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Boring and Lining Horizontal Emplacement Holes

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BORING AND LINING HORIZONTAL EMPLACEMENT HOLES

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under

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ABSTRACT

Systems for and techniques for constructing suitable emplacement holes are being considered for an underground nuclear waste repository. This study is an investigation of methods to bore and line horizontal boreholes of varying lengths. The development prototype boring machine already designed has been selected to bore the long holes (350 ft.), while the method selected to bore short holes, 42, 58, and 75 ft.) involves two separate systems: one to bore the hole, the other to line the hole. The systems described in this report are not off-the-shelf, but represent a reasonable extension of current technology.

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QUALITY ASSURANCE

This report was done in accordance with Sandia National Laboratories (SNL) Design Investigation Memo (DIM) 202 and conforms to the quality requirements of a QA Level III task. The DIM's are controlled by the SNL Department Operating Procedure titled "Design Investigation Control," DOP 3-4, which details the methods for (1) planning, (2) documenting, (3) initiating, (4) accepting, and (5) reviewing a design investigation task.

The Robbins Company is an acknowledged leader in the design on drilling and tunnel boring equipment. They have worked many years on drill equipment concepts related to the Mined Geological Disposal System at Yucca Mountain. During the course of this study several technical meetings were held between SNL and the Robbins Company to assure adequate exchange of information.

The report is being issued under the requirements of DOP 6-2 "Reviewing, Approving, and Issuing Technical Information Documents". This procedure requires that as a minimum the document shall undergo an independent technical review, a SNL line review, a Project Office policy review, and a SNL final review prior to publication.

EXECUTIVE SUMMARY

Currently, machines and methods are being considered for constructing suitable emplacement holes in an underground nuclear repository in tuff. This study examines design concepts for systems that will bore and line a 37-in. diameter, 42-, 58-, 75-, and 350-ft long horizontal holes holding 1, 2, 3, and 15 containers, respectively.

As described in this report, a machine with an active guidance system has already been designed by The Robbins Company to accurately bore and line horizontal holes up to 600 ft. This development prototype boring machine, with a minor modification, has been selected as the preferred method for boring the 350-ft-long emplacement holes.

Although the development prototype boring machine could be used for shorter holes, simpler, more economical alternatives have been investigated. An active guidance system is not necessary to maintain the accuracy of holes up to 75 ft, and, as a result, a boring machine with a passive (stabilized) drill has been selected for the short hole.

The concept selected for constructing the short holes consists of a machine to bore the hole and a machine to line the hole. The use of a pilot hole has been rejected because accuracy can be maintained while boring short holes in a single pass. Inserting liners as a separate operation not only simplifies the operation but provides a clean bore for inspection between boring and lining. Because inserting the liner is a common, current technology, the concept was not investigated. A drawing of the lining machine was developed based on current technology and engineering judgment, and the design of the boring machine has been emphasized in this report.

The selling prices of the short hole boring and lining systems described in this report are approximately $935,000 for each boring system and $581,000 for each lining system, based on 1988 dollars. These prices are based on similar equipment (e.g., mobile raise drills) currently manufactured by The Robbins Company. Prices of items not typically used were solicited from vendors.

The total cost per container for drilling and lining the emplacement holes was figured for each of the three hole lengths. Based on the cost of cutters, maintenance items, major overhaul of the equipment, and depreciation, the total cost per container to drill and line the emplacement holes is $3,559, $2,253, and $1,822 for 42-, 58-, and 75-ft boreholes, respectively.

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1.0 INTRODUCTION

1.1 Background

The work described in this report has been performed for Sandia National Laboratories as part of the Yucca Mountain Project. Sandia is one of the principal organizations participating in the Project, which is managed by the U.S. Department of Energy, Nevada Operations Office. The Project is part of the DOE program to safely dispose of spent fuel from nuclear power plants and high-level waste from defense programs.

Currently, two emplacement configurations, vertical and horizontal, are being considered for the repository. The method of boring and lining vertical holes has been studied and reported in the "Final Report for Repository Drilled Hole Methods Study" (Robbins, 1984). The alternative methods and systems selected to bore and line horizontal holes with a 37-in. diameter are examined in this report.

1.2 Objectives of the Study

The objectives of this study were to develop design concepts, as described in Problem Definition Memo (PDM) 75-5, for systems capable of boring and lining horizontal holes of varying lengths (42, 58, 75, and 350 ft long) and, based on the design concept selected, provide operating data (including manpower requirements) and capital and operating costs for the production systems, and costs and schedules for testing a prototype system. Identifying the required technology and operations has been emphasized in this report rather than establishing precise design specifications.

1.3 General Considerations

This study has been directed toward the concept design of production systems for boring and lining horizontal boreholes, although some consideration has been given to the prototype system that will be used to begin production (Section 7). Unless otherwise noted, the equipment design requirements listed below are not necessarily in accordance with the Subsystem Design Requirements (SDR) or the Reference Information Base (RIB) because this work is related to identifying design options not necessarily contained in the SDR or RIB. The requirements used were those given in DIM-202 Sections III and IV.

- travel through drifts measuring 20 ft x 12 ft 6 in. with a roof radius of 11 ft 5 in. (modified SCP/CDR excavated dimensions less 6-inch wall standoff clearence);

- operate in emplacement drifts measuring 22 ft x 12 ft 6 in. with a roof radius of 13 ft 6 in. (modified SCP/CDR excavated dimensions less 6-inch wall standoff clearance);

- drill 42-, 58-, 75-, and 350-ft boreholes within tolerances of 6.4, 8.4, 12.6, and 6.0 in./100 ft, respectively (See Appendix A); and

- operate under the following subsurface conditions and rock properties (these characteristics are in accordance with NNWSI reference properties listed in the RIB):

  - ambient air temperature of 20° to 32°C,
  - ambient rock temperature of 32°C,
  - relative humidity up to 100%,
  - 4,000 ft above sea level,
  - densely welded devitrified tuff,
  - rock that may contain vugs,
  - unconfined compressive strength of 171 MPa (24,320 psi),
  - tensile strength of 16.9 MPa (2,403 psi), and
  - dry bulk density of 2.55 g/cm.

In order to evaluate the relative effectiveness of each production system, criteria were established, and an abbreviated tradeoff study was performed.

1.4 Criteria

The criteria are as follows: (1) simplicity of design; (2) mobility of equipment between holes; (3) hole accuracy (as specified in Section 2.2); (4) cycle time for setup, boring, and tear down; and (5) cost of the system.

1.5 Organization of the Report

Section 1 gives the background, objectives, and criteria for this study and discusses the general considerations used during the study. Section 2 briefly describes the machine selected to bore and line the long holes and discusses the method used to identify alternatives for boring and lining short horizontal holes. Section 3 describes the machine and details the operations for boring the short hole. Section 4 describes the liner jack and the operations for lining the short hole. Section 5 gives the manpower and schedule requirements and lists the costs for the production machines. Section 6 presents the conclusions reached during this study, and Section 7 addresses the program to design, fabricate, and test a prototype boring system for short horizontal holes.

2.0 BORING AND LINING THE HORIZONTAL HOLE

2.1 Boring Method Considered for the Long Hole

The development prototype boring machine (DPBM), as shown in Figure 2-1, was designed to bore and line horizontal boreholes up to 600 ft. With some minor modifications, specifically smaller thrust cylinders, the DPBM has been selected as the system for boring and lining long horizontal boreholes (350 ft). This machine lines the hole as boring progresses and features a laser guidance system and in-hole drive. The DPBM has been described in the "Design of a Machine to Bore and Line Long Horizontal Holes in Tuff" (Robbins, 1987).

Although a machine with an actively steered bit, such as the DPBM, could be used for boring holes up to 75 ft long, simpler, lower cost alternatives, such as a system with a stabilized bit, are well within the limits of current technology. Efficient hole drilling also depends on effective muck handling. Mucking methods, therefore, have been analyzed separately from methods of cutting the rock. Both the drilling and mucking methods are discussed in the following sections.

2.2 Boring Methods Considered for the Short Hole

One objective of this study has been to identify an effective, simple, and economical boring method that is accurate to 6.4, 8.4, and 12.6 in. for 37-in.-diameter boreholes, 42, 58, and 75 ft long.

2.2.1 Assumptions

Two assumptions were made before evaluating the alternative methods of drilling the short holes.

- Boring and lining were considered separate operations, thus permitting complete inspection of the unlined borehole and simplifying machine operation and design.

- The 75-ft borehole was used as the basis for the investigation. Systems found suitable for the 75-ft hole were also considered suitable for the shorter 42- and 58-ft holes.

2.2.2 Preliminary Identificaton of Boring and Lining Methods for the Short Hole

Based upon the drilling design experience a boring system consisting of a derrick, two-piece drill string, stabilizer, cutterhead assembly, and an auger mucking system was selected as appropriate equipment which would satisfy the criteria in Secton 1.4 (design, simplicity, mobility, hole accuracy, cycle time, ability to operate under conditions underground and cost). This system is described, in detail, in Section 3.0.

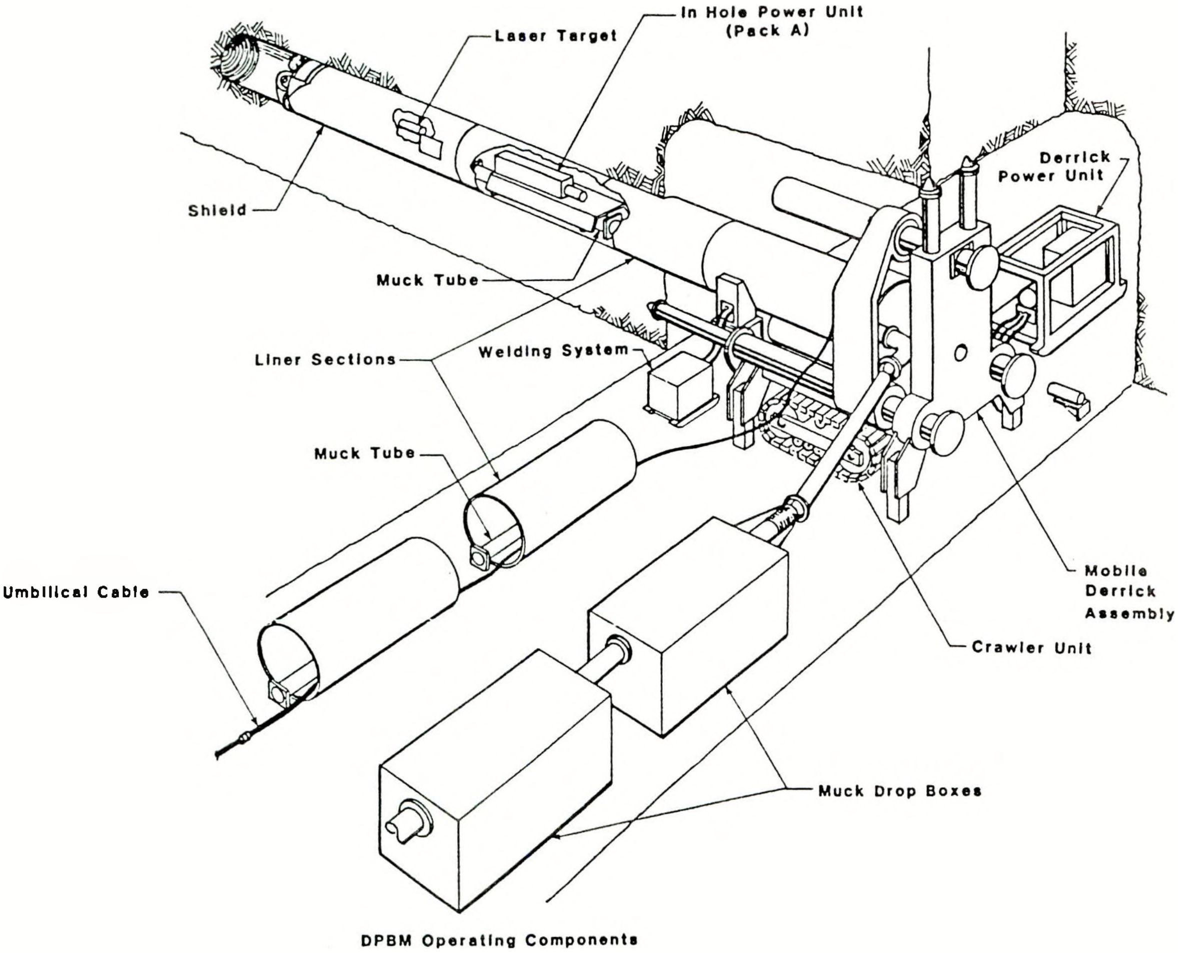

Figure 2-1. Development Prototype Boring Machine (Source: Robbins, 1987)

2.2.3 Analysis of Boring Blind, Unpiloted Holes

Over the last 15 yr, Robbins has produced 36 boxhole drills that can bore nearly straight, blind, unpiloted holes (50 to 60 in. in diameter at inclines from vertical) to 45°, up to 130 ft long. However, beyond 130 ft, the bore begins an accelerating deviation. At approximately 300 ft, a typical deviation is 1 to 2%. Based on these field data, a maximum deviation of 0.6% has been predicted for a borehole up to 75 ft long. Table 2-1 lists the expected maximum deviations for the three lengths considered.

TABLE 2-1

EXPECTED HOLE DEVIATIONS

Hole Length (ft)	Maximum Allowable Deviation (in.)	Maximum Expected Deviation at 0.6% (in.)
42	6.4	3.0
58	8.4	4.2
75	12.6	5.4

2.2.4 Conclusion

Drilling a pilot hole before boring a 37-in. borehole was considered. Based on a review of historical data, engineering judgment, and the additional cost and drilling time, the pilot hole was rejected. Although use of a pilot hole would likely improve the accuracy of the holes, a system that uses a stabilized bit can adequately drill short horizontal holes within the maximum expected tolerances without drilling a pilot hole.

2.3 Mucking Methods Considered

A variety of mucking methods were selected for further study: a vacuum bailing system, a mechanical slusher, and three mechanical screw conveyors.

2.3.1 Vacuum Bailing System

Because the use of bailing liquids in the underground repository is not desirable, the only fluid considered for the bailing system was air. Although effective, a vacuum bailing system with a dust free bore has not been considered further because of the (1) high capital cost, (2) significant filter maintenance, and (3) high noise levels in the work place.

2.3.2 Mechanical Slusher

The mechanical slusher consists of a slusher bucket traveling behind the cutterhead during boring. When full boring ceases, the bucket is pulled back to the drift, emptied, and then returned to the working face.

The use of a slusher system was abandoned because of the more complex operating sequence and the boring delays caused by emptying the slusher bucket.

2.3.3 Mechanical Screw Conveyors

The mechanical screw-conveyors (auger) include three alternatives.

- A full-size auger section with a helix of approximately 36 in. transmits thrust and torque to the bit while removing the muck. There is a 1/2-in. clearance between the auger blades and the walls of the hole.
- A full-size auger section with a diameter of approximately 35 in. is housed within a 36-in.-od nonrotating conveyor tube and transmits thrust and torque to the drill bit.
- A reduced-size auger section with an outside diameter of approximately 11 in. is housed within a nonrotating tube and transmits thrust and torque to the drill bit.

The three screw conveyors are compared in Table 2-2. There may be some minor variations between production rate assumptions used in the tables and those that may have been used in development of the total system life cycle costs (TSLCC). These are a reflection of minor changes in technology, equipment, or design that have been generated in the conceptual design phase of the drilling systems.

2.3.4 Conclusion

A mechanical screw conveyor with a reduced-size auger (11-in. diameter) has been chosen from among the alternatives because it (1) does not cause overboring, (2) leaves a small amount of residual muck in the hole, (3) is easier to handle, (4) requires the least additional thrust and torque, and (5) requires the least special structural enhancement to the derrick. With the exception of leaving a small amount of residual muck in the hole, which results from enclosing the screw in an outer thrust tube, all other positive attributes of the 11-in. auger result from its lower section weight.

Placing the liners into prebored holes has been considered separately from boring the short hole. Because pipe jacking is a common, current technology, no special concepts were investigated. The liner-jacking system is described in Section 4.

TABLE 2-2

COMPARISON OF THE SCREW CONVEYOR OPTIONS

	Option 1 Full-Size 36-in. Open Auger	Option 2 Full-Size 35-in. Shielded Auger	Option 3 Reduced-Size 11-in. Shielded Concentric Auger
Bit Type	Simple	Simple	Required muck pickup thrust bearing
Rotating Member	Auger section	Auger section	Auger section
Thrusting Member	Auger section	Auger section	Thrust beam
Torque Required	Potentially high	Potentially high	Moderate
Extra Thrust Required	Yes	Yes	No
Muck in Hole	Yes	Insignificant	Insignificant
Weight of Drill Section	High*	Higher	Moderate
Overboring	Possible	Unlikely	No
Hole Deflection	Possible	Unlikely	No
Number of Pieces to Change per Stem	One	One - Two	One
Ease of Dust Suppression**	Three	Two	One
Stouter Derrick Required	Yes	Yes	No

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*Reference case.
**One = easiest.

3.0 BORING SYSTEM SELECTED FOR THE SHORT HORIZONTAL BOREHOLE

3.1 Description

The boring system selected for the short hole consists of a derrick, two-piece drill string, stabilizer, cutterhead assembly, and a mucking system with an 11-in. auger (Figure 3-1). Operating controls are mounted on a separate console near the derrick. Hydraulic power for the derrick and crawler is provided by an electrically driven power pack cooled by water.

This boring system uses proven technologies in a new design. Although some of the components in the system are not standard, all are adaptations of similar components used on existing machines and are described as follows.

- Derrick Assembly

  The derrick assembly, illustrated in Figure 3-1, includes the following.

  - Crawler Assembly

    The crawler assembly is similar to the crawler designed for the DPBM with a hydraulically driven pivot mechanism added. This feature allows the derrick assembly to rotate for alignment.

  - Jacks

    A motorized mechanical screw jack is fitted at each of the four corners of the derrick assembly. These jacks lift and level the machine to accurately collar the hole.

    Two thrust reaction jacks, mounted at the rear of the machine, operate in line with the two main thrust cylinders. During setup, the thrust cylinders are extended until the pointed pads on the rod ends make contact with the side wall opposite the rock face being drilled. The thrust cylinders have sufficient lateral float to enable the pads to be securely positioned.

    In the event the cutterhead becomes stuck during pullback, two additional pullback reaction jacks can be secured against the wall being drilled.

  - Rectangular Beams

    The two rectangular beams connecting the front and rear frames attach the derrick to the crawler and support the muck conveyor suspended between them.

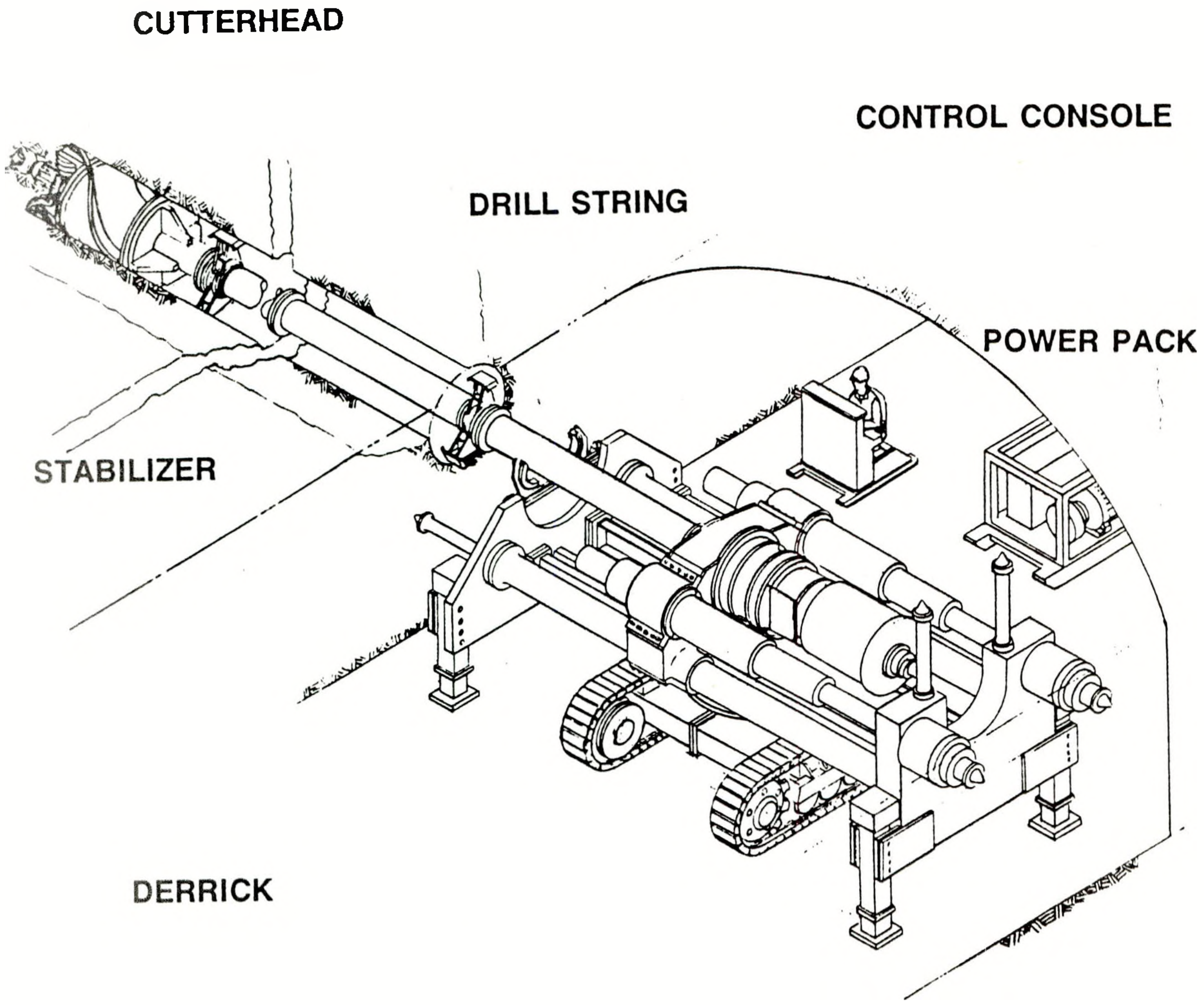

Figure 3-1. Boring System for the Short Hole

- Muck Conveyor

  The muck conveyor, consisting of a hydraulic drive, head pulley, tail pulley, belt, support roller muck scraper, and support structure, is suspended between the crawler attachment beams of the derrick assembly. As the crosshead traverses along the guide columns during boring, muck is transferred into the crosshead by the drill string and is deposited on the conveyor and moved toward the rear frame for removal.

- Front Frame

  The front frame, a steel member attached to the rear frame by two columns and two beams, provides stiffness to the column member and is used to attach the drill string support assembly during boring.

  The drill string support assembly consists of a hinged plate, two swing cylinders, one clamp cylinder, and two clamp arms. This assembly supports the drill pipe extending from the borehole during pipe changes. The assembly is rotated upward by the two swing cylinders, and the clamp cylinder activates the two clamp arms to grip the drill pipe during changes.

- Rear Frame

  The rear frame, a steel weldment, has two vertical torque reaction jacks attached to it. These reaction jacks are extended upwards against the roof of the drift.

- Crosshead

  The crosshead is moved back and forth between the rear frame and the front frame by two cylinders and is guided by bushings that slide on the outside of the guide columns. The purpose of the crosshead is to transmit the force from the two thrust cylinders evenly to the nonrotating thrust tube of the drill pipe; to provide a mounting face for the drive train assembly, which permits a portion of the drill string to rotate; and to provide an area for the muck to be transferred from the drill string to the conveyor.

- Thrust Cylinders

  The double acting, two-stage thrust cylinders are attached by their barrels to the crosshead. The eyes of the piston rods are attached to the rear frame by expansion pins.

- 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 columns by the crosshead are in turn transmitted to the rear frame through crown coupling fixtures. These columns have a hard-chromed outer surface for lasting wear.

- Drive Train

  The drive train consists of an electric motor, a clutch, and a single-speed gearbox. The motor is 100 hp, totally enclosed, fan-coiled, and runs at 885 rpm. The drive shaft is hollow to allow air to pass through to the tricone bit for cleaning and cooling. The clutch provides a mechanical means of preventing over torquing of the drill string during a stall. A single-speed gearbox connects the drive motor to the drill string, reducing the speed of the motor to the required speed of the cutterhead.

- Drill String

  The drill string sections consist of an outer, nonrotating tube that transmits thrust and an inner, rotating tube that transmits torque to the cutterhead. Helical blades are attached to the inner tube, allowing it to function as a screw conveyor to transport the rock chips out of the hole while rotating the cutterhead.

- Stabilizer

  A nonrotating stabilizer is attached to the drill string at every other drill string joint (every 16 ft) to prevent the thrust tube from buckling and to stabilize the drill assembly during boring. Each stabilizer has three arms located 120° apart.

- Cutterhead

  The cutterhead assembly includes distinct rotating and nonrotating sections.

  The front face of the rotating section of the cutterhead consists of a flanged steel weldment with four cutter housings attached. The cutters are 12 in. in diameter, multirow with tungsten carbide inserts. The inner two cutters have two rows of inserts, and the outer two cutters have three rows of inserts. The center of the front face is threaded to accept a bit stabilizer approximately 18 in. long, into which a standard 11-in.-diameter tricone bit is threaded.

  This protruding tricone bit and stabilizer facilitate collaring and guidance during drilling. The tricone bit is flushed and cooled by compressed air.

  The back side of the rotating cutterhead is machined to accept the inner face of the main bearing. The bearing assembly is a double-row tapered roller bearing that accepts both radial and thrust loading from the cutterhead assembly. The bearing consists of two bearing cones, a common bearing cup, and a spacer for proper separation of the two cones. The bearing is sealed with dual cone toxic seals to prevent contamination from the outside and loss of bearing lubricant.

Attached to the back face of the cutterhead is the drive shaft adapter, which links the torque tube and screw conveyor of the drill string to the rotating section of the cutterhead.

- Muck-Handling System

  While boring is taking place, the rock cuttings are moved to the base of the derrick as follows (Figure 3-2).

  - Compressed air moves the rock chips created by the tricone bit back about 18 in. to the face being cut by the main cutterhead.

  - The muck created by the tricone bit and the main cutters drops to the bottom of the hole. Helical blades mounted at the periphery of the cutterhead move this mass back to the interface between the rotating and nonrotating portions of the cutterhead. At this point, the blades trap and raise the muck to the top of the hole where it falls into a drop box and then into the screw conveyor inside the drill string.

  - The screw conveyor transports the muck to the crosshead of the derrick. The muck then falls through an opening at the bottom of the crosshead onto a V-belt conveyor that is an integral part of the derrick and that runs the entire path covered by a stroke of the crosshead.

  - The muck is then discharged from the V-belt conveyor onto a conveyor or vehicle for removal from the repository.

- Pipe Handling

  Drill pipe sections are stored on carts that will move them to the boring sites. Stabilizers are premounted on every other drill-string section to avoid attaching them during drilling, thus minimizing cycle time. The pipe-storage and transport cart must allow the sections with the installed stabilizers to be properly nested.

  The drill pipe is stored so that the stabilizers are oriented correctly when loaded into the derrick. Sections of drill pipe are loaded on and removed from the derrick by a hydraulic pipeloader that pivots.

  When adding a section to the drill string, the section is clamped by two hydraulic cylinders, the inner rotating portion of the section is first joined by a splined connection, and the outer nonrotating thrust tube is then coupled by bolting the flanges together.

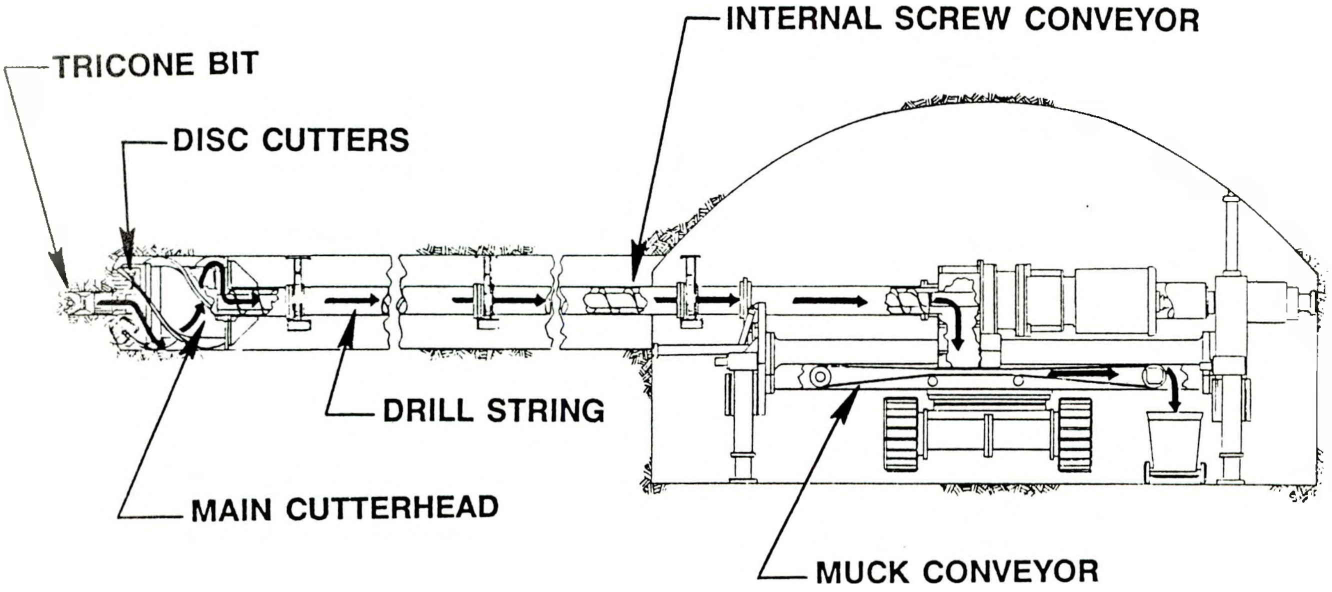

Figure 3-2. Flow of Muck

- Power Pack

  The power pack provides the hydraulic supply for the derrick and crawler. A double-ended electric motor drives two variable displacement pumps. The larger pump supplies low pressure fluid for rapidly traversing the crosshead and for driving the crawler. The smaller pump supplies the thrust that positions the derrick, operates the various jacking systems, operates the muck conveyor, moves the pipe support plate cylinders, and operates the pipeloader.

  The feed rate for the thrust cylinders is controlled by a variable flow control valve on the operator's console. Suction strainers and high pressure, return filters are incorporated in the system, and a reservoir retains sufficient hydraulic fluid for the system. Removable hoses with sealing quick disconnects at both ends are connected to the derrick.

  The power pack also includes a cabinet, which houses the majority of the components making up the electrical system. This unit includes all transformers, circuit breakers, fuses, starters, contactors, electrical torque limit system components, and a low voltage starting system (motors and dc power supply).

- Operator's Control Station

  The control station is a skid-mounted unit complete with seat for the operator. After the machine is set up, all hydraulic and electrical functions for operating the drill are controlled from the console, which is mounted on the station stand and is coupled to the power units by trailing cables and hydraulic hoses.

3.2 Specifications

Condensed specifications for the boring system are listed in Table 3-1.

3.3 Operations

Operation of the short hole boring system follows a repetitive sequence of events from setting up the machine at a work site to moving equipment to the next site when the hole has been completed.

3.3.1 Mobilization

Mobilization includes the activities related to setting up the equipment once it is at a new boring site, such as connecting all utilities. The crawler is maneuvered until the centerline of the derrick pivot is positioned adjacent to the intended boring site. The upper derrick assembly is rotated 90° using the integral pivot mechanism and is positioned as follows.

TABLE 3-1

CONDENSED SPECIFICATIONS FOR THE SHORT-HOLE BORING SYSTEM

Bore Diameter	37 in.
Thrust	250,000 lb
Torque	16,000 ft-lb
Head Rotation	32 rpm (fixed speed)
Cutterhead	100 hp
Power Pack	75 hp
Bailing Air	125 cfm free air at 60 to 80 psig
Instantaneous Boring Rate	10 ft/hr
Width*	8 ft 6 in.
Height*	7 ft 0 in.
Length*	18 ft 6 in.
Weight*	40,500 lb

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*Includes crawler.

- Align the derrick with the borehole by using the four leveling jacks.
- Extend the thrust reaction jacks until they make contact with the rear wall and lock them.
- Extend the torque reaction jacks until they make contact with the roof and lock them.
- Check the alignment and readjust the jacks, if necessary.

3.3.2 Collaring

Starting or "collaring" a hole is critical to the accuracy of the final bore. Attempting to collar the hole by thrusting the 37-in.-diameter cutter against the rock face causes the bit to "walk." To minimize this tendency, a special feature has been provided.

The cutterhead has a "snout," consisting of an 11-in.-diameter stabilizer approximately 18 in. long that protrudes from the face of the main cutters. A standard tricone bit threaded into this snout contacts the rock face first. By the time the main cutters contact the face, the snout has drilled approximately 18 in. into the rock. The steps for collaring are as follows.

- Lower the drill string support mechanism attached to the front frame of the derrick to allow the cutterhead assembly to pass. Once the cutterhead has passed, the support is rotated back to its vertical position.

- Begin rotating the cutterhead as it approaches the hole target. Very light thrust is applied; the actual penetration rate during collaring will be determined by the operator. However, progress will be slow to ensure the straightest hole possible.

Collaring tends to be a dusty operation. The integral muck-handling system is not effective until the cutterhead is fully collared in the hole (about 4 ft). During collaring, the rock cuttings fall out of the hole, and some method of collecting this muck (approximately 2 yd^3) needs to be determined.

The transition from collaring to standard boring is simple. Because the machine operates at constant RPMs, thrust is simply increased once the cutterhead has been collared securely within the bore.

3.3.3 Boring

A normal boring cycle is based on an 8-ft section of drill string. Boring continues until the crosshead has been extended a full stroke. A new section of pipe is then added as follows.

- Secure the end of the last in-hole section with the clamping device mounted on the drill string support mechanism.

- Disconnect the last section at the crosshead. Retract the crosshead.

- Using the pipe loader, swing a new section into position on the derrick.

- Slide the crosshead forward. Match up the spline connection of the inner screw conveyor with the drive connection on the crosshead. Bolt the outer thrust tube to the crosshead.

- Reduce pressure slightly on the holding clamps of the pipe loader. Slide the crosshead with the new section forward to the in-hole section being held by the drill string support mechanism.

- Match up and connect the two sections.

- Release all clamps. Pivot the pipe loader away.

- Begin boring.

3.3.4 Demobilization

Demobilization is the process that starts when boring has been completed and that ends when the entire system has been transported to the next work site. The boring system is demobilized as follows.

- Remove all drill string sections in the reverse of the way in which they were inserted.

- When only the cutterhead assembly remains in the hole, connect it to the crosshead. Pivot the support mechanism of the drill string down and pull the entire cutterhead assembly into the derrick. Raise and secure the drill string support mechanism.

- Retract the thrust and torque reaction cylinders, retract the leg jacks, and pivot the upper derrick assembly 90°. Disconnect all utilities. Secure for movement.

- Transport the system components to a new boring site.

4.0 LINING SYSTEM SELECTED FOR THE SHORT HORIZONTAL BOREHOLE

As with boring the hole, lining the hole is a repetitive sequence of events from mobilization through demobilization of the derrick. The liner-jacking system shown in Figure 4-1 is described as follows.

4.1 Description

The liner jack derrick consists of a front frame, a rear frame, a crosshead, two thrust cylinders, two guide columns, two beams, and a crawler assembly. The crawler assembly is similar to that used for the short-hole boring machine described previously in Section 3.0. An automatic orbital welding machine, used to join the sections of the liner, moves along a circular track clamped adjacent to the joint on one of the liner section.

4.2 Specifications

Condensed specifications for the liner-jacking system are listed in Table 4-1.

TABLE 4-1

CONDENSED SPECIFICATIONS FOR THE LINER-JACKING SYSTEM

Diameter of Liner	36-in. outside diameter
Thrust	300,000 lb
Power Pack	75 hp
Width*	8 ft 6 in.
Height*	7 ft 6 in.
Length*	15 ft 0 in.
Weight*	30,000 lb

---

*Includes crawler.

4.3 Operations

As with boring the short hole, lining the short hole repeats a series of steps from mobilization through teardown and transport when the hole has been completed. The hole will have been inspected before the liner is inserted.

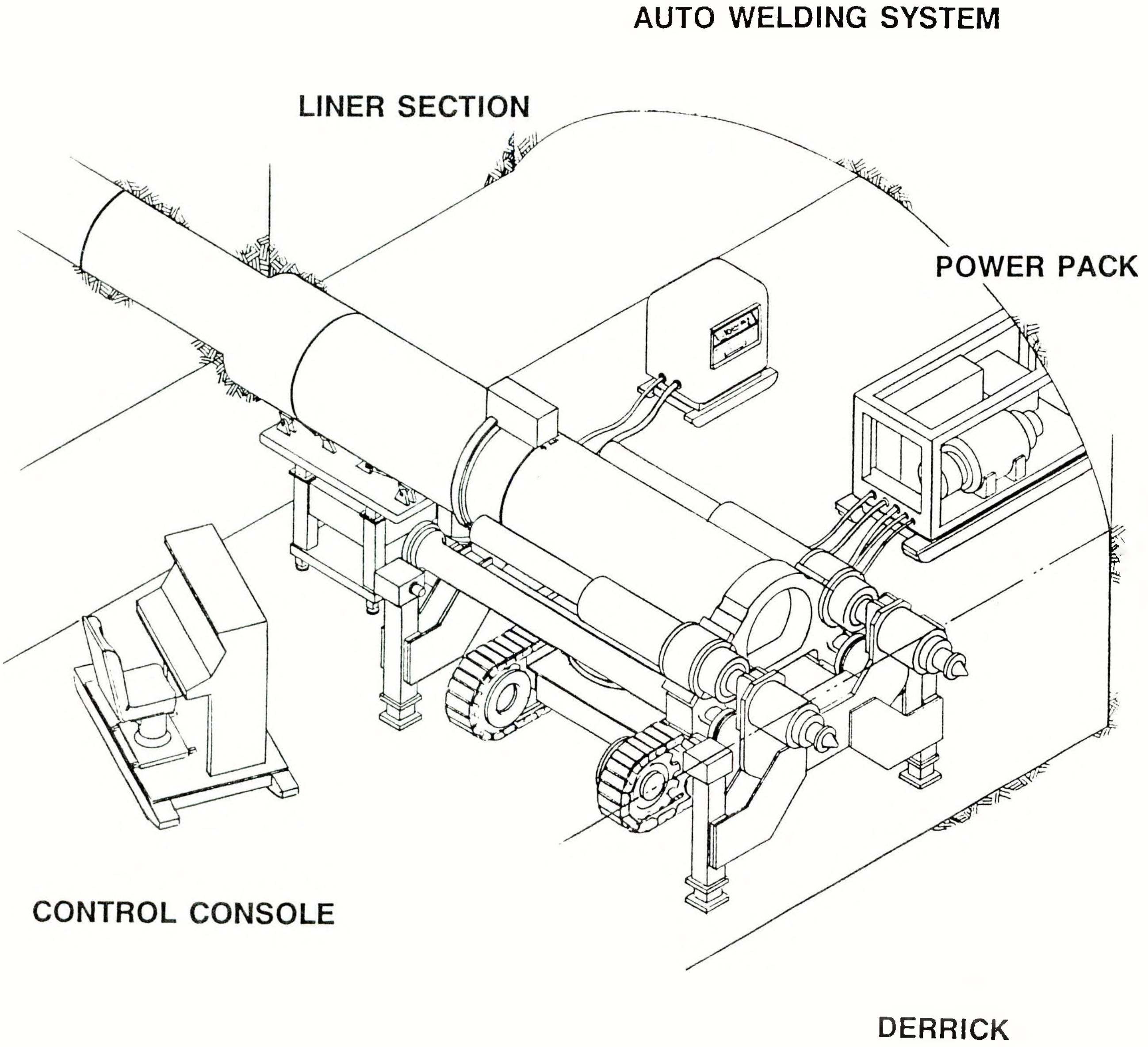

Figure 4-1. Lining System for the Short Hole

4.3.1 Mobilization

Utilities are connected when the system's components are at the work site. By maneuvering the crawler, the centerline of the derrick pivot is positioned adjacent to the borehole. The upper derrick assembly is rotated 90° using the integral pivot mechanism and is positioned as follows.

- Align the derrick with the borehole by using the four leveling jacks.
- Extend the thrust reaction jacks until they make contact with the rear wall and lock them.
- Check the alignment and readjust the jacks, if necessary.
- Install the liner support bridge between the derrick and the collar of the hole.

Once the derrick has been aligned, the first liner section is pushed into the hole.

4.3.2 Adding Liner Sections

The following sequence is repeated until the hole is fully lined.

- Load a new liner section on the derrick and advance it until it mates with the last in-hole liner.
- Install the track and head of the automatic welding machine.
- Weld the joint and remove the welding machine and clamps.
- Inspect the weld.
- Jack the entire liner section into the hole.
- Load a new liner section on the derrick.

4.3.3 Demobilization

Demobilizing after completely inserting the liner is simpler than demobilizing after boring a hole because no in-hole sections need to be removed. Demobilizing the equipment includes

- loading a new liner section on the derrick;
- using the new liner section to push the in-hole liner string to its final position;
- retracting the new liner section onto the derrick;
- removing the liner support bridge;

- retracting the thrust reaction cylinders, retracting the leg jacks, pivoting the upper derrick assembly 90°, disconnecting all utilities, securing the liner insertion system for movement; and

- transporting the system to a new site.

5.0 SCHEDULE, MANPOWER REQUIREMENTS, AND COSTS FOR SYSTEMS TO BORE AND LINE THE SHORT HOLE

5.1 Schedule and Manpower Requirements

Favorable and unfavorable scenarios have been used to assess schedule requirements. Competent, qualified personnel have been assumed to work in both cases. In the favorable scenario, it has been assumed that the personnel are familiar with the peculiarities of the rock and the environment and that no major delays occur. In the unfavorable scenario, it is assumed that there are minor equipment problems, personnel are not familiar with the specific equipment or procedures, or unexpected geology is encountered.

In both scenarios, no delays are allowed for muck removal from the work site or for major equipment breakdowns. Mine utilities (power, compressed air, and utility water) are presumed to be readily available at the work site. There may be some minor variations between the production schedules used in the following tables and those that may have been used in the development of the TSLCC. These are reflections of minor changes in the technology, equipment, or design that have been generated in the conceptual design phase of the drilling systems used in this study.

5.1.1 Boring the Emplacement Hole

Table 5-1 lists the times needed to completely bore the short holes for both the favorable and unfavorable scenarios. The favorable and unfavorable times have been averaged, and it is estimated that it will take 2.3, 2.8, and 3.3 days to completely bore the 42-, 58-, and 75-ft holes, respectively (based on two 8-hr shifts/day and an 80% usage rate).

TABLE 5-1

TIME NEEDED TO BORE THE SHORT HOLE

I. Boring Cycle Times

Activity	Hours/Shift Favorable	Hours/Shift Unfavorable
(A) Mobilize, Align, and Test (per hole)		
Position power pack and control console	0.5	1.5
Pivot derrick	0.5	1.0
Hook up cables and hoses	1.0	1.5
Raise derrick and align	1.0	2.5
Complete hookups	0.5	1.0
Test derrick	0.5	1.0
SUBTOTAL (A)	4.0	8.5
(B) Collar Hole (per hole)		
Drill 4 ft (low thrust)	2.0	2.0
Prepare for boring	0.0	0.5
SUBTOTAL (B)	2.0	2.5

TABLE 5-1

TIME NEEDED TO BORE THE SHORT HOLE (concluded)

I. Boring Cycle Times

	Hours/Shift	
Activity	Favorable	Unfavorable
(C) Bore Hole (per 8-ft section)		
Attach stabilizers	(already done)	0.5
Load new section	0.1	0.2
Connect sections (2 joints)	0.3	1.0
Drill 8 ft	0.9	1.3
Break joint connection	0.1	0.3
Retract crosshead	0.1	0.2
SUBTOTAL (C)	1.5	3.5
(D) Retrieve Drill String (per 8-ft section)		
Retract crosshead and string	0.1	0.1
Break joint connection	0.2	0.5
Remove section	0.1	0.2
Advance head, make joint	0.1	0.2
SUBTOTAL (D)	0.5	1.0
(E) Demobilize and Travel (per hole)		
Lower derrick and rotate	0.5	1.0
Disconnect and secure lines	0.7	1.5
Secure equipment and travel	2.3	3.0
SUBTOTAL (E)	3.5	5.5

II. Summary of Cycle Times

	Per Hole		
Activity	Favorable	Unfavorable	Average
(A) Mobilize, Align, and Test	4.0	8.5	
(B) Collar Hole	2.0	2.5	
(E) Demobilize and Travel	3.5	5.5	
TOTAL	9.5	16.5	13.0
	Per 8-Ft Section		
(C) Bore Hole	1.5	3.5	
(D) Retrieve Drill String	0.5	1.0	
TOTAL	2.0	4.5	3.25

III. Boring Time Calculations

(Shift hours--based on average times)	Length of Hole		
	42 ft	58 ft	75 ft
Number of 8-Ft Sections	5	7	9
Hour/Section (section x 3.25)	16.25	22.75	29.25
Hour/Hole	13.0	13.0	13.0
TOTAL TIME/HOLE (100% usage)	29.25	35.75	42.25

Based on field service experience, a crew of three persons is required per shift: one operator and two helpers.

5.1.2 Inserting the Liner

Table 5-2 lists the times needed to line the short horizontal holes for both the favorable and unfavorable scenarios. It is estimated that it will take 1.6, 2.2, and 2.7 days to completely line the 42-, 58-, and 75-ft holes, respectively (based on two 8-hr shifts/day and an 80% usage rate). As with boring, an average of the favorable and unfavorable times has been used for these calculations.

The liner-jacking crew will consist of three persons: an operator, a welder, and a utility man.

5.2 Costs

The costs in this study have been based on production machines. Nonrecurring engineering costs for the first production machines have not been included here but would likely be paid for in a prototype project. The costs indicated below are for equipment designed and built to commercial construction standards. There may be other variations between the cost and assumptions used in the following cost tables and those that may have been used in the development of the TSLCC. These are a reflection of changes in the technology, equipment, or design that have been generated in the conceptual design phase of the drilling systems used in this study.

5.2.1 System Unit Prices

The selling prices of the short-hole boring and lining systems described in this report are approximately $935,000/boring system and $581,000/liner-jacking system, fob factory, based on 1988 dollars. These prices have been based on similar equipment (e.g., mobile raise drills) currently manufactured by The Robbins Company, and prices of items not typically used have been solicited from vendors (e.g., the automatic welding machine). Prices of the boring and lining systems for the short hole include

- Boring System
  Boring machine with crawler
  Cutterhead and one set of cutters
  Drill string sections for drilling 75 ft
  Auxiliary equipment (power pack, control console, pipe loader)

- Liner-Jacking System
  Liner-jacking machine with crawler
  Automatic welding machine
  Auxiliary equipment (power pack, control console, pipe loader)

These prices are for fully operational systems. However, there are other necessary services and/or equipment that have not been included, such as

- electricity, air, and water available at the work sites;

TABLE 5-2

TIME NEEDED TO LINE THE SHORT HOLE

I. Lining Cycle Times

Activity	Hours/Shift Favorable	Hours/Shift Unfavorable
(A) Mobilize, Align, and Test (per hole)	2.0	6.0
(B) Handle Liner (per 8-ft section)		
Load on derrick with in-hole liner	0.25	0.50
(C) Weld Liner (per joint)		
Install alignment device	0.10	0.10
Tack weld	0.20	0.40
Engage auto welder	1.75	0.10
Remove alignment device	0.10	0.10
Inspect weld	0.25	0.75
SUBTOTAL (C)	2.40	3.1
(D) Jack Liner and Withdraw Head	0.25	0.25
(E) Demobilize and Travel (per hole)	2.0	3.0

II. Summary of Cycle Times

	Per Hole Favorable	Per Hole Unfavorable	Average
(A) Mobilize, Align, and Test	2.0	6.0	
(E) Demobilize and Travel	2.0	3.0	
SUBTOTAL	4.0	9.0	6.5

	Per Intermediate Liner (first and last section excluded)		
(B) Handle Liner	0.25	0.50	
(C) Weld Liner	2.40	3.10	
(D) Jack Liner	0.25	0.25	
SUBTOTAL	2.90	3.85	3.375

	First Liner Favorable	First Liner Unfavorable	Average
(B) Handle Liner	0.25	0.50	
(D) Jack Liner	0.25	0.25	
SUBTOTAL	0.50	0.75	0.625

	Last Liner		
(B) Handle Liner	0.25	0.50	
(C) Weld Liner	2.40	3.10	
(D) Jack Liner	0.25	0.25	
(E) Load New Liner	0.25	0.25	
(F) Jack Liner and Withdraw	0.25	0.25	
SUBTOTAL	3.40	4.35	3.875

TABLE 5-2

TIME NEEDED TO LINE THE SHORT HOLE (concluded)

III. Lining Time Calculations (Shift Hours--based on average times)	Length of Hole		
	42 ft	58 ft	75 ft
Number of 8-Ft Liners (excluding first and last)	3	5	7
Variable Time (intermediate liner x 3.375)	10.125	16.875	23.625
First Liner	0.625	0.625	0.625
Last Liner	3.875	3.875	3.875
Per Hole	6.500	6.500	6.500
TOTAL TIME/HOLE (100% usage)	21.125	27.875	34.625

- conveyance of muck from the work site during boring;
- utility wagons for hauling drill string sections and liner sections between sites;
- consumable welding materials; and
- service and repair equipment for maintenance of the systems.

5.2.2 Number of Systems Required

The number of boring and lining systems required in a repository will depend on the length of the hole finally selected and the number of containers emplaced per day.

For this study, a scenario has been created in which eight containers are emplaced each day. Emplacement occurs during one shift, and boring and lining the emplacement hole occur during the remaining shifts.

Table 5-3 lists the requirements for the three alternative lengths for the short hole. Included at the end of this table is an analysis of the effect of various usage rates on the number of systems required.

5.2.3 Operating Costs

This section deals only with operating the boring and lining systems. Labor costs and cost of services are not included.

5.2.3.1 Cutters and Maintenance Items

The number of cutters and quantity of maintenance items depend on several factors including geology, climate, and the skill level of the operators. Following are approximations of these costs.

TABLE 5-3

NUMBER OF BORING AND LINING UNITS REQUIRED*

Boring Machine

	Length of Hole/Number of Containers			
Requirements	42 ft/1	58 ft/2	75 ft/3	Comment
Footage Required/Day	336	232	200	
100% Usage (hour/hole)	29.25	35.75	42.25	Taken from Table 2-5
80% Usage (hour/hole)	36.56	44.69	52.81	100% time/.80
Days to Bore the Hole	2.29	2.79	3.30	80% time/16 hr
Mean Footage Bored/Day (feet/machine/day)	18.38	20.77	22.72	
Number of Machines Required	18.3	11.2	8.8	
TOTAL NUMBER OF MACHINES	19	12	9	

Liner-Jacking Machine

	Length of Hole/Number of Containers			
Requirements	42 ft/1	58 ft/2	75 ft/3	Comment
Footage Required/Day	336	232	200	
100% Usage (hour/hole)	21.125	27.875	34.625	Taken from Table 2-6
80% Usage (hour/hole)	26.41	34.84	43.28	100% time/.80
Days to Line the Hole	1.65	2.18	2.71	80% time/16 hr
Mean Footage Lined/Day (feet/machine/day)	25.45	26.63	27.73	
Number of Machines Required	13.2	8.7	7.2	
TOTAL NUMBER OF MACHINES	14	9	8	

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*Assumptions:
8 containers/day
80% usage of equipment
16 productive hours/day

Cutters are expected to cost \$33.37/yd^3 of excavated material, while maintenance items should average \$1.00/yd^3. These cutter costs have been approximated based on a cost of \$20,000/dress of cutters and an average life per cutter of three million rolling feet. The cost of cutter and maintenance items has been figured by hole length as shown in Table 5-4.

The number of boring and lining systems decreases both as the usage time increases and as the length of the hole increases, as shown in Table 5-5.

TABLE 5-4

CUTTER AND MAINTENANCE ITEM COSTS

Length of Hole (ft)	Material Excavated (yd^3)	Cutter Cost/ Hole ($)	Maintenance Cost/Hole ($)	Total Cost/ Hole ($)
42	11.6	387	12	399
58	16.0	534	16	550
75	20.7	691	21	712

TABLE 5-5

EFFECT OF THE USAGE RATE ON THE NUMBER OF UNITS REQUIRED

	USAGE (%)	Length of Hole		
		42 ft	58 ft	75 ft
Boring Machines	60	25	15	12
	65	23	14	11
	70	21	13	10
	75	20	12	10
(projected usage)	80	19	12	90
	85	18	11	9
	90	17	10	8
	95	16	10	8
	100	15	9	7
Jacking Machines	60	18	12	10
	65	17	11	9
	70	15	10	9
	75	14	10	8
(projected usage)	80	14	9	8
	85	13	9	7
	90	12	8	7
	95	12	8	6
	100	11	7	6

5.2.3.2 Major Overhaul and Replacement of Components

The life of each system is nearly indefinite with proper care and maintenance. The optimum period for a major overhaul has been determined to be 5,000 hr of operation.

Based on previous experience with similar drilling equipment, the cost of a major overhaul has been estimated at 18.5% of the total capital cost or $172,975 for the boring equipment and $107,485 for the lining equipment.

Using the hours per hole from Tables 5-1 and 5-2 for the boring and lining units, respectively, the amortized overhaul costs for these units for each hole length are calculated as follows in Table 5-6.

TABLE 5-6

AMORTIZED OVERHAUL COSTS FOR THE BORING AND LINING UNITS

Operations	Length of Hole 42 ft	 58 ft	 75 ft
Boring			
Hours/Hole (100% usage)	29.25	35.75	42.25
Number of Holes/5,000 hr	171	140	118
Equivalent Overhaul Cost	$1,012	$1,237	$1,462
Lining			
Hours/Hole (100% usage)	12.12	27.88	34.62
Number of Holes/5,000 hr	237	179	144
Equivalent Overhaul Cost	$454	$599	$744
TOTAL BORING AND LINING COSTS	$1,466	$1,836	$2,206

5.2.4 Effective Cost Per Container

The same scenario of placing eight containers per day is used for the following calculations. The number of boring and lining units is shown in Table 5-3. Depreciation of the initial capital costs of the unit should be considered in calculating effective cost per container. A 3-yr amortization schedule for drilling and heavy construction equipment is common.

In calculating the depreciation of the equipment, a factor of 80%, an assumed two-shift/day operation for boring and lining, and a 7-day week with no holidays are used. Thus, the equipment is available 5,840 hr/yr (16 hr/day x 365 days/yr).

Using the hours per hole (80% usage) from Table 5-3, the equipment depreciation costs per hole are calculated in Table 5-7. All costs are summarized in Table 5-8.

TABLE 5-7

EQUIPMENT DEPRECIATION COSTS

	Length of Hole		
Operations	42 ft	58 ft	75 ft
Boring			
Hour/Hole (80% usage)	36.56	44.69	52.81
Equivalent Holes/Year	160	131	111
Equivalent Holes/3 yr	479	392	332
Depreciation/Hole	$1,951	$2,385	$2,818
Lining			
Hour/Hole (80% usage)	26.41	34.84	43.28
Equivalent Holes/Year	221	168	135
Equivalent Holes/3 yr	663	503	405
Depreciation/Hole	$876	$1,155	$1,435
TOTAL	$2,827	$3,540	$4,254

TABLE 5-8

COST PER CONTAINER

	Length of Hole / Number of Containers		
Costs	42 ft/1	58 ft/2	75 ft/3
Cutters and Maintenance Items	$399	$550	$712
Overhaul Amortization	$1,466	$1,836	$2,206
Depreciation	$1,694	$2,119	$2,547
TOTAL PER HOLE	$3,559	$4,505	$5,465
TOTAL PER CONTAINER	$3,559	$2,253	$1,822

6.0 CONCLUSIONS AND OTHER CONSIDERATIONS

6.1 General Conclusions

With the exception of the long, 350 foot, horizontal boreholes the boring systems proposed for the short holes will use proven technologies in a new design. Although some of the components in the systems are not standard, all are adaptations of similar components used on existing machines.

Two separate systems have been selected to bore and line the short holes (42, 58, and 75 feet). The boring systems use a passively steered stabilized bit to bore the 37-in-diameter hole in a single pass. No pilot hole is required to meet the specified maximum allowable deviations. The lining system is basically a pipe-jacking machine; an automatic welding machine ensures uniform, high quality welds.

The long horizontal boreholes will be bored and lined using a system described in "Design of a Machine to Line a Long Horizontal Hole in Tuff" (Robbins, 1987).

6.2 Other Considerations

Some issues arose during the study of boring and lining horizontal holes, which were not pursued because they either involved modifying the current design of the repository or else were ancillary to the task at hand. These issues, however, are presented below for consideration.

6.2.1 Emplacement Drift Roof Profile

The emplacement drift roof radius has been specified as 13 ft 6 in. The roof curves down to a point on the wall below the top of an emplacement hole. This will cause difficulties during collaring because only the upper portion of the cutterhead will make contact with the rock until the bit is fully collared. The curvature of the rock wall can be removed either when excavating the emplacement drifts or as an added step in the boring sequence.

6.2.2 Alternative Mucking Method for the 42-Ft-Long Hole

When a mucking system for the short holes was being considered, the full-size, 36-in-diameter auger was not chosen because of the possibility of overboring, excessive hole deflection, and high torque. In our judgment, this reasoning was definitely valid for the 58- and 75-ft-long holes and very likely for the 42-ft holes.

If, however, the 42-ft horizontal hole is finally selected for the repository, the alternative large-diameter auger should be considered for a prototype testing program. If proven satisfactory, its advantage is a simpler although heavier drill string, and no stabilizers are required. The time cycle previously described would not be altered by this alternative.

7.0 FABRICATION AND TESTING OF A PROTOTYPE SYSTEM

The production system design concepts have been described in the preceding sections. This section describes the work performed to produce and test a prototype system that bores short horizontal emplacement holes. The prototype activity consists of (1) design, fabrication, and shop testing; (2) functional testing; and (3) proof-of-principle testing.

7.1 System for the Short Hole

Inserting the liner is not included in this prototype development program because pipe jacking is a common practice that uses current technologies. Only the boring system needs to be subjected to prototype development.

7.1.1 Design, Fabrication, and Shop Testing

The prototype boring system is essentially the production system described in previous sections with certain items omitted to minimize the cost (e.g., the prototype will be skid mounted with no provisions for a powered pivot).

Figure 7-1 presents the proposed schedule for designing, fabricating, and testing the prototype. The total time required for this program is estimated at approximately 20 months from receipt of the order and a list of the technical requirements.

Testing in the shop will be limited to checking movements for interferences and confirming compliance with specified ratings (RPM, traverse speeds, etc.).

7.1.2 Functional Testing

When shop testing has been completed, the system will be taken to a quarry in the Puget Sound area of Washington where two holes, 42 and 75 ft, will be bored. The purpose of this test series is to verify that the boring system operates properly and to establish a base line for the operating characteristics.

The following data will be collected from the functional tests: torque, RPM, thrust, penetration rate, and effectiveness of muck collection. When each hole has been completed, the deviation will be measured. The time needed to design, fabricate, and test the prototype will be studied as shown in Figure 7-1.

A special thrust reaction fixture will be required and provided for these quarry tests (Figure 7-2).

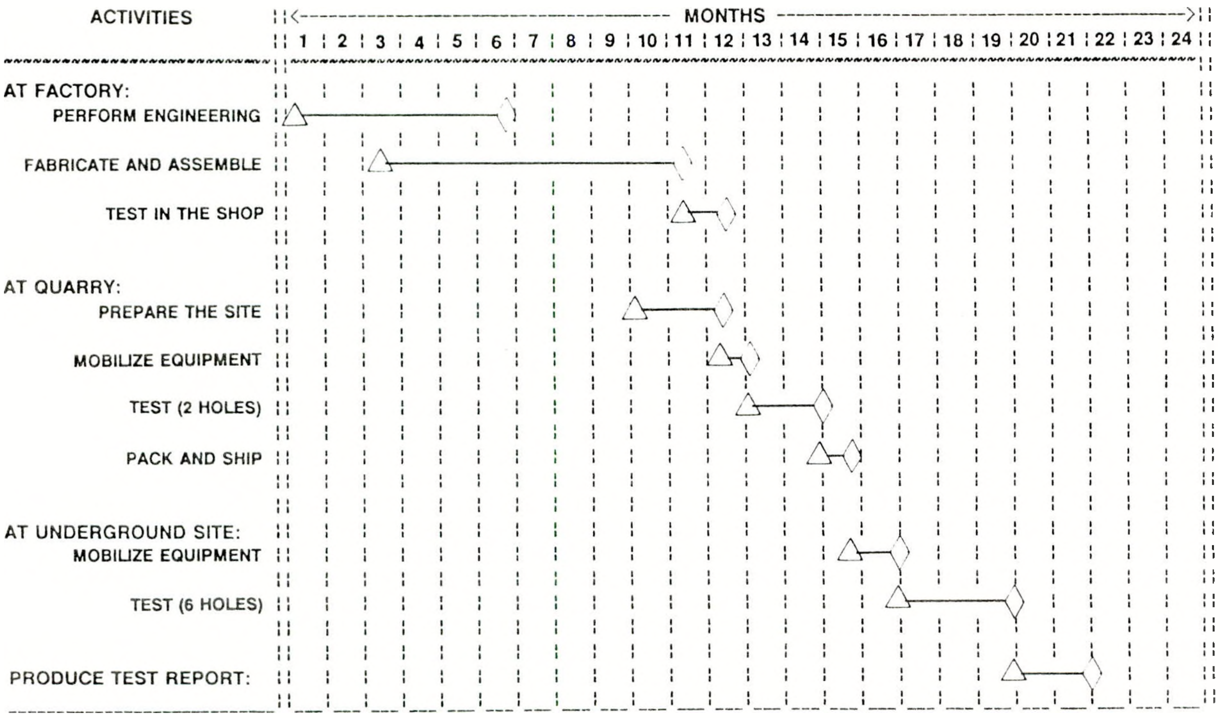

Figure 7-1. Timeline for Designing, Fabricating, and Testing the Prototype to Bore the Short Hole

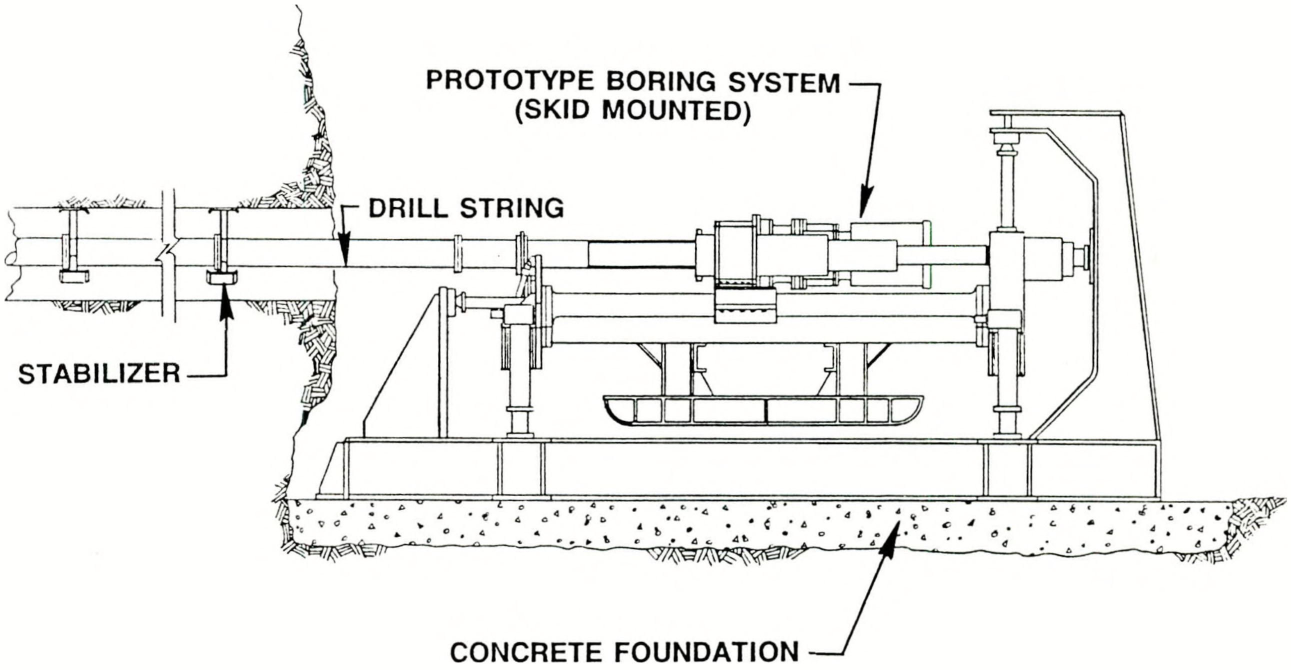

Figure 7-2. Thrust Reaction Fixture

7.1.3 Proof-of-Principle Testing

When the quarry tests have been completed successfully, the prototype system will be moved to an underground site specified by Sandia National Laboratories for final testing. The test series will consist of six 75-ft holes. Each hole will be bored in stages of 42, 58, and 75 ft, and hole deviations will be measured at the end of each stage.

During the drilling tests, the same data will be collected as in the functional test with the addition of cutter wear measurements for predicting the life of the cutter (Figure 7-1).

7.1.4 Mucking Option

As mentioned in Section 6.3.2, a possible alternative exists for mucking the 42-ft-long holes. A full-size (36-in.) unshielded auger may be used instead of the two-piece drill string described in Section 3.1.

Because the full-size auger weighs 2,200 lb/8-ft section and is susceptible to jamming, the evaluation team was concerned that this auger would overbore the hole and would have an increased potential for binding. Nevertheless, if desired, this optional method might also be tested concurrently with the selected, reduced-size auger system.

Adding this mucking alternative to the program affects cost only. The testing schedules will not be affected if the following changes are made.

- Shop Test
  - No change
- Functional (Quarry) Test
  - Bore a 42-ft hole with the alternative mucking system (36-in. auger).
  - Bore a 75-ft hole with the selected mucking system (an outer thrust tube with an inner 11-in. screw conveyor).
- Proof-of-Principle Test
  - Bore the first three holes to a depth of 42 ft using the alternative mucking method.
  - Bore the remainder of the first three holes with the selected mucking system.
  - Bore the remaining three 75-ft holes with the selected mucking system.

7.1.5 Cost of the Prototype Program

7.1.5.1 Basic Program

The cost to design, fabricate, and assemble the prototype boring system and perform the three phases of testing (shop, quarry, and underground tests) will be $2,083,500 based on 1988 dollars. Included in this cost are the

- prototype boring machine including a
  - skid mounted derrick,
  - muck conveyor, and
  - pipe loader;
- drill string including
  - cutterhead with cutters,
  - stabilizers for a 75-ft bore, and
  - drill string sections for a 75-ft bore;
- power pack;
- control console;
- thrust reaction fixture for quarry test;
- shop testing;
- quarry testing with report;
- freight to an underground site (Nevada assumed); and
- underground testing with a report.

7.1.5.2 Program Option

If desired, the full-size mucking alternative may be included in the program for an additional cost of $176,500.

Included in this additional cost are

- alternate drill string sections for a 42-ft bore,
- modifications to the cutterhead that permit use of either type of drill string sections (change part), and
- additional manhours during testing of the modifications to the cutterhead to change the types of drill string sections.

REFERENCES

Robbins (The Robbins Company), "Final Report, Repository Drilled Hole Methods Study," SAND83-7085, prepared for Sandia National Laboratories, Albuquerque, NM, 1984. (HQS.880517.2331)

Robbins (The Robbins Company), "Design of a Machine to Bore and Line a Long Horizontal Hole in Tuff," SAND86-7004, prepared for Sandia National Laboratories, Albuquerque, NM, 1987. (NNA.870728.0071)

APPENDIX A

BOREHOLE DEVIATION TOLERANCES
(taken from DIM-202)

APPENDIX A

For drilling systems that have a steerable drill bit, it is assumed that the borehole centerline will deviate cyclically from a straight line, with a cycle wavelength of L and an amplitude of δ_b, as shown in Figure 1. It is also assumed that drilling and lining of the borehole will occur simultaneously, requiring up to 550,000 lb of trust to be applied through the liner to the bit. The maximum allowable deviation amplitude for this configuration is shown in Figures 2-6 for the various borehole lengths under consideration. The plotted data are also tabulated in Table I. For a borehole length of 350 ft, two figures are presented (Figures 5 and 6). Figure 5 presents the maximum allowable borehole deviation computed for liner insertion operations, and Figure 6 presents the maximum allowable borehole deviation computed for thermal expansion of the liner after waste emplacement. Depending on the deviation cycle wavelength and borehole diameter, the maximum allowable deviation may be dictated by either the liner insertion stresses or thermal stresses that arise after waste emplacement. The drilling system for 350 ft must therefore produce boreholes with deviations less than or equal to the values taken from Figure 5 or Figure 6, whichever is lower.

For drilling systems that do not have a steerable drill bit, it is assumed that the borehole centerline will deviate monotonically from a straight line, with a constant radius of curvature, ρ_b, and a total deviation at the end of the borehole of δ_b, as shown in Figure 7. The maximum allowable deviation for this configuration is shown in Figure 8 for the various borehole lengths under consideration. The plotted data are also tabulated in Table II. These results are for the case of thermal expansion after waste emplacement and are thus independent of whether borehole lining is done simultaneously or sequentially with borehole drilling. Data are not presented for a borehole length of 350 ft because it is assumed that any system selected for that configuration would have a steerable drill bit.

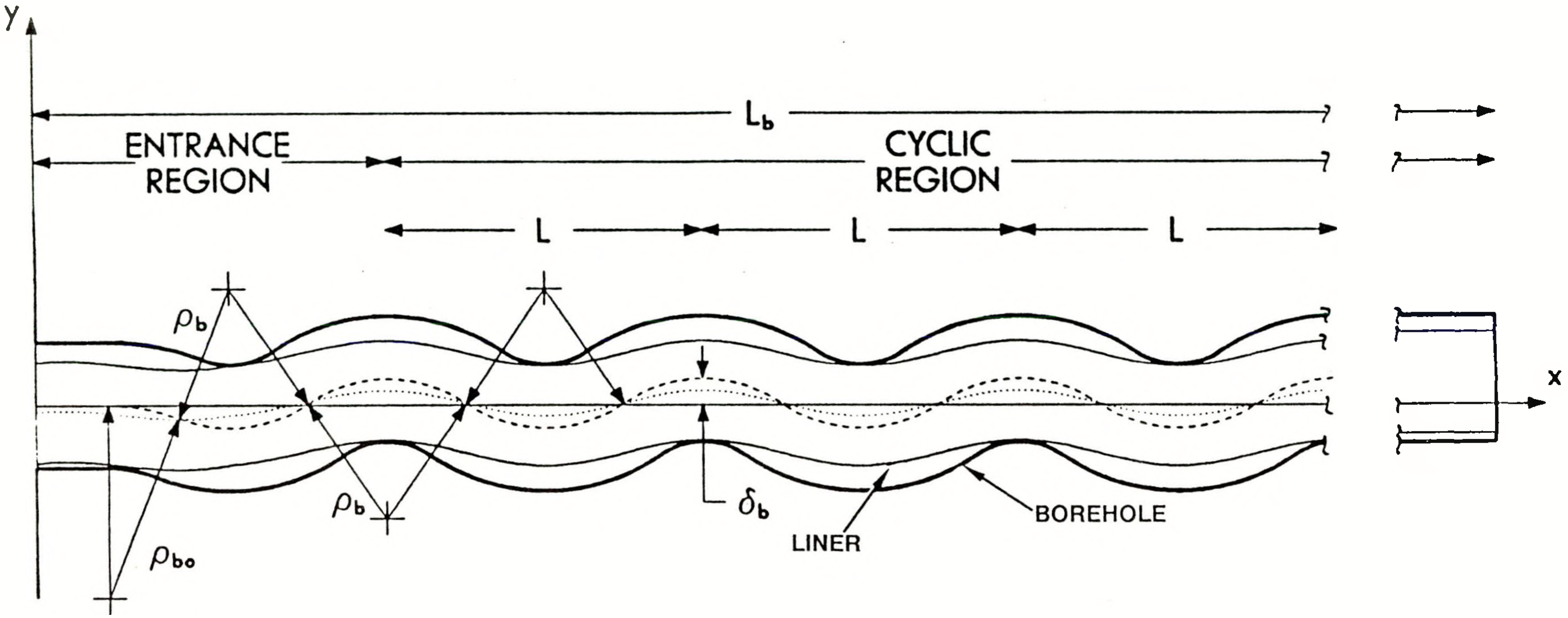

Figure 1. Assumed Borehole Configuration With Steerable Bit

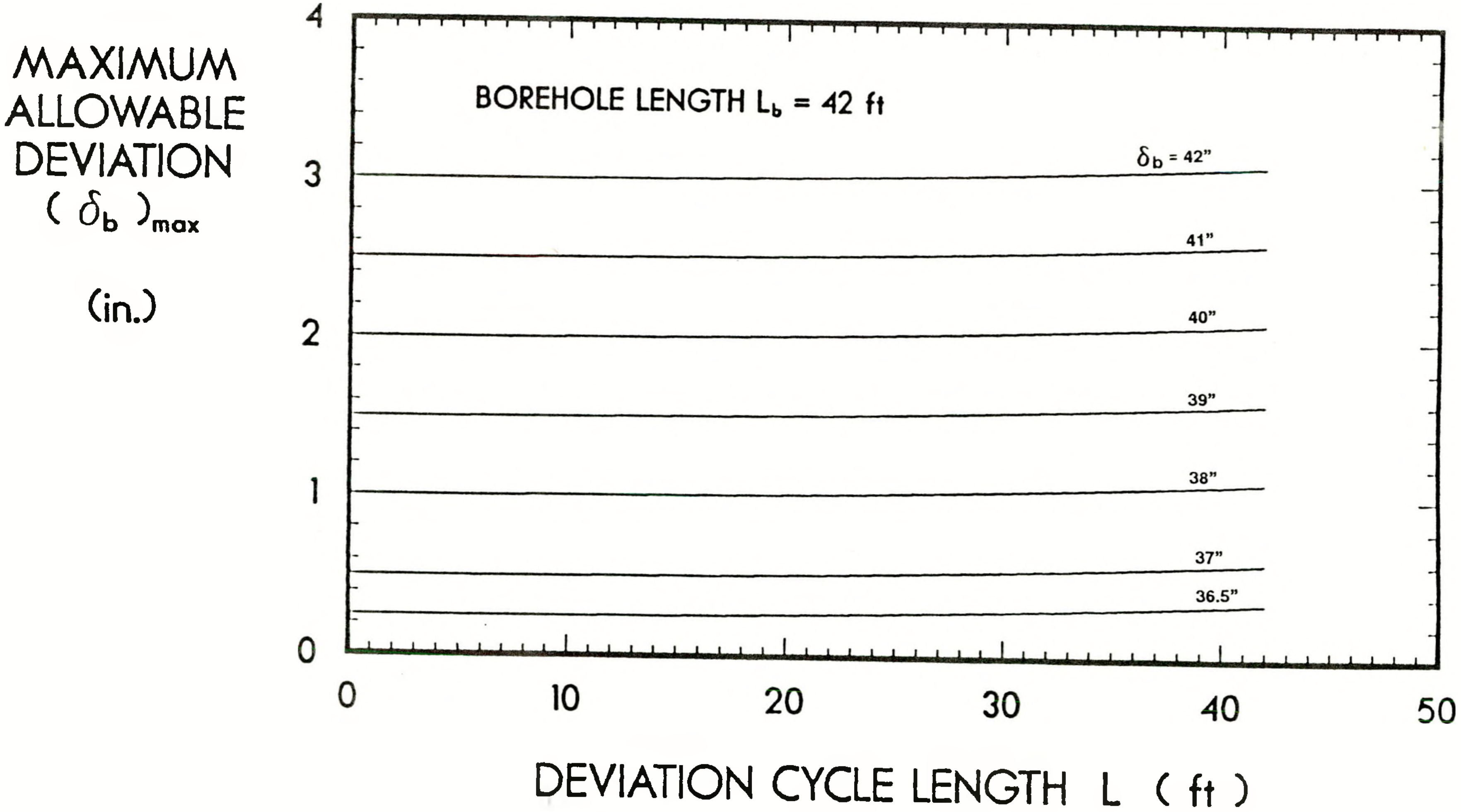

Figure 2. Maximum Allowable Borehole Deviation for 42-ft Borehole Drilled With Steerable Bit

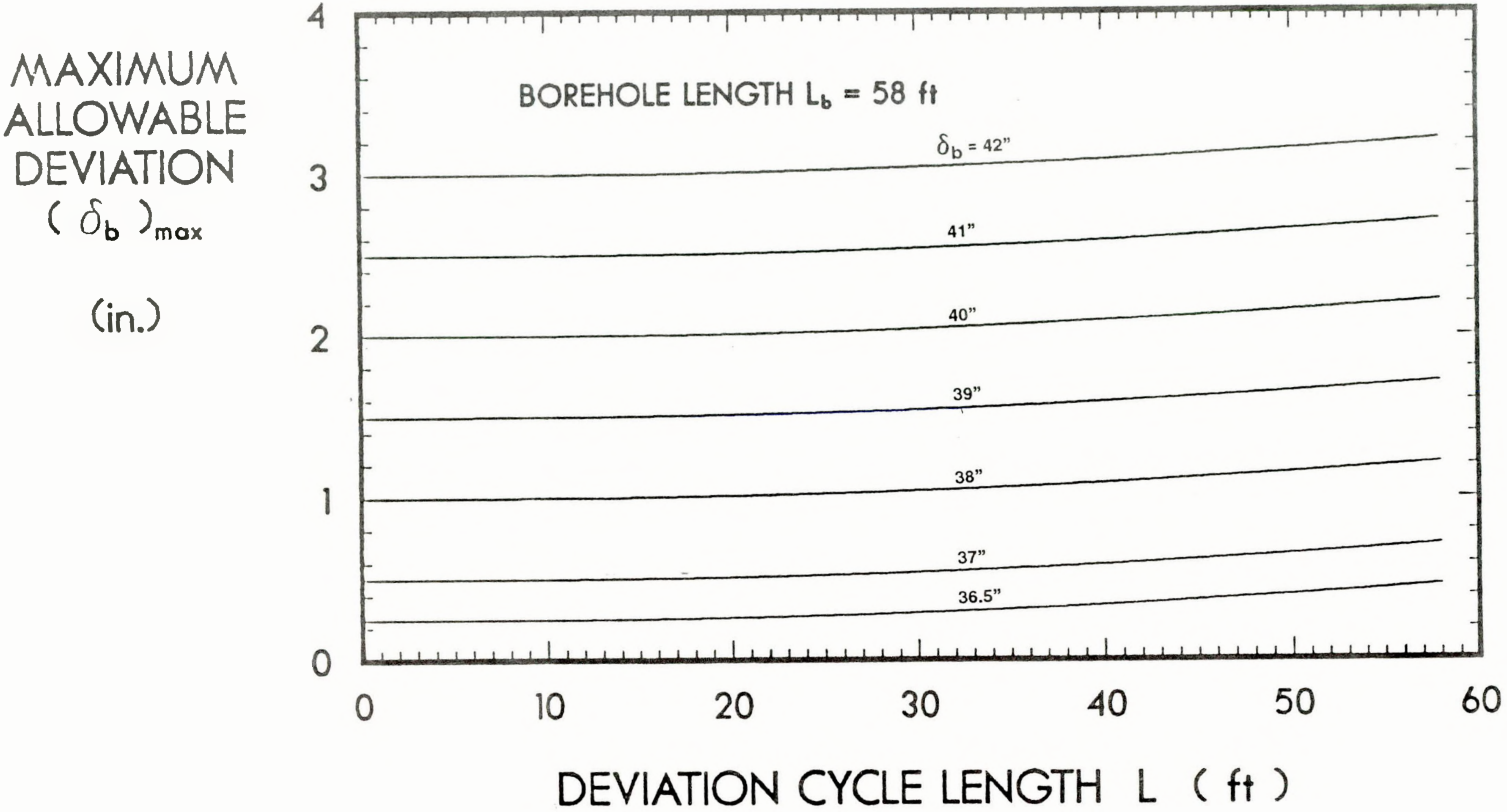

Figure 3. Maximum Allowable Borehole Deviation for 58-ft Borehole Drilled with Steerable Bit

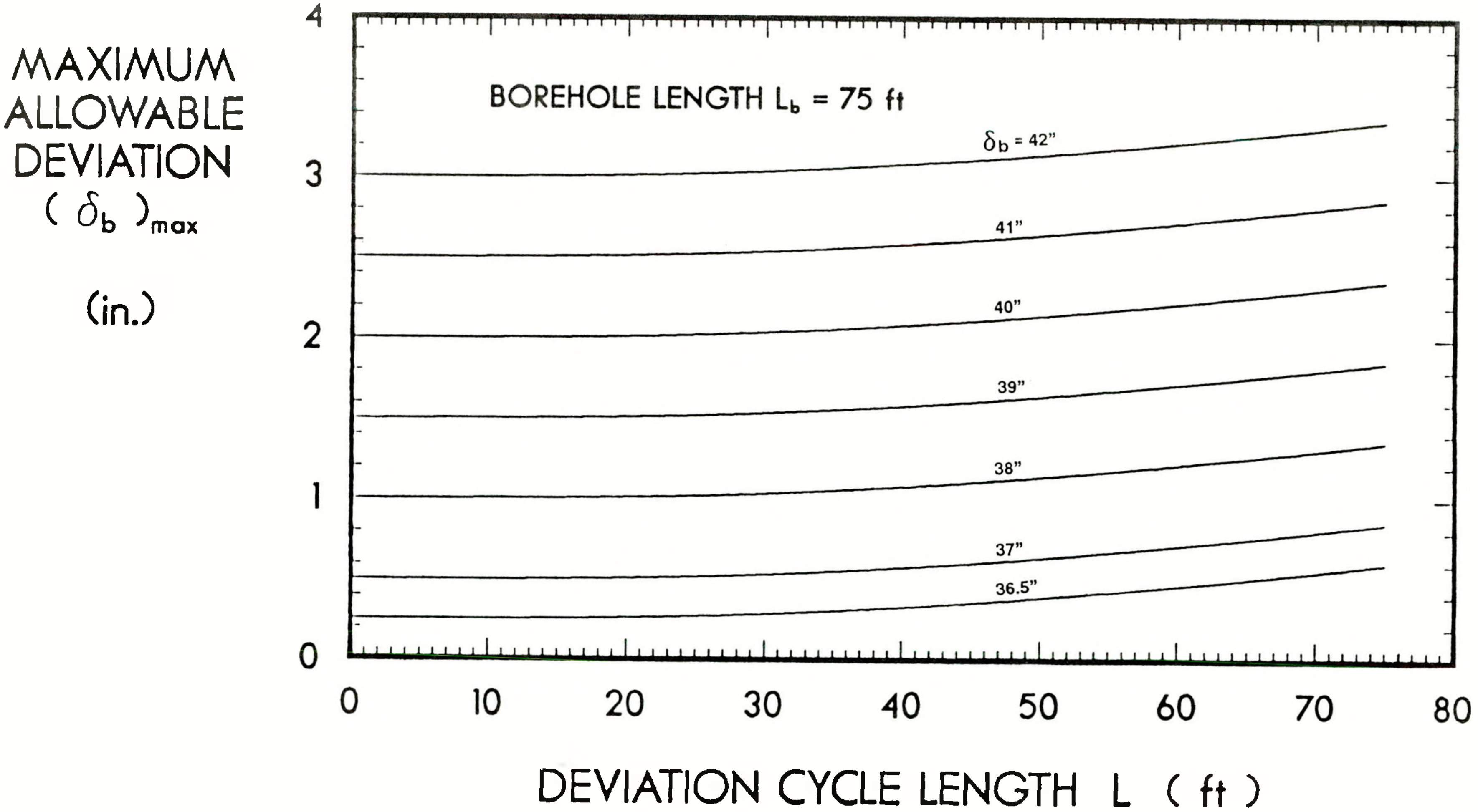

Figure 4. Maximum Allowable Borehole Deviation for 75-ft Borehole Drilled With Steerable Bit

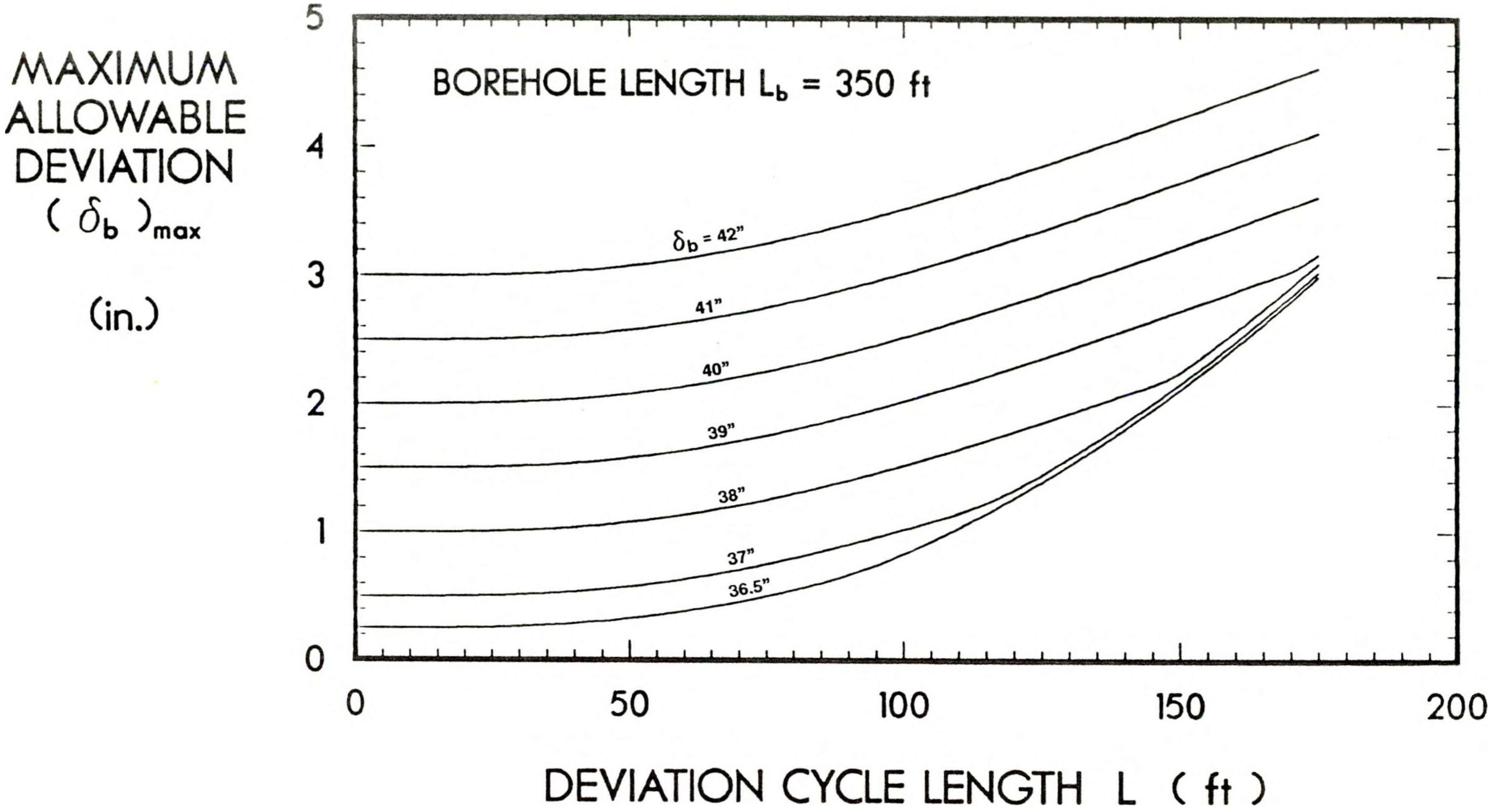

Figure 5. Maximum Allowable Borehole Deviation For 350-ft Borehole Drilled With Steerable Bit (Based on Liner Insertion Stresses)

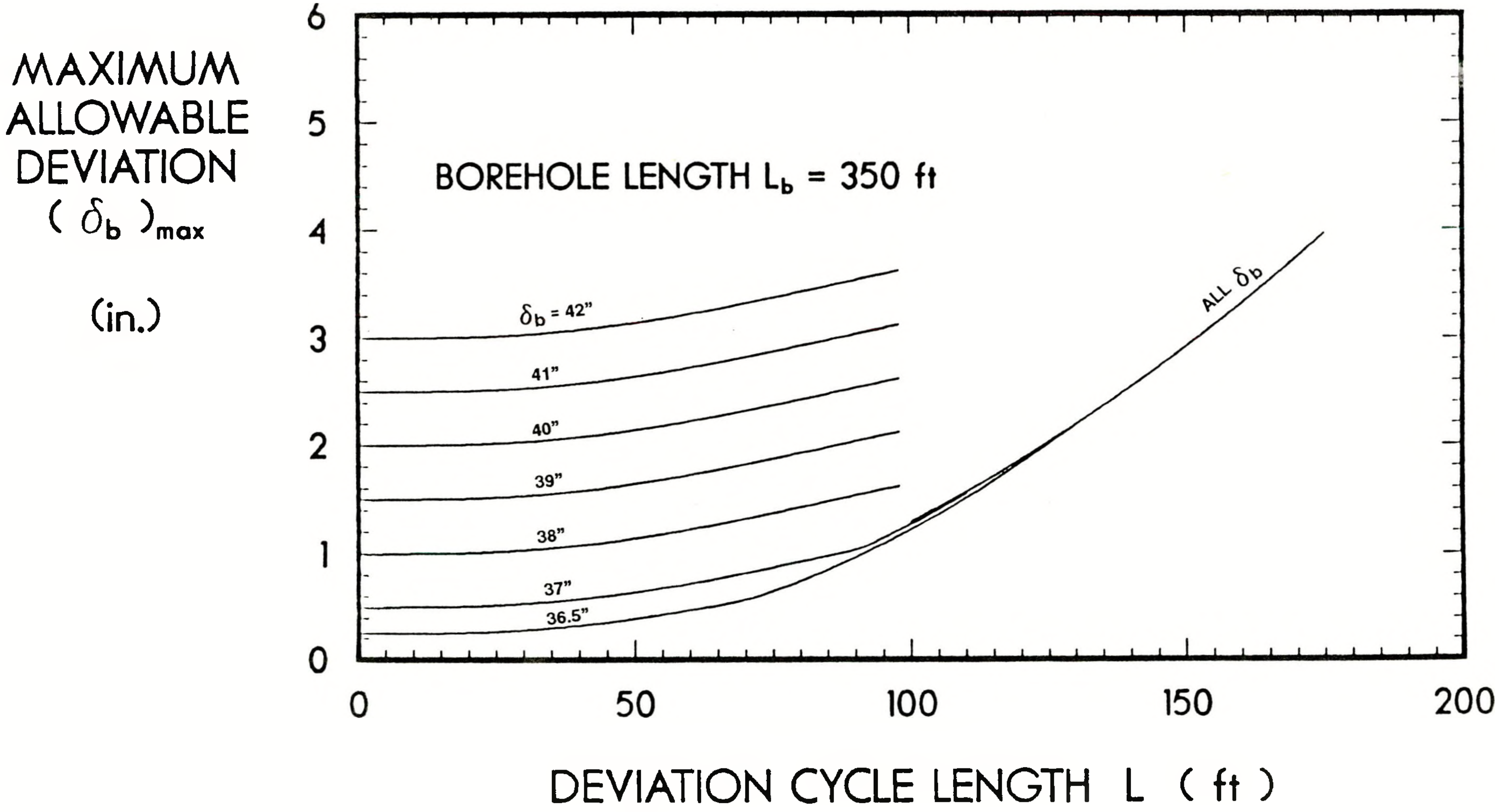

Figure 6. Maximum Allowable Borehole Deviation for 350-ft Borehole Drilled With Steerable Bit (Based on Thermal Stresses After Emplacement)

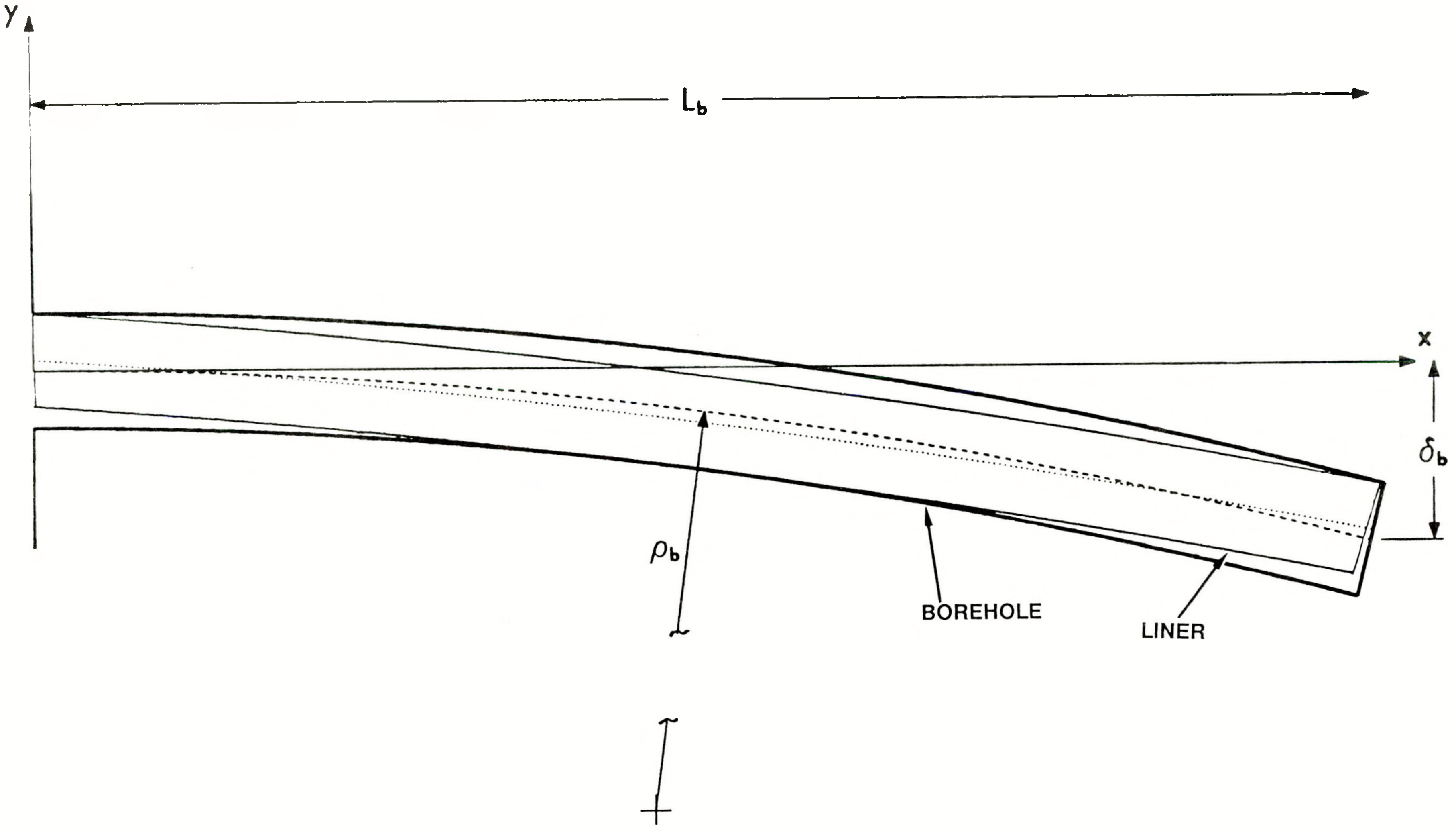

Figure 7. Assumed Borehole Configuration With Non-Steerable Bit

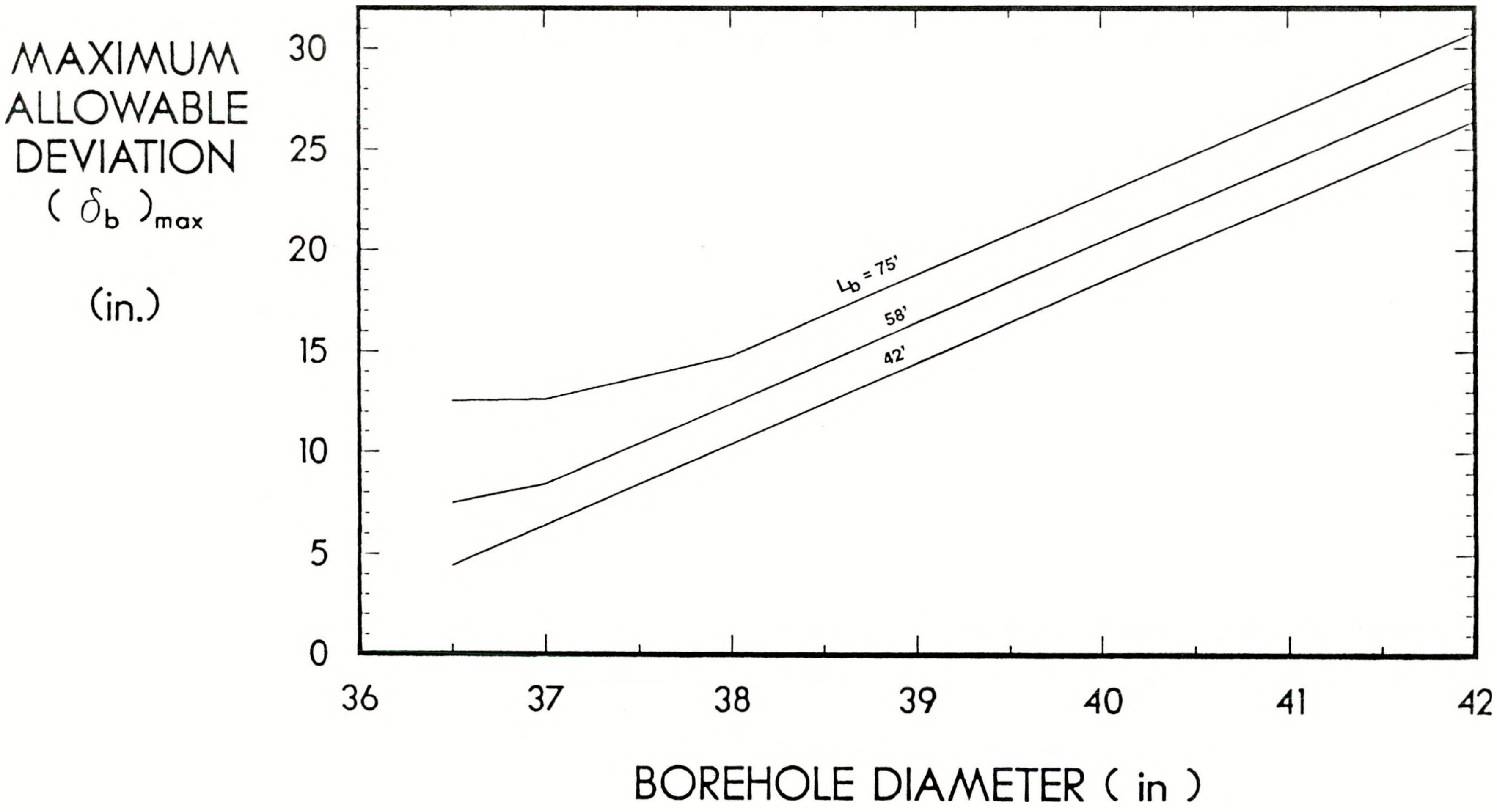

Figure 8. Maximum Allowable Deviation for Boreholes Drilled With a Non-Steerable Bit (Based on Thermal stresses After Emplacement)

TABLE I
MAXIMUM ALLOWABLE BOREHOLE DEVIATION WITH A STEERABLE DRILL BIT

		$(\delta_b)_{max}$ (INCHES)						
LB (FT)	L (FT)	DB = 36.5	37	38	39	40	41	42 in
42.	10.	0.252	0.502	1.002	1.502	2.002	2.502	3.002
42.	20.	0.265	0.515	1.015	1.515	2.015	2.515	3.015
42.	30.	0.297	0.547	1.047	1.547	2.047	2.547	3.047
42.	40.	0.345	0.595	1.095	1.595	2.095	2.595	3.095
42.	42.	0.357	0.607	1.107	1.607	2.107	2.607	3.107
58.	10.	0.251	0.501	1.001	1.501	2.001	2.501	3.001
58.	20.	0.263	0.513	1.013	1.513	2.013	2.513	3.013
58.	30.	0.292	0.542	1.042	1.542	2.042	2.542	3.042
58.	40.	0.338	0.588	1.088	1.588	2.088	2.588	3.088
58.	42.	0.350	0.600	1.100	1.600	2.100	2.600	3.100
58.	50.	0.401	0.651	1.151	1.651	2.151	2.651	3.151
58.	58.	0.462	0.712	1.212	1.712	2.212	2.712	3.212
75.	10.	0.251	0.501	1.001	1.501	2.001	2.501	3.001
75.	20.	0.261	0.511	1.011	1.511	2.011	2.511	3.011
75.	30.	0.288	0.538	1.038	1.538	2.038	2.538	3.038
75.	40.	0.332	0.582	1.082	1.582	2.082	2.582	3.082
75.	42.	0.343	0.593	1.093	1.593	2.093	2.593	3.093
75.	50.	0.394	0.644	1.144	1.644	2.144	2.644	3.144
75.	58.	0.453	0.703	1.203	1.703	2.203	2.703	3.203
75.	60.	0.470	0.720	1.220	1.720	2.220	2.720	3.220
75.	70.	0.560	0.810	1.310	1.810	2.310	2.810	3.310
75.	75.	0.609	0.859	1.359	1.859	2.359	2.859	3.359

TABLE I (CONT'D)

		$(\delta_b)_{max}$ (INCHES)						
LB (FT)	L (FT)	DB = 36.5	37	38	39	40	41	42
(BASED ON LINER INSERTION STRESSES)								
350.	10.	0.250	0.500	1.000	1.500	2.000	2.500	3.000
350.	20.	0.253	0.503	1.003	1.503	2.003	2.503	3.003
350.	30.	0.264	0.514	1.014	1.514	2.014	2.514	3.014
350.	40.	0.289	0.539	1.039	1.539	2.039	2.539	3.039
350.	42.	0.296	0.546	1.046	1.546	2.046	2.546	3.046
350.	50.	0.330	0.580	1.080	1.580	2.080	2.580	3.080
350.	58.	0.375	0.625	1.125	1.625	2.125	2.625	3.125
350.	60.	0.388	0.638	1.138	1.638	2.138	2.638	3.138
350.	70.	0.462	0.712	1.212	1.712	2.212	2.712	3.212
350.	75.	0.505	0.755	1.255	1.755	2.255	2.755	3.255
350.	100.	0.836	1.023	1.523	2.023	2.523	3.023	3.523
350.	110.	1.039	1.151	1.651	2.151	2.651	3.151	3.651
350.	120.	1.269	1.333	1.787	2.287	2.787	3.287	3.787
350.	130.	1.527	1.583	1.931	2.431	2.931	3.431	3.931
350.	133.	1.609	1.663	1.975	2.475	2.975	3.475	3.975
350.	135.	1.665	1.718	2.005	2.505	3.005	3.505	4.005
350.	138.	1.751	1.802	2.050	2.550	3.050	3.550	4.050
350.	140.	1.810	1.860	2.080	2.580	3.080	3.580	4.080
350.	150.	2.119	2.163	2.253	2.732	3.232	3.732	4.232
350.	200.	4.027	4.055	4.109	4.164	4.173	4.173	4.173
350.	250.	6.521	6.521	6.521	6.521	6.521	6.521	6.521
350.	300.	9.390	9.390	9.390	9.390	9.390	9.390	9.390
350.	350.	12.782	12.782	12.782	12.782	12.781	12.781	12.781
(BASED ON LINER STRESSES DURING THERMAL EXPANSION AFTER WASTE EMPLACEMENT)								
350.	10.	0.251	0.501	1.001	1.501	2.001	2.501	3.001
350.	20.	0.258	0.508	1.008	1.508	2.008	2.508	3.008
350.	30.	0.280	0.530	1.030	1.530	2.030	2.530	3.030
350.	40.	0.324	0.574	1.074	1.574	2.074	2.574	3.074
350.	42.	0.335	0.585	1.085	1.585	2.085	2.585	3.085
350.	50.	0.389	0.639	1.139	1.639	2.139	2.639	3.139
350.	58.	0.453	0.703	1.203	1.703	2.203	2.703	3.203
350.	60.	0.471	0.721	1.221	1.721	2.221	2.721	3.221
350.	70.	0.567	0.817	1.317	1.817	2.317	2.817	3.317
350.	75.	0.647	0.869	1.369	1.869	2.369	2.869	3.369
350.	100.	1.220	1.270	1.293	1.293	1.293	1.293	1.293
350.	110.	1.509	1.552	1.565	1.565	1.565	1.565	1.565
350.	120.	1.831	1.863	1.863	1.863	1.862	1.862	1.862
350.	130.	2.184	2.186	2.186	2.186	2.186	2.186	2.186
350.	133.	2.288	2.288	2.288	2.288	2.288	2.288	2.288
350.	135.	2.357	2.357	2.357	2.357	2.357	2.357	2.357
350.	138.	2.463	2.463	2.463	2.463	2.463	2.463	2.463
350.	140.	2.535	2.535	2.535	2.535	2.535	2.535	2.535
350.	150.	2.910	2.910	2.910	2.910	2.910	2.910	2.910
350.	200.	5.174	5.174	5.174	5.174	5.174	5.174	5.174
350.	250.	8.085	8.085	8.085	8.085	8.084	8.084	8.084
350.	300.	11.643	11.643	11.643	11.642	11.642	11.642	11.642
350.	350.	15.848	15.848	15.848	15.848	15.847	15.847	15.847

TABLE II
MAXIMUM ALLOWABLE BOREHOLE DEVIATION WITH A NON-STEERABLE DRILL BIT

	$(\delta_b)_{max}$ (INCHES)						
LB (FT)	DB = 36.5	37	38	39	40	41	42
42.	4.432	6.432	10.430	14.427	18.421	22.411	26.397
58.	7.481	8.421	12.420	16.417	20.414	24.408	28.399
75.	12.552	12.641	14.781	18.780	22.777	26.773	30.767

APPENDIX B

INFORMATION FROM THE REFERENCE INFORMATION BASE USED IN THIS REPORT

APPENDIX B

This report contains information from the Reference Information Base as noted in Section 1.3. Use of this information was to provide a general overview of the operating environment of the drilling systems and did not form design criteria which directly influenced the results of the study.

CANDIDATE INFORMATION FOR THE REFERENCE INFORMATION BASE

This report contains no candidate information for the Reference Information Base.

CANDIDATE INFORMATION FOR THE SITE & ENGINEERING PROPERTIES DATA BASE

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