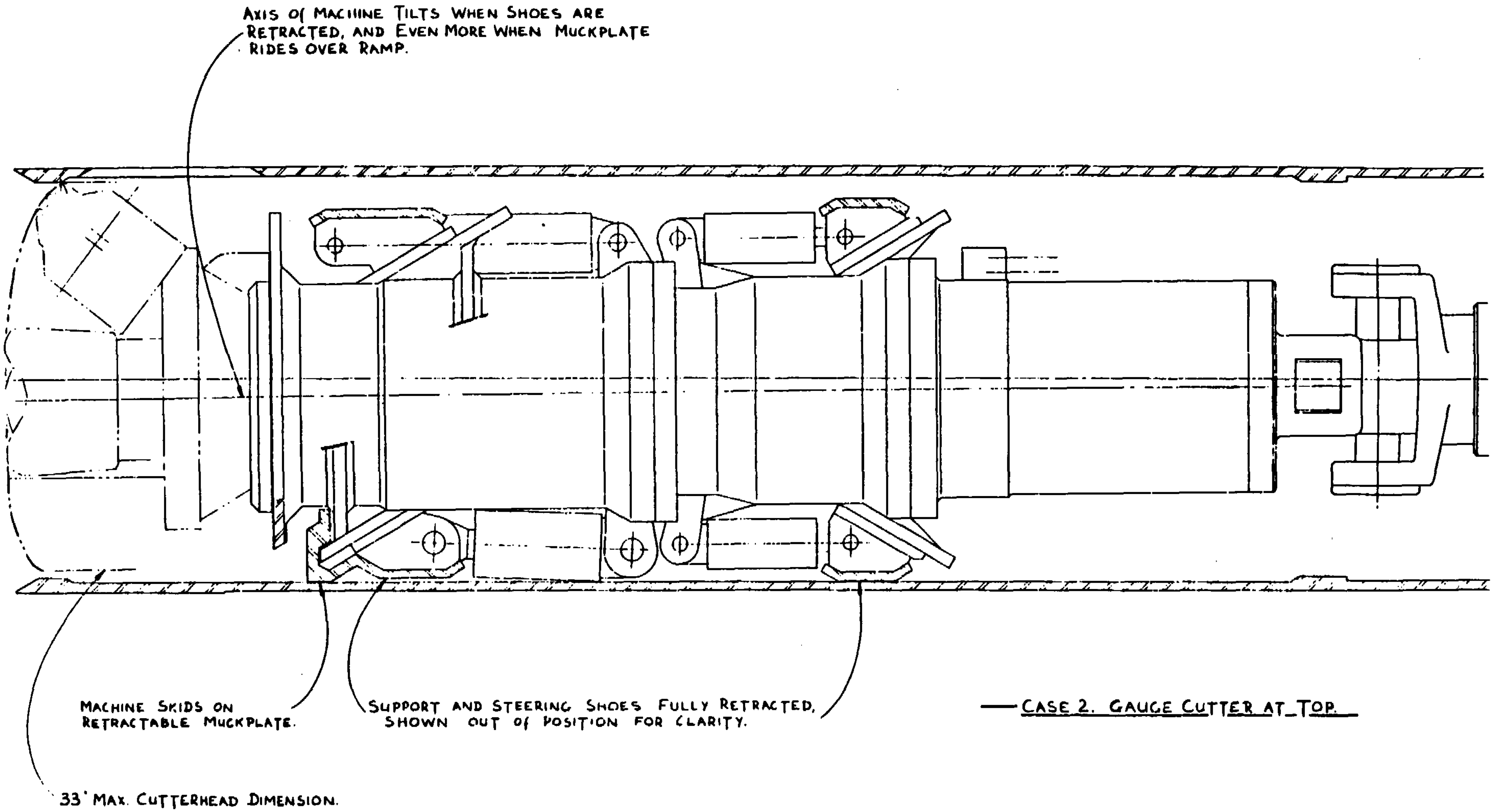
D32886 37" Diameter Horizontal Boring Machine, Sheet 1



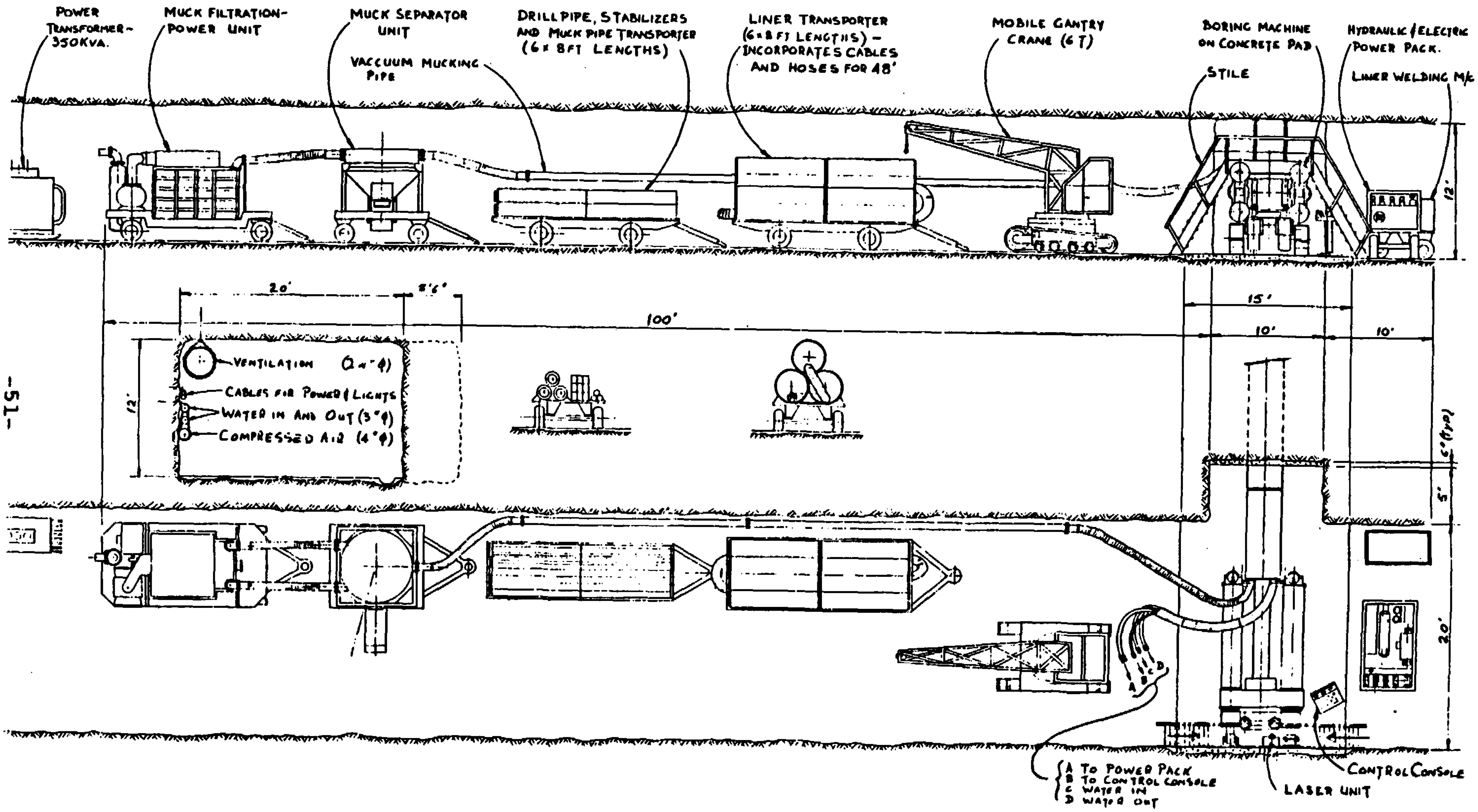
D32886 37" Diameter Horizontal Boring Machine, Sheet 2



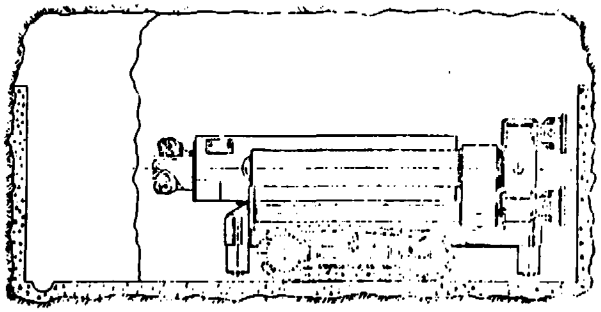
D32925 Withdrawal of Cutterhead, Sheet 1



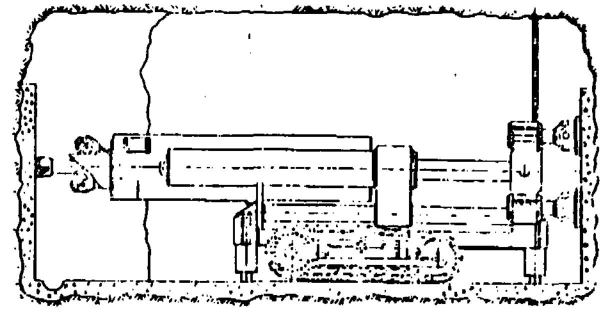
D32925 Withdrawal of Cutterhead, Sheet 2



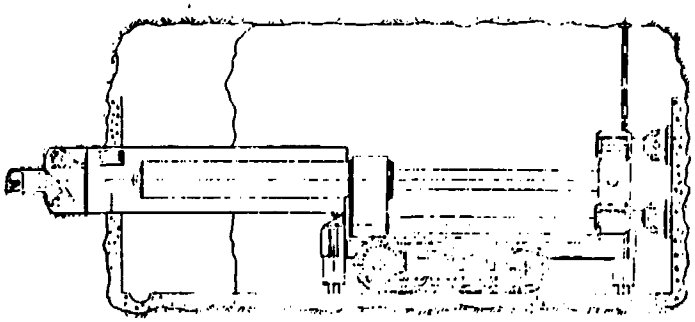
D32894 Site Layout



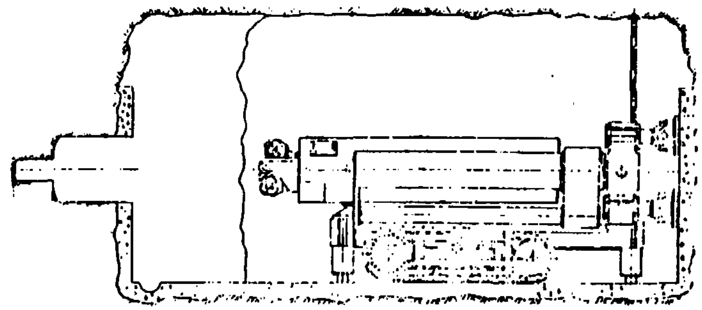
1 MACHINE MOVED INTO DRILLING SITE.



2. CUTTERHEAD EXTENDED FOR COLLARING. MACHINE LEVELED AND LINED UP TO LASER. THRUST AND TORQUE REACTION JACKS EXTENDED. EXTENSION FOR COLLARING-TRICONE BIT FITTED.

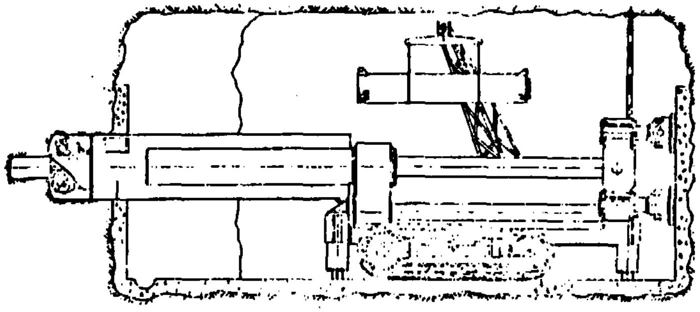


3. MACHINE COLLARED AND CUTTERHEAD DRILLED AWAY TO FULL STROKE OF THRUST CYLINDERS.

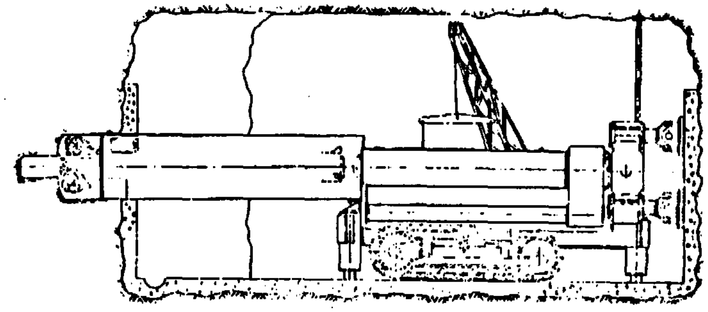


4. CUTTERHEAD FULLY RETRACTED AND COLLARING-TRICONE BIT AND EXTENSION REMOVED.

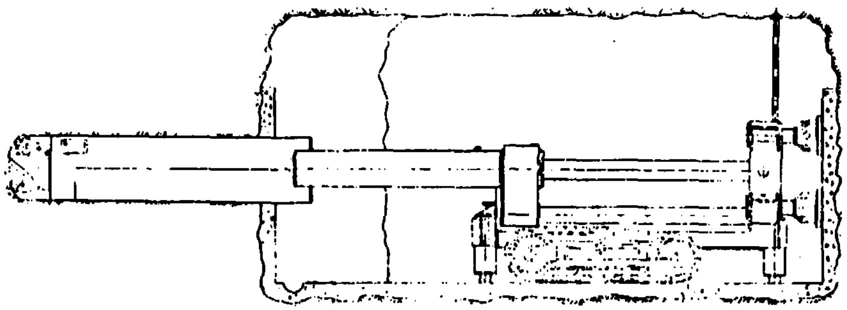
D32917 Boring Procedure, Sheet 1



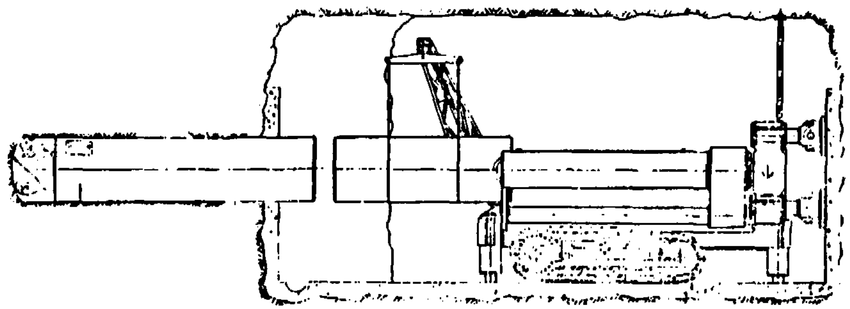
5. CUTTERHEAD REINSERTED INTO HOLE, NEW DRILLPIPE READY FOR INSTALLATION INTO DERRICK.



6. THRUST CYLINDERS FULLY RETRACTED, SHIELD SUPPORTED BY HEADFRAME, NEW DRILLPIPE LOADED INTO DERRICK.

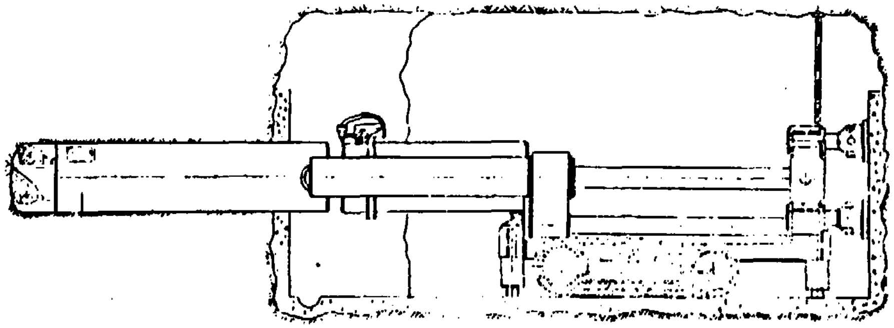


7. BORING CONTINUES TO FULLEST EXTENT OF THRUST CYLINDERS.

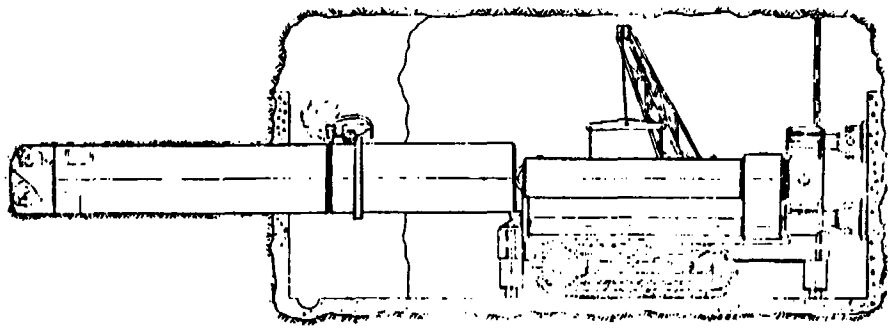


8. DRILLPIPE DISCONNECTED INSIDE SHIELD. THRUST CYLINDERS FULLY RETRACTED; NEW LINER INSTALLED BETWEEN SHIELD AND DRILLPIPE.

D32917 Boring Procedure, Sheet 2



9. THRUST CYLINDERS FULLY EXTENDED AND DRILL-PIPE RECONNECTED INSIDE SHIELD AND DISCONNCTED FROM CROSSHEAD. WELDING M/C ATTACHED TO LINER.



10. THRUST CYLINDERS FULLY RETRACTED, WELDING OF LINER TO SHIELD COMMENCES, NEW DRILLPIPE LOADED INTO DERRICK.

D32917 Boring Procedure, Sheet 3

			-7	-6	-5	-4	-3	-2	-1	PART	DESCRIPTION	MAT'L	PC
										~~D7091-1~~	~~CUTTER ASSY-CARBIDE, 12" DIA, NARROW~~		~~1~~
								—		D7091-2			2
							—			D7091-3			3
						—				D7091-4			4
					—					D7091-5			5
				—						D7091-6			6
			—							D7091-7			7
													8
													9
													10
													11
													12
													13
								1		A16044-1	CUTTER HUB - CARBIDE		14
							1			A16044-2			15
						1				A16044-3			16
					1					A16044-12			17
				1						DM1002-1			18
			1							DM1330-1			19
													20
													21
													22
													23
													24
			1	1	1	1	1	1		C6532	SHAFT		25
			2	2	2	2	2	2		C6533	RETAINER - SHAFT		26
			1	1	1	1	1	1		A12571	SPACER - BEARING		27
			2	2	2	2	2	2		A16999-1	CUP- BEARING		28
			2	2	2	2	2	2		A16999-2	CONE - BEARING		29
			1	1	1	1	1	1		DM1173-1	SEAL SET		30
													31
			2	2	2	2	2	2			O-RING PH2-234-N674-70		32
			8	8	8	8	8	8			SCREW-CAP, SOC. HD. 5/8-11 UNC X 1½ LONG	GR8	33
			4	4	4	4	4	4			PLUG - HEX. SOC. 1/8 NPT		34
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NOTES.

1. FOR ASSEMBLY & MAINTENANCE REFER TO A18239.

3\. WEIGHT: APROX. 158 LBS (71,7 kg)
OIL CAPICITY: APROX. 15 FL. OZ. (444 ml)

4\. STEEL STAMP SERIAL Nº IN LOCATION SHOWN (SHAFT RETAINER). THE SERIAL Nº IS THE Nº WHICH APPEARS AT THE I.D. OF THE HUB WEB & AT THE EXTERNAL HUB FACE.

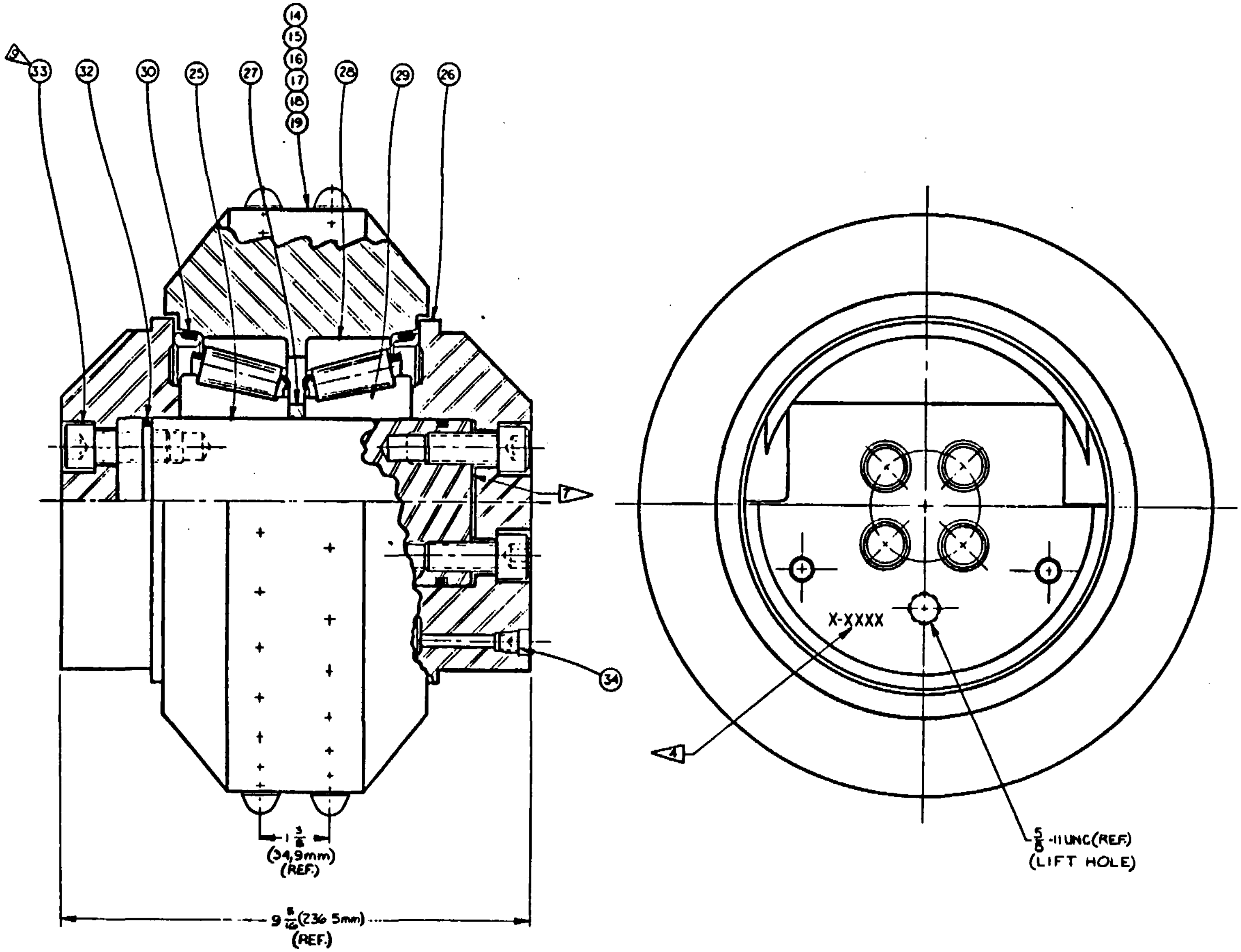
7\. ASSEMBLE SHAFT WITH PART Nº AT THIS END.

9\. APPLY "LOCTITE" Nº 271 TO THE THDS OF PC. 33 & TO THE MATING THDS OF PC. 25. THREADS MUST BE CLEAN & GREASE-FREE BEFORE APPLYING "LOCTITE."

10\. PAINT PER ORDER SPEC.

11\. SEE DWG. C9027 FOR LIST OF CUTTER TOOLS.

D7091 Cutter Assembly, Carbide 12 inch, Narrow 2 Row, Sheet 1



D7091 Cutter Assembly, Carbide 12 inch, Narrow 2 Row, Sheet 2

			-7	-6	-5	-4	-3	-2	-1	PART	DESCRIPTION	MAT'L	PC
										~~D12401-1~~	~~CARBIDE CUTTER ASSY., TRI-CONE ABUTTED, 12"DIA~~		1
								–		D12401-2	CARBIDE CUTTER ASSY., TRI-CONE ABUTTED, 12"DIA		2
							–			D12401-3	CARBIDE CUTTER ASSY., TRI-CONE ABUTTED, 12"DIA		3
						–				D12401-4	CARBIDE CUTTER ASSY., TRI-CONE ABUTTED, 12"DIA		4
										~~D12401-5~~	~~CARBIDE CUTTER ASSY., TRI-CONE ABUTTED, 12"DIA~~		5
				–						D12401-6	CARBIDE CUTTER ASSY. TRI-CONE ABUTTED, 12"DIA		6
			–							D12401-7	CARBIDE CUTTER ASSY. TRI-CONE ABUTTED, 12"DIA		7
													8
													9
													10
													11
													12
								1		A19601-1	CARBIDE CUTTER HUB		13
							1			A19601-2	CARBIDE CUTTER HUB		14
						1				A19601-3	CARBIDE CUTTER HUB		15
													16
				1						DM11594	CARBIDE CUTTER HUB		17
			1							DM13534	CARBIDE CUTTER HUB		18
													19
													20
													21
													22
			1	1		1	1	1		D-7345	SHAFT		23
			1	1		1	1	1		C6533	SHAFT RETAINER		24
			1	1		1	1	1		A12511	BEARING SPACER		25
			2	2		2	2	2		A16999-1	BEARING CUP		26
			2	2		2	2	2		A16999-2	BEARING CONE		27
			1	1		1	1	1		DM1175-1	SEAL SET		28
			2	2		2	2	2		A8357	HEX. SOC. PLUG, 1/8 NPT		29
													30
			1	1		1	1				O-RING #2-234-N674-70		31
			4	4		4	4	4			SOC. HD. CAP SCREW 3/8-11UNC × 1½ LONG	GR.8	32
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NOTES:

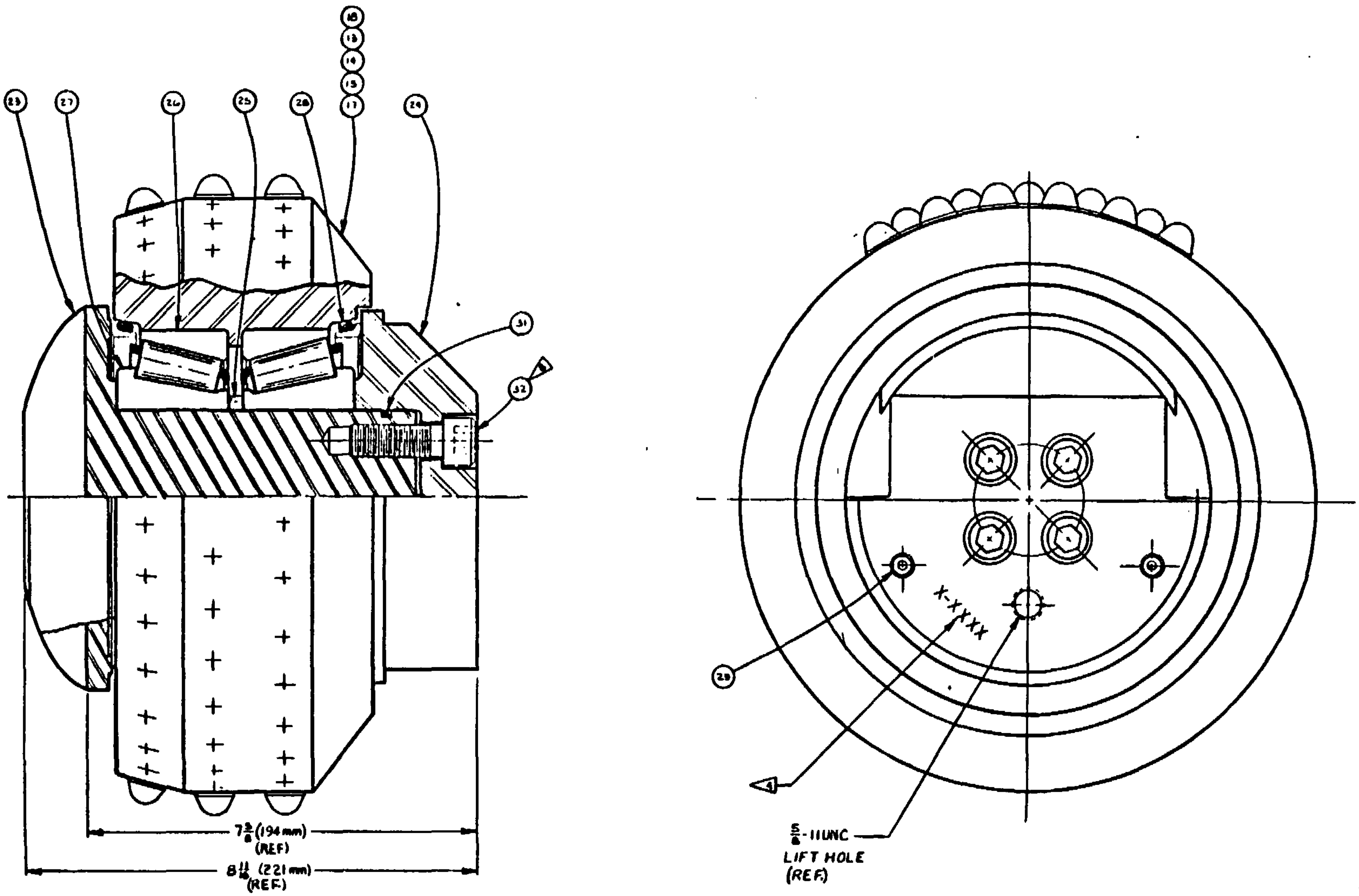
3. WEIGHT: APROX 152 LBS. (70 kg)
OIL CAPICITY: APROX 15 FL.OZ. (444 ml)

4. STEEL STAMP SERIAL Nº IN LOCATION SHOWN (SHAFT RETAINER). THE SERIAL Nº MUST BE IDENTICAL TO THE ELECTRO-ETCHED Nº APPEARING ON THE I.D. OF THE HUB WEB & THE EXTERNAL HUB SHOULDER FACE.

5. APPLY "LOCTITE" Nº 271 TO THE THDS. OF PC. 32 & TO THE MATING THDS. OF PC. 23. SURFACES MUST BE CLEAN & FREE OF GREASE BEFORE APPLYING "LOCTITE."

PAINT PER ORDER SPEC.

D12401 Cutter Assembly, Carbide 12 inch, Tri-cone Abutted, Sheet 1



D12401 Cutter Assembly, Carbide 12 inch, Tri-cone Abutted, Sheet 2

ATTACHMENT 3

Welding Description

THE ROBBINS COMPANY

MEMORANDUM

TO: Jim Heinzman, Marketing

FROM: Bob Buhl, Engineering

SUBJ: Pipe Welding and Inspection

DATE: January 25, 1984

Pursuant to your request regarding pipeline fabrication and inspection, the following comments are offered for your consideration. Based on data received, pipe joining would be conducted in a confined area, entailing numerous weld joints on a planned production schedule. The quality of the welds would probably have to meet requirements of ANSI B31 and/or ASME Section III.

1. Fabrication

   Due to a timely production schedule and working space limitations, it is necessary to utilize programmed, fully automatic pipe welding equipment. Such equipment would probably utilize dual welding process capability to produce the quality of weld required. Welding would commence, without backing or consumable inserts, with a GTAW root, probably 3 passes at 10-14 in. per minute. After completion of the root, the welding process would change to GMAW or FGAW for an oscillated fill at 18-24 in. per minute (6 passes). This type of equipment is commercially available, however, at this time I am awaiting trade name and pricing data from a local welding supply firm.

2. Inspection

   The joint edge preparation, fitup gap, root pass and completed weld would receive visual examination, preferably by an AWS certified welding inspector. The completed joint would then be radiographed by isotope/film wrap method requiring only one two minute exposure. With proper shielding, personnel need only move back six ft. during exposure period. Film processing and interpretation should be accomplished within a maximum time span of 20 minutes and probably an average of 15 minutes from the time the film is removed from the weld joint. Ultrasonic examination is not considered because inspection time would run 45-60 minutes per joint after the pipe cooled to below 200° F and no tangible record, such as identified film, exists. It is anticipated inspection would be a subcontracted service and would cost approximately $80.00 per weld joint.

JH:dp

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