COAL MINE RESCUE AND SURVIVAL SYSTEM

VOLUME III

RESCUE SUBSYSTEM

FINAL REPORT

September 1971

Prepared for

BUREAU OF MINES
U.S. Department of the Interior

Under Contract H0101262

By

WESTINGHOUSE ELECTRIC CORPORATION
Special Systems
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CHAPTER 1
INTRODUCTION

This volume constitutes the final report for the Rescue Subsystem portion of the Coal Mine Rescue and Survival System program conducted by the Westinghouse Electric Corporation under contract to the United States Bureau of Mines (Contract Number H0101262 dated June 17, 1970). The program was directed by the Special Systems Department of the Westinghouse, Baltimore, Maryland facility.

The basic objectives of the CMRSS program were to develop and test hardware to determine the efficacy of a variety of coal mine rescue and survival concepts and techniques. These concepts were drawn from two major sources: the Request for Proposal from the Bureau of Mines and the final report on the Mine Rescue and Survival Study conducted by the National Academy of Engineering (NAE).

Both of these documents recommended that the overall Coal Mine Rescue and Survival System comprise three subsystems: the Survival Subsystem, the Communications Location Subsystem, and the Rescue Subsystem. These subsystems are covered by Volumes I, II, and III, respectively, of this final report.

Each of the major tasks, corresponding to the three subsystems, was conducted by a subcontract organization. The Rowan Drilling Company, Inc., of Houston, Texas, was selected to conduct the design, development, and test on the Rescue Subsystem.

Once trapped miners are located by the Communication/Location Subsystem of the CMRSS or by other means, it is the purpose of the Rescue Subsystem to complete a probe hole as soon as possible from the surface to their location through which their survival needs can be met until a rescue hole reaches them in a minimum of additional time. The entire operation must be carried out without creating additional hazards for the men trapped underground.

Two separate rotary type drilling rigs, along with their associated drilling equipment, have been assembled to carry out the probe and the rescue drilling operations (see figure 1-1). Much of the equipment selected for assembly of the two drill rigs consists of standard items available from drilling equipment manufacturers; however, special requirements of the Rescue Subsystem, such as safety of trapped miners and helicopter or aircraft transport, made extensive special detail design and fabrication of equipment components necessary. Drilling industry experience gained by the Rowan Drilling Company during several decades of drilling small diameter holes has been applied to the design of equipment and drilling procedures for the probe rig operation, and the best current industry practice, developed only in recent years for the drilling of large diameter holes, has been applied to the design of equipment and drilling procedures for use with the rescue rig. Thus the two drill rigs and the operating techniques which make up the Rescue Subsystem represent current state of the art in the commercial drilling industry.

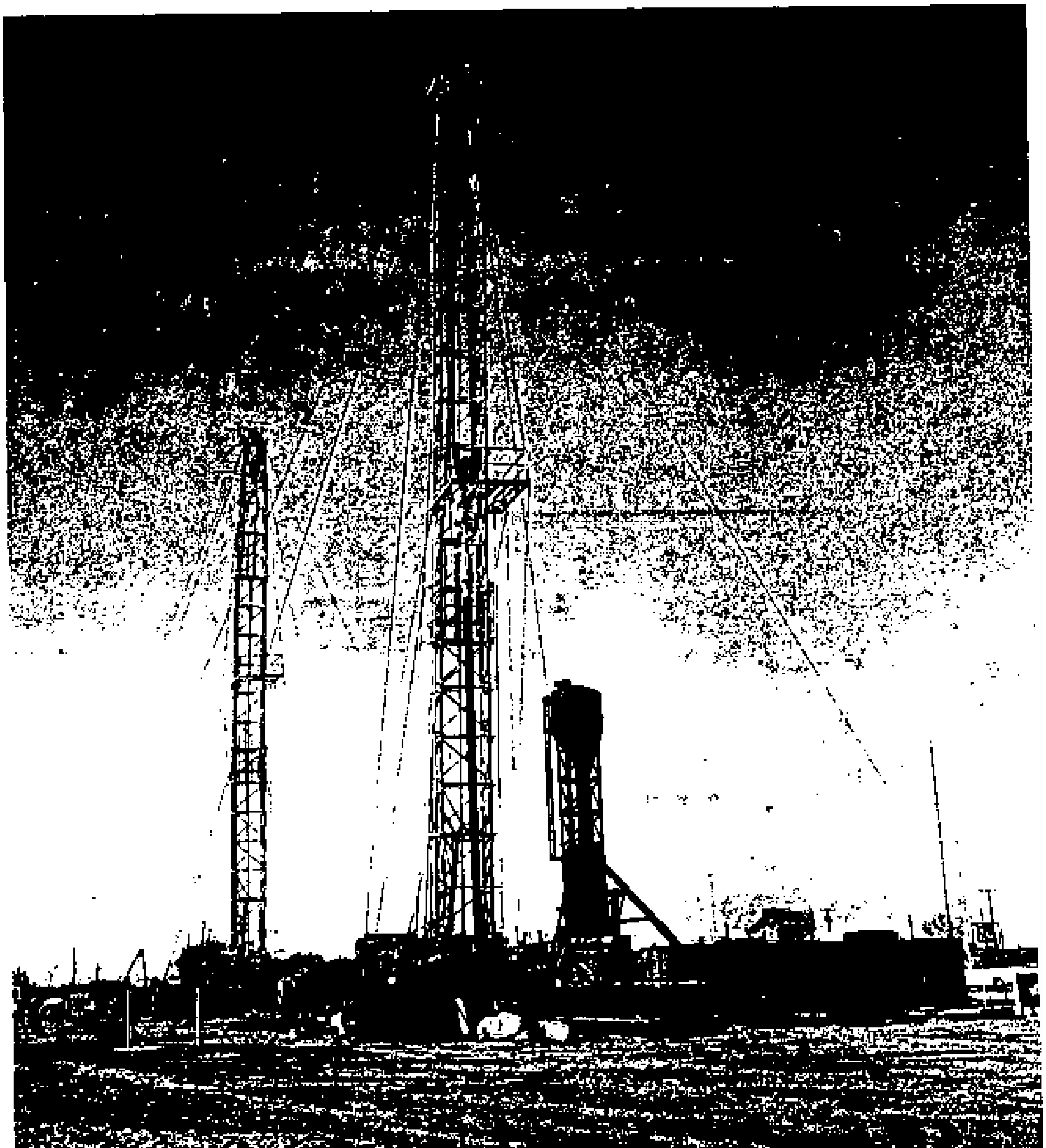

Figure 1-1. Rescue Rig (Foreground) and Probe Rig (Background)

CHAPTER 2
DESIGN

The overall direction of system design efforts and the choice of alternatives was dominated by the mandatory system performance characteristics and the schedule requirements of the contract.

The Request for Proposal which led to the contract limited the period of performance to 1 year. This mandatory requirement made it necessary to adapt existing designs and component hardware in configuring the two drilling systems. Once an adaptive (as opposed to an innovative) development approach was accepted, it became possible to complete the job within the 9-month period proposed by Westinghouse and incorporated in the contract but only with a highly compressed schedule which allowed only 5 months for the design phase which extended from subcontract award to completion of functional testing prior to the system demonstration. Consequently, equipment choices were based primarily on mandatory system performance parameters, taking into account the objectives of demonstrating the mine rescue potential of the NAE concept, and delivering hardware which could be further optimized for operational use by adding and modifying equipment without necessitating wholesale replacement.

The mandatory performance requirements, which dictated the size of the drill rigs and influenced characteristics affected by size, were the capability of both rigs to drill to 2,500 feet, the minimum hole sizes specified, and the requirement for transportability by freighter aircraft and heavy lift helicopter. Other contractual performance goals influenced design and resulting performance capability to the degree which was possible in view of the time constraint.

SECTION I
DESIGN CONSIDERATIONS

This section presents the special design considerations through which final design criteria were established. Included herein are the Rescue Subsystem performance goals and limitations and the results of the geological predesign study of the Appalachian region considered the primary area of mine emergencies.

HARDWARE CRITERIA AND PERFORMANCE GOALS

The National Academy of Engineering report, "Mine Rescue and Survival," established basic system specifications and operational capabilities for the Rescue Subsystem. Initial criteria specified in that report underwent additional scrutiny by the Bureau of Mines and further definition through subsequent analysis of subsystem requirements. As a result of these coordinated efforts, final requirements and anticipated performance goals were set forth in the Bureau of Mines contract with Westinghouse Electric Corporation.

The contract required a complete, self-sufficient drilling rig including supporting equipment on skids for each of the probe and rescue drilling operations. Hole diameter specifications were set at a minimum of 6 inches for the probe hole and 18 to 28 inches for the rescue hole. The Bureau of Mines imposed a depth capability of 1,500 feet with the possibility of being easily extended to 2,500 feet. This required sizing all machinery with a suitable safety factor for the weight and power required to handle 2,500-foot drill strings on both rigs. Hole deviation was limited to 2 degrees per 500 feet to ensure the necessary drilling accuracy required to locate miners trapped underground.

Drilling penetration rates are of the utmost importance to the success of mine rescue operations. Although the contract noted that varying geological conditions may constrain drilling progress, drill penetration goals were established for probe and rescue drilling operations. Probe hole penetration goals were 100 feet per hour in 12,000-psi compressive strength rock and 20 feet per hour in 25,000-psi rock (strong quartzite). For rescue drilling, the Bureau of Mines desired rates of 17 feet per hour in 12,000-psi rock and 6 feet per hour in 25,000-psi rock.

The acquisition and maintenance of drilling rigs and trained skilled crews are neither feasible nor economical for individual coal mine regions. Therefore, drilling equipment and qualified rescue personnel must have a marked degree of mobility to cover all possible mine emergency situations. To achieve this mobility, the equipment should be transportable by truck, cargo aircraft, and helicopter. Cargo aircraft can speed deployment over long distances and heavy lift helicopters can overcome severe accessibility problems in the vicinity of a mine emergency. An additional requirement was that the equipment must be quickly reassembled upon arrival at the emergency site. Crews must be drawn from active drilling areas as quickly as possible.

The contract specified supply of all auxiliary equipment necessary to operate the drilling rigs and effect the rescue. Specific hardware requirements, however, were not rigidly established but emerged from available technology, operational and terrain exigencies, and mobility considerations. These final hardware criteria are discussed in Section II of this chapter.

GEOLOGICAL AND OPERATIONAL SUMMARY

To establish subsystem requirements and performance goals in terms of final equipment design and drilling procedures, a predesign study was conducted of operational and geological possibilities and constraints. The study reviewed such problems as terrain, stratigraphy, formations, and ground water production in the Appalachian area. Various drilling procedures and equipment were also evaluated for potential use in probe and rescue drilling. As a result of this study, conversion from specifications to final design was facilitated and compliance with required performance enchanced.

Since a predominant portion of all underground bituminous coal mining in the United States is in the northern Appalachian basin, this region was chosen as the primary area of operations.[1] Nevertheless, the Rescue Subsystem must also have application to other coal mining regions with only limited modification for geological differences.

A detailed account of Appalachian geology appears in U.S. Geological Survey Professional Paper 580, "Mineral Resources of the Appalachian Region." Most of the coal mined in this area is from bituminous beds located in sedimentary formations of Pennsylvanian age (approximately 250 million years old) in the Appalachian Plateaus physiographic province. Some anthracite coal is mined in the Valley and Ridge physiographic province east of the Plateaus. Anthracite production represents only 2 percent of the total coal tonnage of the region. Therefore, the predesign study concentrated on the Plateaus province where mine emergencies are expected to be more frequent.

The Plateaus province extends from southern New York across western Pennsylvania, southeastern Ohio, West Virginia, eastern Kentucky and central Tennessee into northern Alabama. Figure 2-1 outlines the extent of the Plateaus province in the Appalachian region. Briefly, the landform is described as a dissected plateau with steep slopes of up to 45-degree angularity and relief of 500 to 1,500 feet. Except for thick glacial deposits in the northern portion, soils are generally thin, and the drainage pattern is either random or dendritic. Surface and near surface rock units are predominantly flat lying sandstone, siltstone, and shale.

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[1] Bidders Conference - CMRSS - demonstration was to be made within 100 miles of Charleston, West Virginia.

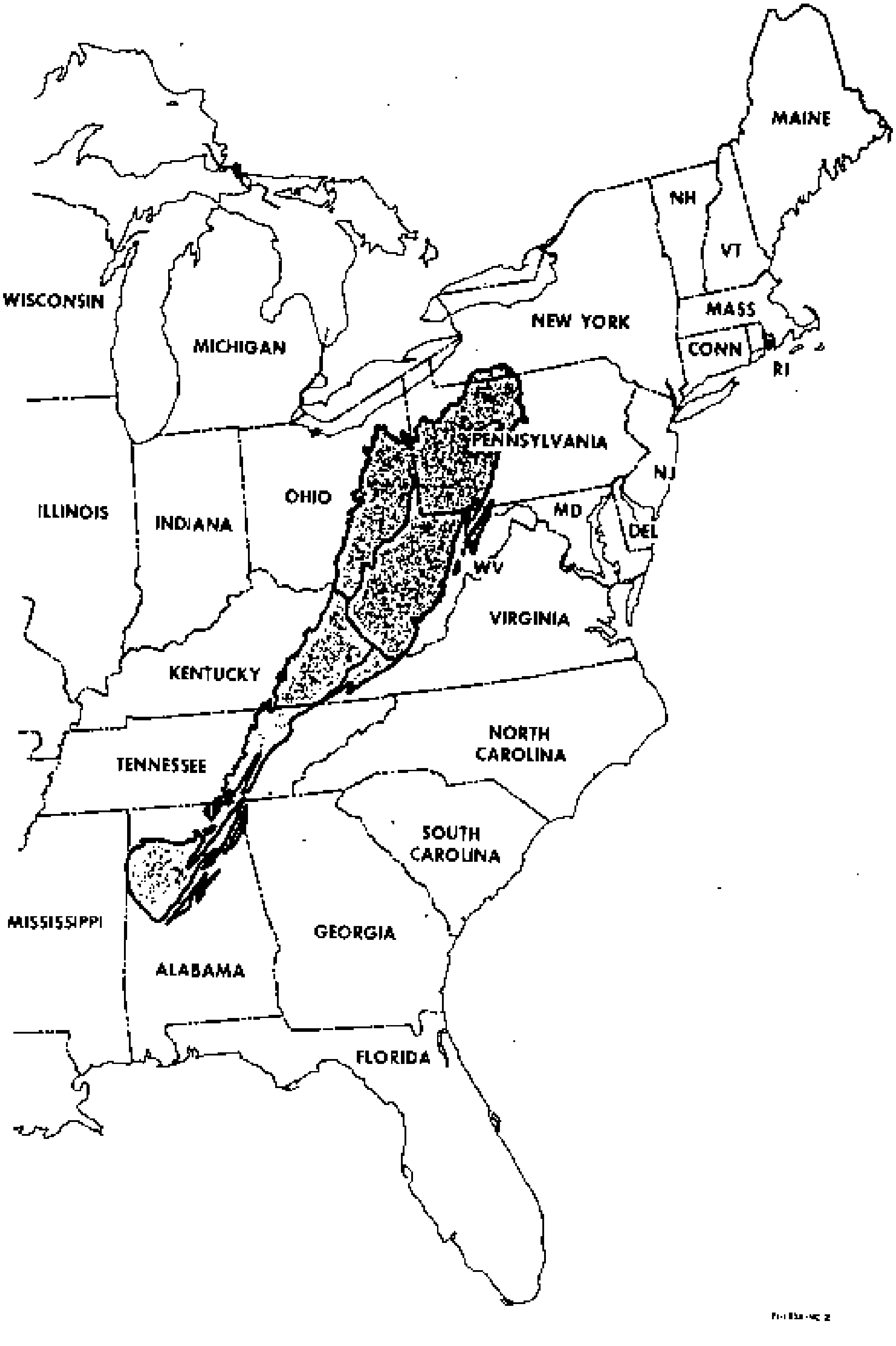

Figure 2-1. Extent of the Plateaus Province in the Appalachian Region

Structurally, coal beds in the Plateaus province are nearly horizontal in most places with local open folds and arches. Low - and high-angle faults exist in scattered areas. Varying in thickness from only a few inches to 8 feet, these beds occur at irregular stratigraphic intervals in the Pennsylvania age rock. Stratigraphy and the interval between coal seams are not always uniform, but rock strata apparently conform to a general sequence. Figure 2-2 depicts this general formation pattern and indicates that the predominant rock types are the same as those on the surface: sandstone, siltstone, and shale.

During the predesign study, it became apparent that drilling operations in the Appalachian Plateaus province must make provision for a number of anticipated climatic conditions and geographic difficulties. The sedimentary type formations that exist in the coal mining region determined the selection of drill bits and collar, rig power, circulating media, and much of the ancillary equipment. Similarly, the steep slopes and altitudes of 3,000 to 4,800 feet presented additional predesign problems. To avoid unnecessary delays during actual mine rescue operations, bulldozers were required in the event that leveling operations prior to rig assembly became necessary.

In the Plateaus province average yearly rainfall of 35 inches and from 20 to 100 inches of annual snowfall posed transportation problems. Under such conditions, the narrow and winding mountain roads that are prevalent in this area might prohibit transportation by truck. In addition to the narrowness of the roads, a number of low underpasses and limited bridge capacities further hinder transportation by truck.

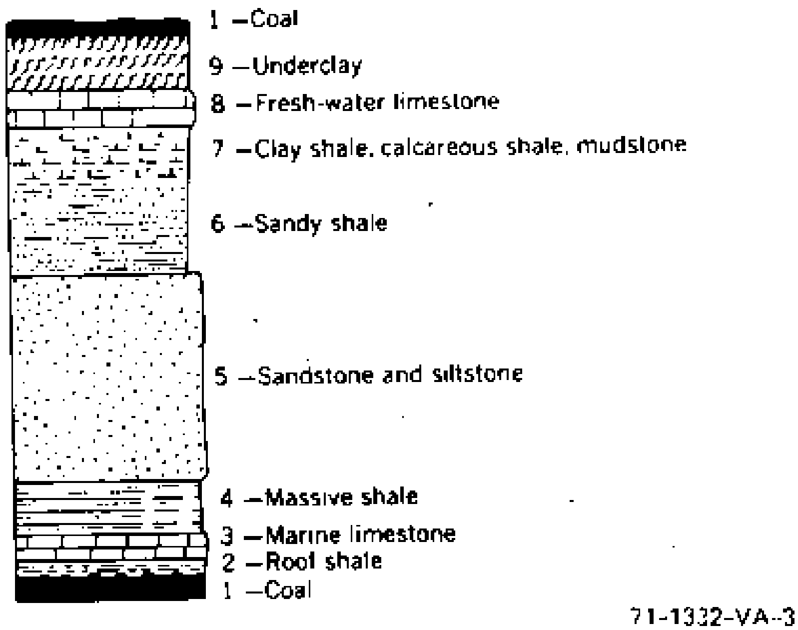

Figure 2-2. Typical Stratigraphy of the Plateaus Province

Drilling systems must be able to operate at temperatures down to -20°F in the winter.

Hydrology in the Plateaus province is favorable for the use of air as the circulating medium. Although generalization is difficult for such a large area, ground water tends to concentrate in the valleys along the natural topographic drainage pattern. Water found in the higher regions (where most of coal mining takes place) is usually transient water moving through fracture systems or small amounts of water attributable to formation porosity.

In the Appalachian Plateaus province, probe and rescue drilling operations will, for the most part, encounter only stable sedimentary rock formations with a minimum of sloughing and caving. Coupled with the fact that extensive water production is unlikely, the lack of significant sloughing and caving indicates only a limited need for casing reinforcement. Nevertheless, occasional washout of soft clay areas and coal and hard rock cave-in are possibilities and cannot be entirely discounted. These contingencies were thus provided for in the equipment design capabilities.

SECTION II
DESIGN IMPLEMENTATION

This section describes the final design phase of the Rescue Subsystem portion of the CMRSS program. Design selections and various alternatives are explained in detail for all phases of the system. Subjects covered in the following paragraphs include methods, circulation, downhole packages, and basic rig design for the probe and rescue drilling operations; ancillary equipment; drilling layout; transportation; and fabrication and assembly.

PROBE AND RESCUE DRILLING

The CMRSS contract established hole diameters at a minimum of 6 inches for the probe hole and a range of 18 to 28 inches for the rescue hole. In the design implementation phase of the program, operational efficiency and equipment availability were the major determining factors in the final selection of hole diameters.

The choice of 8-3/4 inches, an oil drilling industry standard, for the probe hole ensured immediate procurement of the downhole tool package and better system efficiency than smaller standard sizes. The quality and expected life of the large assortment of drill bits available in the 8-3/4-inch range are significantly better than the 6-1/4-inch drill bit standard. Also, with the larger bit size, heavier drill collar weight per inch of bit diameter can be obtained commercially, which is advantageous to penetration rate.

A diameter of 28-1/2 inches was chosen for the rescue hole size over smaller alternatives because it offers better drill bit selection, increased weight concentration near the bit, and more adequate casing capabilities. The 28-1/2-inch size enables the use of a commercially available big-hole bit with replaceable cutters loaded by 24-inch outside diameter donut weights which fit around a standard 12-inch outside diameter mandrel. This configuration provides heavier loading per inch of bit diameter for drilling near the surface and therefore higher initial penetration rates than can be obtained with a standard drill collar. Also, the concentration of weight near the bottom of the drill string enhances drilling accuracy. The wide selection of field-replaceable cutters available for this bit size are of advantage in achieving the best combination of penetration rate and bit life over a wide range of formation characteristics. Although standard tricone bits are available up to 26 inches in diameter, they are produced in only a limited variety of bit faces. Furthermore, a 26-inch tricone bit cannot accommodate 24-inch donut weights, the smallest which are commercially available.

The larger size drill pipe required for the 28-1/2-inch hole is advantageous for reverse air vacuum circulation. Similarly, the 8-3/4-inch probe hole also permits larger drill pipe than smaller holes, improving the possibility of using reverse air circulation for probe drilling. In addition to mechanical efficiency, the larger probe and rescue holes are physically better suited to the objectives of probe and rescue drilling. The few added inches facilitate passage of equipment, survival needs, and especially the rescue capsule.

DRILLING METHODS AND PROCEDURES

Rotary-type drilling has had the widest application of any method in the drilling industry. In rotary drilling, a drill bit or cutter is attached at the downhole end of a string of joined drill pipe sections extending to the surface rig. Drilling is usually accomplished by rotating the entire downhole assembly causing the drill bit to roll across the bottom of the hole and cut into the formation rock. The force on the cutting elements is provided either by the weight of the drill pipe and heavier sections of such pipe in the hole near the drill bit called drill collars or by force applied at the surface such as by transfer of the weight of the rig to the drill pipe column in various methods called "pulldown." Weight at the bottom of the hole, common in oil well drilling and large hole rotary drilling, tends to drill straighter holes because of the pendulous nature of the force. Pulldowns often bend the drill string slightly at each joint since the joint cannot be perfectly true and rigid and the forces must be transmitted from the surface all the way to the cutter bit. This can cause unacceptable deviations requiring detection and measurement as well as correction by techniques which are well established as feasible but quite time consuming. A suitable circulation method of air, water, or mud pumped through the drill pipe cleans the drill bit and lifts the formation cuttings from the hole.

Crewmen attach a special hexagonal section of pipe called a kelly to the drill pipe section nearest the surface. The kelly turns by means of special drive bushings housed within a circularly moving table and consequently causes the rotation of the downhole assembly. Figure 2-3 illustrates the rotary-type drilling assembly used in the rescue rig. The probe rig differs only in the downhole tool assembly configuration.

Various other drilling methods were considered, but all proved to be less adaptable than rotary drilling to rescue drilling purposes. Churn drilling is a generally outdated method in which the formation rock is broken by raising and lowering the drill bit in a churning motion. This method was quickly dismissed because of insufficient bit life.

A number of specialized drilling techniques have recently been developed. These methods include high-pressure water jet drilling, laser beam drilling, explosive or electric charge drilling, and thermal or flame jet drilling. All of these techniques could have application in rescue drilling operations, but many have had only limited field testing and some would be extremely dangerous at the breakthrough point. Percussive techniques, such as air hammers, have potential for special conditions including augmenting effective probe bit loading near the surface. Percussive techniques can be combined with rotary drilling.

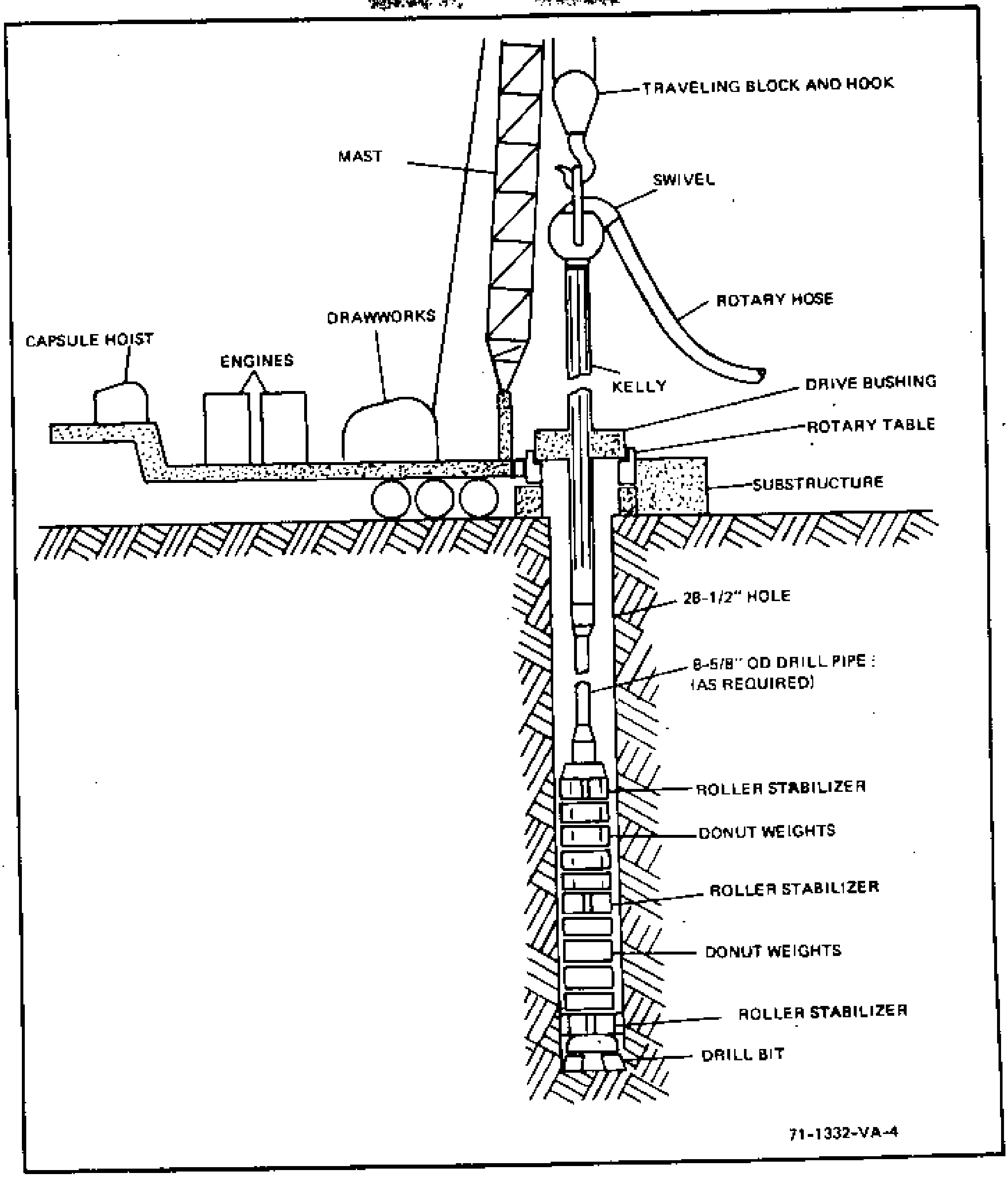

Figure 2-3. Typical Rotary Type Drilling Assembly

Thus, rotary drilling best exemplified compliance with stated specifications and performance goals. Overall penetration rates are considered optimum using rotary drilling, and equipment, both primary and ancillary, is readily available in proven reliable designs. Furthermore, the safest circulation medium for rescue drilling, air, is easily adaptable to rotary drilling, and pinpoint accuracies are possible.

A final advantage of rotary drilling was its flexibility: the capability to incorporate other drilling techniques in the rescue proceedings without restarting the hole. Most of the other techniques would, on the other hand, require major reworking and replanning to convert to rotary drilling if the need arose during rescue operations.

CIRCULATION SYSTEMS AND CASING PROGRAMS

In rotary drilling, a circulation system is used to remove formation cuttings from the bottom of the hole. The choice of the most effective medium is contingent on a number of factors including hydrology, formation types and fault systems, penetration necessities, and in rescue drilling, the miner's safety (the possibility of flooding a large volume of liquid at the point of breakthrough into the mine).

The direction of the circulation medium is either direct or indirect (reverse). In direct circulation, the medium flows through the drill pipe, across the drill bit face, and returns via the annular portion between the pipe and the hole to the surface. Indirect circulation simply reverses this direction of flow. The medium flows down the hole and returns through the drill pipe.

Air or water forms the basis of all circulation media. However, air circulation demonstrates significant advantages for probe and rescue drilling operations. In relatively dry and stable formation areas similar to the Appalachian region, air circulation produces excellent penetration rates and long bit life. Liquid or liquid-solid substances, on the other hand, do not offer comparable penetration rates and bit life and require lengthy casing operations. In areas where fracture systems tend to break down if a liquid substance like drilling mud is used, drilling operations and penetration rates are inhibited because casing must be set to prevent excessive circulation medium loss. Therefore, the CMRSS program anticipated the use of drilling mud or other suitable liquid-solid mixtures only when excessive water production or other factors invalidated air circulation procedures.

AIR CIRCULATION

Air circulation studies included both direct and indirect circulation processes. Among those methods studied were reverse air vacuum circulation, reverse low-pressure air circulation, and direct compressed air circulation including air/mist and air/foam variants.

In reverse air vacuum circulation, a vacuum is applied to the inside of the drill string at the rig level causing air flow up the drill pipe due to atmospheric pressure existing at the bottom of the hole. Rotary-type positive displacement blowers create the vacuum. The blowers selected for use in the probe and rescue drilling operations must maintain sufficient flow velocities to lift the formation cuttings from the hole. Vacuum pressures of 16 inches of mercury and flow velocities of 3,000 feet per minute are sufficient for the probe and rescue operations.

Formation cuttings are removed from the airstream by a cyclone type separator using a high-volume water spray to wash the cuttings into a steel mud pit for disposal. Figure 2-4 is a diagram of the direction of flow, blower operation, and cutting separation for the reverse air vacuum method.

Although the prime application of vacuum circulation is in dry formations, rescue drilling will function successfully with some water entry. If water entry is approximately 10 gallons per minute, the formation cuttings will have low enough viscosity to prevent drill pipe clogging. If small amounts of moisture cause the formation cuttings to cake and lodge in the drill pipe, the addition of approximately 8 gallons of water per minute to the hole will restore proper operation. Excessive water production prohibits vacuum circulation and necessitates conversion to another method.

Reverse air vacuum circulation fulfills the basic requirements in both probe and rescue drilling. It minimizes hole erosion near the surface and the liklihood of cave-in resulting from unstable cutting deposits when drilling through higher level mine workings above the trapped miners. Also, reverse vacuum circulation avoids the disposal of rock dust blown out of the hole when the direct method is used. A concern expressed in the NAE report for need to cover or close the probe hole while drilling the rescue hole is eliminated when the cuttings are controlled as they are with the reverse air vacuum technique.

The primary disadvantage of reverse air vacuum circulation concerns probe drilling operation. The comparatively small-bore drill pipe more easily clogs when a small amount of water is present. A review of the geometry of the bearing surfaces necessary to provide the forces to the conical cutters from the drill pipe and yet be small enough to allow openings for circulation medium passage to lift chips and as well cool the bearings shows the difficulty in optimizing the cutter design for penetration for a given rock material. In the case of the probe hole, the 8-3/4-inch diameter was expected to provide sufficient size for use of the vacuum system in many types of strata. The solution to this problem would require lengthy experimentation beyond the time constraints of the 9-month contractual period to determine a workable combination of vacuum pressures, air flow velocities, and water flooding techniques. Also, cleaning air tends to bypass the bottom, and air velocities are more limited at bit choke points than with the direct air circulation method.

Reverse air vacuum circulation was chosen as the primary method for rescue drilling and an alternative for probe drilling. In the case of rescue drilling, it is the only method that supplies air flow velocities sufficient to lift formation cuttings. Direct air circulation is impractical in large hole drilling because a prohibitively large air flow volume would be required to produce velocities sufficient for cuttings removal.

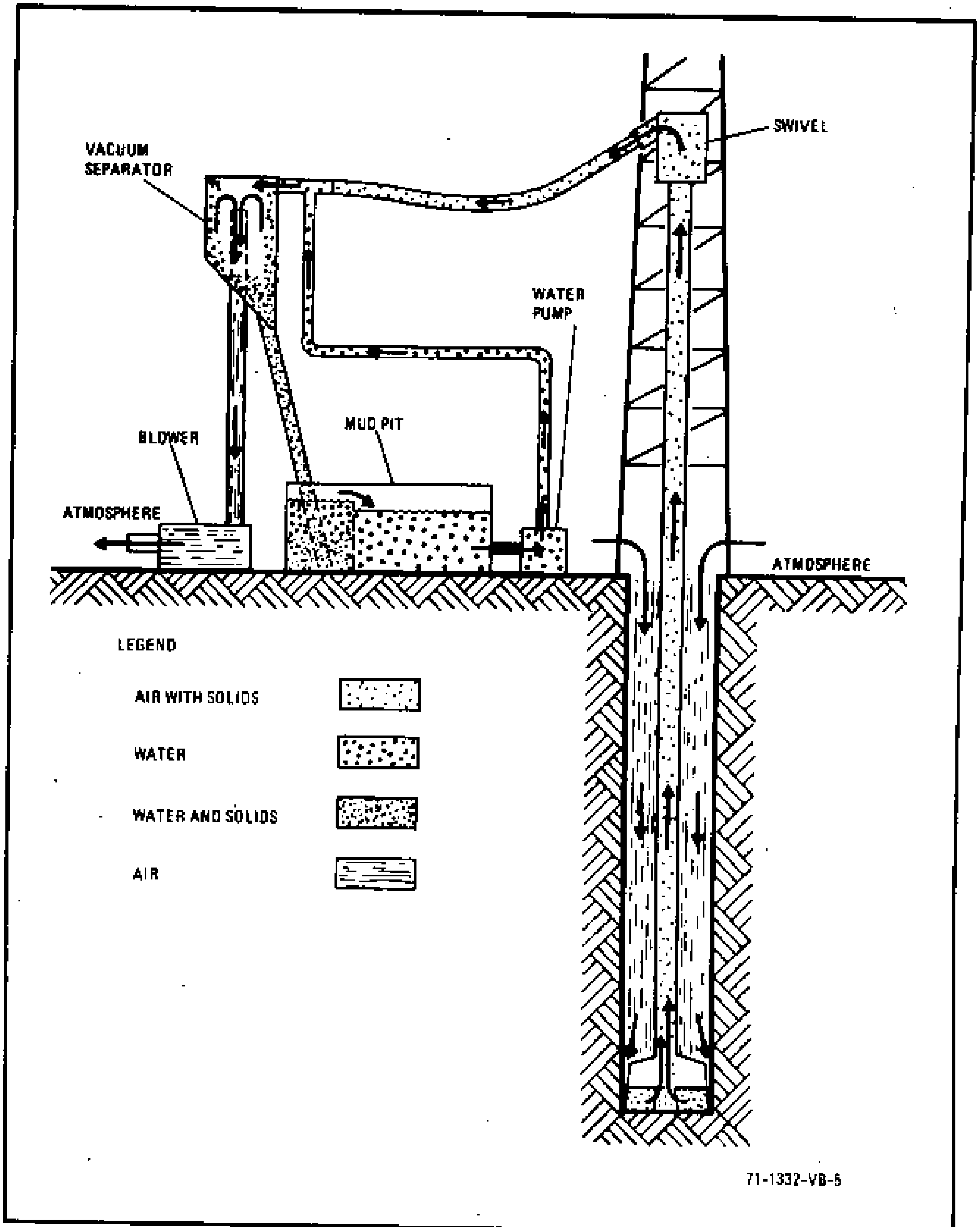

Figure 2-4. Reverse Air Vacuum Circulation

Reverse low-pressure air circulation injects large volumes of pressurized air into the annulus to generate the flow velocity up the pipe necessary to extract cuttings. This circulation system was discarded for Rescue Subsystem drilling because air pressure is difficult to maintain in areas where fracture systems exist.

Although rejected for rescue drilling, direct air circulation was chosen as the primary circulation system for probe operations. In this method, a high-pressure compressor (up to 300 psi for this operation) forces air down the drill pipe, cleaning the drill bit, and back up the drill pipe annulus. This technique is the most widely used air circulation method in the drilling industry for conventional size holes in relatively dry formation areas.

The flow rate of 1,200 cfm is necessary to provide adequate hole cleaning when drilling the 8-3/4-inch probe hole using direct compressed air circulation. Figure 2-5 depicts the operation of compressed air circulation in probe drilling. Direct air circulation can cause bottom hole pressures of 100 psi or more in deep holes when considerable formation water is present. At shallower depths of a few hundred feet in dry formations, pressures will still be in the 30- to 50-psi range. This characteristic must be taken into account at mine breakthrough in cases where roof fragments propelled by this force could strike personnel. Circulation can be interrupted before breakthrough or the vacuum method may be substituted.

To prevent dust and cuttings emission from the top of the hole, the use of direct compressed air circulation requires that a seal be applied around the kelly to cause the air to flow out away from the machinery area.

Also considered were air/mist and air/foam variants of the direct compressed air method. With the air/mist method, a water base mixture, normally with a detergent additive, is injected into the compressed air, usually to keep wet formation cuttings from caking up in the hole. With the air/foam method a special liquid is injected which mixes with the compressed air, producing a heavy foam similar in density and texture to aerosol types of shaving cream. The air/foam medium operates independently of air velocity and is therefore the only direct circulation medium that supplies the necessary lifting capability for rescue operations. Both systems can withstand large amounts of water production. Also, both systems generate undesirable bottom hole pressures restricting their use to those times when excessive water production precludes the use of air.

MUD CIRCULATION SYSTEMS

The most widely used liquid-based circulating medium in the drilling industry is a substance called drilling mud. Both direct and indirect circulations are possible with this substance. Cutting lifting capability is often improved by the mud viscosity resulting from the addition of bentonite gel and other additives, and the hydrostatic head created by the mud aids in holding back water, oil, or gas entry into the drilled hole.

Basically, direct and reverse circulation procedures for the use of drilling mud are similar to the air systems previously discussed. The Rescue

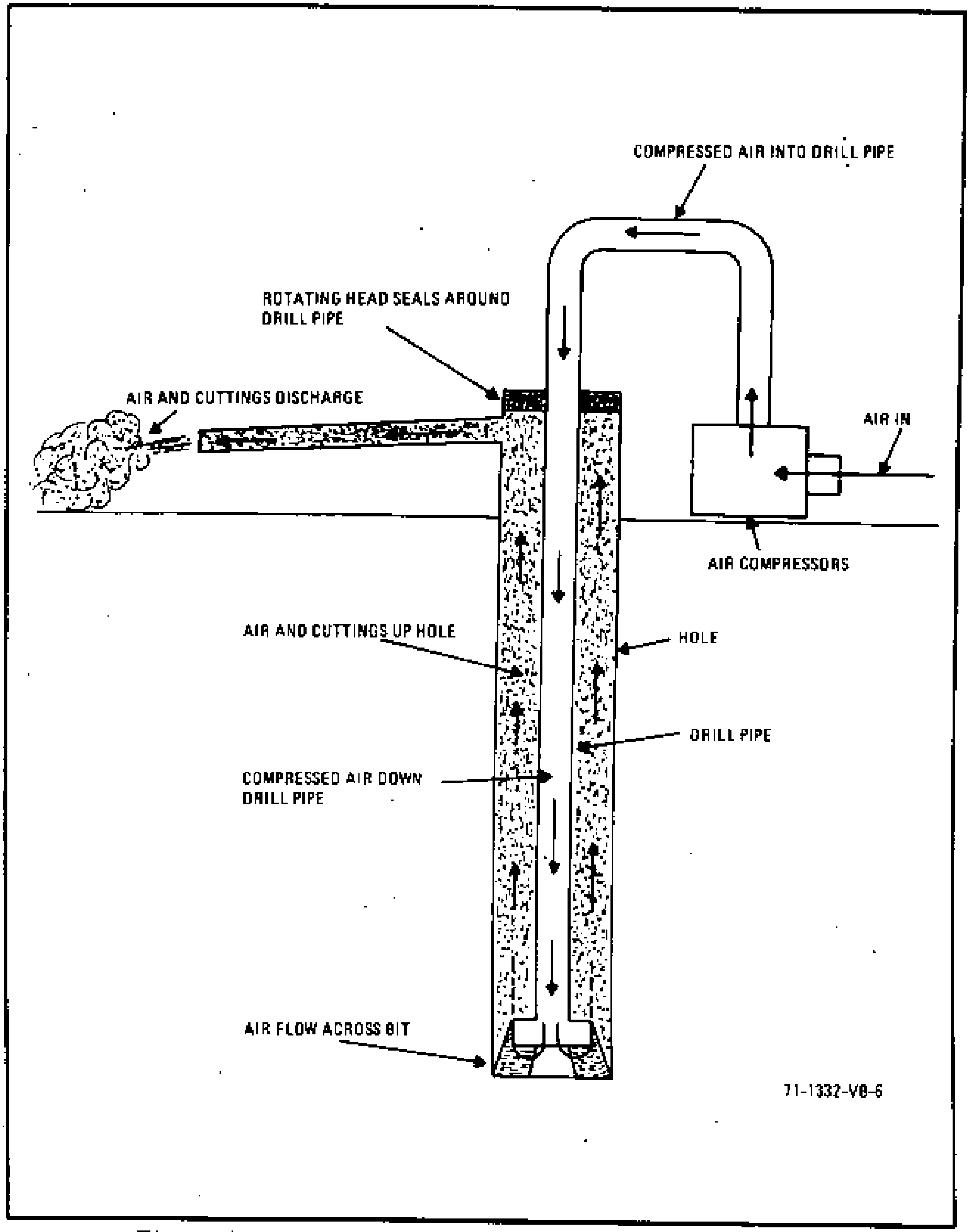

Figure 2-5. Direct Circulation With Compressed Air

Subsystem provides the capabilities of direct and reverse mud circulation for the probe hole and reverse mud circulation for the rescue hole. The air compressor supplied for direct compressed air circulation of the probe hole is satisfactory for mud circulation requirements. For the rescue hole, however, a flexible, small-diameter tube for pumping compressed air must be run inside the drill pipe to create adequate reverse airlift flow.

Both direct and indirect mud circulation systems require conversion to air circulation before breakthrough. Although mud circulation capabilities are available for use in probe and rescue operation, these systems will be implemented only when all other alternatives have proven inadequate. The direct circulation of drilling mud is outlined in figure 2-6.

CASING REQUIREMENTS

Casing requirements for probe and rescue drilling are not expected to be extensive. If drilling operations encounter light soil, soft formations, or surface water during the first few feet of drilling, a minimum casing program will be followed. This program involves the enlargement of the probe and rescue holes to 17-1/2 and 37-1/2 inches respectively. These diameters will be drilled as deep as required but probably will be to a depth of from 20 to 40 feet. Then casing of 13-3/8 and 36 inches will be set to this depth. If no further sloughing results, drilling will continue to completion at diameters of 8-3/4 and 28-1/2 inches.

It is unlikely that additional casing will be required. However, if excessive ground water occurs, a comprehensive sequential casing plan is possible for implementation. This program is graphically presented for probe and rescue drilling operations in figures 2-7 and 2-8.

DOWNHOLE PACKAGE DESIGN

Drilling experience with small and large diameter holes indicated two distinct downhole tool packages for probe and rescue drilling. In order to maintain sufficient air flow velocities and achieve good bit cleaning, the downhole assemblies were designed using the largest practical bore sizes for drill pipe and other downhole equipment.

The downhole tools required for the 8-3/4-inch probe hole are conventional and readily procured in considerable variety from stock. The rescue hole, however, dictated the use of a big-hole-type drilling assembly which has only recently come into general use. The advantages of the big hole assembly are that greater weight concentration can be applied to the drill bit and better stabilization is possible than with smaller conventional assemblies.

DRILL BIT SELECTION

Specific drill bits and cutters for the probe and rescue drilling systems were selected on the basis of rig ratings, circulation methods, and the range of formation characteristics which may be encountered during probe and rescue drilling operations.

Formation characteristics were evaluated by means of drillability tests carried out by the Smith Tool Company during December on 23 core samples from the Appalachian region. As a result of these tests, Smith type

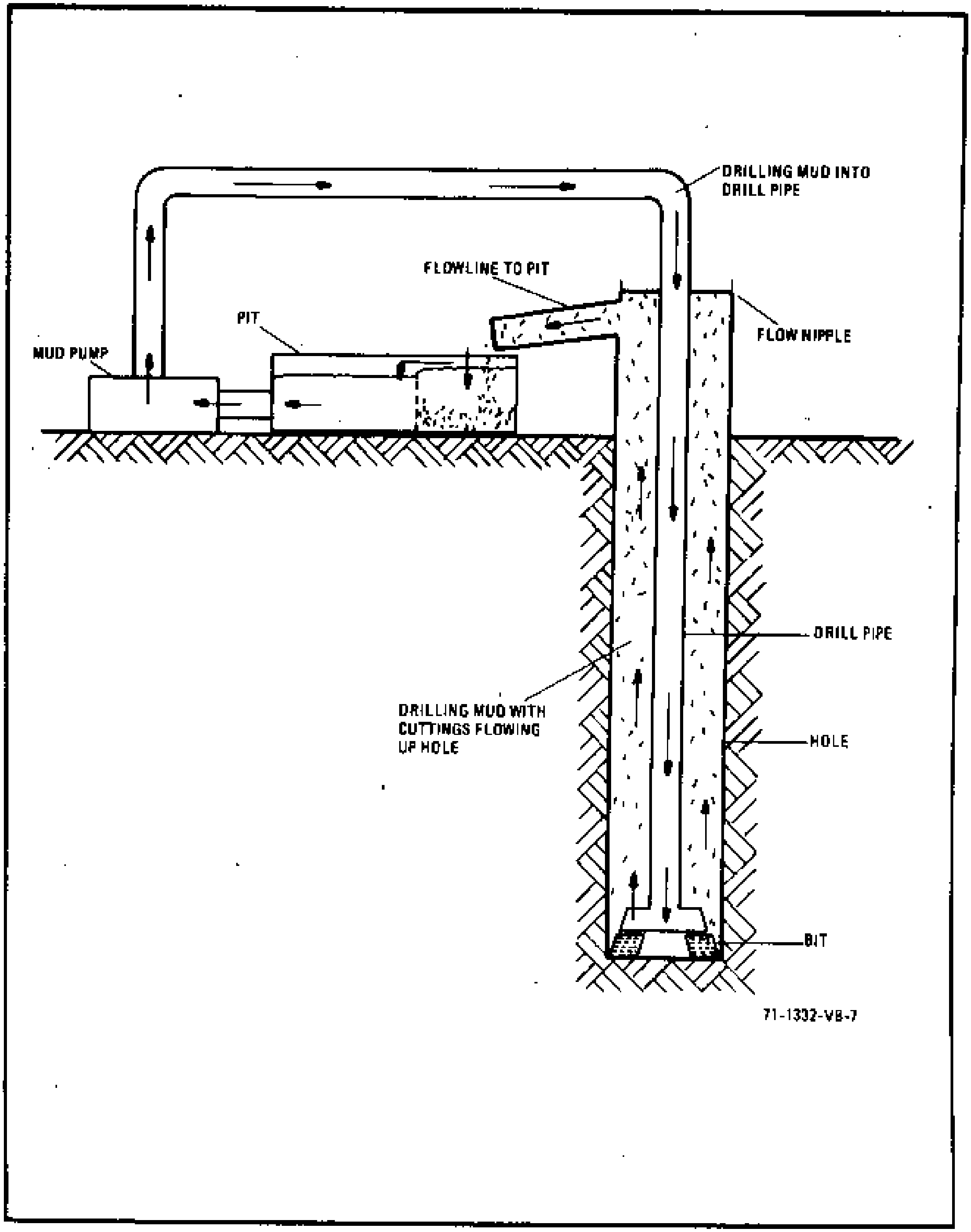

Figure 2-6. Direct Circulation With Drilling Mud

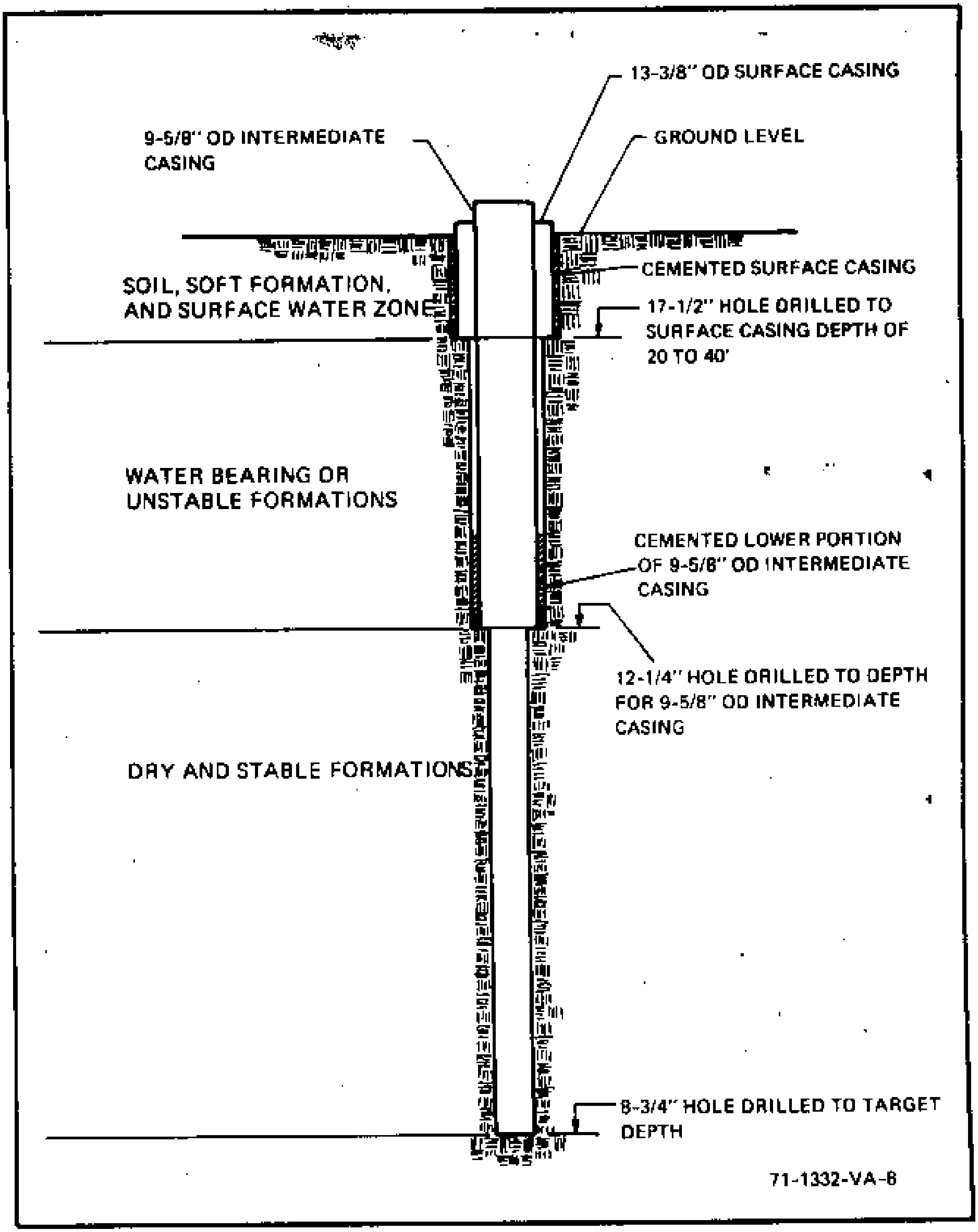

Figure 2-7. Hole Diameter and Casing Program for the Probe Hole Drilling Through Water-Bearing or Unstable Formations

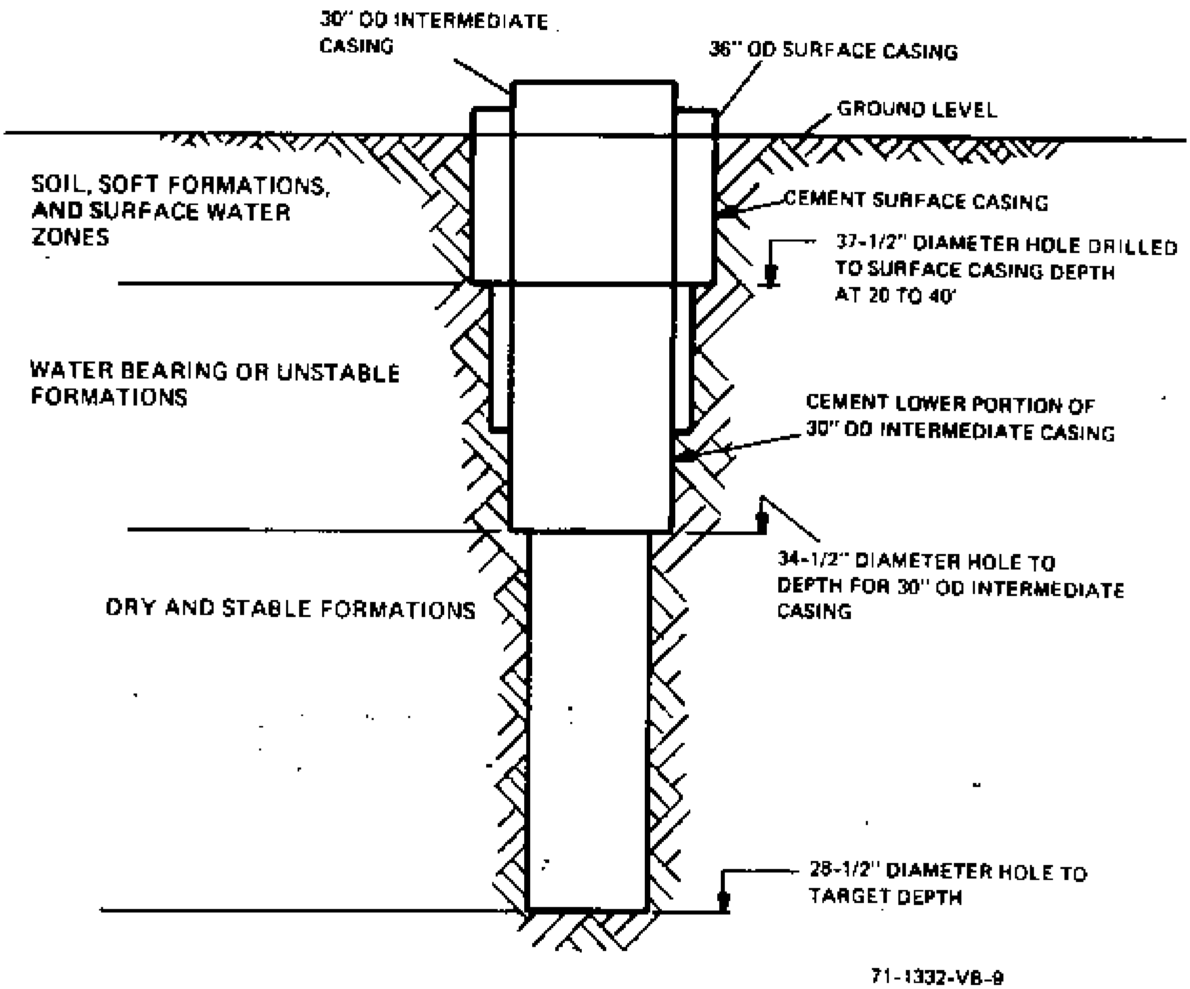

Figure 2-8. Casing Program for Rescue Hole

7 tungsten carbide insert bits and cutters were recommended for best average penetration rates and bit lifetimes in drilling both holes. For softer formations, medium length, milled tooth bits and cutters were recommended. Figure 2-9 shows an 8-3/4-inch tungsten carbide tricone bit, and figure 2-10 pictures a 28-1/2-inch replaceable cutter bit body with milled tooth cutters.

In conjunction with the drillability tests, the Smith Tool Company also calculated rates of penetration and operating lifetimes of the recommended bit and cutter types for each formation sample tested using bit loads and rotating speeds in the primary operating ranges of the two drilling systems. Table 2-1 gives the results of these performance calculations for probe hole drilling using a Smith type 7JS tungsten carbide bit. The calculations predicted average penetration rates of 21.1 and 25.7 feet per hour with bit loadings of 20,000 and 30,000 pounds at a rotating speed of 60 revolutions per minute. This compares to an average penetration rate of 22.35 feet per rotating hour observed during the demonstration in West Virginia when drilling between 100 and 700 feet with an average bit loading of 20,000 pounds and a rotating speed averaging 49 revolutions per minute.

Table 2-2 presents the results of these calculations for rescue hole drilling. For a 28-1/2-inch bit with Smith type 7 cutters loaded to 60,000 pounds, an average penetration rate of 6.6 feet per hour was predicted for a rotating speed of 25 revolutions per minute, increasing to 8 feet per hour at 35 revolutions per minute. During the demonstration in West Virginia, an average

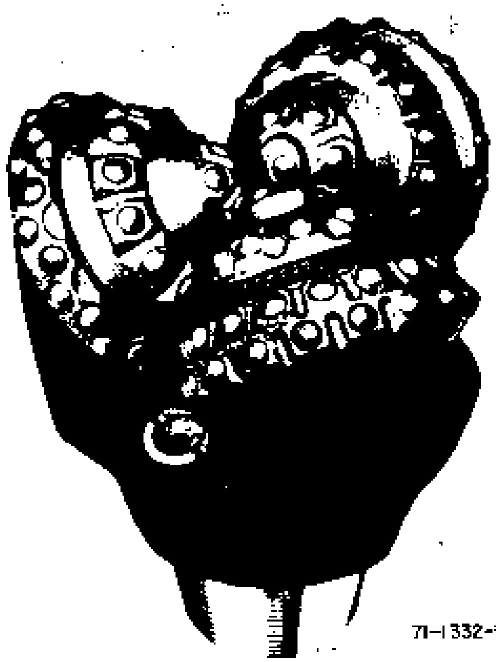

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Figure 2-9. Probe Hole 8-3/4-Inch Tungsten Carbide Tricone Bit

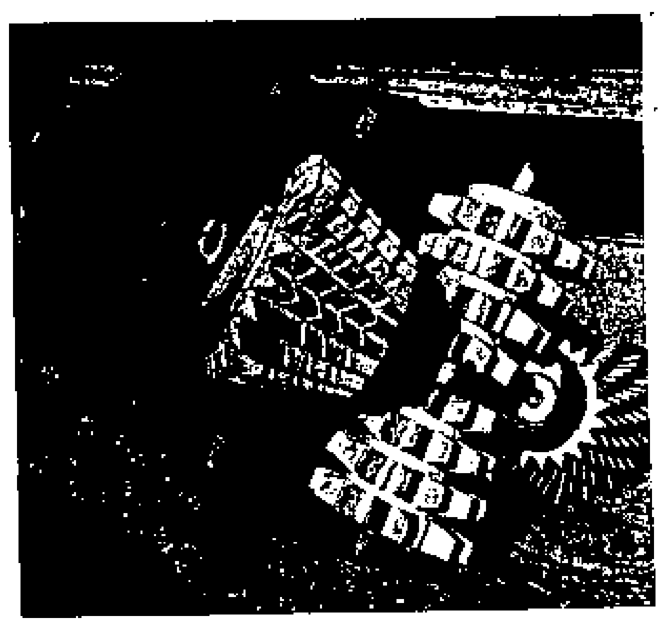

Figure 2-10. Rescue Hole 28-1/2-Inch Milled Tooth Cutter Bit

rate of penetration of 7.9 feet per rotating hour was recorded between 78 and 721 feet with an average of 50,000 pounds on the bit and 36 revolutions per minute rotating speed.

TABLE 2-1
CALCULATED PENETRATION RATES WITH AN 8-3/4-INCH SMITH SPECIAL TYPE 7JS BIT

Sample Number	Compressive Strength (psi)	RATE OF PENETRATION (ft/hr)	
		20,000 lb on Bit at 60 rpm	30,000 lb on Bit at 60 rpm
1	8,000	23.5	28.5
2	10,000	20.4	24.7
3	13,000	18.7	22.7
4	12,000	19.9	24.4
4a	13,000	19.7	23.9
5	5,000	31.5	38.3
6	20,000	15.1	18.7
7	5,000	33.1	40.2
8	6,000	31.0	37.3
9	8,000	27.3	33.0
10	8,000	25.9	31.5
11	11,700	19.9	24.4
12	15,000	17.5	21.6
13	12,000	21.7	26.5
14	15,000	18.4	22.7
15	15,000	19.3	23.8
16	25,000	12.7	15.7
17	12,000	20.9	25.7
18	17,000	15.7	19.3
19	15,000	16.7	20.4
20	15,000	16.6	20.4
21	10,000	21.6	26.1
22	15,000	17.5	21.6
23	10,000	22.7	27.5
Average		21.1	25.7

Estimated Bit Life: 55 Hours for Both Conditions

TABLE 2-2
CALCULATED PENETRATION RATES FOR 28-1/2-INCH BIT

Bit Body: Smith flat bottom type with two series GT gage cutters and one series 16 inch CT center cutters.

Cutter Types: Milled Tooth: Smith Type 2
Tungsten Carbide Insert Teeth: Smith Type 7

Sample Number	Compressive Strength (psi)	RATE OF PENETRATION (ft/hr)			
		60,000 lb on Bit at 25 rpm		60,000 lb on Bit at 30 rpm	
		Type 7 Cutters	Type 2 Cutters	Type 7 Cutters	Type 2 Cutters
1	8,000	7.4	2.8	8.9	3.4
2	10,000	6.4	2.3	7.6	2.8
3	13,000	5.9	1.8	7.0	2.1
4	12,000	6.3	2.1	7.5	2.5
4a	13,000	6.	1.8	7.4	2.2
5	5,000	9.9	5.2	11.8	6.2
6	20,000	4.8	1.1	5.8	1.3
7	5,000	10.4	5.4	12.4	6.5
8	6,000	9.6	4.6	11.6	5.5
9	8,000	8.5	3.5	10.2	4.2
10	8,000	8.2	3.1	9.8	3.7
11	11,700	6.3	2.1	7.5	2.5
12	15,000	5.5	1.4	6.6	1.7
13	12,000	6.9	2.2	8.2	2.7
14	15,000	5.8	1.5	7.0	1.8
15	15,000	6.1	1.5	7.3	1.9
16	25,000	4.0	0.7	4.8	0.8
17	12,000	6.6	2.1	7.9	2.5
18	17,000	5.0	1.3	6.0	1.6
19	15,000	5.2	1.3	6.3	1.6
20	15,000	5.2	1.3	6.3	1.6
21	10,000	6.7	2.5	8.1	2.9
22	15,000	5.5	1.5	6.6	1.9
23	10,000	7.1	2.6	8.5	3.1
Average		6.6		8.0	

Estimated Bit Life: Type 7 Cutters - 143 hours at 25 rpm
119 hours at 30 rpm

Type 2 Cutters - 106 hours at 25 rpm
88 hours at 30 rpm

DRILL PIPE HANDLING AND SELECTION

When the top end of the drive section of the kelly (the hexagonal portion) is down to the top surface of the drive bushing in the rotary table, a new piece of drill pipe must be added. This process is called "making a connection." Because of the importance of minimizing drilling time-out for making connections, the probe and rescue drilling systems employ a "double elevator" method for this function. The double elevator method eliminates the need for laying down the kelly in order to attach the new piece of drill pipe to the bottom of the kelly. First the drill string is raised until the kelly is fully up and the saver sub is clear of the drive bushing. The kelly and saver sub assembly is disconnected from the rest of the drill string at the joint to the uppermost drill pipe section with the drill string retained in the rotary table with wedge-shaped slips which hold the full weight of the raised drill string and tool assembly. The new piece of drill pipe is then linked to the kelly saver sub with a pair of elevators (see figure 2-11). The kelly with its saver sub, the double elevators, and the new length of drill pipe are then all hoisted into the air in the mast; and the lower end of the new pipe is joined to the top of the drill string. When this connection is torqued, the drill string is lowered until the new drill pipe upper threaded section is near the top of the rotating table. At this point the drill string is again held by the wedging slips, the elevators are removed, the lower end of the kelly saver sub torqued to the drill string, and the drill string lowered to allow the blocks to be inserted in the rotating table to engage the lower end of the kelly drive section. (In the case of the rescue rig the kelly drive section is already engaged in a rolling block assembly which itself engages lugs in the rotary table when the kelly is down in a driving position.)

Drilling now proceeds until the upper section of the kelly is down close to the rotary table at which time the cycle can be done again.

If drill bit cutters require changing or other difficulties necessitate removing the drilling tools from the hole, the drillers extract the string from the hole and disconnect it in sections of two joints each, approximately 63 feet long, known as double stands. These stands of drill pipe are setback in the drill rig finger board in the vertical position.

As drilling progresses and single joints of drill pipe are required for connections, the individual joints are pulled onto the rig floor directly from special drill pipe bins located at ground level adjacent to the drilling rig. Upon completion of the hole, the drill string is disconnected into single sections and returned to the bins directly from the rig floor. Use of these drill pipe bins facilitates drill pipe transportation and expedites its handling at the drill site.

The drill pipe for probe operations is a drilling industry standard with outside and inside diameters of 5 and 4.27 inches. This relatively large size pipe increases the capability for both direct and indirect air circulation. In direct circulation, the use of 5-inch drill pipe decreases the annular area of the hole thus increasing air velocity and lifting capability. Also, this

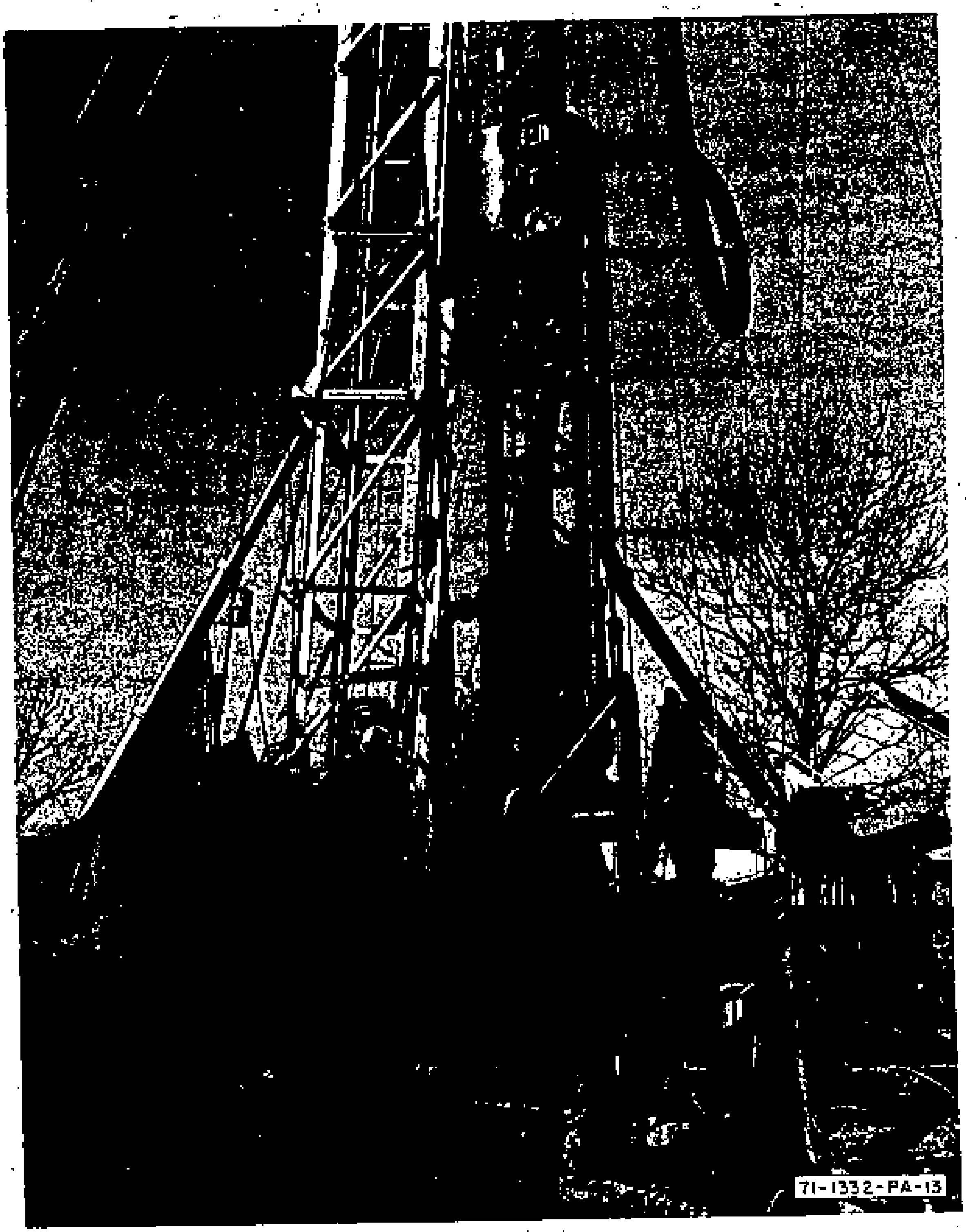

Figure 2-11. Drill Pipe Elevators

larger size drill pipe lessens the liklihood of cuttings clogging the pipe therefore enhancing the possibility of reverse circulation for the probe hole.

In order to attain the most advantageous air flow during reverse air circulation, Rescue Subsystem design personnel selected the largest pipe practical for rescue drilling. The critical outside and inside diameters are 8-5/8 and 7-1/2 inches.

Tool joints used for connection are coarse-threaded shouldered rotary tool joints. The tool joints for the 5-inch probe hole pipe have an outside diameter of 6-3/8 inches and an inside diameter of 3-3/5 inches. For the rescue hole joints, the outside and inside dimensions are 11-1/4 and 9-3/4-inches respectively. The length of these pipe sections averages 31-1/3 feet, and probe and rescue pipe weights per foot are 19-1/2 and 51 pounds. Both pipes chosen have tensile strengths in excess of all anticipated requirements.

For probe drilling operations, standard 7-inch, 30-foot-long drill collars give additional weight to the drill bit. Stabilizers were not supplied for the demonstration because the need for them was considered small. However, if drilling deviation proved inordinately high, a stabilizer would be placed approximately 60 feet above the bit to swing the bit back to vertical.

The primary component of the downhole rescue drilling assembly is the 12-inch outside diameter by 7-1/2-inch inside diameter mandrel. The mandrel, composed of three sections, forms the foundation on which the other components are assembled. The lower section is 10 feet long with a roller-type stabilizer permanently installed at the end nearest the drill bit. This lower end of the mandrel, shown in figure 2-12, has a 4-inch flange which connects to a matching flange on top of the replaceable cutter bits. Two additional sections of 20 and 30 feet extend the total length of the mandrel to 60 feet.

Most of the weight in the drilling assembly is supplied by the 21 cast steel donut weights which fit around the mandrel. Each of these weights weighs approximately 1,900 pounds with a diameter of 24 inches and a length of 24 inches. The weights are cast in two interlocking pieces for easy placement and removal around the assembled mandrel shaft.

To center the drilling assembly in the hole and ensure needed drilling accuracy, two roller stabilizers are mounted on the assembly in addition to the one affixed to the lower end of the mandrel. These two additional stabilizers have four replaceable rollers. Three heavy holddown clamps prevent the stabilizers from rotating on the mandrel.

When the 60-foot mandrel is fully assembled with the 21 donut weights, three stabilizers, and three holddown clamps, the total assembly weighs 63,700 pounds. This high weight concentration immediately above the drill bit provides a plumb bob effect which helps to keep the hole straight. The upper portion of the drilling assembly for the rescue rig appears in figure 2-13.

Although not specifically part of the downhole tool assemblies, the kelly and swivel are integrally involved with its rotation. A 6-inch nominal size

Figure 2-12. Lower Mandrel Section

kelly was chosen for probe hole drilling, and the kelly for rescue hole drilling has a diameter of 10 inches. Both kellys are 40 feet long and offer 37 feet of working space for easy connection. Tension and torque ratings for the kelly selected meet all drilling operation requirements.

The rotary table rotates the kelly by means of the special roller-type drive bushings housed within the table. These roller bushings create less frictional drag on the kelly than more conventional drive bushings.

The swivel connected to the top of the kelly permits rotation of the drill string and provides a means of circulating fluid through the rotary drill string. The swivels chosen for probe and rescue drilling are standard except for the unusually large internal diameters. Under static conditions, the 4-inch probe swivel is rated at 150,000 pounds and the 8-inch rescue swivel is rated at 350,000 pounds. At 40 revolutions per minute, the rescue swivel rating drops to 225,000 pounds. For transportation purposes, the 64-foot-long rotary hose supplied with the rescue swivel is divided into two 32-foot sections.

BASIC RIG DESIGN

The Wilson Super "38" probe rig and Wilson Mogul "42" rescue rig are nearly identical in envelope dimensions, functional design, and component arrangement. However, to fulfill their special applications and goals, the rigs underwent a number of important modifications.

A major design achievement was rig disassembly into component modules of 18,000 pounds or less for helicopter transportation. In addition, dimensional restrictions and other mobility requirements were necessary to ensure transportation of the rigs by truck and cargo aircraft.

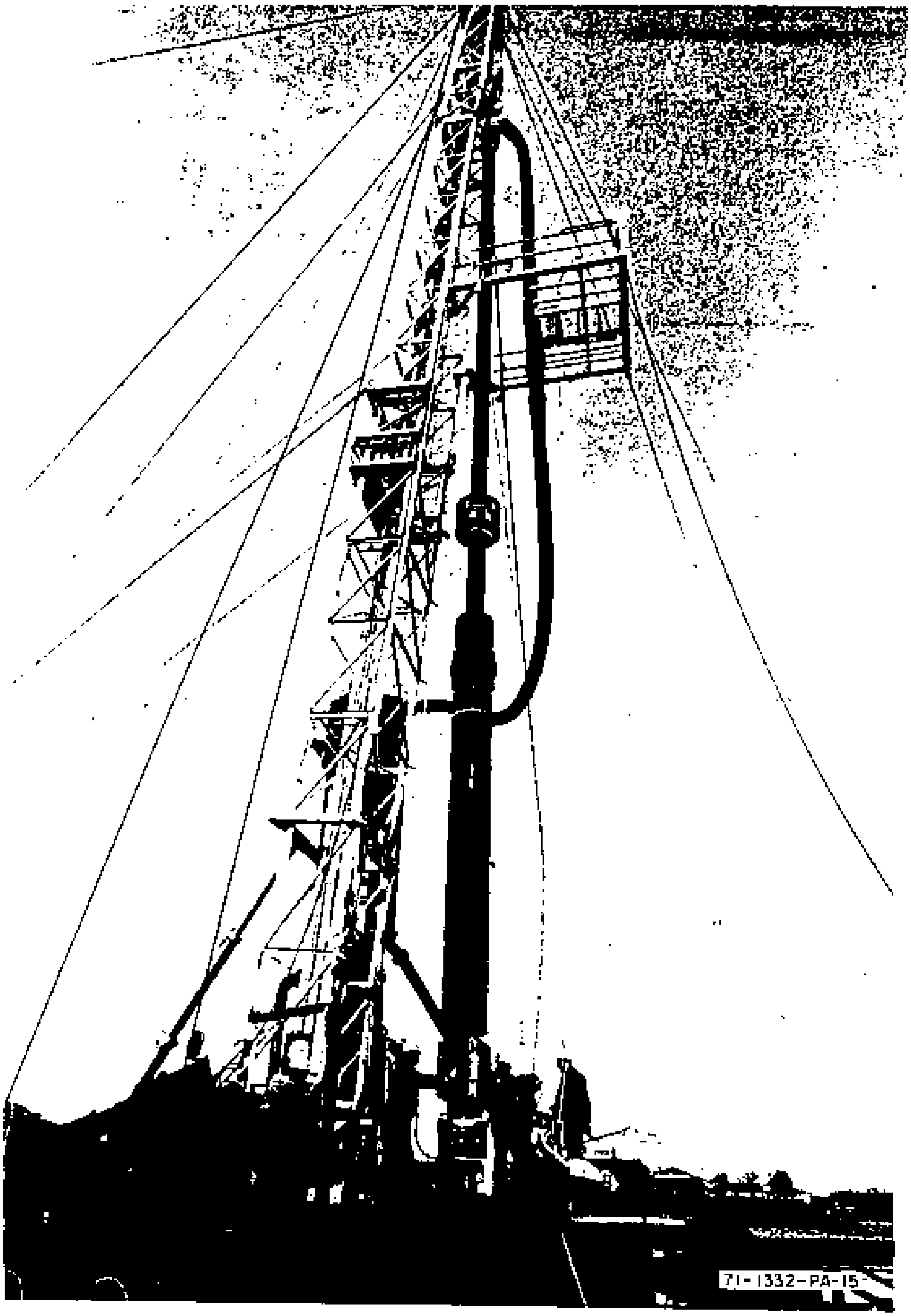

Figure 2-13. Rescue Rig Drilling Assembly

Safety considerations also significantly influenced the design of rigs. A particular area of design interest from this standpoint involved the personnel hoists of both the probe and rescue rigs.

Although distinctions do exist between the probe and rescue rigs, fundamental similarities ensure the capability of either rig to perform both drilling operations in the event of rig failure or transportation mishap. Improvisation and imaginative adaptation will centainly be necessary in such an event, but the importance of this capability cannot be overstated when men's lives are at stake.

STRUCTURAL CAPABILITIES

The Rescue Subsystem drill rigs must have the capability of drilling the 8-3/4 and 28-1/2-inch probe and rescue holes to a depth of 2,500 feet. Therefore, selected components must exhibit sufficient structural weight capacities to maintain the downhole package at that depth.

The probe downhole assembly weighs 71,400 pounds. With the additional weight of the block and hook and an overpull requirement of at least 40,000 pounds to lift dragging or stuck tools, the minimum advisable hookload capacity approximates 115,000 pounds. The Wilson Super "38" Trailer Rig selected for probe drilling provides a hoisting capacity of 180,000 pounds. This capacity complies with all requirements with an ample margin of safety.

The Wilson Mogul "42" Trailer Rig selected for rescue drilling has a hook rating capacity of 300,000 pounds. This selection offers sufficient lifting capacity for the 206,000 pounds of downhole equipment and affords an adequate overpull capacity.

RIG POWER

Two General Motors diesel power units supply the necessary power for each rig. Series 6V-71 units power the probe rig, and series 8V-71 units drive the rescue rig. Under emergency conditions, either series could supply sufficient power for probe or rescue drilling.

The engines, equipped with Twin-Disc torque converters, drive the rigs through a chain and sprocket compound. Four hoisting speeds are made possible by the use of air clutches operating various chain and sprocket combinations. The chain drives are fully enclosed and oil bath lubricated.

Diesel fuel tanks integral with the engine bases are provided with sufficient capacities for the term of expected initial rescue operations prior to logistic resupply.

RIG DRAWWORKS

The drawworks for both rigs is a single-drum type with brake rings at each end of the drum. Channeled with LeBus-type grooving, the drums spool 1-inch-diameter wirerope for the probe rig and 1-1/8-inch-diameter wirerope for the rescue rig.

The only major distinction in the drawworks for the two rigs is the installation of a 15-inch double-type hydrotarder on the rescue drawworks for lowering its heavier loads into the hole. The rigs have make-up and breakout cathead shafts, and the rotary table moves by means of an air clutch-controlled sprocket.

RIG MASTS

The special mobility requirements of the Rescue Subsystem determined the overall design of the probe and rescue rig masts. These masts are a special telescoping design, fabricated of high-strength steel, with a removable upper section. This removable upper section permits the lower telescoped sections to remain within the transportation maximum length of 39 feet required in many states and by the C-130 cargo airplane. When fully extended, the masts stand 102 feet above ground level providing sufficient working space to make mousehole-type connections. The mousehole is a shallow slanting hole in which pipe is placed during connections. Although both rigs are similarly configured, the larger hook capacity of the rescue rig results from the larger and heavier structural members and provides the extra lifting capability needed for the rescue rig.

The masts are erected by a three-stage hydraulic cylinder and are extended upward to their full height by a long single-stage hydraulic lift. This operation is pictorially demonstrated in figure 2-14. In the normal operating mode, the masts stand at an angle of 3-1/2 degrees from the vertical and four 1/2-inch wireline guys, tied to dead men or other anchors, give additional support to withstand severe wind loads which could affect the stability particularly when the racking board is full of pipe. Outriggers provided on the trailer unit stabilize the trailer rig during the raising of the masts.

To string lines to the blocks, the probe rig crown block has four main sheaves and the rescue rig has five. A racking board (finger board or platform) which automatically extends into the operating position as the mast telescopes upward, provides adequate space for racking 2,500 feet of drill pipe in double stands (2 sections). Because of the additional weight of the 8-5/8-inch diameter drill pipe, the board for the rescue rig is somewhat larger.

RIG TRAILERS

The trailers for both rigs are deep frame chassis type beam construction with three-axle assemblies using 10 x 20-inch, 12-ply tires. A fifth wheel is attached to a gooseneck section of special design and is removable for aircraft transportation. Four hydraulic jacks operated by the rig hydraulic power system aid in leveling the entire drill rig; six screw type jacks maintain the level position during operation. Both trailers are designed to be moved into position over rough terrain by bulldozers and winches.

RIG SUBSTRUCTURES AND ROTARY TABLES

Drive pins join the probe rig substructure to the mast base; adjusting pins, located at the end opposite the mast, support and level the rig floor. A 17-1/2-inch rotary table is positioned on the substructure to line up with the rig blocks.

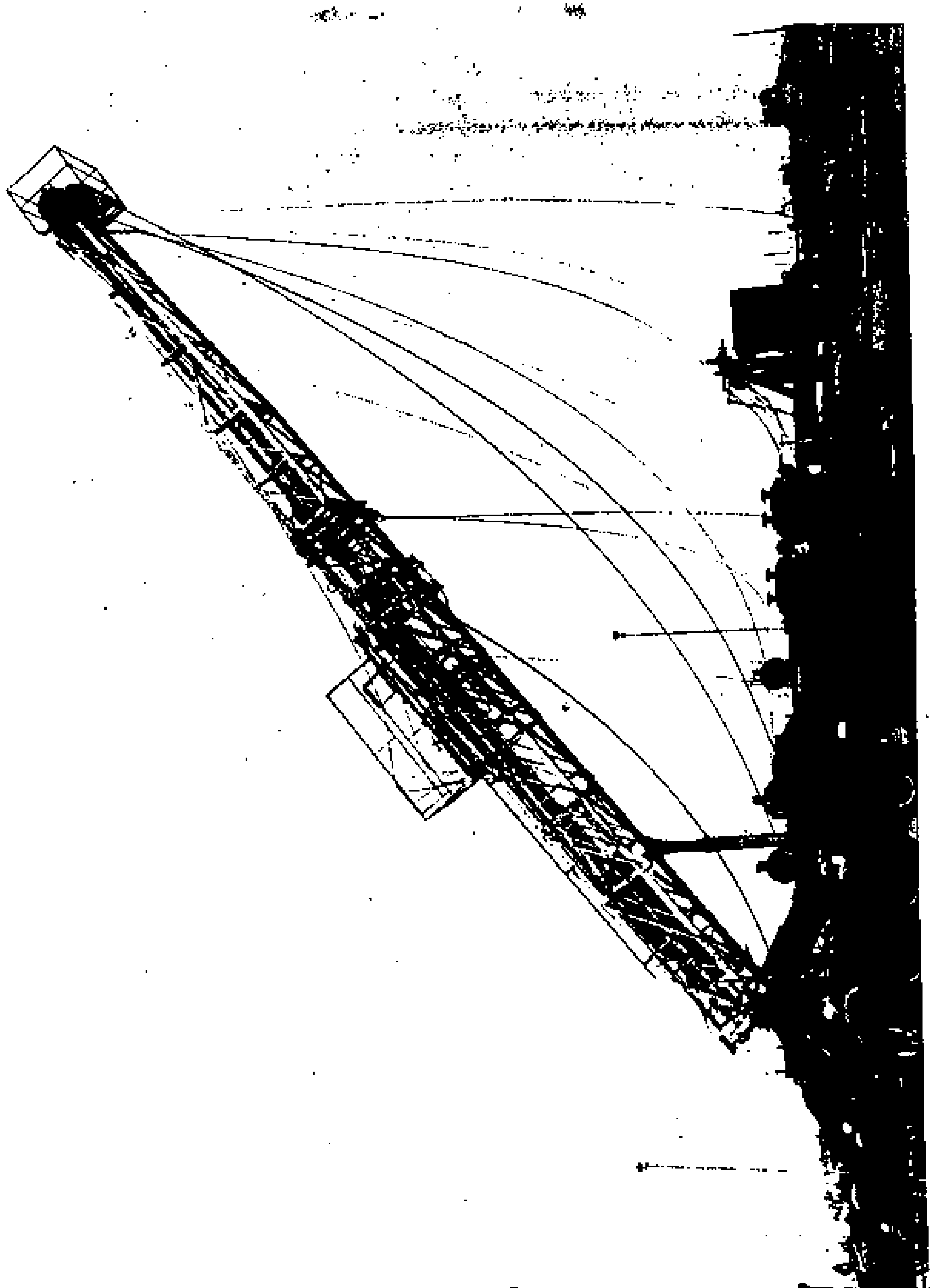

Figure 2-14. Rig Mast Erection

Heavy-duty screw jacks, which facilitate leveling, support the rescue rig substructure at its four corners. Although the Y-base of the drill rig holds the substructure in its proper position, the drill rig does not support the load in the substructure. A 37-1/2-inch rotary table was selected for the rescue rig to provide sufficient area to use the 34-1/2-inch hole opener if necessary without removing the rotary table.

Both rotary tables turn by means of a fully enclosed oilbath chain drive connected to the cathead shafts of the rig. Wings on the substructure provide working space around the rotary table.

HOISTING EQUIPMENT

Rated at a capacity of 150,000 pounds, the traveling block for the probe rig provides three 24-inch sheaves for 1-inch-diameter wirerope. The block for the rescue rig with a capacity of 300,000 pounds has four 30-inch sheaves grooved for 1-1/8-inch wirerope. The hooks provided with the blocks have the same nominal capacities as the probe and rescue rigs. The wireropes used for hoisting are 6 x 19 improved plow steel grade with a wire core.

Links and elevators selected for the rigs are rated as high or higher than the traveling block. Extra elevators and special short links make connections possible without laying down the kelly and swivel, even when mousehole connections are not possible. Figure 2-11 shows the elevators and special short links.

PERSONNEL HOISTS

Personnel hoists for the Rescue Subsystem required special design to meet safety requirements. Two hydraulic motors drive the hoist using a screw-type gear drive. The hoist must be powered during both ascent and descent; therefore, the hoist drum is never out of gear and inadvertent spinning is not possible. Raising or lowering of the line is automatically stopped as soon as hydraulic power to the motors is shut off. As an added safety precaution, the personnel hoists have a manual friction-type brake.

The wirerope selected for use with the personnel hoist is 1/2-inch diameter, 18 x 7, improved plow steel fiber core, antispin wire rated at 19,700-pound breaking strength. This wirerope operates over a special 24-inch-diameter sheave provided in the crown block. The Rescue Subsystem provides a wirerope length more than adequate for operating to a depth of 2,500 feet.

ANCILLARY EQUIPMENT

To support the basic drill rig at the drill site, the Rescue Subsystem required various auxiliary items of drilling equipment. Most of the auxiliary equipment needed for the subsystem supports the circulation system. Much of this equipment, including water, air and fuel piping, was permanently mounted on skids. The skids provide a secure foundation for equipment items and facilitate loading and transportation. Quick-connect hoses permit rapid connection of the piping between skids during rig-up of the equipment.

STEEL MUD PIT

A skid-mounted steel mud pit stores the fluids used for the reverse vacuum air and indirect mud circulation systems. Shown in figure 2-15, the mud pit includes an electric double-deck vibrating screen shale shaker which removes the coarser formation cuttings from the circulating fluid. The shale shaker is installed on a special hinged mount which allows it to be lowered into the mud pit for transportation. Suction piping and valves are permanently mounted in the pit skid for quick assembly of the mud pit at the mine emergency site.

VACUUM SEPARATOR SKID

The cyclone type separator and the vacuum blower unit comprise the separator skid. The diesel powered blower units; air, water, and fuel piping; and the water spray nozzle at the special separator inlet were all integrated into a compatible system design.

S. & R. Tool Company prepared the detailed fabrication design for the basic vacuum separator from design drawings and specifications supplied by Rowan.

The preliminary design specified the overall size and layout of the vessels and the piping and indicated the desired method of raising the vacuum separator to the operating position with hydraulic cylinders.

The separator skids for probe and rescue operations are nearly identical except that the rescue separator skid has a higher capacity rotary blower. Both systems use Sutorbilt rotary blowers producing 22 inches of mercury working vacuum. The rescue system has a series 3200 unit delivering 3,100 cfm. The probe system is equipped with a series 3000 unit which supplies 1,800 cfm.

UTILITY SKID

The utility skid consolidates into one module several items of equipment which would be awkward to transport individually. Two Gorman-Rupp model 14C-2B, 4-inch, centrifugal, solids-handling pumps with associated valves and manifold piping are installed at one end of the skid. According to the circulation system in use, these pumps can perform several different pumping assignments using a permanently installed manifold system. General Motors model 2-71 diesel units supply the power for these pumps.

Other units installed on the utility skid include the start up air compressor and the electric generator unit. The model 325 Quincy air compressor, powered by an air-cooled diesel engine, connects to a 60-gallon vertical air receiver. The unit supplies air for starting the diesel engines which power the drill rigs, pumps, and blowers. The engines are equipped with air starters for better starting under the cold weather conditions expected during winter.

The electric generator unit and its powering engine are small units intended for emergency use only. Electric power requirements for the drill rigs are supplied from large portable generators or from commercial power lines, if available. The utility skid also contains an electric fuel

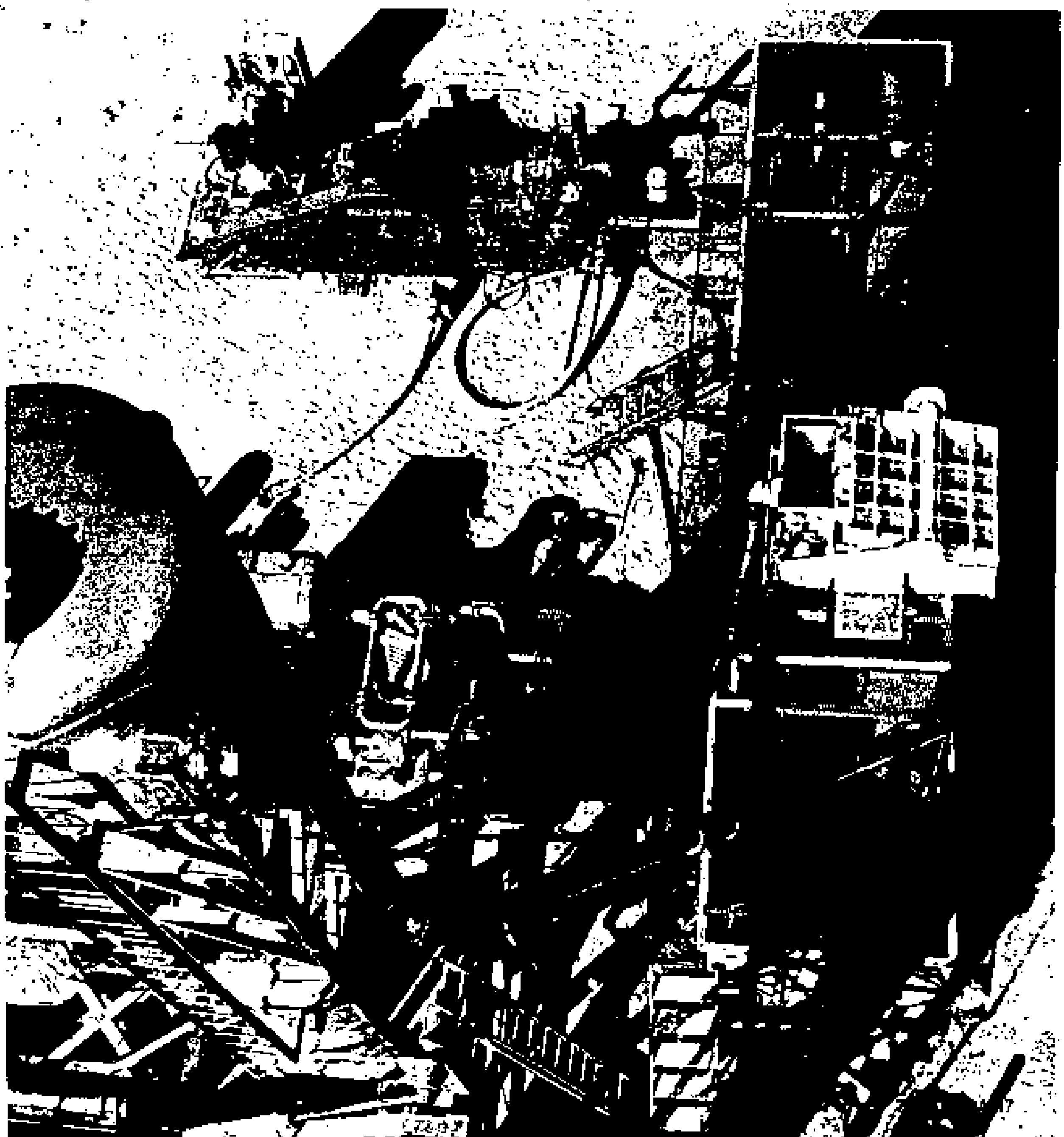

Figure 2-15. Steel Mud Pit and Shale Shaker

pump, fuel filter, and a 1,000-gallon diesel fuel storage tank which provides operating fuel for a period of from 24 to 48 hours. This unit is also an emergency provision. Fuel must normally be supplied for extended normal operation by logistic supply trucks.

WATER STORAGE TANK

A skid-mounted cylindrical water tank with a capacity of 270 barrels supplies on-site water storage during drilling operations. This tank guarantees a minimum supply of available water and reduces the number of tank trucks necessary.

HIGH-PRESSURE MUD PUMP

For probe drilling, a skid-mounted, high-pressure mud pump and a diesel power unit provide the capability for mud and water circulation of the 8-3/4-inch hole. Suction and discharge piping are installed at the filtered end of the mud pit so that the pump will pick up mud with the least amount of formation cuttings.

DRILL PIPE STORAGE BINS

Drill pipe bins provided for the probe and rescue rigs ensure expeditious loading and transportation of drill pipe, collars, and other drilling tools. Using only a truck winch line, these bins load a full truckload of pipe or other tools in only a few minutes. A removable door at the end of the bin closest to the drill rig provides needed drill pipe accessibility.

PROBE AND RESCUE RIG LAYOUT

The general overall layout of rig equipment for both rigs appears in figure 2-16. The equipment, intentionally arranged close to the drill rig, reduces the overall working area and shortens the time required for many

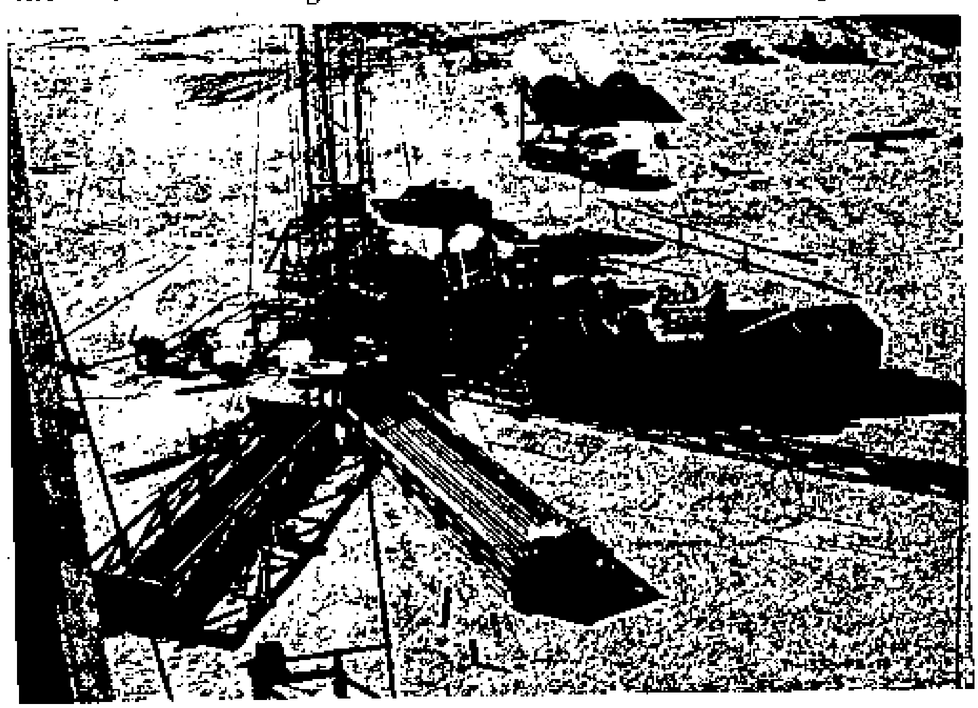

Figure 2-16. Probe Rig Layout

operations including pipe connections and drill bit changes. The rescue rig requires a slightly more spacious working area to handle the larger drill pipe and heavier tools. As shown in the photograph, this layout is suitable for direct mud circulation or reverse air vacuum circulation. The substitution of a high-pressure air compressor for the vacuum separator skid converts the circulation method to direct compressed air. A high-pressure compressor is required for the direct circulation to provide sufficient air flow velocities to lift cuttings from the hole bottom.

The location of the pipe bins adjacent to the substructure facilitates drill pipe loading and unloading and leaves more space on the driller's side for handling of other tools. Since all piping connections between skids are made by flexible hoses, some variation in the layout of figure 2-16 is possible. This versatility allows the assembly of the drill rig on sites which are not level. However, significant departures from the layout of figure 2-16, which requires a level area, reduce operational efficiency.

TRANSPORTATION

Terrain difficulties indigenous to most coal mining regions required the most efficacious transportation design of the Rescue Subsystem. Therefore, the system was designed for transportation by truck, cargo aircraft, and helicopter.

Since drill rigs and associated equipment are ordinarily transported by truck, no significant deviations from existing design practices were necessary to permit truck transportation. However, the skid module concept hastens truck loading and unloading and reduces or eliminates the requirement for cranes and high capacity forklifts since only winch lines are necessary. Miscellaneous small items of drilling equipment do require gin-pole equipped trucks or crawler tractors for loading and unloading purposes.

Helicopter transportation is limited by two factors, weight and distance. Although the lifting capability of the Sikorsky S-64 Skycrane helicopter is somewhat greater for short distances, a maximum load of 18,000 pounds was used in designing equipment packages for helicopter transportation. Since equipment is suspended below the helicopter during transportation, the size and shape of the packages were not a design problem.

For cargo aircraft transportation, size, not weight, became the principal design determinant. A weight limitation of 40,000 pounds presented few design problems; but length, width, and height restrictions of 39 feet, 7 feet 10 inches, and 8 feet 5 inches determined the size of the skid modules. All the skid modules were designed to be handled as single indivisible units. However, the larger modules have various removable sections to remain within the parametric restrictions of cargo aircraft transportation. Two of these removable units were the telescoping mast and the trailer gooseneck section. Disassembly at the warehouse and reassembly on site of the probe and rescue drill rigs requires an additional 72 hours, 36 hours for each operation.

FABRICATION AND ASSEMBLY

Procurement

The goal of Rescue Subsystem procurement was to obtain the best equipment in the required short time. During the first 2 months of the contract, major equipment purchase orders were completed. However, procurement of materials and services for yard assembly of the rigs and associated equipment continued through December, 1970 until the rigs were ready for shipment to Charleston, West Virginia.

After a thorough examination of potential suppliers to determine cost and equipment applicability to Rescue Subsystem purposes, procurement was initiated. Although only equipment of the highest quality was purchased, major savings resulted from the procurement of standard equipment, whenever possible, at the original manufacturer's discount price rather than through a drilling supplier.

Nevertheless, the specialized performance requirements of the Rescue Subsystem required the manufacture or fabrication of many items. These items, constructed according to design specifications and drawings, include the vacuum separator unit, mud pit, water tank, and pipe lines.

Special Items

For a variety of reasons, considerable welded fabrication of special structural, piping, and equipment items including some rescue rig skids was performed by the drilling subcontractor. Some items had to be field-designed and fabricated to ensure proper fitting. Furthermore, many items could not be readily procured, and the preparation of specifications and drawings from which these items could be fabricated was considered impractical. In addition to the limited time available for procurement, another factor that led to field design was that more exacting supervision could be given to design and fabrication at the subcontractor site.

Yard Assembly

The assembly of the rescue rig preceded that of the probe rig and both rigs were virtually completed by December 11, 1970 when the preliminary field start-up testing and demonstration was conducted.

The stringent schedule for Rescue Subsystem drilling equipment delivery and testing necessitated that the assembly of ancillary items begin prior to drill rig delivery at the Odessa yard of the Rowan Drilling Co. Much of the rig equipment was not delivered until the first part of December, and the last item, a standby generator set, arrived on December 28th, two days before the first truckload of equipment left the yard enroute to Charleston, West Virginia.

Experienced drill crew members assembled both the probe and rescue rigs. Special craft services, personnel, and welders were obtained as necessary. Experienced drill rig mechanics performed final fitting checks and general inspection of the engines and drilling equipment.

CHAPTER 3
OPERATIONAL PROCEDURES AND DEMONSTRATION SUMMARY
SECTION 1
PROCEDURES

MOBILIZATION

The design of the Rescue Subsystem incorporates special features to permit transportation of the equipment by ground and air. Ground transportation involves the use of heavy-duty tractors to tow the probe and rescue rig trailers and their associated equipment from the storage facility to the emergency area. Prior to initiating the move from the storage area, program personnel should request a state highway patrol escort.

At the emergency area, the equipment remains in a staging location until drill site preparation is completed and the most expeditious route to the drill site is selected. Then, the rigs and only that portion of the auxiliary equipment which is required are moved from the staging area to the drilling locations. Equipment used in this operation includes heavy-duty and off-highway-type trucks and specially equipped rig-up and gin-pole type trucks or caterpillar tractors for movement of the skid modules.

Deployment distances over 500 miles or emergency sites inaccessible to surface transportation without extensive road building indicate the consideration of airlift. However, transportation by either cargo aircraft or helicopter requires additional procedural steps and attendant extra time. For both operations, the Rescue Subsystem includes provisions for breaking down the rigs into either five or seven-module packages. If distance dictates the use of cargo aircraft, the Rescue Subsystem is transferred to trucks upon arrival at the airport.

RIG UP

If the drill rigs remain at the staging area to await completion of drill site preparation, the drill crew will prepare units for rapid rig up and perform such tasks as install the catheads and fingerboards, hook up the temporary air lines, and test the engines.

After transportation to the drill site area, rig up commences. The two rigs can be assembled simultaneously if it is possible to determine the location of the rescue hole prior to probe hole drilling or if two probe holes are required. If this is not the case, rescue rig up follows completion of the probe hole. In the following discussion, simultaneous drilling is assumed.

The trucks back the rig trailers onto their respective hole locations. The Y-base of both rigs must be 48 inches above ground level and 63 inches from the center of the proposed hole. The next step is to move the utility sheds into position as outlined in figure 3-1 or as appropriate to special sites.

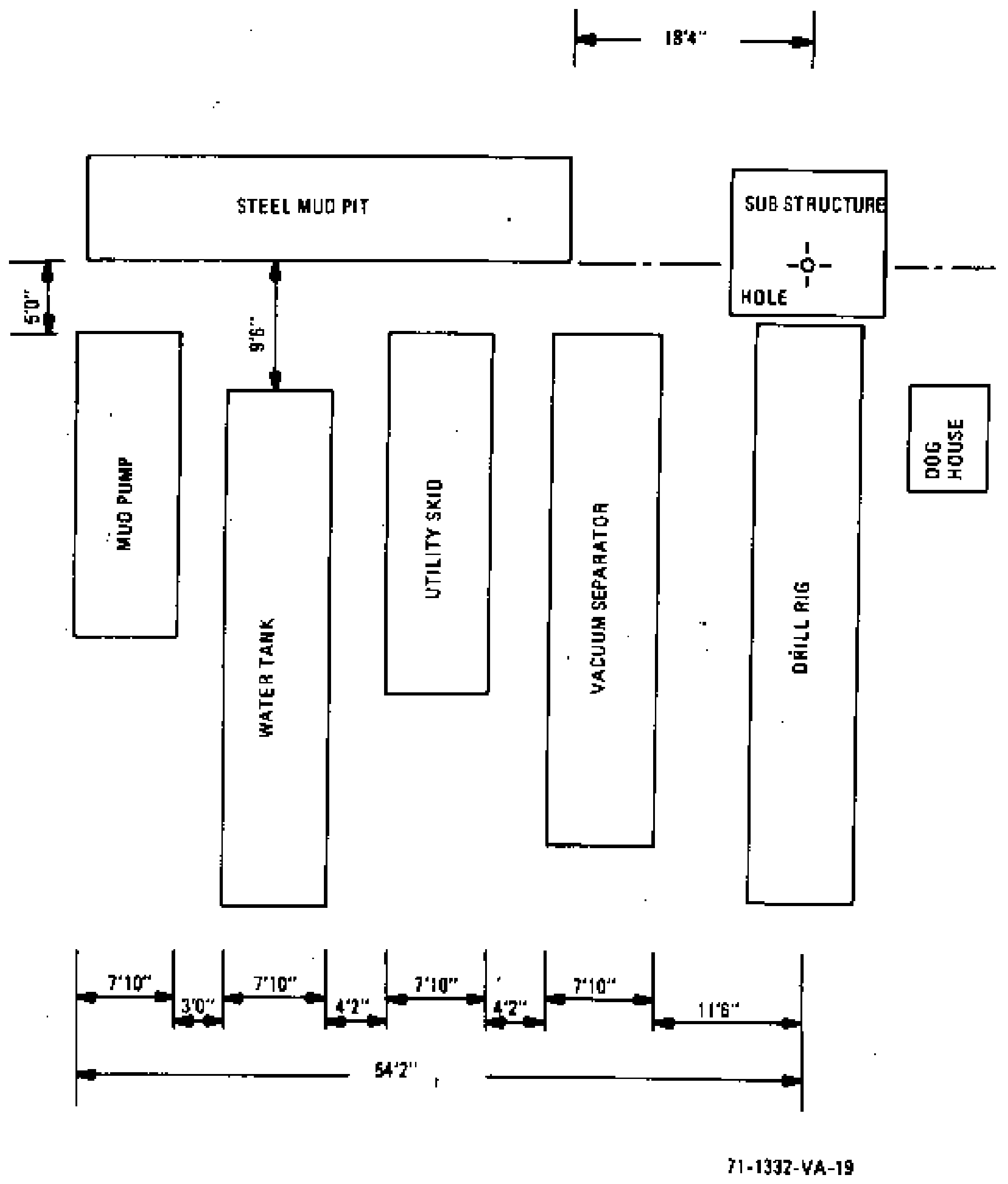

Figure 3-1. Equipment Layout for Probe and Rescue Rigs

The crew members then make all the necessary air and water base connections and start the compressor engine.

Using the hydraulic leveling rams, workmen level the probe and rescue rig trailers and swing the outriggers out to the operating position. The next step is the extension of the leveling screws, supported by the matting board, to stabilize the rig laterally. Guy wire tie-down anchors are installed.

The respective hydraulic systems raise the probe and rescue masts to the vertical position and telescope the upper portion of the mast to its fully extended position. After hooking the guy wires to the anchors, the drill crew positions the front steel substructure on the previously installed matting boards. The substructures and rotary table are then set into position using a heavy-duty, rig-up, gin-pole truck or tractor. The probe substructure is pinned to the Y-base of the rig and the rescue substructure is connected to its Y-base with turnbuckles. If the primary method of circulation, direct compressed air, is the selection for an actual emergency, rig-up personnel locate the compressor unit adjacent to the drill rig and connect the high-pressure piping from the units to the standpipe. They also install a low-pressure rotary head under the rotary table to deflect return air and cuttings away from the rig.

If reverse air vacuum circulation is used for either rig, the vacuum separator skid is positioned next to the rig trailer. Crewmen connect air and fuel lines to the blower engine and start the engine to power the hydraulic system pump. The hydraulic system then raises the separator to the vertical working position, and the drill crew connects the 8-inch steel vacuum lines from the separator tank to the vacuum blower unit and the 8-inch water and cuttings discharge line from the separator to the mud pit.

After the pipe bins are located in a convenient working position near the catwalk, the crew assembles the kelly, swivel, and kelly drive bushing. One end of the rotary hose is joined to the swivel gooseneck, and the other end of the hose is connected to the vacuum separator, air compressor, mud pit or mud pump, depending on the circulation system to be used.

Drilling operations then begin. The drill bit assembly is dropped a few feet to begin the hole. This procedure, called spudding, can only be used for the first few feet because of the necessity for a straight hole. This same requirement also restricts the weight that initially can be applied to the bit and the speed of rotation.

When drill string connections are necessary, the drill crew uses the double elevator procedure for picking up the drill pipe to prevent laying down the kelly and swivel. Trips for bit changes or other reasons require standing back the drill pipe in doubles in the mast. After connections or other operations are finished, drilling resumes.

As the bit nears target depth, the Rescue Director reduces the weight on the bit and decreases the rotary speed. After probe breakthrough into the mine, the probe hole is used to supply immediate life support and hard wire communication. When the rescue hole reaches completion, a rescue capsule can be lowered into the mine, a miner enters the capsule, and the capsule returns to the surface. This operation is repeated until all trapped miners are freed.

After rescue operations are completed, rig down of the Rescue Subsystem is begun. Then the holes are closed or cased and capped and general clean up operations completed.

SECTION II
DEMONSTRATION

This section briefly describes the preliminary drill rig tests performed at Odessa, Texas and recounts, in depth, the events of the Rescue Subsystem formal test demonstration in West Virginia.

PRELIMINARY TESTS

The purpose of these tests was to acquaint U. S. Bureau of Mines and Westinghouse Electric Corporation CMRSS program personnel with the equipment layout, transportation, support requirements, and general operating procedures of the probe and rescue rigs.

On December 16, 1970 at Odessa, Texas, the probe drill rig, initially configured for transporting, was physically moved a short distance, set up and configured for drilling, spudded in, and actually operated to drill a hole to a depth of about 60 feet. The entire operation was accomplished in 1 hour and 55 minutes by a regular drill crew employing standard procedures. On this same day the rescue rig, which was not moved but had been previously set up in readiness for drilling, was operated to drill from an initial depth of 20 feet to a final depth of about 60 feet. Reverse air vacuum circulation was employed during both demonstrations. Neither the probe nor the rescue drill bits showed appreciable wear. Equipment problems were confined to clogging at the probe rig gooseneck by moist clay cuttings. A fitting was welded to the gooseneck to permit water flushing.

TEST DEMONSTRATION

As contractually required, an exhaustive demonstration of the Rescue Subsystem portion of the Coal Mine Rescue and Survival System was conducted near Gary, West Virginia in the Plateaus province of the Appalachians.

Executed under simulated emergency conditions, the demonstration gave program personnel an opportunity to test the performance of the Rescue Subsystem in terms of mobility, rig assembly and layout, drilling progress and accuracy, and safety.

In early January, 1971 the probe and rescue rigs and all supporting equipment arrived at the warehouse Staging Facility in South Charleston, West Virginia. Minor reassembly, required after shipment, was performed to complete preparation of the equipment prior to the demonstration. The exact date and location of the demonstration was not released in order to lend more realism to the operation. It was only stated that January 18, 1971 was the approximate date set for the demonstration, and the location was to be within a 100-mile radius from Charleston, West Virginia.

Westinghouse developed an overall test and demonstration plan that included mobilization procedures and assignments of responsibilities. Three drill crews of five men each were selected from the drilling subcontractor's personnel. The plan specified commercial aircraft as the method of crew transportation to the emergency site. All support functions necessary to maintain the crews and other personnel at the site were the responsibility of Westinghouse. In addition, the prime contractor supplied such supporting functions as trucking and road construction.

NOTIFICATION AND MOBILIZATION

Issuance of the simulated mine emergency alert came two days prior to expectation, which provided a true test of emergency mobilization capabilities. The alert was received at Rowan's Midland, Texas office at 12:10 PM central standard time on Saturday, January 16, 1971. The location of the emergency was the United States Steel Corporation Mine, Number 14, near Gary, West Virginia. The Rowan project manager and deputy project manager took the first available flight from Midland at 3:30 PM on the day of notification. Arriving in Atlanta and finding no available flights to Charleston that night, the two men flew to Roanoake and drove the remaining distance to the mine through heavy snowfall arriving at 4:00 AM on Sunday, January 17, 1971.

Prior to that time, the utility skid module had been dispatched from the Staging Facility, and the remainder of the probe drilling equipment was moved out as more trucks became available.

Personnel from the Westinghouse Rescue Director's office and mining personnel reviewed the simulated emergency with Rowan's representatives. The cooperation of the mining personnel in supplying information on local conditions was very useful in formulating the probe hole drilling plan.

Rowan project superintendent, two drillers, and six crew members arrived in Charleston shortly after 10:00 PM on Sunday, the 17th. Because of bad weather and limited Sunday airline schedules, their trip from Midland required 15 hours. At 12:30 PM on Sunday, the probe rig trailer and two truckloads of auxiliary equipment arrived at the mine. The rig and other equipment were unloaded at a staging area established on a bench (level area) formed by earlier strip mining operations above the mine. Truck tractors aided by bulldozers moved the trailer mounted probe rig and skid-mounted modules up the steep grades of the dirt mountain road. The equipment was parked in a staging area near the expected probe hole site, and the trucks returned to Charleston for the remainder of the drilling equipment.

On Monday morning, January 18, all rig engines were started and checked out, and catheads removed for transportation were reinstalled on the rig.

The remainder of the drilling personnel, a driller and six crew members arrived at the probe site at 8:00 PM Monday. The three drilling crews were organized so that crew shift changes would occur daily at 8:00 AM, 4:00 PM, and 12:00 midnight.

SITE PREPARATION

The Westinghouse logistics support organization was primarily responsible for the preparation of the drill site area, responding to requirements dictated by the driller. The plan was for probe hole drilling to precede that of the rescue hole. The initial surveyed location of the probe hole was about 30 feet below the outer edge of a strip mine plateau whose embankment descended for several hundred feet at an inclination in excess of 45 degrees. In the initial effort to prepare a site for the probe rig which would center the table directly over the intended hole location, three bulldozers were used to lower the level of the part of the plateau adjacent to the hole location by pushing dirt over the edge of the plateau. This was time consuming, and ultimately proved to be impossible because of a rock ridge which was only about 4 feet below the level of the plateau, in some places. In order to accelerate the start of spotting and rigging the probe drill, the decisions were made to relocate the hole site to a point which was on the plateau, very near the edge and to suspend dozer operation before the site was completely level, with final leveling of the rig to be accomplished by means of the hydraulic and screw jacks on the rig.

The rescue hole was subsequently located about 15 feet southwest of the probe hole, and this site required little additional preparation.

PROBE HOLE DRILLING

Since the probe hole operation preceded the rescue drilling operation, the discussion of the rig up and drilling for the probe and the rescue holes will be segregated in order to present a more coherent chronological account of the demonstration.

RIG UP

The probe rig trailer arrived at the drilling site shortly before 7:30 AM on Tuesday, January 19, 1971. By that time bulldozers had cleared and leveled an area of adequate size to accommodate the rig, and rig up commenced immediately.

The leveling of the rig trailer with the hydraulic and screw type jacks was difficult, due to several problems related to the drill site area. The area proved to be rougher than desirable. Specific time-consuming operations necessitated by the unevenness of the area and the closeness of the bench edge included hand excavation to place matting boards under the jacks and placement and leveling of the mud pit, vacuum separator skid, and other modules.

As rig up continued on January 19, 1971, periodic hard snowfall and continual high winds retarded assembly operations. With snow and ice on all the equipment, normally minor rig-up tasks became increasingly difficult. The slick surface of the work area required the use of bulldozers to aid truck movements. In addition to impeding the rig up, the severe weather caused safety problems for the drill crews.

By 6:00 PM on Tuesday, the 19th, the rig up of the probe rig and equipment was virtually completed. However, the drive shaft and impeller of one of the 4-inch centrifugal water pumps were frozen. By 10:00 PM the drill crew had replaced the pump with an identical one from the rescue rig utility skid. Several valves and lines in the circulating system had become frozen during the pump exchange. The use of diesel-fueled smudge pots thawed those fittings and probe drilling began on Wednesday, January 20, at 2:00 AM. Figure 3-2 shows the probe rig on location at the demonstration site.

DRILLING

The probe hole was spudded (dropping the drill bit assembly a few feet) with an 8-3/4-inch-diameter milled tooth type tricone bit. Reverse air vacuum circulation was used for the upper portion of the hole. Abnormally low rotating speeds necessitated by binding at the swivel caused by low temperatures, low weight on the bit, and hard rock encountered 4 feet from the surface severely restricted initial penetration rates.

The drill penetrated from 3 to 5 feet/hour when drilling to a depth of 30 feet in 6 rotating hours. The next 33 feet were drilled in 7 hours rotating time with the addition of a 7-inch outside diameter 2,600-pound drill collar.

During this second phase of drilling, reverse air vacuum circulation was apparently successful in cleaning the hole. The slow penetration rates were not the result of inefficient hole cleaning but of limited weight on the bit. Small amounts of water, however, were entering the hole and resulted in periodic plugging of the gooseneck swivel, requiring manual cleaning. Drilling progressed to a depth of 69 feet, where mechanical difficulties experienced with the rotary blower unit resulted in conversion to the direct compressed air method, using a rented compressor.

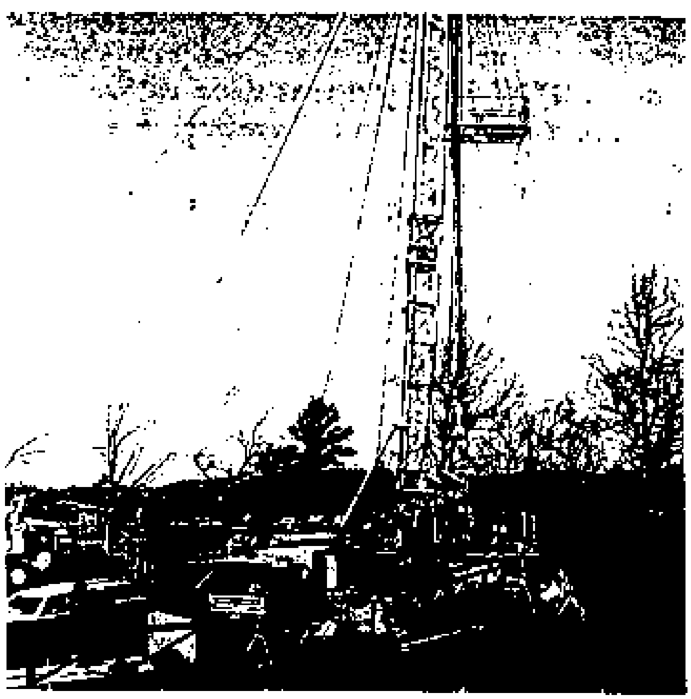

Figure 3-2. Probe Rig on Demonstration Site

While drilling with the reverse air technique, the injection of water at the gooseneck and down into the hole in limited amounts helped to prevent the collection of formation cuttings inside the drill string. Subsequent experience gained in drilling the rescue hole indicated that a higher water injection rate might have facilitated probe drilling. Moreover, the small valve which regulates the water flow to the gooseneck froze and shut off water injection. The addition of salt to the water did not resolve this problem. A solution was still pending when the blower problem dictated a change of circulation systems.

After conversion to the direct compressed air method of circulation, drilling of the probe hole resumed. The 10 drill collars were added as each 30-foot section of hole was drilled. Penetration rates gradually increased as each drill collar was added to the string. However, it was only at a depth of 300 feet that the full drill collar weight of 25,000 pounds could be concentrated on the drill bit.

On Thursday, January 21, the drilling had reached a depth of 327 feet; on Friday, hole depth increased to 742 feet with an average penetration rate for that day of 21 feet per rotating hour. Breakthrough at 778 feet occurred on Saturday, January 23, at 3:00 AM. A summary of the drilling progress and penetration times appears in table 3-1. Figure 3-3 shows graphically the variation of penetration rate with hole depth, and figure 3-4 is a penetration-time profile for probe drilling.

The compressed air procedure worked satisfactorily for probe rig drilling. Using a compressor with a maximum rating at 100 psi, developed pressures were 60 psi for the shallow portion of the hole (to 327 feet) and 100 psi for the remainder of the hole. As the drill bit approached the mine roof, rotation was alternated with circulation to remove cuttings in order to avoid high air pressure at breakthrough.

Occasionally, formation water did restrict cuttings return, but the quantities were not great enough to prevent dusting or to preclude the possibility of explosive coal dust in the hole when drilling through overlaying coal seams.

At a depth of 741 feet, probe drilling reverted temporarily to the reverse vacuum method, but this proved to be unsatisfactory after only 1 foot of drilling. The extremely low penetration rates at this time were caused by the removal of the bit skirts for compressed air circulation. In reverse vacuum air circulation these skirts produce the nozzle effect to supply the necessary air flow velocity across the bottom of the hole for effective cleaning.

Drill rig personnel maintained telephone communications with underground observers throughout the probe bit breakthrough. The driller watched the rig's weight indicator and received good indication of the breakthrough because as the bit penetrated into the mine the weight supported by the drill rig gradually increased indicating less and less support at the bottom.

TABLE 3-1
SUMMARY OF PROBE HOLE DRILLING PROGRESS AND PENETRATION RATES

Drilling Interval (ft)	Footage Drilled	Rotating Time (min)	Average Drilling Rate (ft/hr)	Rotary Speed (RPM)	Weight On Bit (lb)
30	0-30	360	5.0	30-50	2,000
33	30-63	420	4.7	40-60	4,000
9	63-69	210	1.7	40-60	7,000
13	69-82	270	2.9	45-60	7,000
17	82-99	55	18.5	45-65	7,10,000
30	99-129	132	13.6	65	10,000
29	129-158	118	14.7	45	10,000
29	158-187	68	25.6	45-55	10,000
30	187-217	39	46.2	60	14,000
30	217-247	106	17.0	62	16,000
29	247-276	118	14.7	50-60	20-22,000
30	276-306	98	18.4	47-50	22,000
30	306-336	44	40.9	45-50	22,000
30	336-367	62	29.0	45-50	22,000
30	367-403	118	15.3	45-50	24,000
31	403-434	86	21.6	45	22-24,000
31	434-465	38	48.9	45	22,000
30	465-495	80	22.5	45	22,000
28	495-523	98	17.1	45-65	24,000
30	523-553	56	32.1	45	24,000
30	553-583	90	20.0	45-50	22,000
31	583-614	88	21.1	45-50	22,000
32	614-646	92	20.9	45-50	22,000
31	646-677	74	25.1	45-50	22,000
32	677-709	32	60.0	45-50	22,000
32	709-741	40	48.0	55	22,000
-	741-741.25	32	0.5	55	22,000
31	741-772	154	12.1	60	20,000
5	772-777	68	4.4	40-80	5-20,000

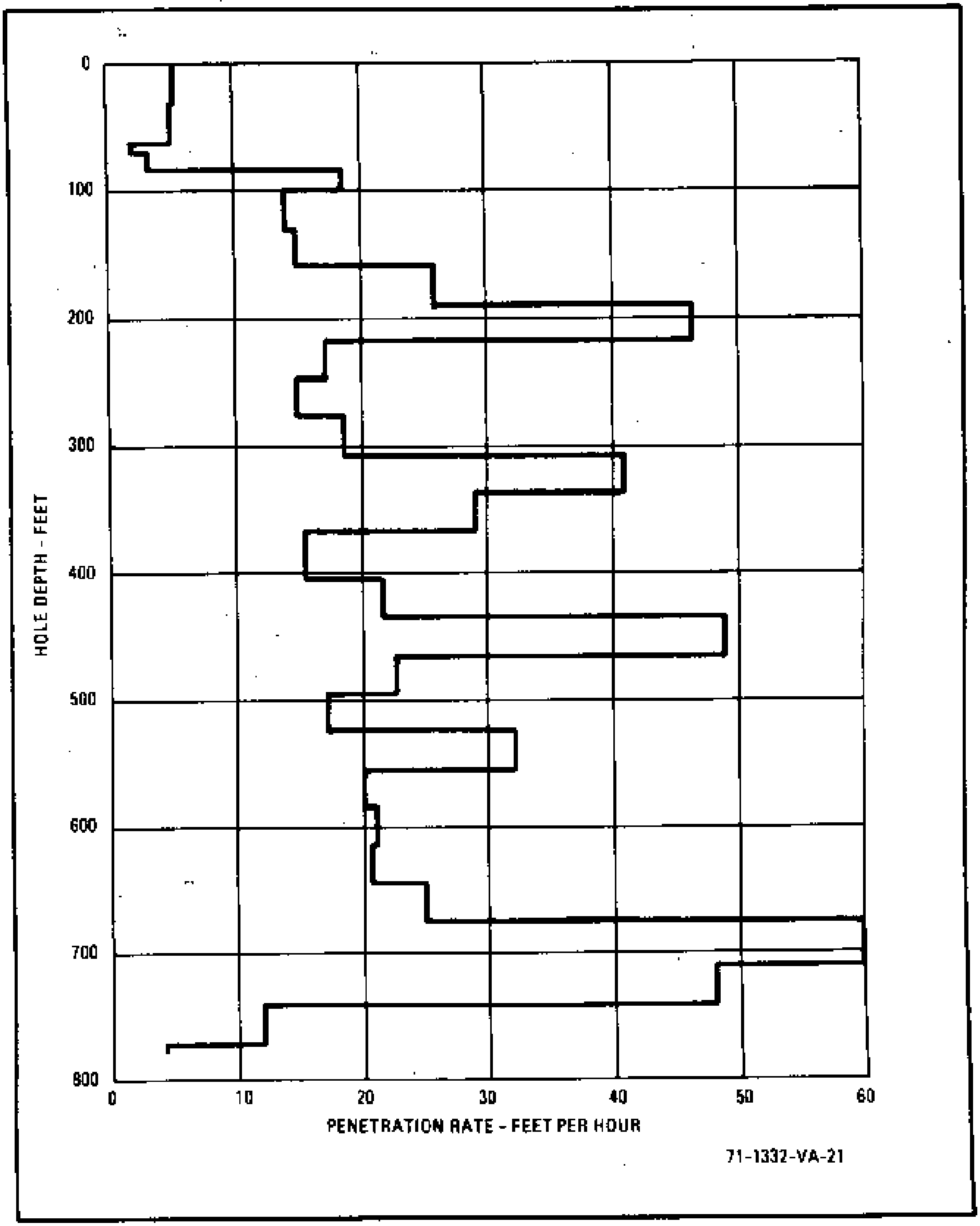

Figure 3-3. Probe Hole Penetration Rate Diagram

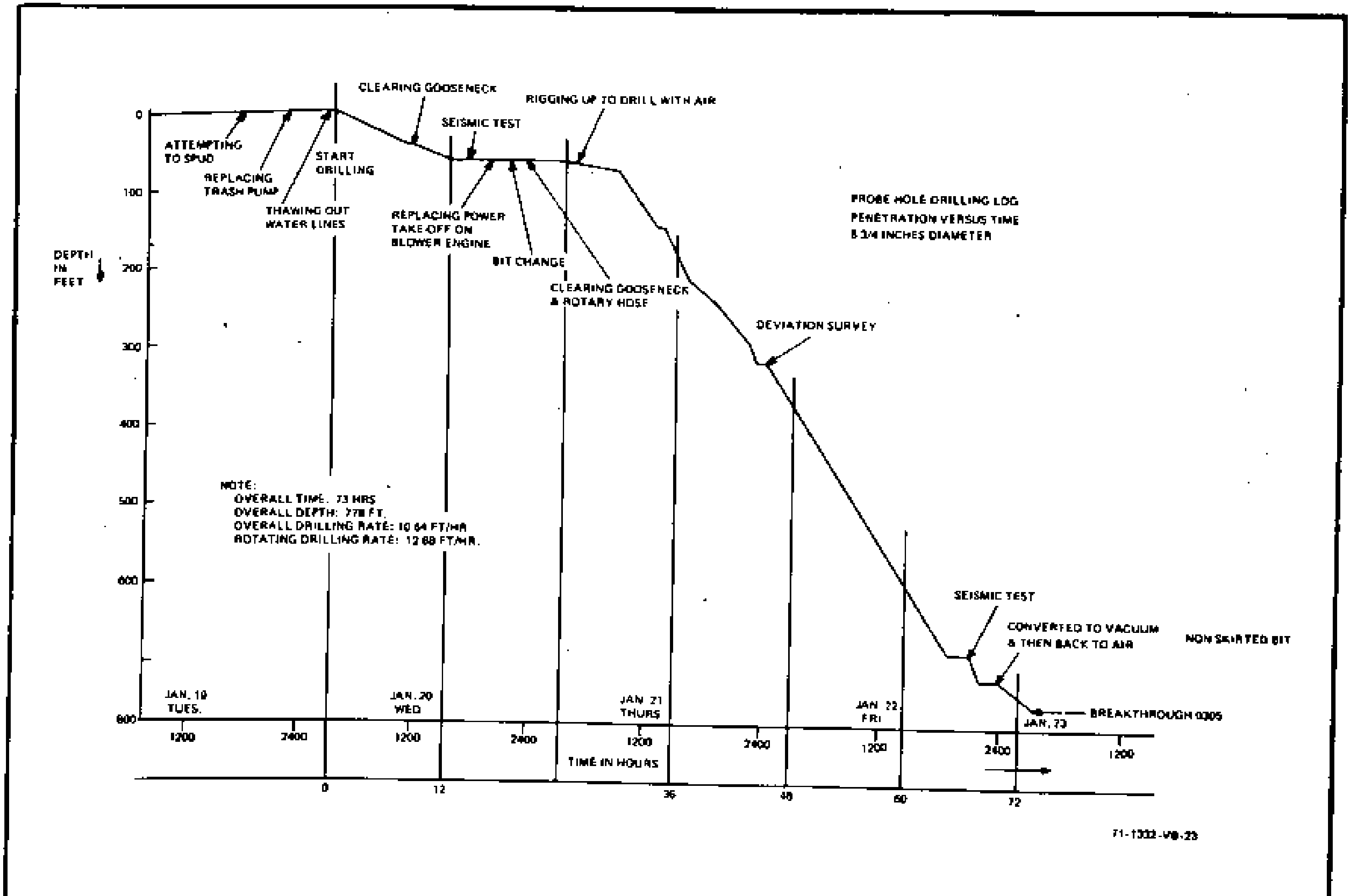

Figure 3-4. Probe Hole Penetration-Time Profile

Underground personnel took photographs of the drill bit at the point of breakthrough in the mine roof. The drill string was pulled from the hole and set back in the probe rig mast in doubles; the drill bit was removed and examined. A simulated survival package consisting of such items as a blanket, small tools, a sound-powered hand set, and food and drinking containers was lowered through the hole into the mine.

The drill crew ran the drill pipe and collars back into the hole and conducted two directional surveys with a gyroscopic directional tool inside the pipe. From the in-run survey, the calculated bottom hole displacement was 4.14 feet from the surface location in a North 36°27' West direction. The displacement indicated by the out-run survey was 3.73 feet at North 26° 48' West. Hole inclination was less than 1/2 degree.

RESCUE HOLE DRILLING

At 1:30 PM on Saturday, January 23, crew members started to rig down the probe unit. The rig was towed off the probe hole and rig up for the rescue hole was begun at a location approximately 15 feet from the site of the probe hole.

RIG UP

By 6:00 PM on the 23rd, most of the major equipment modules were in place, and drilling personnel began to connect water, fuel, and air lines, and all engines were started. Under conditions of extreme cold and high winds, work continued throughout the night and into the morning of January 24, 1971.

The rescue rig tower was raised and secured by guy wires. The next step was to position and level the 37-1/2 inch rotary table and to connect the rotary chain drive. On Sunday morning, January 24, the rescue rig was operational and picked up the 28-1/2-inch drilling tools.

DRILLING

At 11:00 AM on Sunday the 24th, the driller spudded the rescue hole using two steel donut-type weights. For starting the hole, due to the low substructure, the regular kelly drive bushing was modified by use of a special kelly drive extension provided specifically for this purpose. When the driller reached sufficient depth, the extension was removed and the regular kelly drive bushings were employed.

Limited weight on the bit slowed drilling of the upper portion of the hole. As depth increased, steel donut weights were added to the drilling assembly, which improved penetration rates. Formation water encountered early in the drilling required the injection of water into the hole at the swivel gooseneck in order to prevent formation cuttings from clogging the pipe, gooseneck, or swivel.

One significant problem was the continuous and rapid collection of fine cuttings in the steel mud pit. Cuttings are normally pumped across a double-deck vibrating screen called a shale shaker. This shaker is equipped with a 12-mesh upper screen deck and a 40-mesh lower screen deck. The cuttings partially plugged the 40-mesh screen deck causing excessive loss of circulating water over the side of the pit. For this reason, the 40-mesh screen was removed. However, it then became occasionally necessary to stop drilling, empty the mud pit, and clean out the cuttings.

The rescue rig hole reached a depth of 44 feet on the first day of drilling. Daily drilling progress reports and penetration rates are shown in table 3-2. The penetration curve appears on figure 3-5, and the penetration-time profile appears on figure 3-6.

With the exception of repeated clogging of the mud pit, there were no significant problems down to a depth of slightly more than 600 feet, reached on Friday, 27 January, after a rotating time of 87-1/2 hours. At this depth, drilling slowed because of excessive bit wear. The decision was made to change the bit, but there was a considerable delay in pulling the drill string. This difficulty was due to a large (about 100 pounds) wedge-shaped rock which had fallen from the side of the hole and lodged on top of one of the stabilizers. Inspection of the bit showed that the two center cutters had locked, probably due to small rock fragments from the broken formations between 590 and 614 feet. After rotation was impaired, the cutters dragged, shearing off the tungsten carbide cutter teeth.

A replacement bit, also equipped with tungsten carbide gage cutters, drilled from 614 feet to breakthrough. This phase of drilling proceeded in almost the same manner as the upper portion of the hole. However, initially drilling was quite rough, despite a gradual weight concentration on the bit. This difficulty indicated that rock had fallen into the hole during the removal of the string to change bits.

The overall drilling rate was slow, due in part to occasional soft formations which caused plugging of the air circulation system. A weight of 50,000 pounds was used on the drill bit until it drilled into the mine at 778 feet on Sunday, January 31, at 5:45 PM. The drill bit missed the center of the target by only 2-1/2 feet. After a series of photographs of the 28-1/2 inch drill bit extending from the mine roof were taken, the drill string was pulled from the hole and disconnected. By 8:00 AM on Monday, February 1, the drill pipe disassembly had been completed.

Examination of the drill bit showed that cutter damage had again caused the slow penetration rates. Most of the tungsten carbide inserts were either missing or broken. However, the milled tooth cutters were in comparatively good condition. The second bit drilled for only 38 hours, considerably below the estimated life of 88 to 100 hours. Analysis seemed to indicate that the brittle inserts were broken by the loose, uneven rocks in the hole at the start of the run or by broken carbide pieces remaining in the hole after the removal of the first bit. Supporting this conclusion is the fact that the inserts which had not broken off were not badly worn and the rugged milled tooth center cutters did not fail.

After the drill string was withdrawn, a 24-inch-diameter capsule was lowered into the hole to simulate recovery of the trapped miners. On Monday, February 1, this capsule was connected to 1/2-inch nonrotating wirerope

TABLE 3-2
SUMMARY OF RESCUE HOLE DRILLING PROGRESS AND PENETRATION RATES

Drilling Interval (ft)	Footage Drilled	Rotating Time (min)	Average Drilling Rate (ft/hr)	Rotary Speed (RPM)	Weight On Bit (lb)
0-4	4	189	1.3	5-10	2-4,000
4-13	9	158	3.4	5-10	2-4,000
13-28	15	166	5.4	5-10	2,4,000
28-41	13	78	10.0	5-10	2-4,000
41-48	7	94	4.5	5-10	10-20,000
48-74	26	262	6.0	5-10	10-20,000
74-98	24	158	9.1	33	54,000
98-129	31	168	11.1	33	54,000
129-158	29	210	8.3	33	54,000
158-191	33	174	11.4	33	54,000
191-222	31	160	11.6	36	50,000
222-252	30	194	9.3	36	50,000
252-283	31	216	8.6	36	50,000
283-315	32	184	10.4	36	50,000
315-347	32	204	9.4	36	50,000
347-378	31	196	9.5	36	50,000
378-409	31	192	9.7	36	50,000
409-440	31	194	9.6	36	50,000
440-470	30	192	9.4	36	50,000
470-502	32	242	7.9	36	50,000
502-534	32	258	7.4	36	50,000
534-565	31	224	8.3	36	50,000
565-596	31	282	6.6	36	50,000
596-605	9	153	3.4	36	50,000
605-612	7	190	2.2	36	50,000
612-626	14	214	3.9	36	50,000
626-658	32	418	4.6	36	50,000
658-689	31	348	5.3	36	50,000
689-721	32	276	7.0	36	50,000
721-751	30	374	4.8	36	50,000
751-778	27	526	3.1	36	50,000

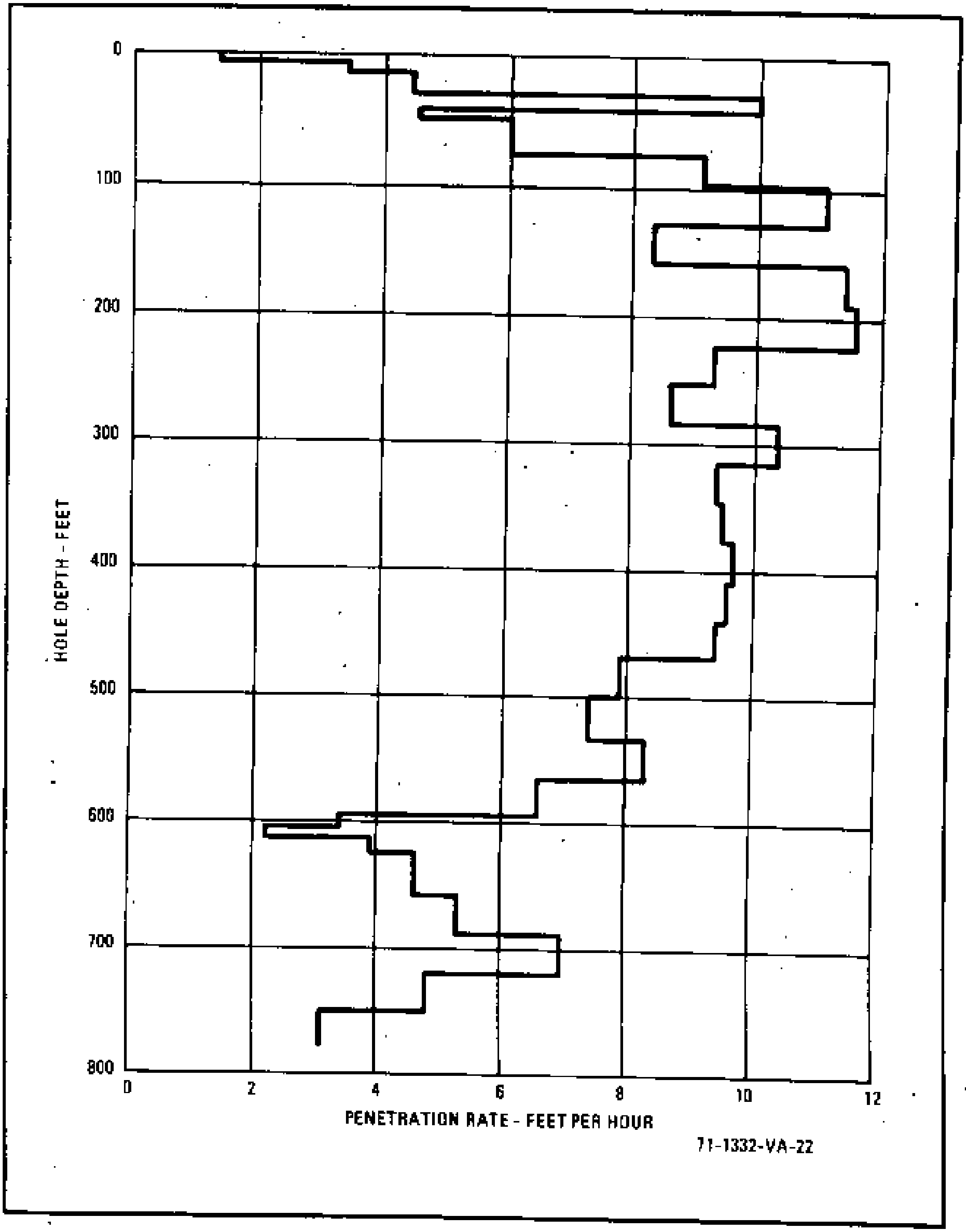

Figure 3-5. Rescue Hole Penetration Rate Diagram

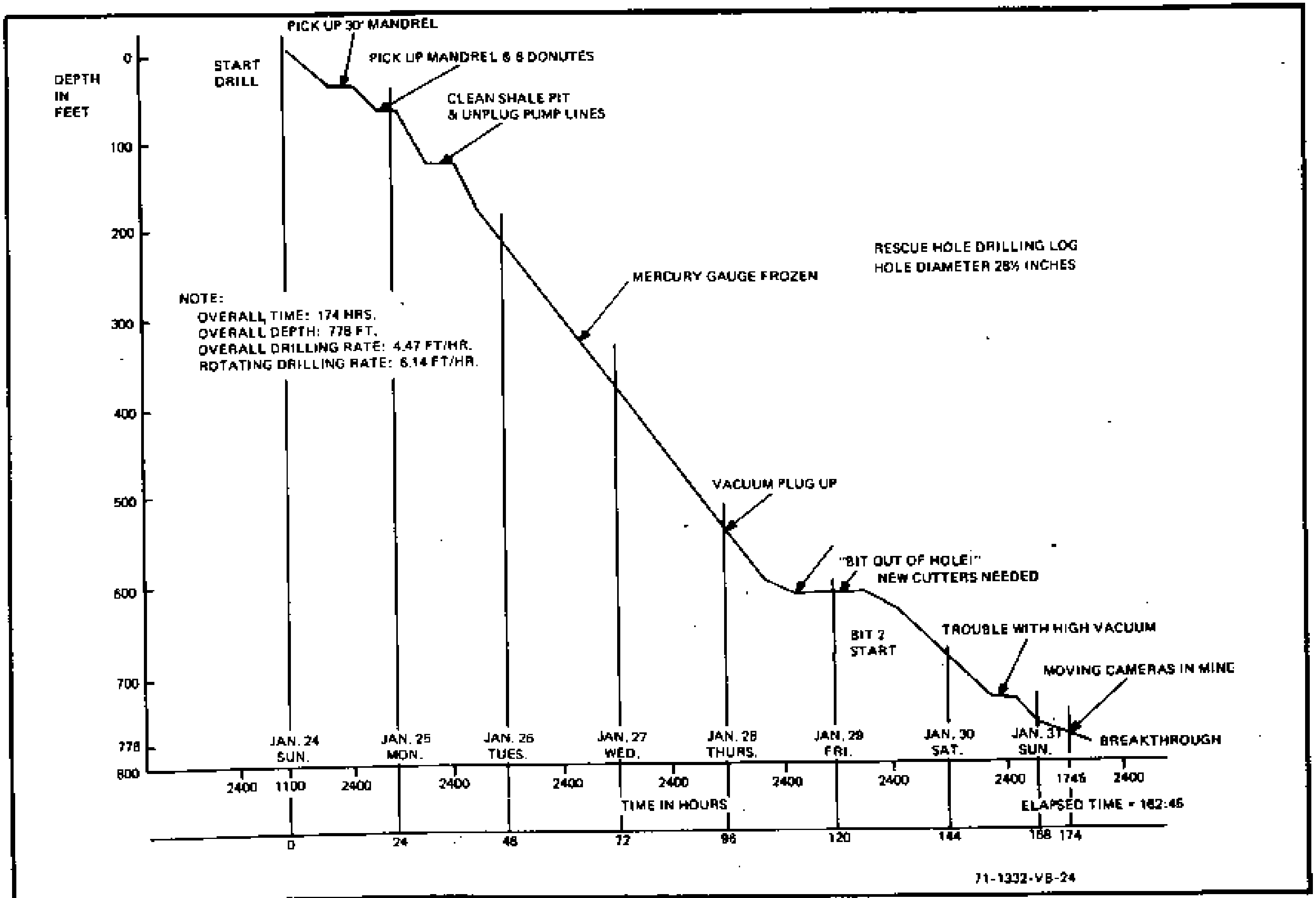

Figure 3-6. Rescue Hole Penetration-Time Profile

which was spooled on the rescue rigs personnel hoist. The capsule was then lowered through the hole, set on the mine floor, and photographed. The capsule did not drag or hang throughout the simulated recovery exercise, which shows that the hole was very straight and smooth. When this exercise was completed, dismantling of the drill rig was commenced.

ANALYSIS OF PROBE AND RESCUE DRILLING

Probe and rescue hole drilling operations achieved their objectives, successfully revealing the capabilities and the limitations of the two drilling systems under severe environmental conditions.

For the probe hole drilling with an average weight of 20,000 pounds and an average rotating speed of 50 rpm, the average penetration rate was 22.35 feet per rotating hour. In rescue drilling, the average penetration rate from 78 to 721 feet was 7.9 feet per rotating hour with instantaneous rates ranging from 2.2 to 11.6 feet per hour. Both drilling performances compare favorably with the rates predicted by Smith Tool Company, based upon laboratory tests. Their predictions were 21.1 feet per rotating hour for probe drilling and 8 feet per rotating hour for the rescue drilling.

Improvement is required in probe penetration rates for the beginning portion of the hole, where weight concentrations are inadequate for good penetration rates with conventional oilfield type rotary drilling equipment. Several methods for achieving this were investigated during the predesign phase of procurement. These techniques include the air hammer drill, downhole hydraulic motors, and mechanical or hydraulic pulldown arrangements. The air hammer drill offers the greatest opportunity for appreciably improving penetration rates in the first 100 feet. This drill can be used with special solid-type bits as well as the roller-cutter types specially designed for percussive service. This tool has a record of successful drilling application under similar conditions in the Appalachian region and is compatible with direct compressed air circulation. The hydraulic downhole motor is used primarily for directional drilling, but its relatively high rotating speed of 350 rpm partially offsets the adverse effects of low bit weight on initial penetration rates. Pulldown devices effectively offset low bit weight, but frequently result in an off-verticle start to the hole which requires a time-consuming correction to hit the target.

The big hole type assembly used for rescue drilling permitted more weight concentration on the bit during initial drilling. Therefore, penetration rates in rock near the surface were comparatively better than for probe drilling. The short drilling assembly and kelly drive extension provided for the rescue rig operated successfully during the demonstration.

The severe weather experienced during probe and rescue drilling was the most difficult operational problem. The subfreezing temperatures caused extensive freezing problems, especially with the water circulation system, and required considerable on-site improvisation. Winterization equipment can be provided for the drill rig and would improve Rescue Subsystem operation in extremely adverse weather.

During rescue drilling, continuous injection of water down the hole and at the swivel gooseneck effectively prevented damp formation cuttings from collecting in the drill string to the point of blocking circulation. Restrictions at the throat of the 28-1/2-inch bit body may have contributed to the plugging tendency. The water injection procedure was also necessary for the probe rig when reverse circulation was used. Occasionally very soft formation strata also caused minor difficulty with plugging. This increased the vacuum at times to the upper operating limit of the rotary blower. It was often necessary to reduce the weight on the bit to penetrate these soft sections.

The basic similarities of the two rigs permit, with certain modifications, the use of the rescue rig to drill the probe hole to the desired depth. The probe rig also has the capability to drill a 28-1/2-inch rescue hole to a depth of approximately 800 feet, which is sufficient for most mine workings. To obtain this potential, additional sets of probe and rescue hole drill pipe and downhole assemblies are required. If concurrent emergencies occurred, two rigs capable of probe hole drilling would be available. Also, two dual-purpose rigs ensure that one would be operational at all times and would enable the other rig to be used for additional testing.

The good performance of both rigs in drilling comparatively straight holes indicates the desirability of drilling vertically from the surface to the target location whenever possible. Although the techniques of directional drilling are well established in the drilling industry, additional tests for rescue-type drilling are required. This procedure also adds time-consuming steps to the operation. The instances in which vertical drilling would not be used would be when the location of a drill site vertically above the target would not be practicable due to adverse terrain or other environmental disadvantages.

CHAPTER 4
CONCLUSIONS AND RECOMMENDATIONS

This chapter reports conclusions and recommendations which are based both on the development and test of the prototype Rescue Subsystem as described in the preceding paragraphs and on Westinghouse observations and analysis of the project in the context of the total system problem and the possibilities for extending subsystem capability.

CONCLUSIONS

General Operation

As was anticipated by the NAE and the Bureau of Mines, the development and demonstration of the prototype Rescue Subsystem as an integral part of a CMRSS has surfaced several significant aspects which require additional analysis, development, and test before the full potential of the basic NAE concept could be utilized. These are discussed below.

National Academy of Engineering Concept

The basic NAE concept for probe and rescue drilling from the surface is a technically feasible and operationally practical means for reducing fatalities among miners trapped underground. The probe hole concept complements and extends the time-limited survival capability provided by breathing devices and refuges. The rescue hole concept complements through-the-mine rescue techniques.

Preparing a position for the probe rig vertically above an underground target in the Appalachian area can consume a disproportionate amount of the total elapsed time from notice of a disaster until a probe hole is completed to the underground target. Directional drilling capability is not as important for the rescue rig since rescue drill site preparation can proceed simultaneously with directional probe drilling from an offset site.

Using standard rotary rig, tools and procedures, drilling the top part of the probe hole without an acceptable deviation from the vertical also consumes a disproportionate amount of time.

Additional procedural integration within the Rescue Subsystem, and also among the Rescue Subystem and interfacing elements of the CMRSS, can effect important savings in total operational elapsed time.

The requirements for two separate rigs, and for both to be capable of drilling to 2,500 feet, resulted in the need for more, larger and heavier equipment than would otherwise have been necessary for the operation.

The existence of two rigs, both built to the CMRSS depth criterion, and both with reverse air circulation equipment, enables each to be equipped for a dual probe and rescue capability.

A Rescue Subsystem capability has been developed and can be enhanced by selecting and adapting the best of the equipment and procedures currently available to satisfy commercial demands. However, realization of the full potential of the Rescue Subsystem concept as a part of an operational CMRSS requires specialized systems analysis and innovative engineering, fabrication, and testing aimed specifically at the mine emergency problem. Such a program will not come about unless sponsored by the Bureau of Mines.

Prototype Subsystem

The prototype development approach has served both its primary purpose of evaluating the Rescue Subsystem concept and performance goals established by the National Academy of Enginnering, and its secondary purpose of providing an operational capability for actual disasters.

The 8-3/4-inch probe hole and 28-1/2-inch rescue hole sizes are larger than the contract required. These larger sizes are considered generally advantageous for the probe and rescue missions.

The two drill rigs and ancillary equipment have ample capability for drilling probe and rescue holes to the 2,500-foot depth required by the contract.

The two drill rigs have the design capability to run any casing string that is likely to be required to overcome adverse formation conditions.

All subsystem equipment is capable of being transported by surface means (truck or rail) or by military air transport or heavy-lift helicopter airlift. However, the 18 to 36 hours required for disassembly, reassembly, and transportation to and from airports limits the utility of air transport (i.e., airplanes only for very long distances and helicopters only for sites impossible of surface access).

The overall design of the two drill rigs provides the capability to employ almost any circulating method currently in use in the drilling industry including dry air, air/mist, air/foam, drilling mud, or water in either the dirct or reverse flow modes. This flexibility enables the rigs to cope with all geological and hydrological conditions.

Vacuum reverse air circulation is the method of greatest utility for the Rescue Rig and may have limited application for the Probe Rig.

Direct compressed air circulation is best for the probe rig in most cases, providing more positive hole cleaning and fewer operational problems, and confining site preparation and rig-up to the basic rig trailer.

Optimizing vacuum drilling with both rigs will require experimental testing with air flow rates and with water and other additives.

When bits were weighted and rotated at their design values, average penetration rates during the operational demonstration were virtually identical with the values projected by laboratory drillability tests. Rescue bit life fell short of predictions due to breakage of tungsten carbide inserts.

Instantaneous penetration rates for both rigs fall short of contractual target values. Penetration rate of the probe rig was very poor near the surface due primarily to low weight available to the bit and secondarily to low rotating speed, the first 100 feet taking 45 percent of the time required to drill the 776 foot hole. The low rate of the probe ring penetration near the surface is partly due to the fact that the rig as designed will not permit normal rotating speeds until the hole is deep enough to stabilize the kelly.

Both rigs are capable of vertical drilling accuracies through horizontally stratified formations which are well within the contractual target of 2 percent per 500-foot average deviation. Accurate drilling in formations which are folded or which have markedly sloping interfaces may require a directional drilling capability for ensuring directional drilling precision.

Both rigs are primarily designed for vertical drilling. The probe rig has a directional drilling capability if provided with commercially available tools such as a downhole hydraulic motor and directional surveying equipment. Directionally drilling the rescue hole is of questionable practicability but may be possible by enlarging a directionally-drilled smaller hole.

At the test demonstration a lack of full winterization of the prototype equipment hampered operating efficiency, safety and comfort.

Both drill rigs are of high quality and are structurally rugged and will prove reliable, durable, and maintainable in operational use. Maintainability has been further enhanced by the careful design of interchangeability of components and parts between the two rigs.

The two rigs are excellent building blocks for further improvements to the Rescue Subsystem capability. Most approaches to increasing performance capability can be accomplished by additions or modifications to this basic equipment. Little replacement or major rework will be necessary.

Each rig may be converted to serve a dual-rescue role with straightforward modifications and additions*. The rescue hole capability of the modified probe rig would be limited to about 800 feet.

RECOMMENDATIONS

Near-Term Tasks

Winterize both rigs.

Maintain both rigs operationally ready.

Keep a rig capable of probe drilling on constant alert at the Charleston, West Virginia Staging Facility to ensure immediate response to actual emergencies.

Investigate a sufficiently large number of mines to determine the range of access road and drill site location construction requirements.

*This conversion will be facilitated by two design features of the subsystem provided under this contract which exceed target specifications. These are the full set of ancillary vacuum drilling equipment which has been supplied with the probe rig and the fact that the rescue rig can also be broken down into packages for air transport or helicopter airlift.

Develop plans and make advance arrangements to ensure that supporting vehicles, equipment, personnel, and supplies are available for emergency use of the subsystem in all mining areas.

Modify rigs and add available tools and equipment to reduce penetration times for the probe hole by increasing penetration rates (particularly near the surface), reducing procedural time-outs, and providing directional drilling capability to reduce site preparation times under difficult access conditions. Measures should include air hammer drilling equipment, additional drill string weighting equipment, downhole hydraulic motors, air compressors of adequate capacity for extreme demands, and means for rapidly changing circulation methods and for more efficient tool handling.

Modify the rescue rig so it can perform the probe mission.

Plan and carry out a field test program with the rescue rig to optimize operating techniques and procedures and gain experience with specialized equipment additions pertinent to both probe and rescue drilling.

Longer Range Tasks

For planning the development of rescue subsystem capabilities beyond the near-term tasks enumerated above, a planning project should be established which would attack the problem on an integrated systems basis. Due consideration should be given to the conclusions of the CMRSS program and the near-term tasks listed above. The project should consider other projects in the Bureau of Mines program and pertinent research and development sponsored by others within the equipment and functional framework of the Rescue Subsystem, efforts concerning interfacing mine survival and rescue capabilities wherever they are underway, and possibilities for technical and procedural innovation. The objective of this project should be to define a program which will minimize total elapsed time from occurrence of an emergency to probe hole contact and final rescue. Development and study should include through-the-mine probe and rescue drilling and applications of smaller drilling technology.