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Operations Manual for

EXTINGUISHING COAL MINE FIRES BY REMOTE SEALING

Vol. I

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FOREWORD

This operations manual describes basic procedures and system specifications for the Remote Mine Sealing System developed under USBM Contract No. H0122046. A detailed description of the development effort may be found in USBM Contract Report No. H0122046, part II.

This Operations Manual was prepared by Foster-Miller Associates, Inc., Waltham, Massachusetts. It describes the basic procedures and system specifications for the Remote Mine Sealing System developed under U. S. Bureau of Mines Contract No. H0122046. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PM & SRC with Mr. Donald Mitchell acting as the technical project officer. Mr. Joseph Herickes was the contract administration for the Bureau of Mines. The program manager at Foster-Miller Associates was Mr. Adi R. Guzdar.

A detailed description of the development effort is provided in the Technical Report, Vol. II of the contractual documentation.

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1. Introduction

This manual was prepared to provide essential information to be used when critical decisions pertaining to mine fire recovery or other disaster situations become necessary. It is a state of the art report based upon technology and instruments developed, under a Bureau of Mines Research Contract. A detailed description of the development work and results of full-scale field testing is contained in the Technical Report, Vol. II, of USBM Contract Report H0122045, "Extinguishing Coal Mine Fires by Remote Sealing."

Further research and development work has been programmed; consequently, a more complete manual providing detailed instructions and describing available instruments and equipment will be published. Those instruments and special equipment described in this manual must be considered prototype; methodology and applied technology will require special expertise. Consequently, any prospective application of this remote sealing technique will require assistance by the United States Bureau of Mines Research organization and experts from the contractor who developed the basic technology and instruments.

2. Remote Sealing System Description

The objective of the system described in this manual is to extinguish coal mine fires by remote sealing of the underground passageways. The system developed is versatile enough to function under a wide range of operating conditions including large variations in passageway geometry, depth of mine, water conditions both in the mine and at the surface, and rubble in the mine passage. The system includes instrumentation for the remote probing of the passageway prior to sealing, a system for sealing the mine passages, and instrumentation for remote monitoring of the quality of the seal during and after construction.

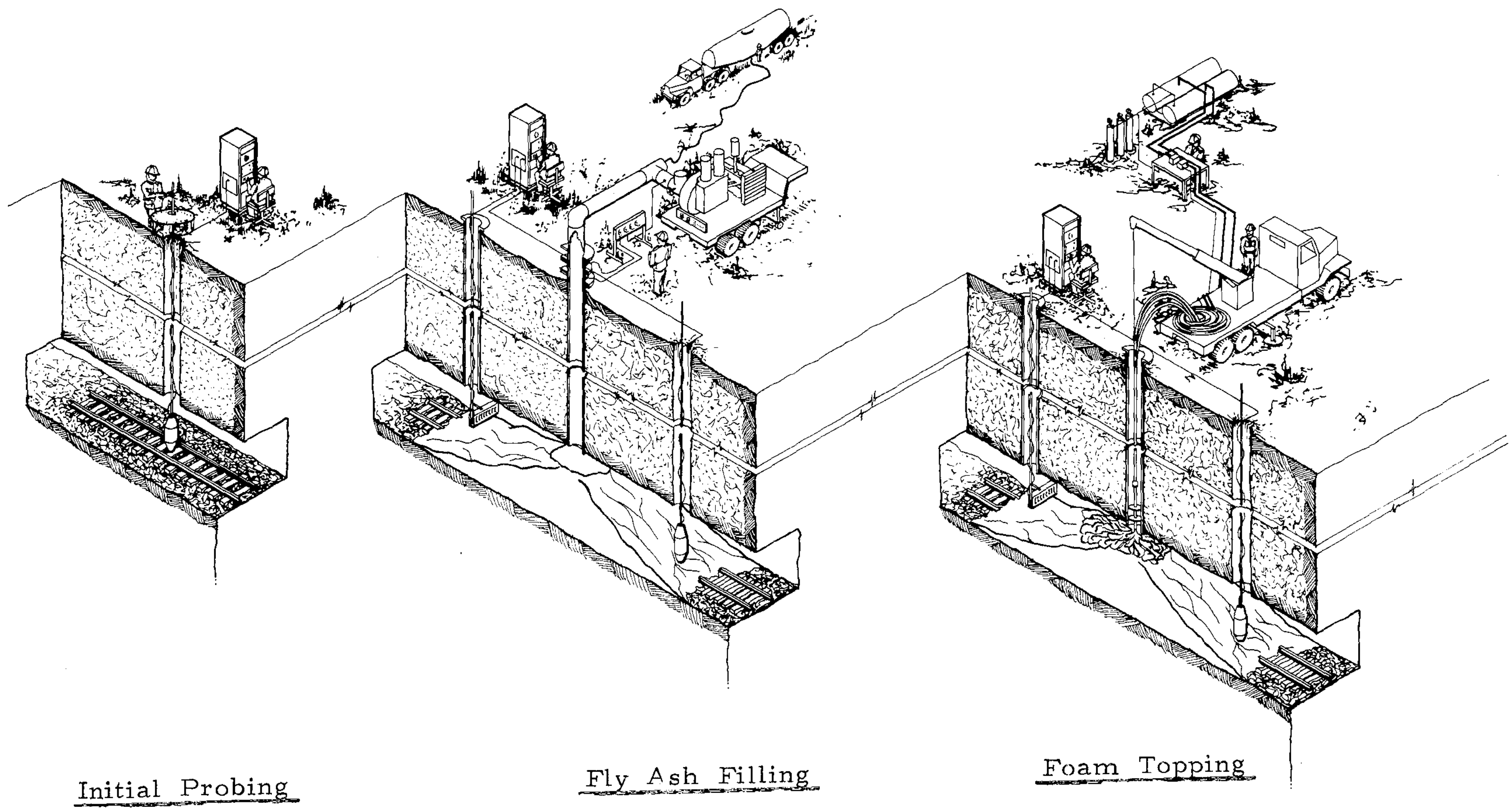
The remote sealing system consists of:

(a) A sonar initial probing system which can operate satisfactorily even in the presence of dense smoke. The system is capable of determining both the local passageway geometry, identifying the presence of cribs and other obstructions, and the position of the borehole in the mine passage.

(b) A mine sealing material system which utilizes fly ash for making the complete seal or as a bulk filler in conjunction with a urethane, froth-foam, seal topping system. The choice of using fly ash alone or fly ash with foam topping depends on a number of factors, such as quality of seal desired, time available per seal, depth of borehole, passageway geometry, and water holding requirement. The fly ash-foam seal is a better seal, capable of sealing against a higher water head than fly ash alone. The fly ash sealing system uses a high velocity technique for injecting fly ash into the mine. This method results in the development of a large crater in the fly ash pile and causes the seal to form first at the ribs and subsequently move in towards the borehole. The presence of the crater eliminates the chance of premature plugging of the borehole and provides a receptacle for the froth foam used to top off the seal. The froth-foam system uses a downhole, static mixing head designed to provide uniform mixing of the foam components.

(c) An acoustic seal checking system which is capable of monitoring the continuous development of the seal during seal construction and providing a sensitive indication of the quality of the completed seal. The system senses the decay in strength of an acoustic signal passing through the sealed passage as a measure of the quality of the seal.

Figure 1 illustrates the operation of the complete remote mine sealing system developed in this program. The system is shown



Remote Mine Sealing System

Figure 1

in various phases of operation at three different sealing locations. A total of 3 boreholes per seal are required, one for sealing and one on either side of the seal for seal checking. The boreholes must be cased and grouted to prevent borehole water flow into the mine passage being sealed.

The various stages in the operation of the remote sealing system are:

(a) Drill, case and grout boreholes.

(b) Probe passageway through main sealing borehole. Retrieve system after completion of probing.

(c) Deploy acoustic seal checking system.

(d) Deliver fly ash through main borehole using high air flow delivery system.

(e) Monitor seal development and terminate fly ash pour either after completion of bulk filling or complete fly ash seal.

(f) Deploy downhole froth-foam system to top bulk-filled fly ash pile.

(g) Complete foam topping while monitoring seal completion with the acoustic seal checker.

(h) Retrieve froth-foam system and acoustic seal checker.

At the first location, shown in Figure 1, the primary borehole has been drilled and the sonar probe has been lowered into the mine passage. The sonar probe is used to scan the passageway to determine local passageway geometry, position of the borehole, cribs, rubble piles, or other obstructions. The display on the surface indicates the distance of a target in any desired direction, as determined by the compass markings on the rotary table at the surface. The probing information is used to establish the operating conditions of the fly ash delivery system. The probe has a range of 30 feet.

The second sealing location shows the fly ash filling operation with the acoustic seal checking system deployed through the two seal checking boreholes. The seal checker consists of a line array of speakers on one side of the seal and a microphone on the other. As the seal develops, the strength of the signal received at the microphone reduces. This reduction in sound level is a direct measure of the percentage of the mine passage area blocked by the seal. The electronic signal processing system includes a pulse-gating technique to eliminate the effect of sound traveling through parallel passageways to reach the microphone.

The fly ash pumping system utilizes the blower contained on the fly ash truck plus an auxiliary, diesel-driven blower, which provides ten times the air flow available from the truck. The truck pumps fly ash through a standard 4-inch hose to a special mixing nozzle, which injects the fly ash into the high-flow air stream from the auxiliary blower and thence through an 8-inch pipe to the borehole. Instruments monitor the air flow rate, fly ash flow rate, and pressure at critical points in the system. This high flow rate system causes the fly ash to form a large crater in the mine passage, permitting the seal to form at the ribs first and then work back towards the borehole. The crater also provides a receptacle for the froth foam used to top off the seal. Typical air flow rates lie in the range of 2500 to 4000 scfm, depending on passage geometry.

The froth-foam topping system is shown in use at the third sealing location with the seal-checking system being used to verify that a 100 percent seal has been formed. The two components of the foam are stored under pressure in the large cylindrical tanks and pumped separately to the remote mixing head, which is lowered by a truck-mounted crane. The two liquid components are combined in the remote mixing head and released from pressure, causing the liquid to froth as it passes through the veins of a static mixer. In this manner, the foam materials are thoroughly mixed with no moving parts in the remotely deployed mixing head.

3. Organization and Planning

The necessity for a capable and efficient organization with detailed plans and assigned responsibilities is vital to successful emergency mine sealing. Lack of efficient organization after mine disasters has resulted in loss of life and property and has prolonged recovery operations.

3.1 Major Planning Tasks

Once a decision has been reached that surface sealing is required, all known conditions pertaining to the fire, its origin, extent, proximity to active workings and gob areas must be studied. The end purpose is to limit the spread of fire, or isolate the fire area, with minimum hazard to workers and in the shortest time.

This will require the determination of underground sites suitable for remote sealing. A primary and secondary plan should be made. All available information pertaining to underground conditions at selected sites should be listed. Surface sites should be studied to determine available roads and what access work will be necessary to drill holes and utilize sealing materials. Conditions of the water table should be checked to determine whether drill holes must be cased to eliminate flow of water. Surface and underground survey nets must be coordinated and surface boreholes calculated.

Local drilling contractors should be contacted and lists of available drilling equipment by sizes and types prepared. Where fly ash or other material is required, suppliers and commitments for delivery must be established. Surface site preparation may require heavy construction equipment which should be arranged.

3.2 Planning and Management Personnel

Personnel comprising the planning teams and having major responsibility for the conduct of the sealing operation should include the following:

1. Officials of the Mine Corporation affected, including:

   (a) A high-level officer with authority to make decisions and authorize expenditures, or designated assistant.

   (b) The Mine Superintendent and Mine Foreman. Because of their specialized mine knowledge, they should serve as advisors and expeditors to coordinate activities.

   (c) The Mine Engineer, to locate borehole sites and establish conditions of underground levels, drainage, depth of overburden and property lines.

2. Officers of the United Mine Workers of America, both District and Local. Such men should be a part of planning and background for decision making. Some member should be permanently assigned to executive teams with responsibility for conducting various phases of the work.

3. Representatives of the District Office for Mine Safety, U. S. Bureau of Mines. These officials should bring through their Bureau contacts special technical assistance, special devices, and

instruments from Bureau Research and Technical support organizations.

4. Representatives of the State Mining Department, to serve as consultants and participate in all planning stages.

5. Manufacturing companies, as consultants familiar with mine disaster recovery and remote sealing operations. Such companies may supply special equipment and instruments as situations develop.

Work scheduling must be conducted in detail in order to assure the maximum concurrent operations with minimum delays. Specific work assignments should be broken down and responsibility assigned to expeditors for each integrated operation. Each 24 hours a conference review of progress and assessment of conditions should be made. Any change in plans must be discussed and understanding reached by all persons involved.

4. Underground Site Selection

The choice of sealing locations will be affected by a number of factors including the size of the fire zone, rate of spread of fire, size of area that is desired to be sealed, known condition of underground passageways, accessability of surface area above the mine, and the need to minimize the number of passageways requiring sealing, etc. It is not the intent of this manual to predict sealing locations for a hypothetical fire. However, where possible, the choice of seal locations should be weighted by the following considerations about the sealing system:

(a) Sealing in smaller passageways can reduce the time and material required.

(b) Choosing areas with a minimum of overburden can reduce drilling times and time for deployment and retrieval of instrumentation.

(c) Seals should be avoided at passageway intersections as this increases the time and material required.

(d) The ideal sealing location is an entry midway between two cross cuts.

Although none of the above conditions are mandatory, they will aid in making the total sealing system faster and easier to operate.

5. Surface Site Preparation

Surface site conditions will have an important bearing upon the success of any remote sealing effort. Important considerations are access roads and bridges that can support the massive fly ash trucks. Using the technology developed, fly ash can be pumped latterly on surface 300 feet. Pumping uphill to the site will reduce this distance. Other site requirements involve access for the driller, his equipment and necessary pipe.

The equipment and material necessary to complete the seal by foam topping will require similar surface area and conditions as those required by the driller and his equipment.

The surface site will serve as a center of operations directing the scheduled arrival of fly ash trucks, monitoring seal progress, supervising additional drill holes and other organization plans and the coordination of concurrent work. The site should provide shelter, telephone service and storage space for critical materials.

Fly ash trucks should be scheduled to maintain a continuous flow of fly ash. This may require standby parking space for waiting trucks and ample room for turn around without interfering with work. Weather may be important and could slow operations unless special precautions are taken.

Where constant access must be provided over unimproved land, the construction of a "corduroy" road is recommended, shown in Figure 2. This type of road, which utilizes rough cut 4 x 6 common in coal mining usage, is quick and easy to build and reasonably inexpensive.

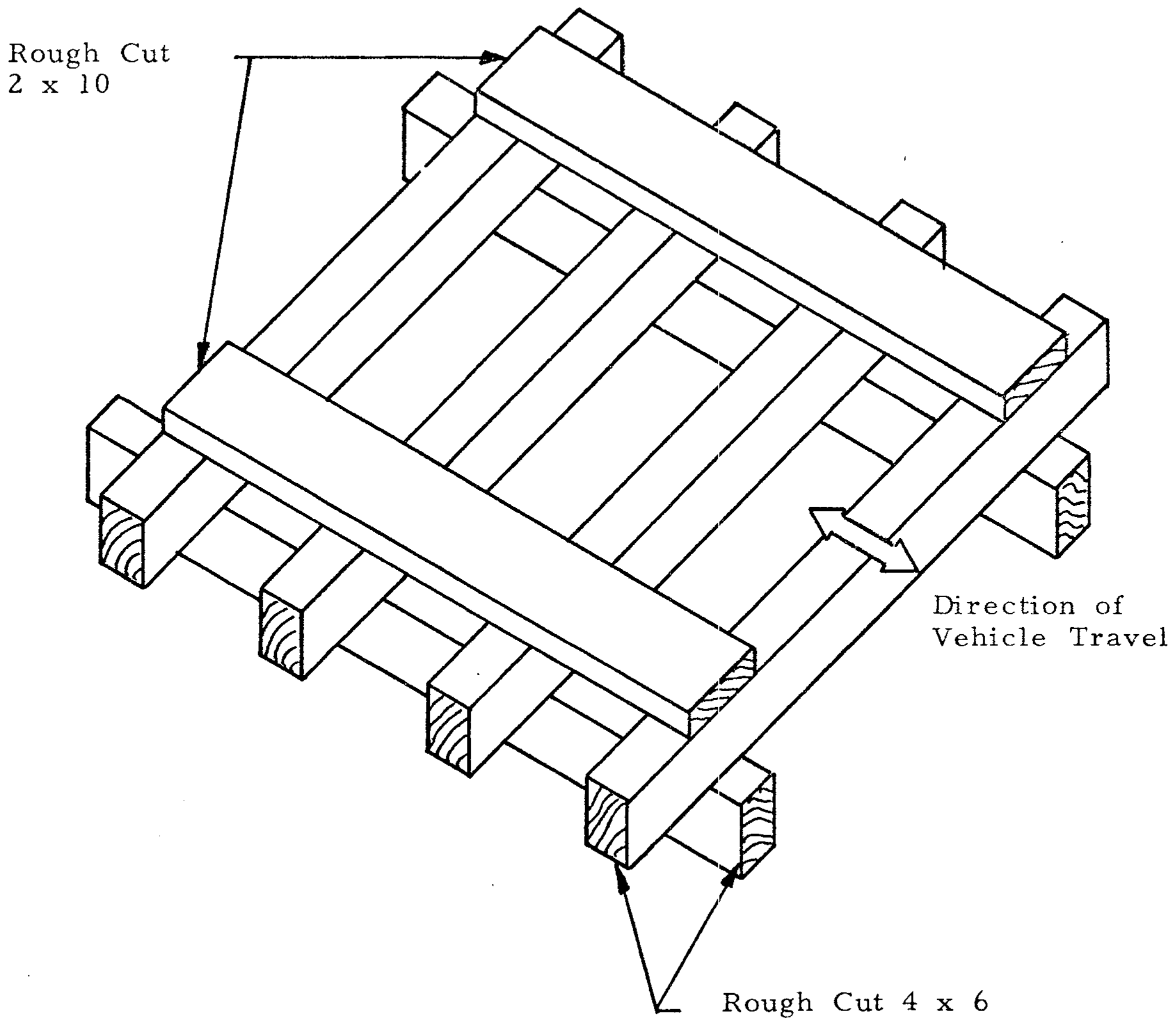
6. Borehole Drilling

Once the location of the desired underground seals has been chosen, a surface survey must be conducted to tie in to the mine survey net. A drilling contractor should be chosen who has both the equipment and expertise required. Where possible, a local driller who has done previous work for the coal company is recommended. The major factors affecting the drilling operation are summarized in Table I.

Representative times for drilling the hole, as a function of borehole depth and diameter, are shown in Figure 3. Depending on factors such as the drilling equipment available and the soil and rock conditions encountered, these times may vary, but they can be used for estimating purposes. Because some holes may not require casing, the time required for casing the hole and pressure grouting are shown separately.

6.1 Borehole Specifications

The factors influencing the location of the primary (sealing) boreholes were discussed in Section 4. The secondary (seal checking) boreholes will be located on either side of the primary



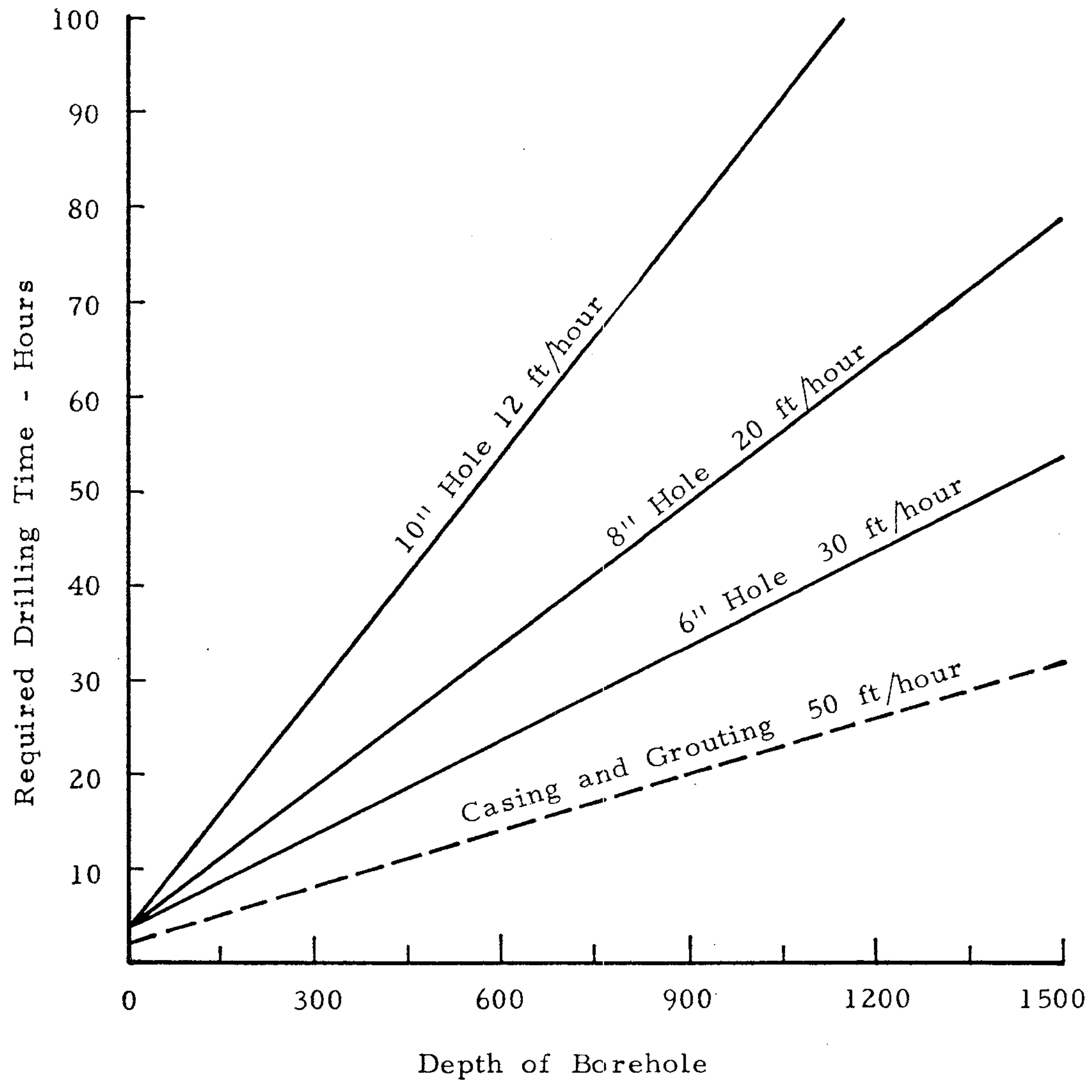
Section of Corduroy Road

Figure 2

TABLE I

EFFECTS OF ON-SITE VARIABLES ON BOREHOLE DRILLING AND CASING

Parameter	Effect on Dilling Operation
Borehole Depth	Increases in depth require proportionally longer drilling times as well as additional materials and equipment. Deeper holes also require greater care to insure borehole intersects passage.
Borehole Diameter	Drilling time and costs per foot increase significantly with the size of the hole required.
Underground Water	The presence of underground water flowing into the borehole requires casing of the hole with considerable increase in time and cost. This casing is required on the main borehole, but may be eliminated in some situations for the seal checker holes.
Soil and Rock Conditions	Unusual soil and rock conditions affect the drilling operation. Voids and underground pools may also affect the grouting operation.
Surface Topography	Surface topography affects the drilling setup time and the access of support equipment.



Required Drilling and Casing Times for Boreholes

Figure 3

hole, 30 to 40 feet inby and outby of the primary hole. The primary borehole and one of the secondary holes must have a 6 inch I. D.; the other secondary hole a 4-inch I. D.

Where water is encountered during drilling, it is required that the borehole be cased and grouted. Therefore, if ground water is anticipated, it should be planned in advance to drill the holes 2-inches oversize to allow for the loss in size when the hole is cased.

6.2 Effects of On-Site Variables on Drilling Operation

The success of the borehole drilling operation is affected by four factors:

(a) The accuracy of the mine map.
(b) The accuracy of the surface survey.
(c) The time and care of the drill operator.
(d) The depth of the borehole.

The accuracy at surveyed locations should assure a tie within two feet. Most mine survey nets are sufficiently accurate for this standard. In the event of any doubt, a check survey should be run and calculated. If the drill encounters solid coal at the passageway depth, the operation should be terminated until the cause of the error has been determined. Many companies offer borehole surveying services which can accurately plot the course of the hole. From this information it can be determined whether the drill strayed from a true course or the survey was inaccurate. In either case, the corrective remedial action will increase the confidence level in the accurate drilling of subsequent holes.

It is important that the urgency of the situation not be allowed to override caution in drilling the holes. The faster the hole is drilled, the more likely that the drill will wander off course.

7. Entry Checking, Sonar Probing

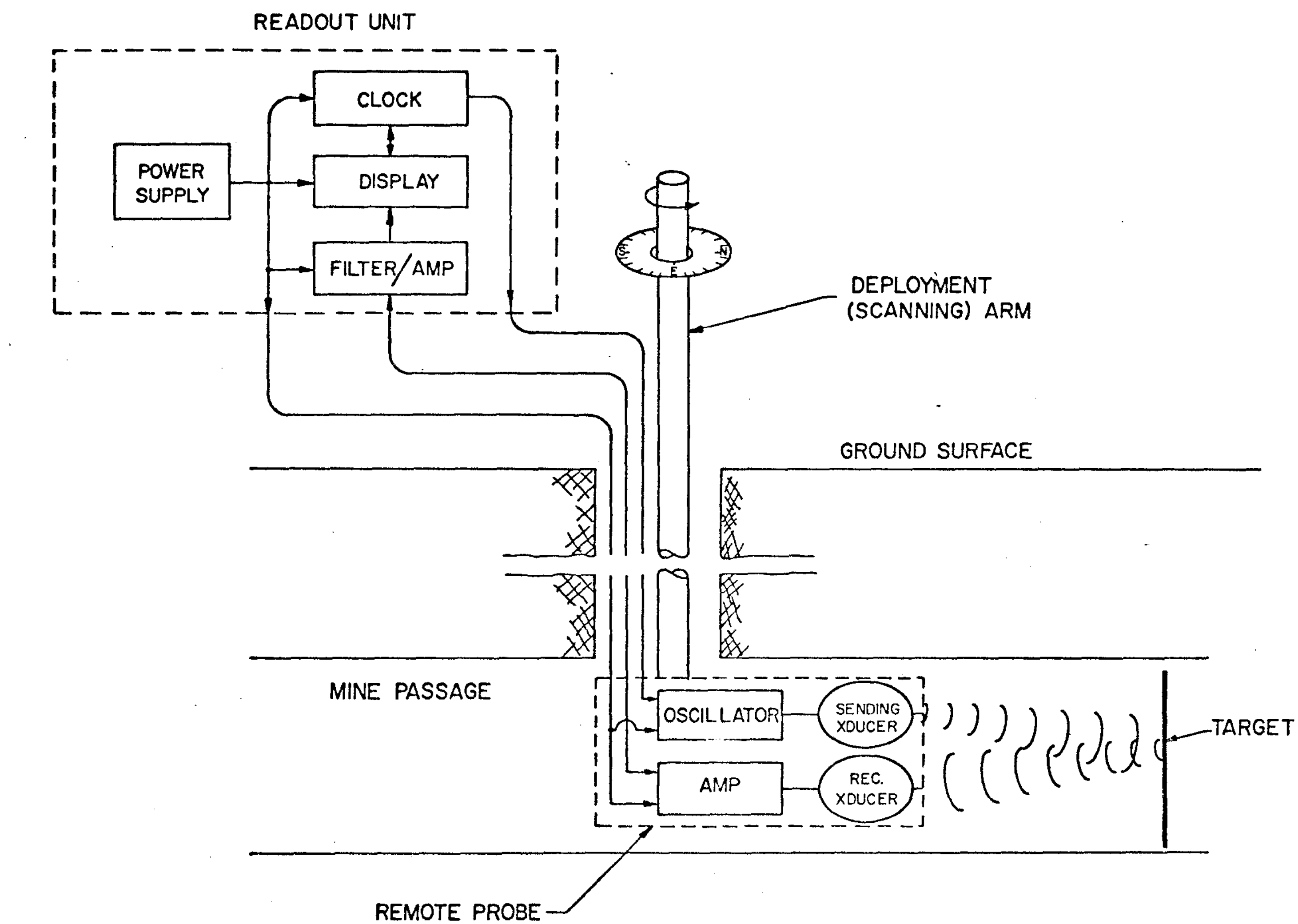
Underground conditions where the borehole enters single entries or intersections are important and influence the manner in which the seal should be made and the probable success for an effective seal. Important factors are caved material, entry geometry, water pools, obstructions that may impede material flow, the location of entry ribs with reference to borehole location, irregularities and roof cavities.

There are several devices or instruments with sufficient capability for this purpose. The most simple is probably remote-control camera or television equipment. Such equipment could be used where visibility is adequate and there is no explosion hazard from methane. To provide a useful tool even when visibility was limited, a prototype sonar probing system has been developed. This unit has the capability of "mapping" the passageway in the immediate area of the borehole, as discussed more fully in Section 7.2.

7.1 Sonar Probing Specifications

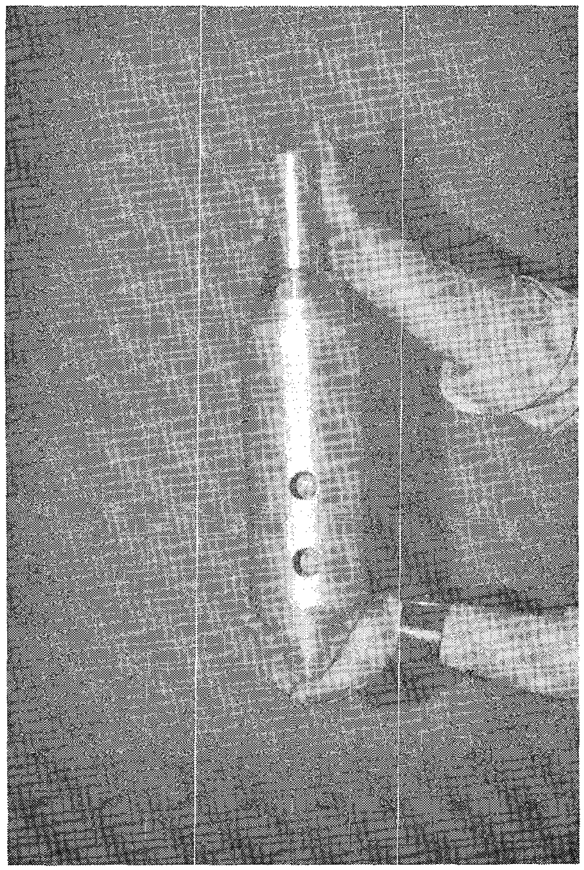
A block diagram of the sonar probing system is shown in Figure 4. The present sonar probing system is comprised of several components, including:

> A sonar probe to be lowered into the mine, Figure 5. This device transmits ultrasonic pulses and picks up the reflections from objects in front of it.
>
> A receiving device to process and display the signals received from the probe, Figure 6.



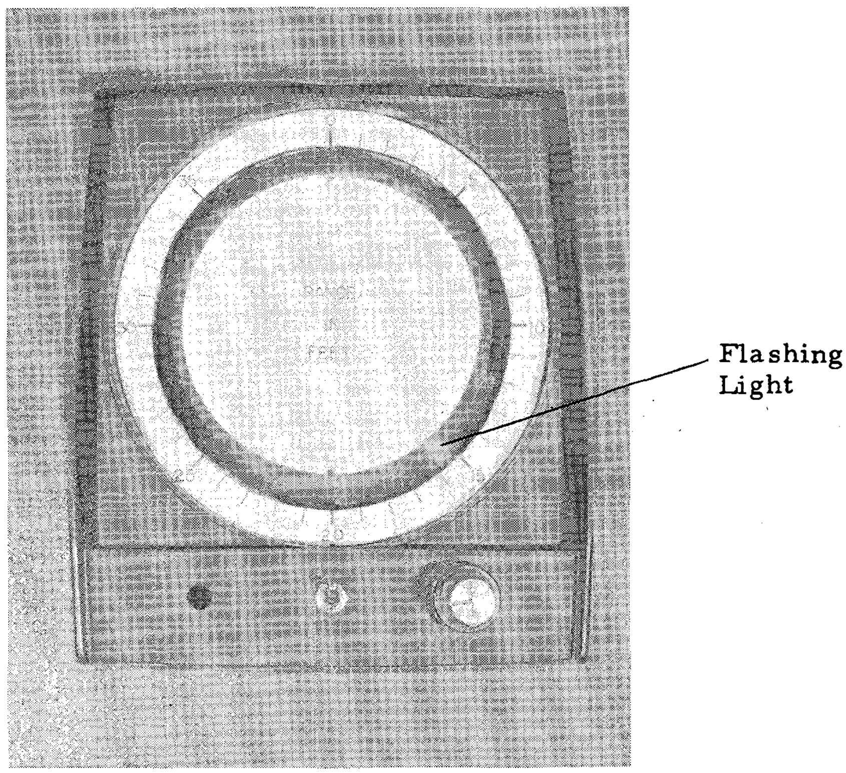
Sonar System Block Diagram

Figure 4



Sonar Housing

Figure 5



Sonar Display, with Flashing Light Indicating a Target at 15 feet

Figure 6

Structural equipment, consisting of a tower 25 feet high used for deploying the pipe string, Figure 7.

A pipe string, fabricated of light metal, that can be joined and lowered into the borehole, Figure 8.

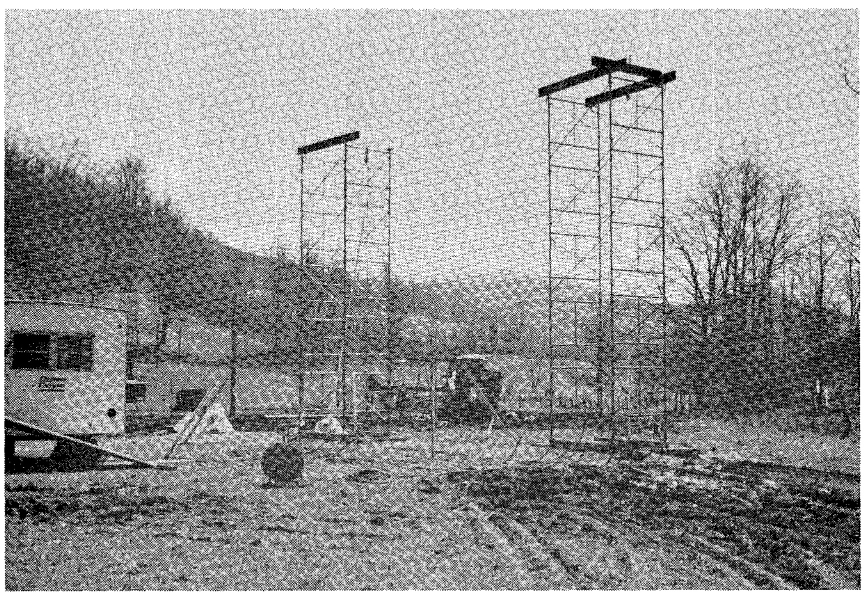
A rotary table assembly used to support the pipe string and orient the sonic emitter, Figure 9.

7.2 Effects of On-Site Variables on Sonar Probing System

Table II summarizes the effects of on-site variables on the sonar probing system. From this table it can be seen that the only factor affecting the time and equipment required for operation is the depth of the borehole. Figure 10 shows the approximate time necessary for sonar probe system operation, including the time required for lowering the probe into the passageway and retrieving it afterwards. Variables affecting confidence in the satisfactory operation of the system include the passage height, condition of the roof, and roof falls or other passageway obstructions.

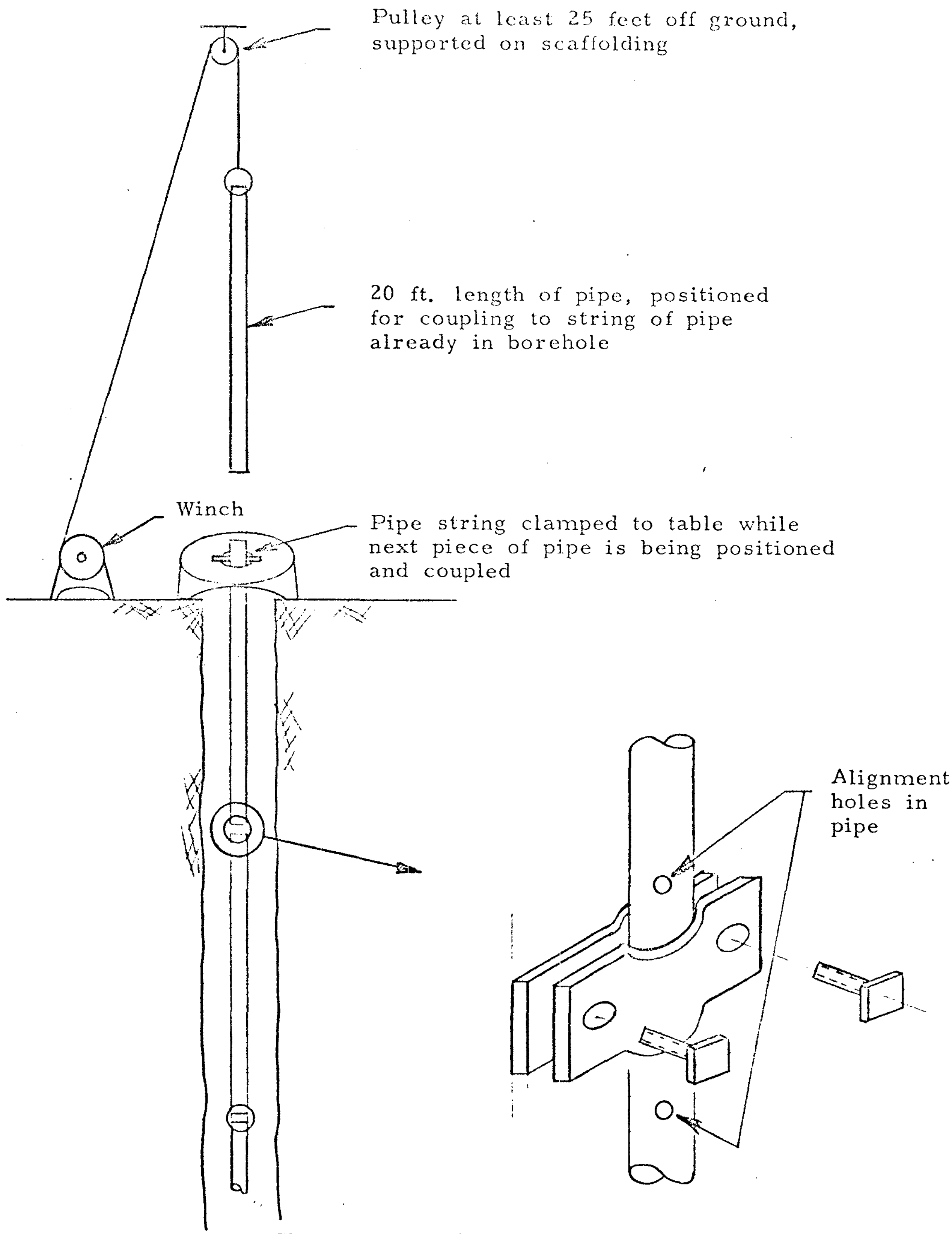
The sonar probing system has a maximum range of thirty feet. This range is sufficient to provide the necessary information for the sealing operation, including the width of the passage, major obstructions in the immediate area of the borehole, and distance from the borehole to each rib.

The effective range of the system may be reduced if the mine passageway is low in height. This is caused by the acoustic properties of the transducers used in the probe, which emit and receive the ultrasonic sound in a cone of space instead of in a



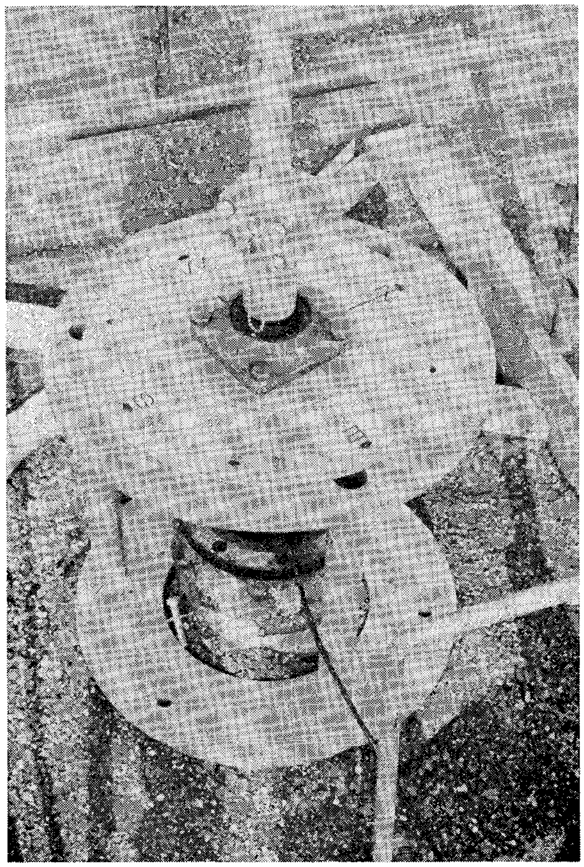
Scaffolding Towers used in Deployment
of Sonar Probe and Acoustic Seal-Checker

Figure 7



Close-Up Sketch of Pipe-Coupling

Figure 8



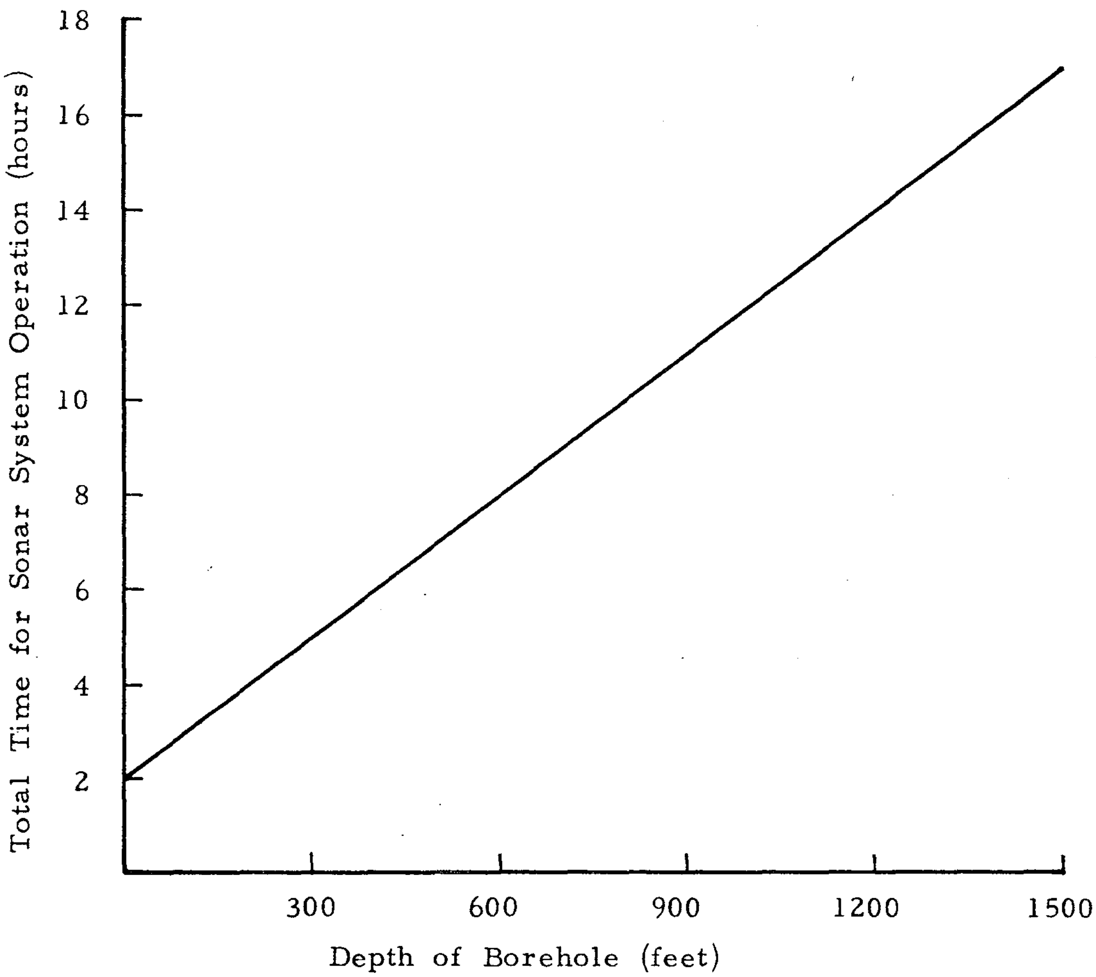
Completed Rotary Table Assembly

Figure 9

TABLE II

EFFECTS OF ON-SITE VARIABLES ON PRELIMINARY PROBING

Parameter	Effects on Sonar Performance
Passage Height	Low roofs can make data interpretation more difficult.
Passage Slope	Minimal effect.
Roof Condition	Rough roof can make data interpretation more difficult.
Passage Blockage	Partial passageway blockage will show on the display; however, proper interpretation can be more difficult.
Borehole Depth	Deeper holes will necessitate longer time for raising and lowering probe; requires more hardware.
Borehole Diameter	Minimal Effect.



Total Time for Sonar System Operation
as a Function of Borehole Depth
Figure 10

straight line. Reflections from targets on the edges of the sound cone will be displayed along with reflections from targets straight ahead. In low coal, the transducer will necessarily be quite close to the mine roof; this situation increases the number of the sound cone which hits the roof and thus increases the number of stray reflections detected by the system. In this case, the range of the device for which valid data is obtainable is curtailed, perhaps to as little as 10 feet in coal seams 3 or 4 feet high.

7.3 Operating Procedure

The equipment required for operation of the sonar system is listed in the Appendix. The sonar probe is lowered down the borehole using twenty foot lengths of aluminum pipe joined together with rigid couplings. This system requires the erection of a 25 foot tower or use of a portable crane to lift a new section of pipe into the air while it is being coupled to the last piece of pipe protruding from the borehole. New sections of pipe are added in the following manner:

1. Raise new section of pipe above the end of the pipe protruding from the borehole (Figure 11).

2. Insert the alignment tool into the alignment holes in the two pieces of pipe (Figure 12).

3. Insert the electrical cable hanger in the Victaulic* coupling. (Figure 13).

4. Install the Victaulic* coupling to clamp the two pieces of pipe together (Figure 14).

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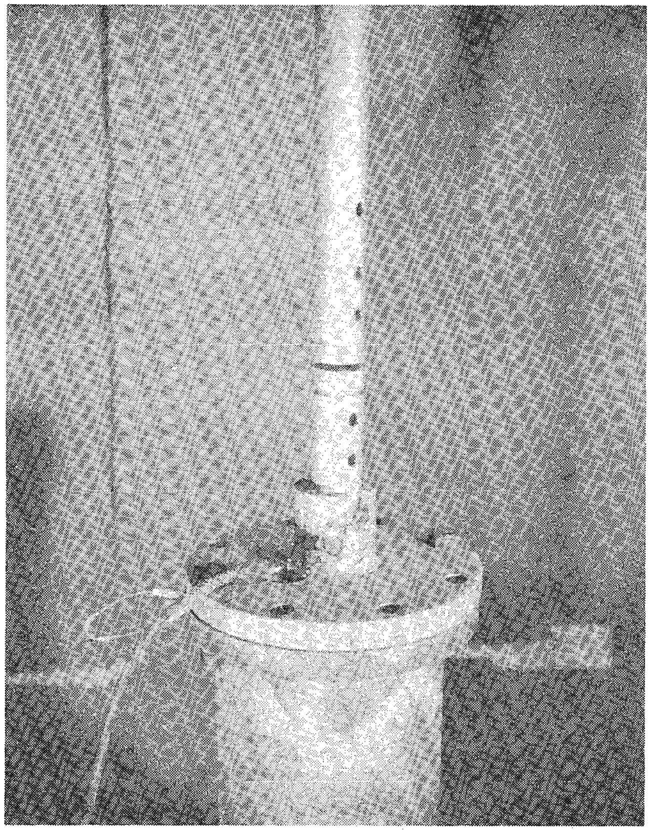
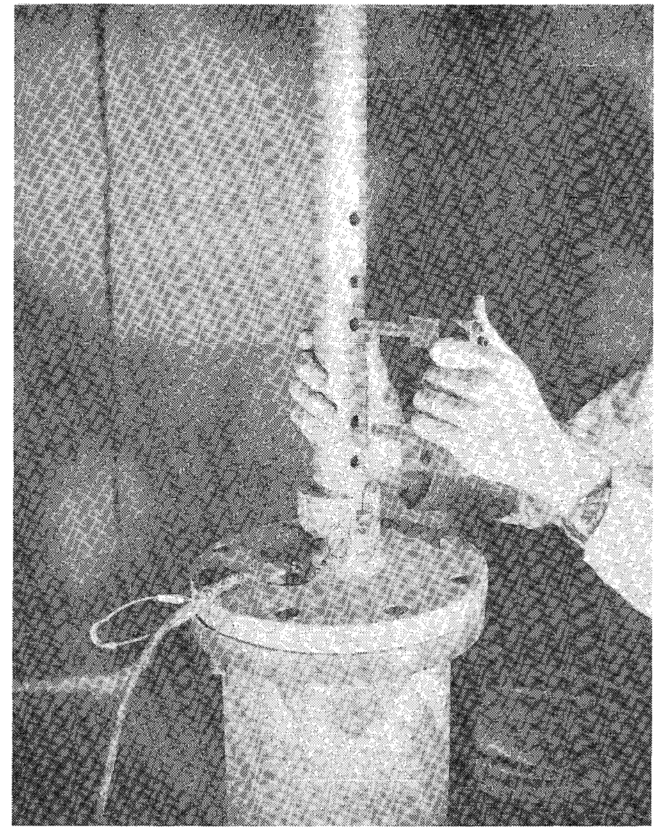
* Trade Name.



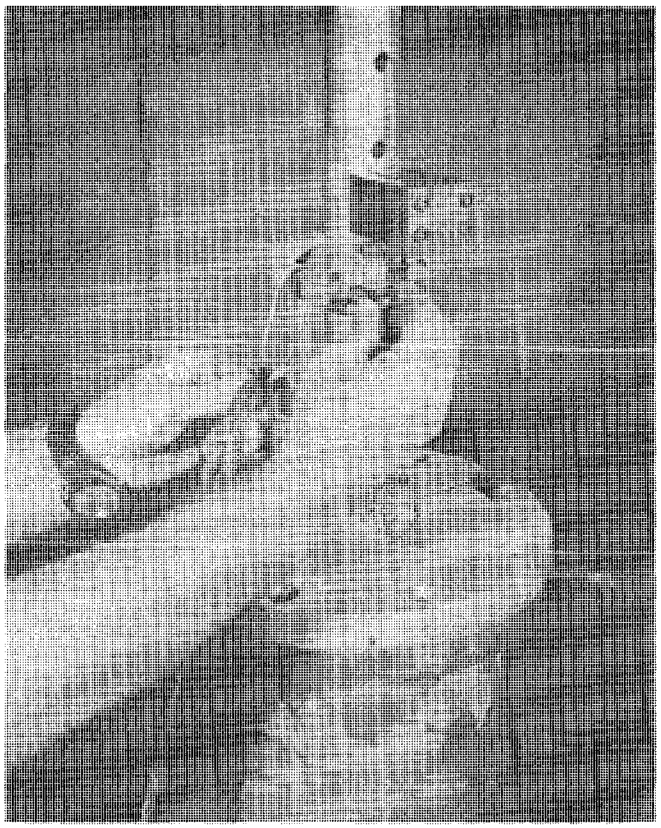
New Pipe Section in Position Above Borehole

Figure 11



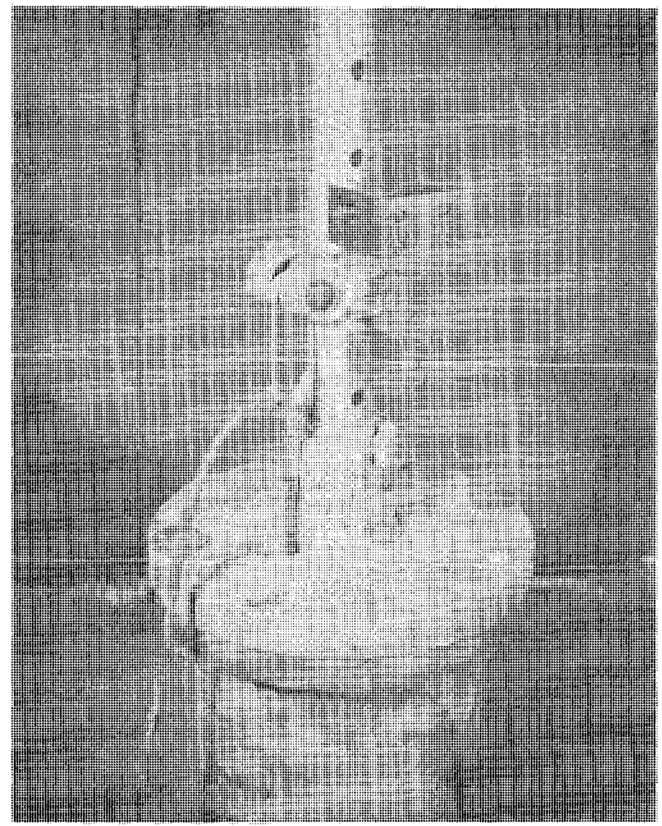
Aligning Pipe Section with Special Tool

Figure 12



Installation of Electrical Cable Hanger

Figure 13



Assembled Pipe Coupling

Figure 14

5. Remote the alignment tool from the pipe sections.

6. Raise the pipe string enough to remove the holding pin (Figure 15).

7. Open the split flange (Figure 16).

8. Lower the pipe stack approximately 20 feet (Figure 17).

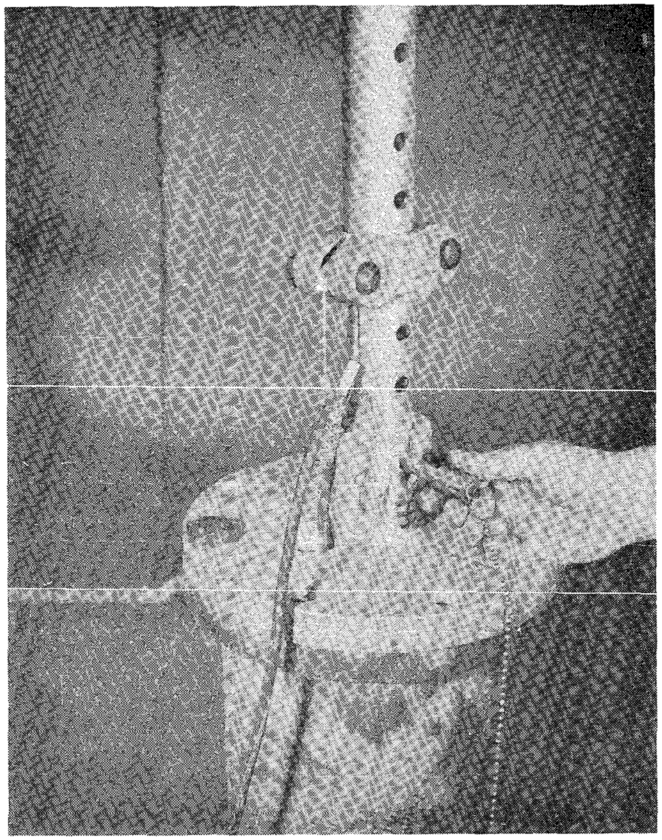
9. Close the split flange (Figure 18).

10. Insert the holding pin in the pipe section and lower the pipe string until the pin supports the weight and the winch cable goes slack (Figure 19).

11. Remove the end cap from the pipe and attach to a new section of pipe.

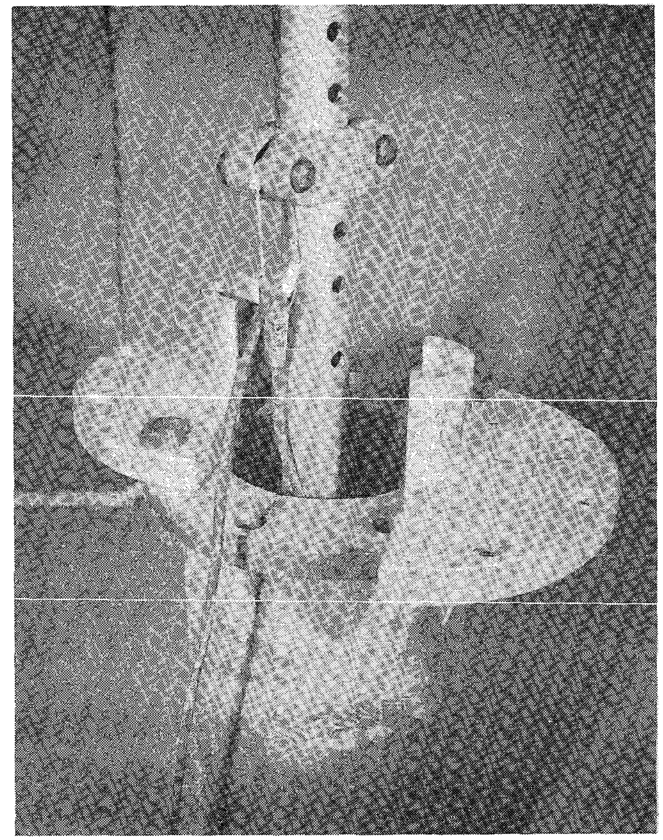
This procedure is repeated until the remote probe is within one pipe length of being in the passageway. Before connecting the last length of pipe, the rotary table is placed over the borehole, and the last piece of pipe is guided through the bearing in the table. When the probe is positioned at the desired height in the passageway, the pointer block is clamped to the pipe just above the rotary table with the pointer oriented with the alignment holes at the end of the pipe. With this block resting on the self-aligning bearing in the rotary table, the entire pipe string is supported by the rotary table. The compass rose on the rotary table may then be aligned with magnetic North.

Once the remote probe is located midway in the passageway, the sonar system is ready for operation. With the sonar



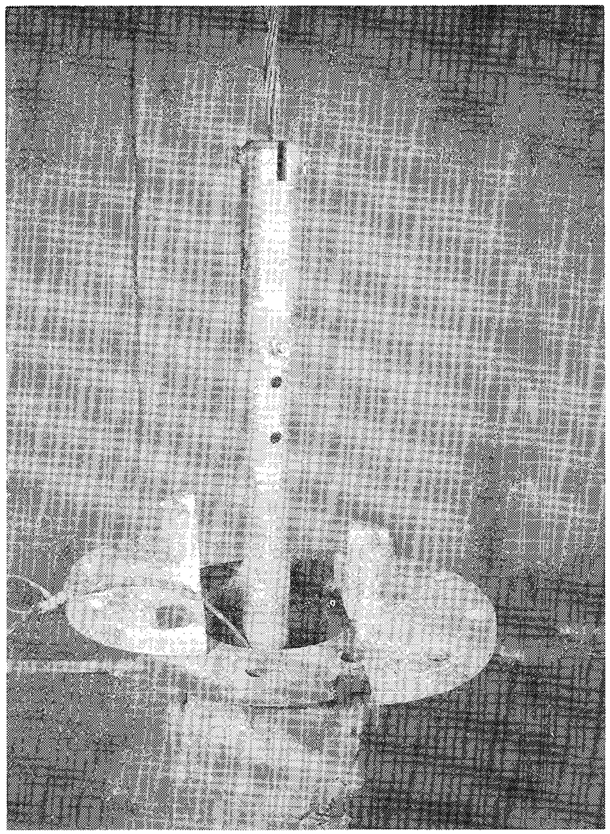
Removal Of Holding Pin

Figure 15



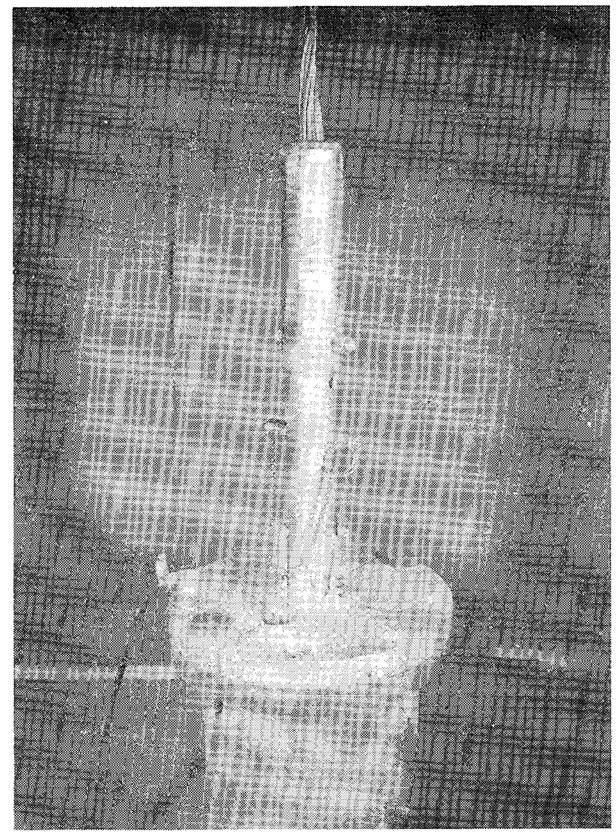
Split Flange in Open Position

Figure 16



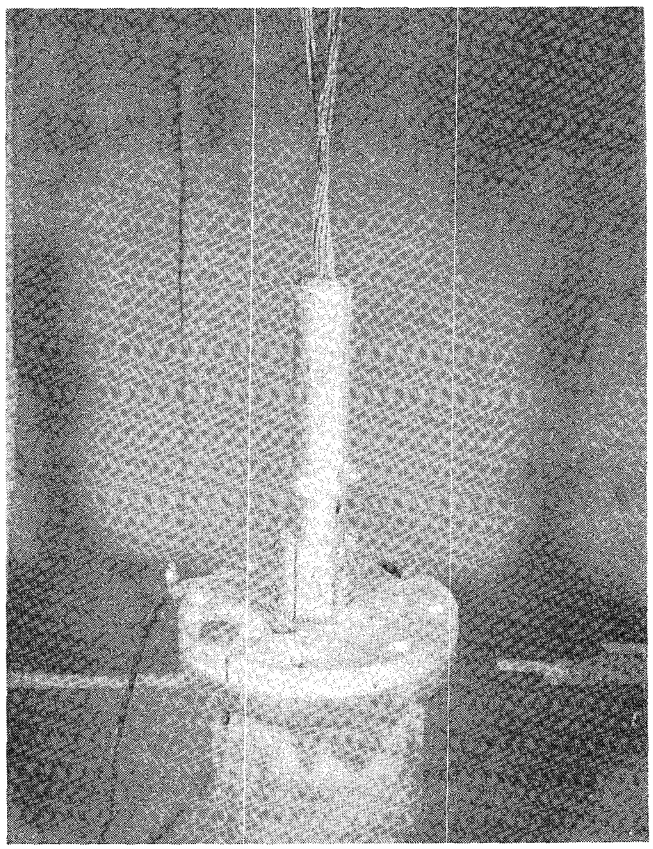
New Pipe Section Lowered 20 feet into Hole

Figure 17



Split Flange in Closed Position

Figure 18



Pipe Section with Holding Pin Resting on Split Flange
Figure 19

device turned on, the distance from the remote probe to the nearest target is shown on the sonar readout unit and the bearing (direction in which the probe is pointed) is indicated by the pointer which is clamped to the pipe string. After each reading, the pipe string is rotated 15° and another data point may then be taken and plotted on polar graph paper. A total of 24 data points will therefore complete a 360° sweep of the passageway and provide a complete map. Where questions exist or more detailed information is required, additional data points may be taken at smaller increments. The sonar probe may also be raised or lowered in the passageway to obtain additional data.

8. Seal Construction, Fly Ash Bulk Filling

The fly ash mine sealing system must be effective if the mine recovery project is to be successful. Fly ash has been used for previous sealing efforts and also backfilling voids in the control of fires in inactive coal mines. Fly ash is usually available at moderate cost, is incombustible and with proper application is a suitable material for pumping through boreholes.

8.1 Fly Ash System Specifications

The system components consist of a fly ash truck which can be connected to a fly ash ejector-mixer by approximately 300 feet of 4-inch-diameter flexible hose. A blower is used to supply auxiliary air to the ejector through a 10-inch-diameter steel pipe. The dilute air-fly ash mixture is then transported from the mixer discharge to the borehole inlet through 8-inch-diameter plastic pipe.

Figure 20 shows a typical plan view of the surface equipment required; the individual items are discussed in more detail in the following sections.

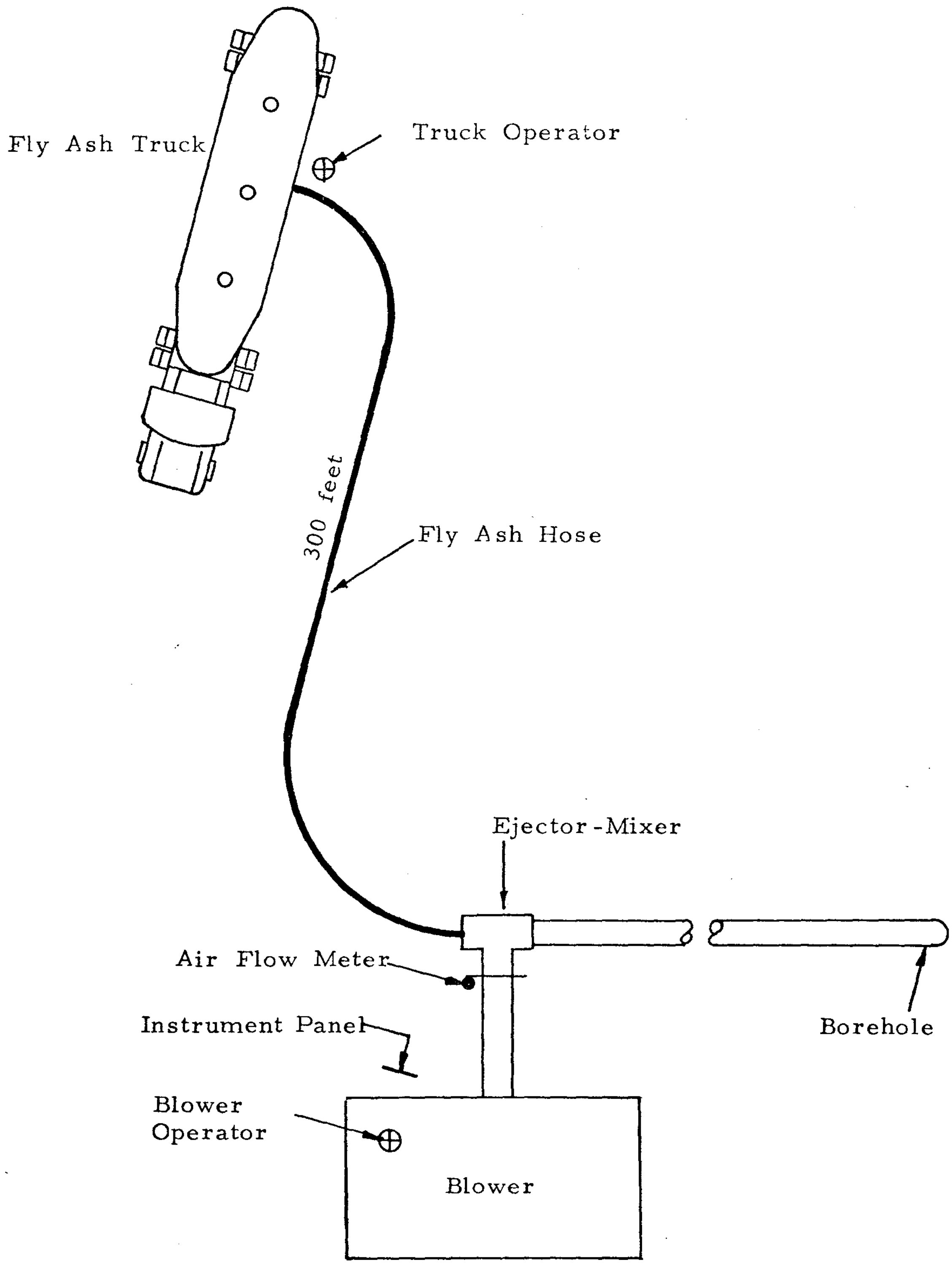
8.1.1 Fly Ash Specifications

There are no special specifications on the type and composition of the fly ash required. As a general rule, any fly ash which can be successfully unloaded pneumatically from a standard fly ash truck is acceptable for use in the fly ash delivery system.

8.1.2 Fly Ash Delivery System

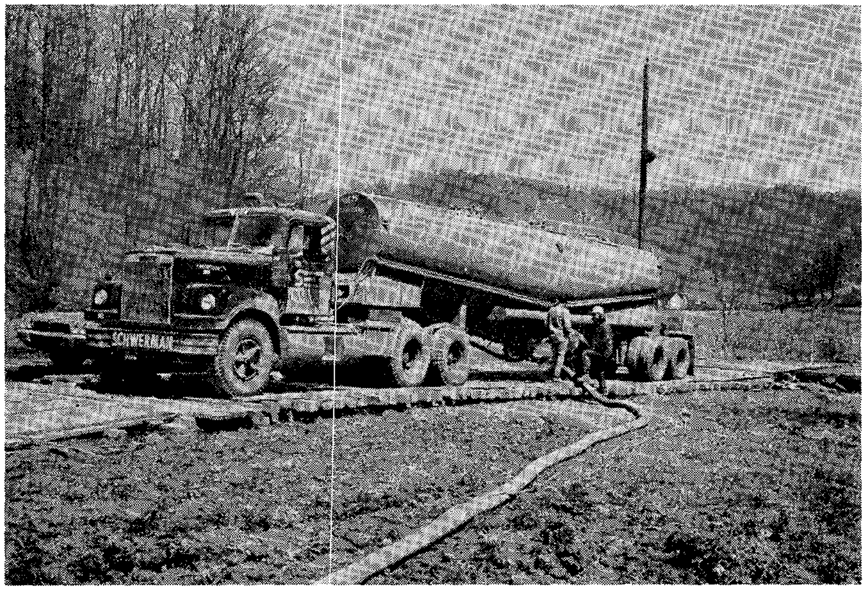
Fly ash is normally delivered to the site in a bulk-hauler truck, shown in Figure 21. The fly ash in the truck is pressurized by injecting air at a pressure of approximately 20 psi; the air injection also helps in agitating and fluidizing the fly ash. The fluidized mixture is discharged under pressure through the 4 inch diameter fly ash hose. A product control valve is provided to control the flow rate of fly ash, and an "air assist" valve diverts air from the blower into the discharge to adjust the fly ash concentration. The object is to obtain maximum fly ash discharge with minimum pressure loss.

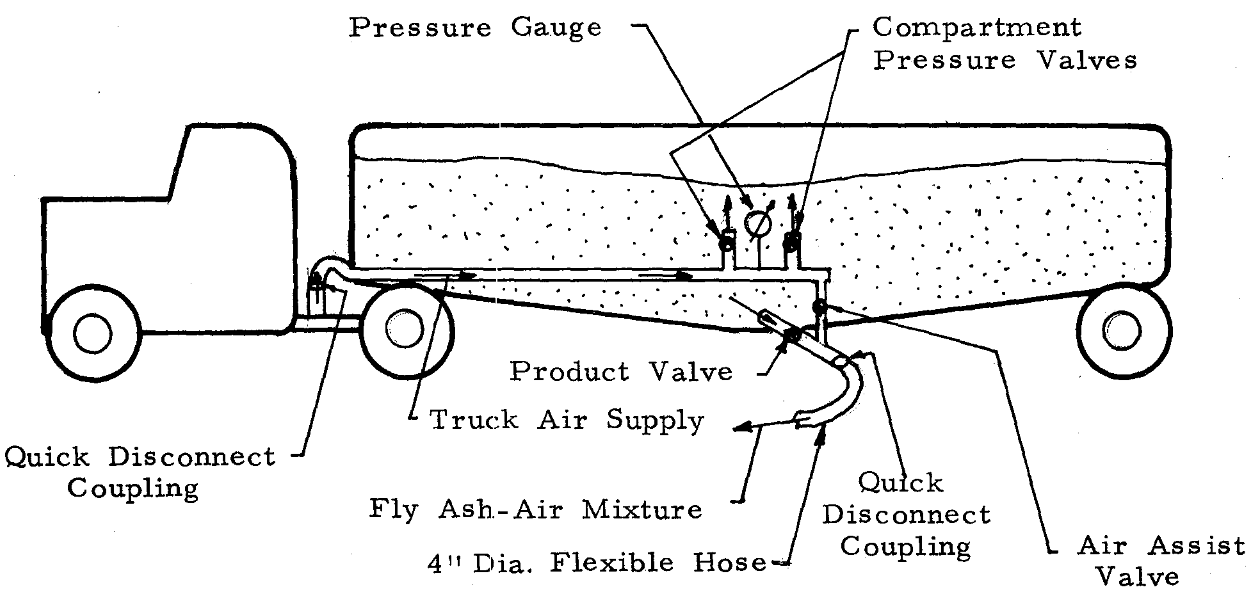
The truck-mounted blowers are either an exhaust driven turboblower or a CEC (Compressor-Engine-Converter) in which two cylinders of the truck diesel engine drive the other four as a compressor. Operating pressures of 15 to 18 psi may be required to overcome the friction pressure drop in the horizontal fly ash line and back pressure from the auxiliary blower used in the sealing system.



Field Layout of Fly Ash Mine Sealing System

Figure 20





Fly Ash Truck and Schematic of Plumbing System

Figure 21

8.1.3 Blower System

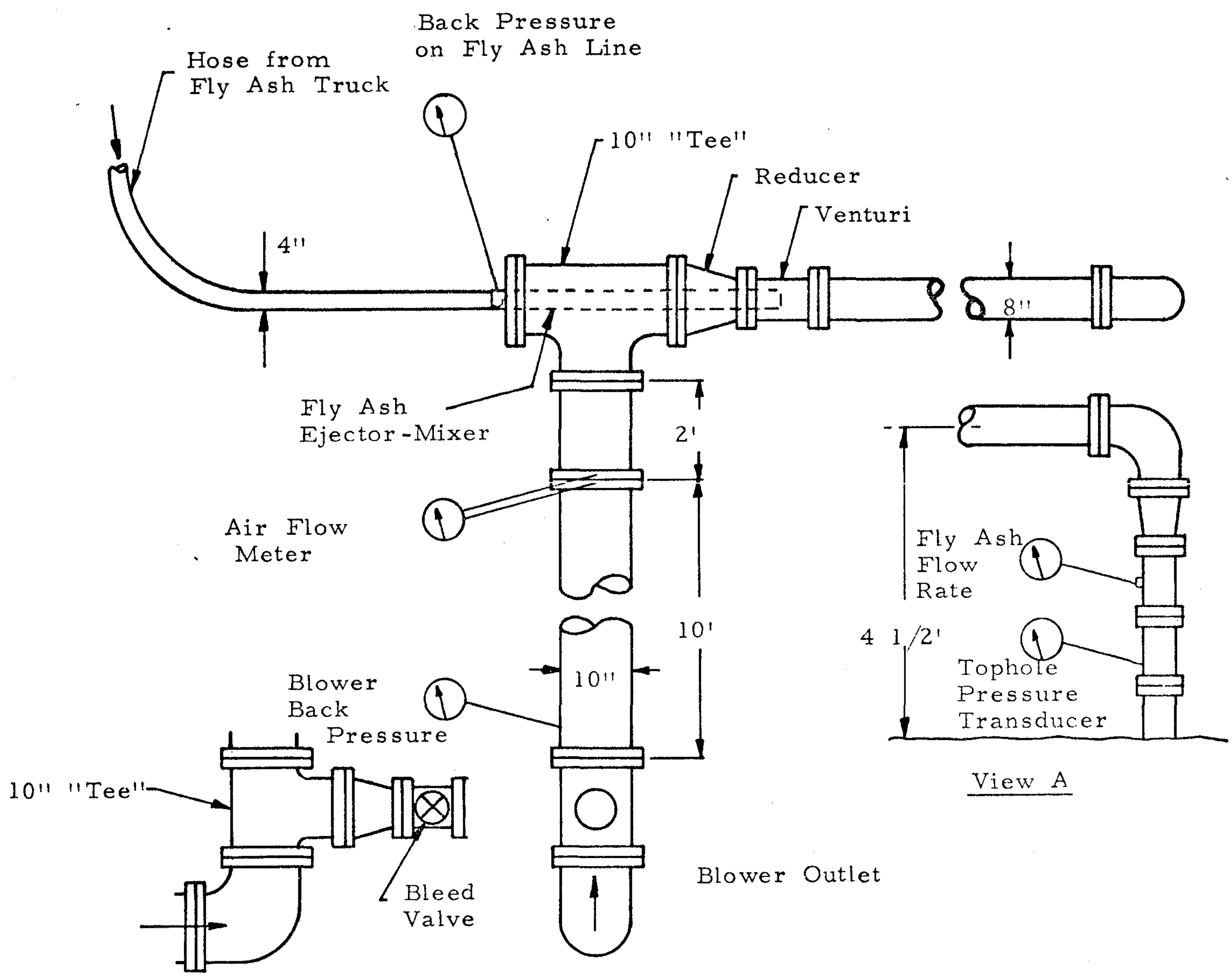
The system requires a diesel-driven rotary positive displacement blower, capable of providing an air supply specified at 5,000 scfm at 10 psi minimum. The USBM can provide assistance in locating a blower suitable for this application. The purpose of the blower is to aerate the fly ash at the ejector-mixer. This permits controlled fly ash pour densities. Previous attempts at remote sealing without auxiliary blowers resulted in borehole plugging at depths beyond 300 feet. It is anticipated that the blower described in this system will be used in conjunction with an inert gas generator, presently undergoing development, as it is not advisable to pump large volumes of oxygen into a fire area that is being sealed.

8.1.4 Plumbing System

Air from the blower passes through a 10-inch-diameter pipe containing a flow meter. The air is mixed with the fly ash from the truck in a 10-inch "T" containing a special mixing nozzle. After passing through a reducer, the fly ash-air mixture travels through 8-inch plastic pipe to the borehole. Instrumentation at the borehole monitors the fly ash flow rate and the pressure. A schematic of the entire plumbing network is shown in Figure 22. The maximum recommended distance between the blower and the fly ash truck (i.e., length of the 4-inch hose) is 300 feet; the maximum recommended distance between blower and borehole (i.e., length of the 8-inch plastic pipe) is 150 feet.

8.2 Effects of On-Site Variables on Fly Ash Delivery System

Table III summarizes the effects of on-site variables on the fly ash delivery system. In general, these variables can affect three parts of the fly ash sealing operation: the required blower air-flow rate, the amount of fly ash required, and the time required. These items are discussed in more detail in the following paragraphs.



Fly Ash - Air Flow System

Figure 22

TABLE III

EFFECT OF ON-SITE VARIABLES ON FLY ASH DELIVERY SYSTEM

Parameter	Effect on Fly Ash Delivery
Passage Width	Increases in passage width increase the required blower capacity. The amount of material and time required for filling increases linearly with passage width.
Passage Height	The amount of material and time required for filling increases with the square of the passage height.
Passage Blockage	Rubble piles or other obstructions reduce the total amount of material required.
Borehole Water Flow	Reliable performance demands casing and grouting to stop water flow.
Passage Water Flow	Performance satisfactory for flows up to 10 gpm. Greater flows require gravel grout technique and cement-fly ash mix, involving increases in setup and sealing time.
Borehole Depth	Increased borehole depth increases blower pressure required. The increased backpressure reduces the truck discharge rate, slowing the filling process.
Borehole Diameter	Smaller borehole diameters increase backpressure and slow discharge rate.
Borehole Surface Location	Truck to blower distance should be minimized to reduce hose length and losses. Blower to borehole position must optimize blower position and plumbing requirements.
Borehole Location in Mine	Mid-passage is most desirable. Seal configuration less desirable when emplaced from the side.

8.2.1 Blower Operating Conditions

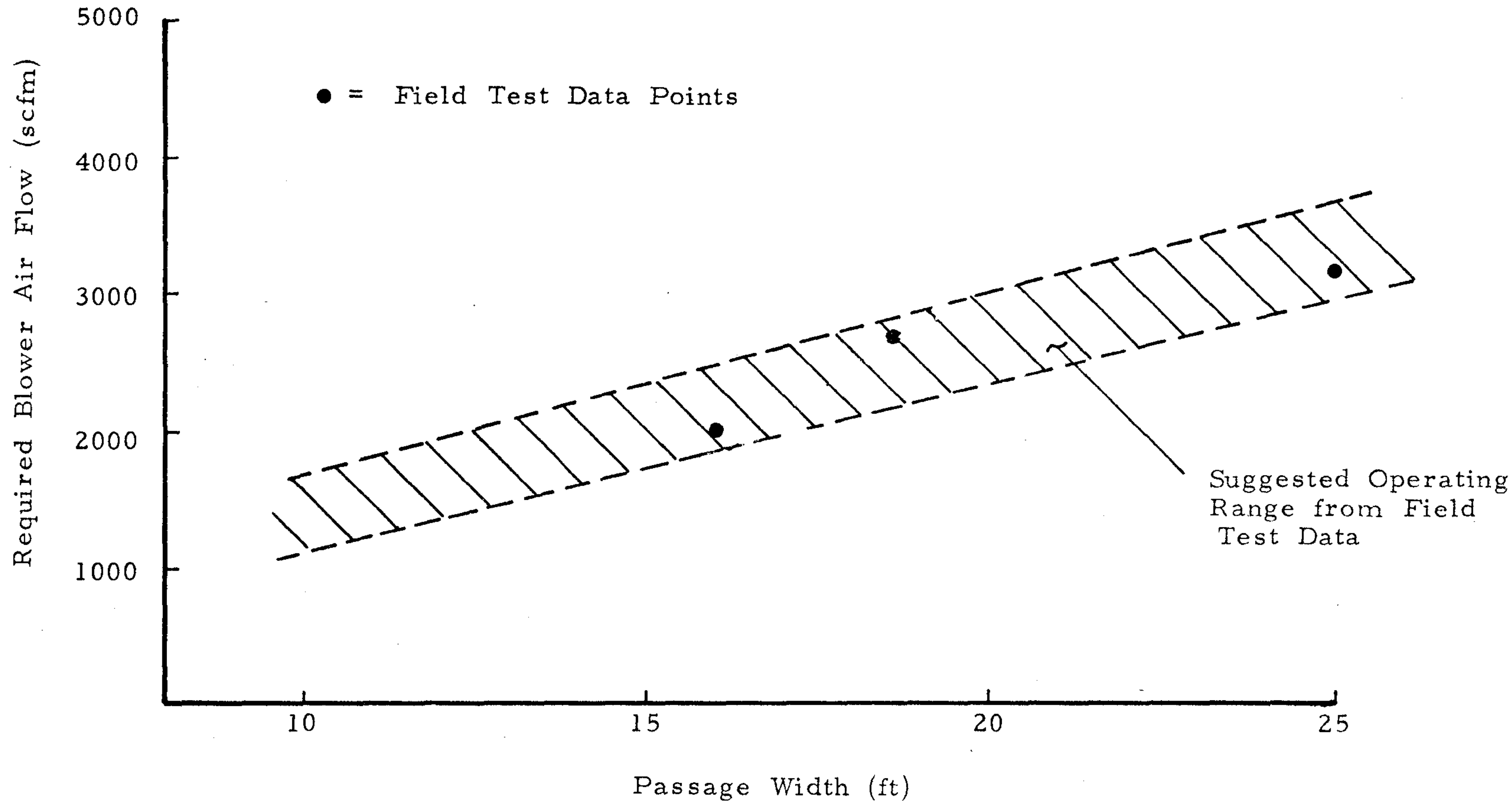
The amount of blower air flow required depends strongly upon the width of the passageway: the wider the passage, the more air flow that is required. The shaded area in Figure 23 shows the recommended range of air flow required for any given passage width.

Passage height also affects the required flow rate but to a lesser extent. It is recommended that an extra 300 scfm of air be used for each foot of passage height below 6 feet. For example, a 6-foot passage 15 feet wide requires 2000 scfm. A 4 foot passage of the same width would, therefore, require 2000 + 2 x 300 = 2600 scfm.

Once the air flow rate has been chosen, the required blower pressure to produce this flow rate will depend upon the length of the borehole, as shown in Figure 24. This relationship can be very important when high flow rates are required in deep mines, as the blower selected must be capable of pressures as high as 20 psig when used for sealing mines under 1500 feet of overburden.

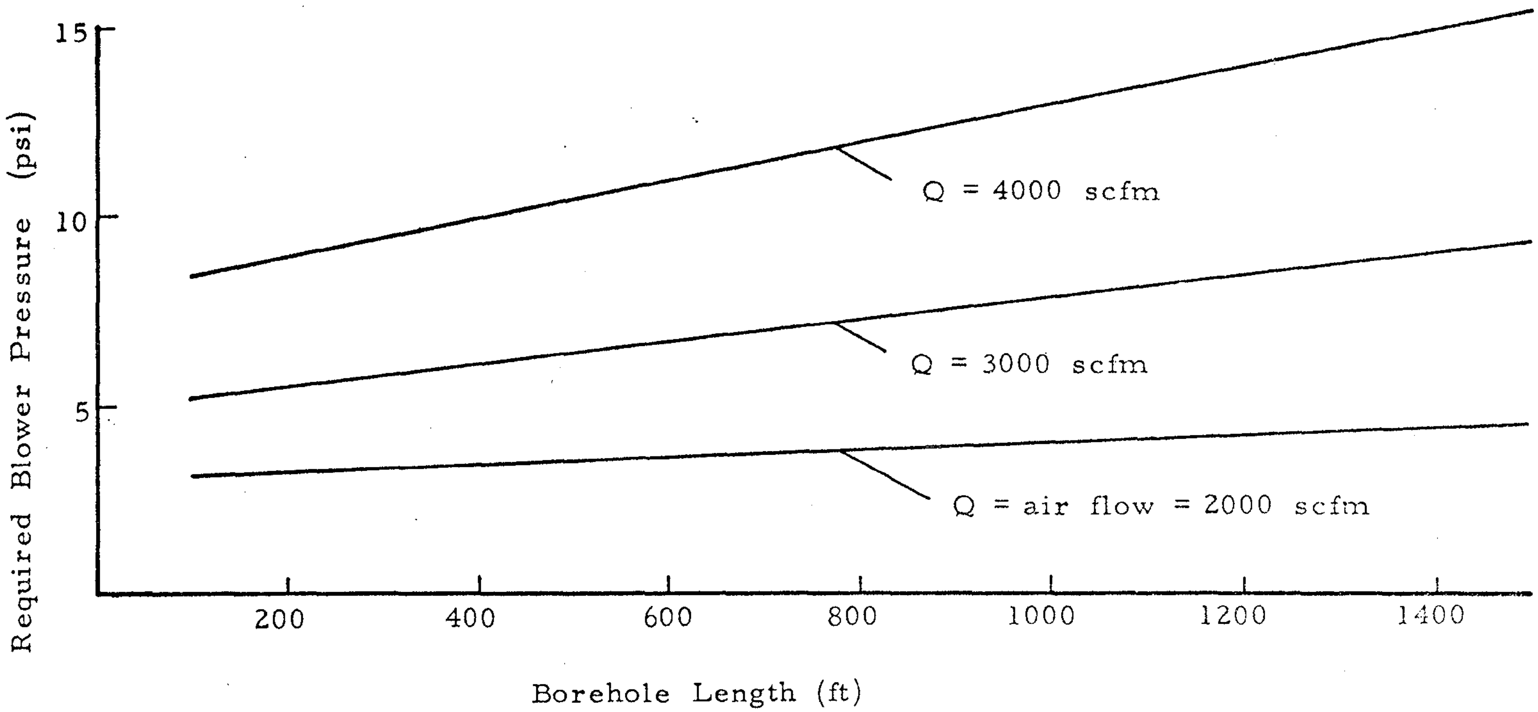
8.2.2 Amount of Fly Ash Required

Two factors will have a major effect on the amount of fly ash required: the size of the passageway and the completeness of the seal required. Note that every seal constructed should be a 100 percent seal; however, it can be made 90 or 95 percent complete with fly ash and then foam topped to achieve air-tightness. Thus, when a 95 percent fly ash seal is mentioned, this does not mean that an incomplete seal is proposed, but rather that the last 5 percent be sealed with foam, as discussed in Section 9.



Required Blower Air Flow for Different Passage Widths

Figure 23



Required Blower Pressure vs. Borehole Length for Different Air Flows

Figure 24

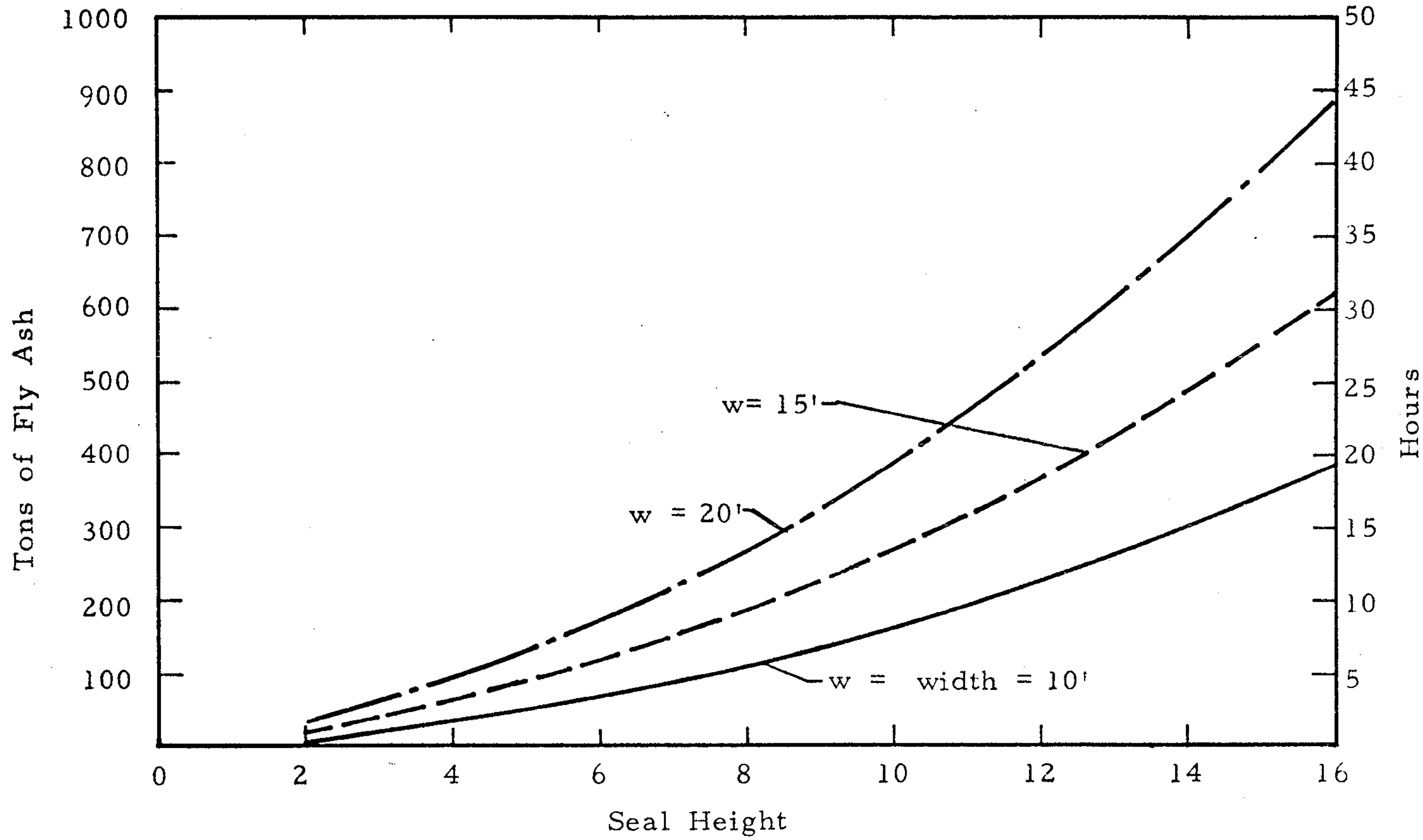
The amount of fly ash required and the approximate time (based upon 1 truckload/hour) to pour it, are shown in Figures 25 and 26. Note that it takes approximately 60 percent more fly ash to go from a 95 percent seal to a 100 percent seal. As the fly ash seal approaches the roof, greater quantities of material are required to produce small reductions in the unsealed area. The total material required to make a 99 percent seal is 50 percent greater than a 95 percent seal. This behavior is due to the fact that the air velocity through the unsealed area increases as the pile builds up and prevents deposition of fly ash in this area. The fly ash spreads laterally, building up the sloping sides of the pile, and reduces the pile angle from a high of 20 degrees to values closer to 10 degrees. Spreading of the seal and reduction in side slope take precedence over height development.

At seal values greater than 90 percent, undesirable spreading of the fly ash can be reduced by lowering the air flow rate in final stages of fly ash sealing. Both fly ash material and sealing time can be saved by using the fly ash only as a bulk filler to make a 90 to 95 percent seal and then making the final seal with foam.

The actual savings in time and material will depend on the size and depth of the mine passage. These savings will be largest for large passages at shallow depths and least for small passages at large depths.

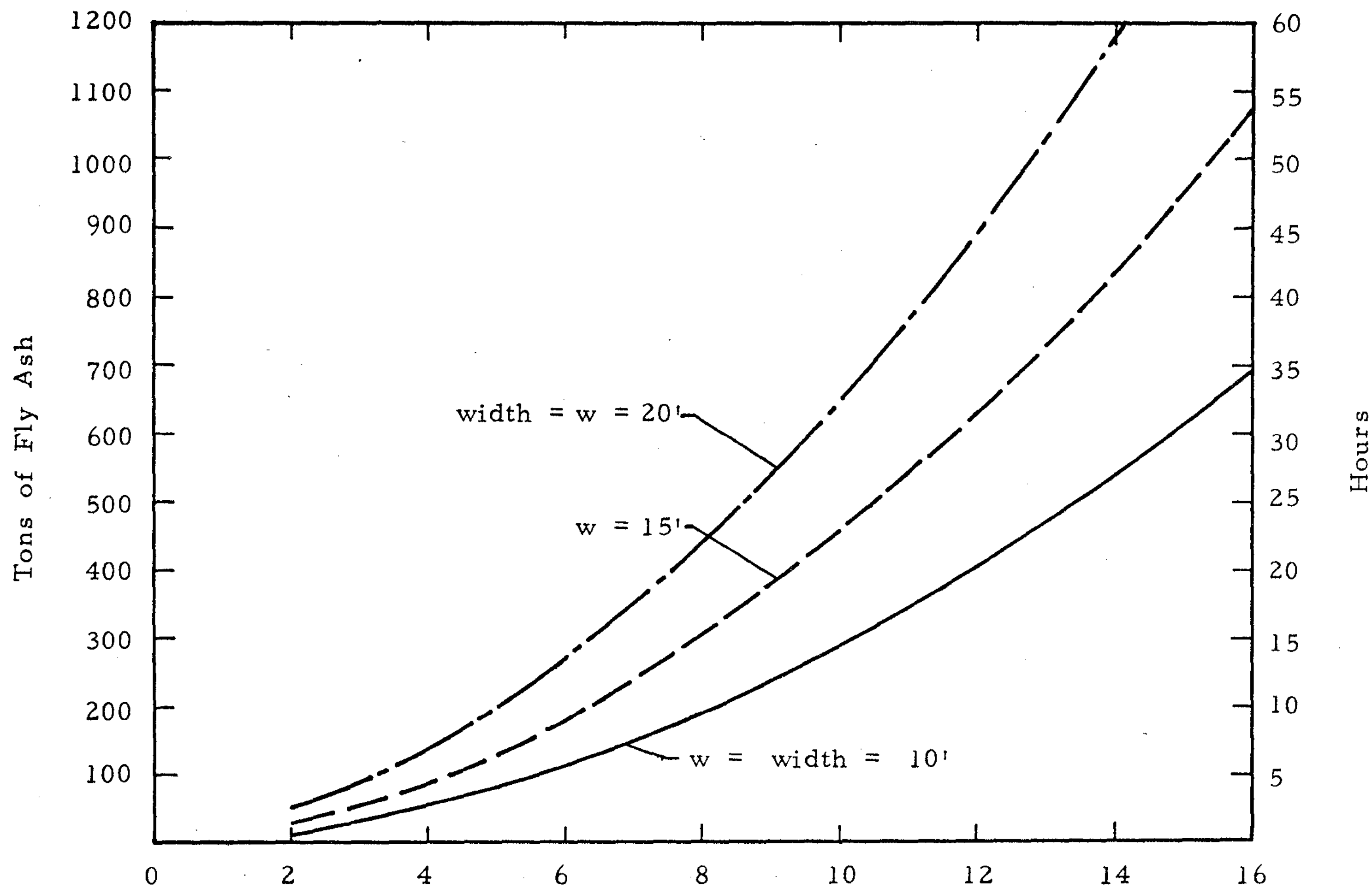
8.3 Operating Procedure

The plumbing system for the fly ash delivery system must be set up as outlined in Section 8.1.4. When planning the sequence of filling operations, it is desirable to place the blower in a central location so that a number of seals may be constructed before the blower requires moving. The pressure transducer and



Amount of Fly Ash for 95 Percent Fly Ash Seal

Figure 25



Amount of Fly Ash for 100 Percent Fly Ash Seal

Figure 26

fly ash flow meter, located at the borehole, must be wired according to the manufacturers instructions with the wires leading back to the instrument readout panel, located next to the blower controls. The air-flow meter, located on the ten-inch pipe, must be positioned so that it is visible from the blower control station.

A minimum of two men are required to pump fly ash, one man at the truck and one man at the blower controls. As soon as the flexible hose is connected to the fly ash truck, the system is ready for operation. A truck load of fly ash is pumped off in the following manner:

1. Start blower, adjust air flow rate according to Figure 23.

2. Pressurize fly ash truck to 20 psi.

3. Open air-assist valve of fly ash truck to purge the 4-inch hose for one minute.

4. Close air-assist valve to allow truck pressure to build back up to 20 psi.

5. Open product valve, use air assist valve as required to maintain 18-20 psi truck pressure.

6. Readjust blower controls to maintain desired air flow rate.

7. Maintain operating conditions indicated in 5 and 6 until the truck is empty. Typically, this should take about 20 or 30 minutes.

8. Continue "pumping" for one minute after fly ash flow meter indicates there is no fly ash in the lines.

9. Stop truck engine, close air assist and product valves and open compartment bleed valve.

10. Stop blower.

It must be emphasized that the following items are mandatory for successful system operation:

1. To prevent fly ash from entering the blower, DO NOT operate the truck fly ash pump unless the blower is on.

2. To avoid damaging overpressure to blower in the event that the borehole plugs, DO ensure that the blower bleed valve is partially open at all times.

3. DO NOT operate the system with truck pressures less than 15 psi; this will cause slow pumping and may plug the 4-inch line.

The procedure outlined above is repeated until the seal checker indicates that the desired level of seal has been attained. Note that the controls and instruments of the fly ash delivery system will give NO indication of seal completeness or impending borehole plugging. The only sign of borehole plugging is a fly ash plume blowing out of the blower bleed valve. If this condition is observed, the truck should be stopped immediately and the blower allowed to run for one minute before shutting it down.

9. Foam Topping System

The foam topping system can be used to finish sealing a passageway which has been 95 percent or more filled with fly ash. The foam topping is most desirable when a large passageway is being sealed, which will require hundreds of tons of fly ash just to complete the last 5 percent of the seal. Use of foam can also reduce the total time required for sealing.

9.1 Foam Topping System Specifications

The system used for foam topping of the seals consists of a proprietory technique developed by Geologic Associates, Inc., Franklin, Tennesse and bearing the trade name "Puff Grout"*. A schematic of the complete foam topping system is shown in Figure 27. The two foam tanks and the central system are located above ground; the mixing chamber and static mixer are deployed downhole by a winch-driven cable system. The froth-foam system contains no pumps or moving parts. Bottled nitrogen supplies the pressure to force the two components through the lines deployed down the bore-hole. The two components are combined at the mixing head and flow through a static mixer and out into the mine passage. The individual items in the system are described in more detail in the following sections.

9.1.1 Component Feed and Flow Metering System

The isocyanate and polyol components of the foam may be stored in tanks and pressurized to 250 psi by bottled nitrogen. The flow control and component metering system consists of a control panel on the surface and two pressure relief valves deployed downhole at the mixing head. The two foam components are fed to the mixing head deployed downhole in the mine through two 3/4-inch diameter, nylon core, Synflex** hose. The use of the dissolved fluorocarbon as a frothing agent requires that the components be maintained at adequate pressure all the way to the point of mixing. If the materials froth in the system prior to mixing, it is difficult to measure the flow and control the mixing ratio.

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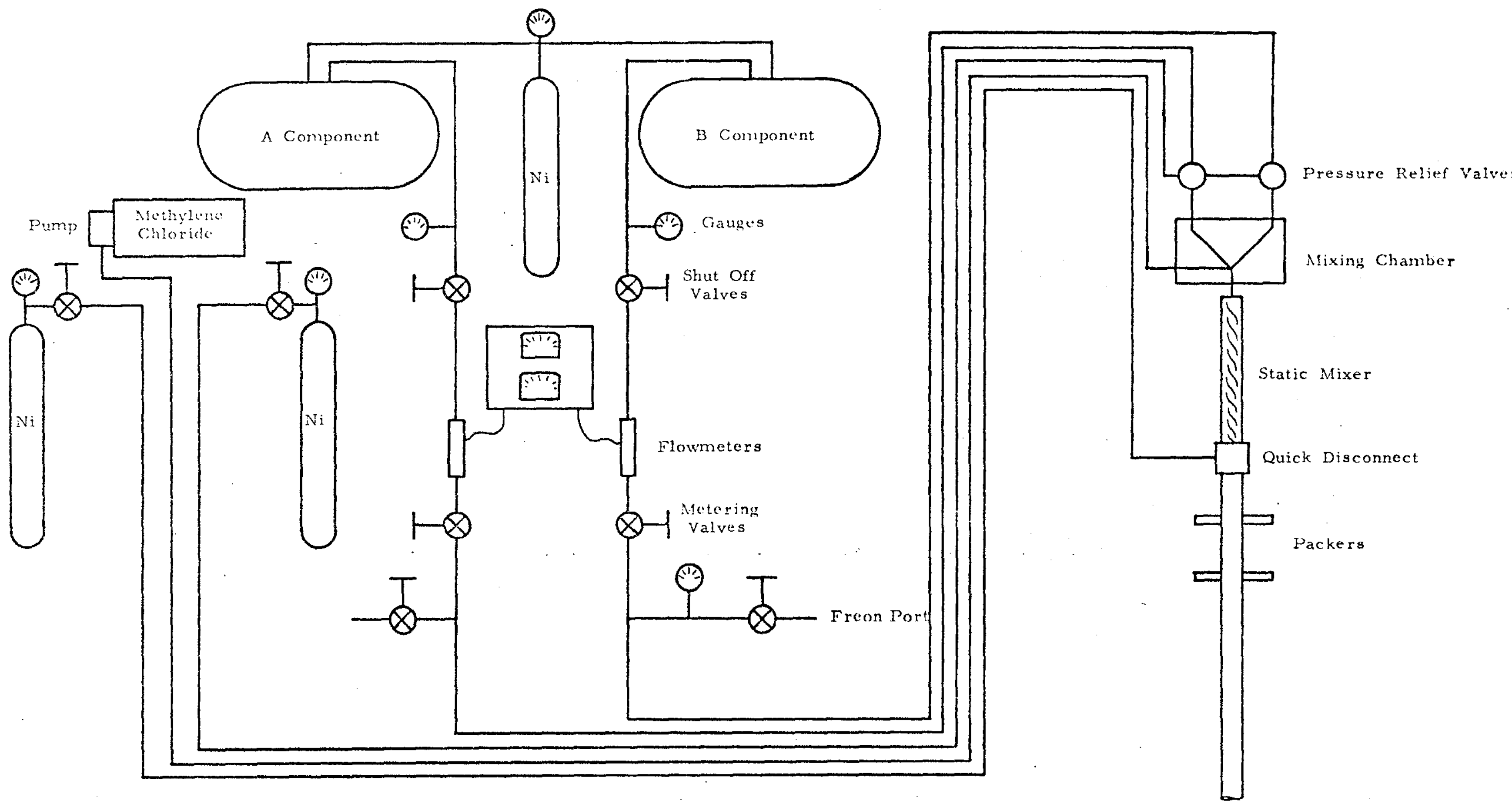
* Patent Pending.

** Trade Name.



Flow Diagram of Froth-Foam System

Figure 27

The system utilizes two variable pressure relief valves, one for each component line; these are located at the mixing head deployed down in the borehole. The relief valves are connected by an air line through a regulator to a nitrogen bottle at the surface. The relief valve pressure is adjusted to maintain sufficient pressure in the lines and prevent frothing. For normal operation this pressure is approximately 100 psi. Figure 28 shows a photograph of the downhole mixing head with the two pressure relief valves assembled.

The on-surface flow meter and control panel are shown in Figure 29. It consists of two Fluidyne* positive displacement-type flow meters to measure the individual component flows, two strainers to filter out any crystallization which could cause clogging of the system, pressure gauges to monitor tank and relief valve pressure, temperature gauges and special stainless steel, teflon-seat ball valves designed for isocyanate service. In operation, the component flow rate is regulated by adjusting the relief back pressure. Two freon injection ports, one for each component line are utilized to charge the empty 500-foot length of Synflex* hose with freon. This freon charging operation is necessary to ensure good component mixing at the start of foaming; it displaces the air which acts as a cushion in the line, and it dissolves in the components providing extra bubbling, frothing, and mixing of the components first entering the mixer.

9.1.2 Component Mixing System

The component mixing system consists of a mixing head for blending the two chemical components followed by a 3-foot long, 1-inch-diameter Kenics* static mixer. The static mixer is followed by a 6-foot length of 1-inch diameter pipe. This pipe

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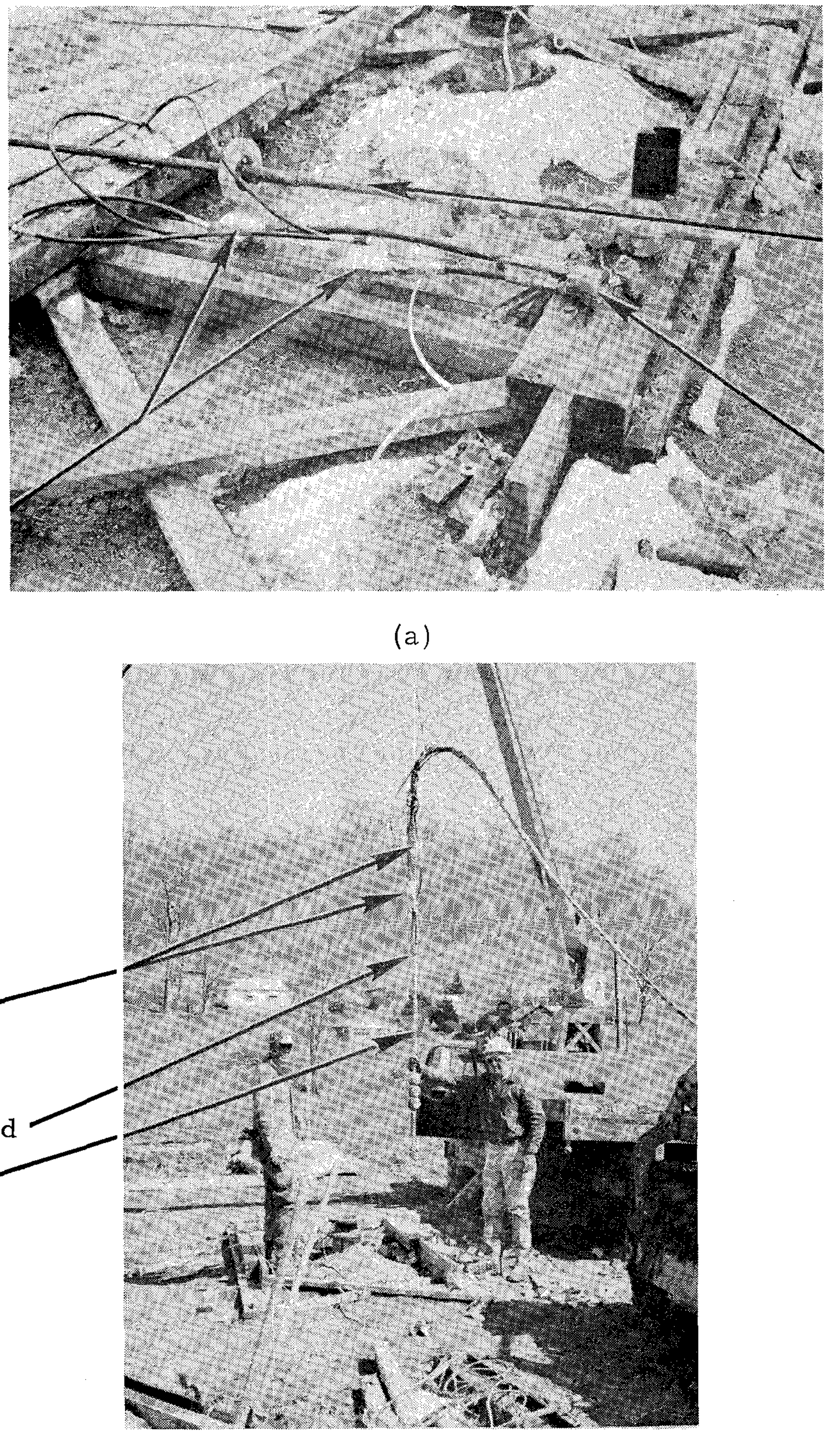
* Trade Names.

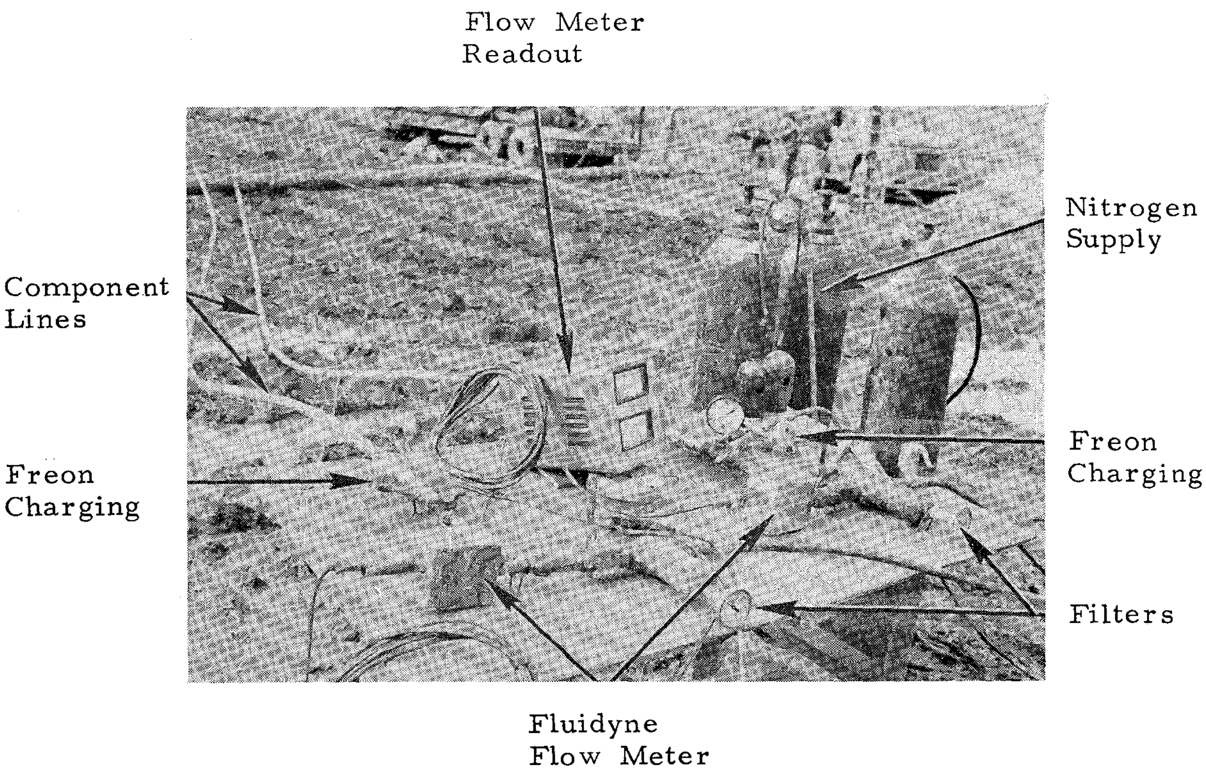


(a)

(b)

Photographs of Mixing Head with Pressure Relief Valves

Figure 28



Flow Control Panel of Froth Foam System

Figure 29

is connected to a second piece of pipe, 10- feet long, by a quick-disconnect, air-actuated coupling. The second pipe has two packers to prevent the foam from flowing back up the borehole. The end of the second pipe is provided with a 1 1/4-inch diameter flat plate disperser and homogenizer for final mixing.

9.1.3 Methylene Chloride System

The inclusion of the methylene chloride cleaning system provides the system with a stop-restart capability. The foaming can be stopped, the mixing section cleaned with methylene chloride and foaming restarted whenever required. A nitrogen actuated reciprocating pump is used to pump the methylene chloride into the downhole mixing head through a 1/4-inch-diameter plastic air line.

9.1.4 Deployment and Retrieval System

A schematic of the deployed foam system is shown in Figure 30. The deployment system uses a truck-mounted hydraulic crane winch to deploy and retrieve the system. Rubber disc packers are used to provide a loose clearance fit with the borehole casing. A set of weights are placed downstream of the Kenics static mixer to aid in lowering. A pneumatically actuated, quick-disconnect coupling is placed immediately below the static mixer and above the rubber packers. The quick disconnect will be actuated from the surface in the event the packing section becomes grouted by the foam. This arrangement allows retrieval of the system containing the major cost items including the mixer, mixing head, relief valves and hoses.

A photograph of the complete assembly is shown in Figure 31 as it is about to be lowered down a borehole. Five separate hoses are deployed in the borehole: Two 3/4-inch-diameter Synflex* hoses for the polyol and isocyanate components,

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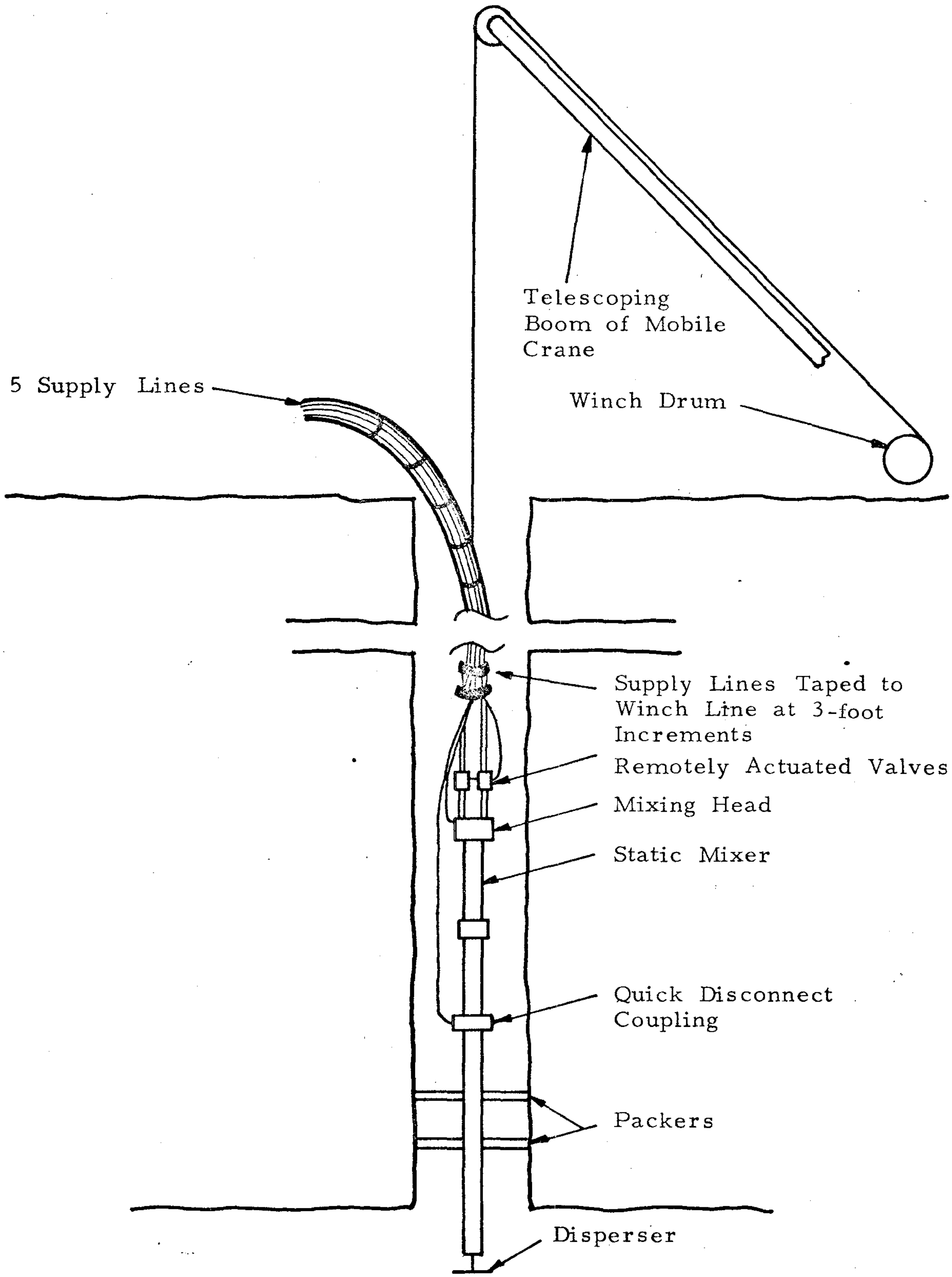
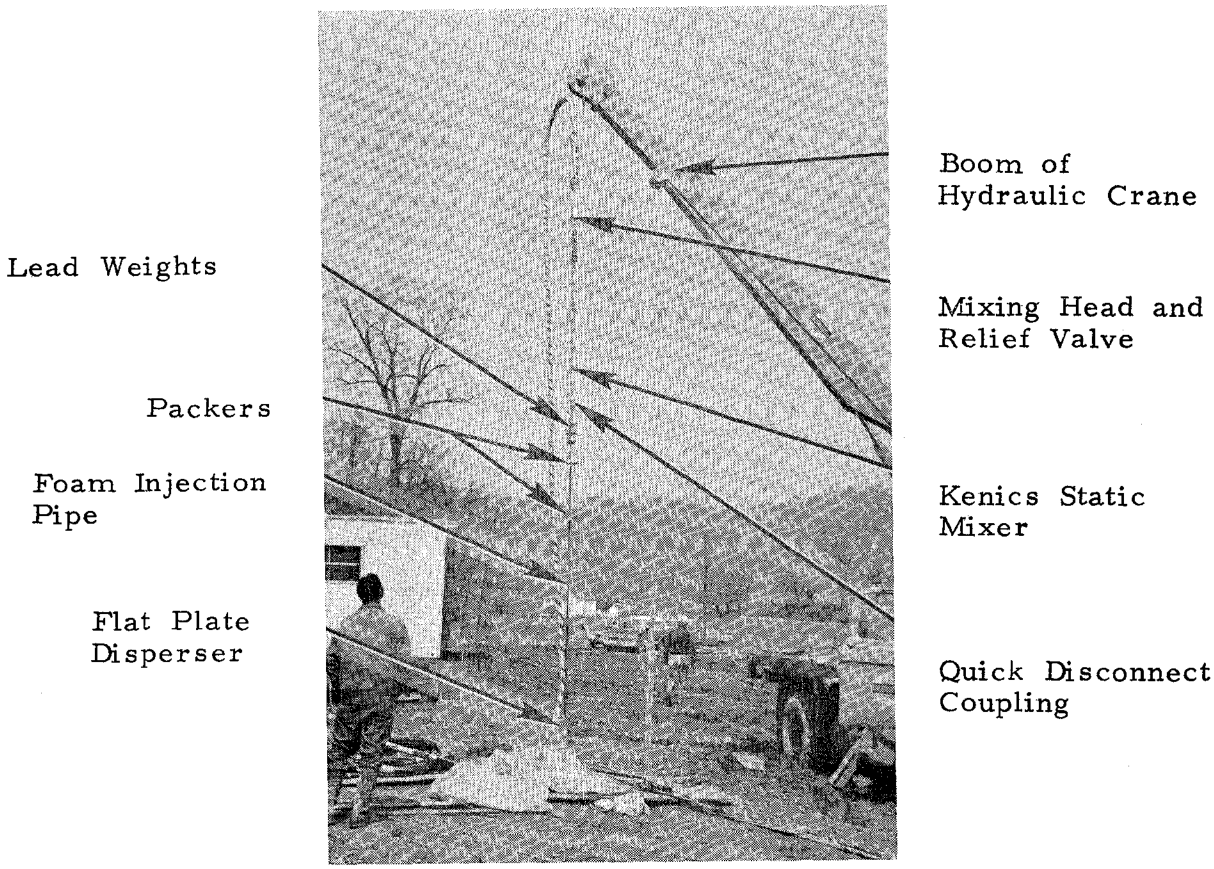
* Trade Name.



Schematic of the Froth-Foam System Deployed in the Mine Passage

Figure 30



Photograph of Complete Assembly of
Downhole Froth Foam System

Figure 31

one 1/4-inch-diameter airline for the pressure regulating relief valves, one 1/4-inch-diameter airline for the quick disconnect coupling, and one 1/4-inch line for the methylene chloride. To avoid snagging, the hose connections at the mixing head, the relief valves, mixing head and hoses must be tightly wrapped with "duct" tape. All five hoses are taped together into a bundle at 3 foot intervals during lowering of the system to prevent the hose from buckling against the borehole wall and jamming when retrieval is attempted.

9.2 Effects of On-Site Variables on Foam System

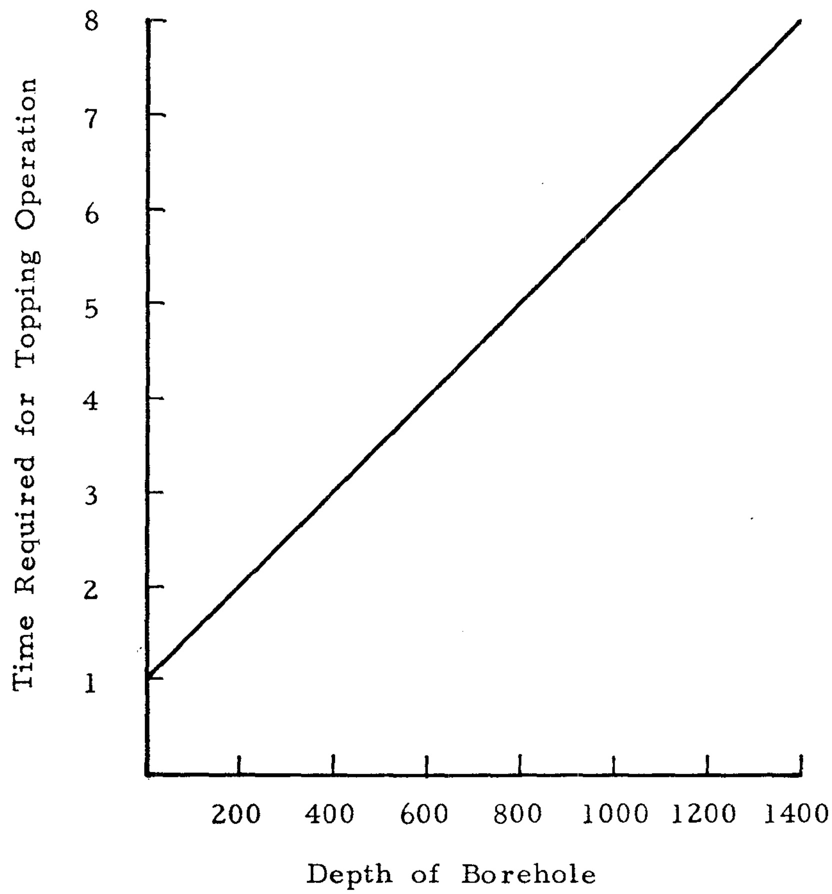
In general, there are three parameters which significantly affect the operation of the foam topping system: borehole depth, borehole diameter, and ambient temperature. Borehole depth affects the deployment and retrieval times and the type of equipment required; the borehole diameter is limited by the size of the equipment which must be deployed downhole, and ambient temperature affects the method of operation and some of the required equipment.

Passageway geometry, including size of passage, local obstructions, and position of the borehole, will have virtually no effect on the system. The froth foam flows around and over most obstructions. Based on the results of simulated full-scale testing and actual field tests, the quality of the seal does not appear to be affected even when the borehole is close to one rib.

The amount of foam required, and the corresponding time required to generate it, is relatively insensitive to passage size. The foam system is to be used only to top off a seal which has been at least 90 percent completed with fly ash. Accordingly, no matter how large the original mine passage cross-sectional area was before fly ash filling, the required sealing area for the foam is relatively small. Like the fly ash bulk-filling operation, the build-up of the foam can be monitored with the seal-checking system. When a 100 percent seal is indicated, the foaming may be terminated. Even though a 100 percent seal has been completed, the foam material will continue to flow with no decrease in the flow rate. In all of the full scale testing and field testing conducted to date with the foam used to top a 95 percent fly ash seal, a 100 percent seal was formed in less than one-half hour. Continued foaming merely increases the thickness of the seal.

Ambient temperature has a pronounced effect on the viscosity of the two components of the foam. Temperatures below 75 degrees F require the foam tanks be supplied with a heating system to keep the polyol and isocyanate warm, such as placing a tarpolin over the tanks and using a portable gas-fired heater. At temperatures below 30 degrees F, additional precautions might be required to keep the deployed hoses warm also. These might include sealing the borehole at the surface to prevent the in-rush of cold air or the use of electrically-heated hoses.

The only parameter affecting the total time required for successful operation of the system is the depth of the borehole. This affects the time needed to raise and lower the system. Figure 32 shows the relationship between the time required and the depth of the borehole. The "constant" time of one hour includes removing the fly ash plumbing from the borehole and setting up the lowering system, as well as the actual foam-topping operation. Additional time is required for locating the foam tanks, nitrogen bottles and other equipment, but this work can be done while fly ash is being poured. One pair of 5000 lb tanks should provide enough material to top off 5 or 6 seals; as the lines may be extended 300 feet horizontally, this means that the foam tanks should never require relocation.



Foam Topping Time

Figure 32

9.3 Operating Procedure

The foam tanks, like the blower, should be placed in a central location where a number of seals may be topped off without moving the tanks. The plumbing and hoses should be assembled as indicated in Figure 27. In cold weather, the foam tanks and coiled hose should be covered with a tarpaulin and a gas-fired space heater used to maintain the foam component temperature between 70° and 80°F. This heating operation must be started at least 24 hours before the foam topping operation is scheduled.

The following procedure should be used to foam-top a fly ash seal:

1. Remove fly ash delivery plumbing from top of borehole.

2. Position boom of winch over borehole.

3. Connect winch cable to foam mixing head.

4. Commence lowering of system down the borehole, measuring the amount of cable being paid out. Use a heavy fabric tape to secure the plumbing and hoses to the cable, continuously for the first 20 feet and at 3-foot intervals thereafter.

5. Lower the unit until the disperser at the end of the assembly is approximately one foot below the mine roof. This location may be computed from mine maps, the drillers log, and/or the data from the sonar probe.

6. Fill the two Synflex* hoses with freon.

7. With the pressure relief valves closed, fill the two hoses with the foam components.

8. Partially open pressure relief valves (nitrogen control pressure approximately 60-80 psi).

9. Adjust pressure relief valves to maintain isocyanate flow rate of 22 pounds/minute and polyol flow rate of 21 pounds/minute. The system will temperature stabilize in about 10 minutes. After that time, minor control changes may be made with the surface metering valves located at the control panel. The pressure relief valves should be set at approximately 180 psi.

10. To stop foaming, pressurize both relief valves to 350 psi. Close the surface metering valves when their respective flow meters indicate zero flow rate.

11. Immediately after foaming is stopped, pump methylene chloride to purge the mixing head. Continue for 3 minutes.

12. Immediately after foaming is complete, pull up on winch to free the mixing head from the foam. Should the end of the mixer be grouted so firmly that winch torque is insufficient, activate the quick-release mechanism.

13. Pull the system out of the borehole, cutting the hoses loose from the winch cable and coiling them on the truck bed.

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* Trade Name.

If another seal is to be foam-topped immediately, the hoses may be redeployed while the foam components are still in the lines. If the system will lie idle for more than 1/2 hour, the relief valves should be opened and the two 3/4 -inch lines flushed with methylene chloride.

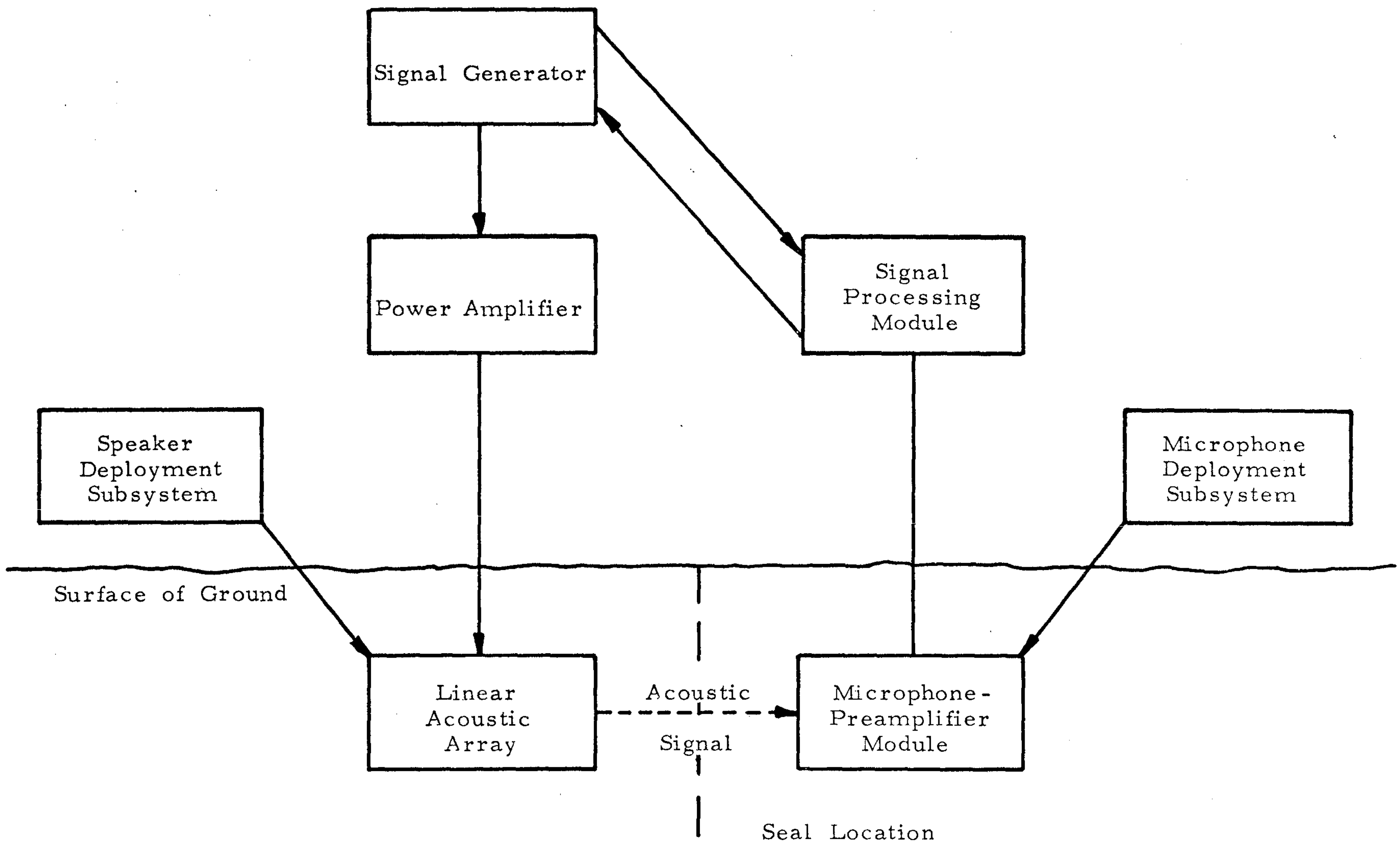
10. Seal Checking System (Acoustic Seal Checker)

Some method to assure that a remotely poured or otherwise constructed seal has effectively blocked the underground mine passage is vital to the success of any mine recovery operation. The method also must operate by remote operation utilizing surface facilities, boreholes, and instruments to enter the mine and evaluate seal effectiveness. The system developed and currently available utilizes acoustical devices, a speaker and microphone which are lowered into the mine. The acoustic signal transmitted through the seal is monitored by the microphone pick-up placed on the opposite side. The intensity of acoustic energy at the monitoring location establishes completeness of the sealing operation.

10.1 Acoustic Seal Checker System Specifications

10.1.1 Electronics Processing System

Figure 33 shows an operational block diagram of the acoustic seal checker system. The heart of the system is contained in the signal processing module. Once every 5 seconds, this unit sends a short pulse to the signal generator, causing the generator to emit a short (1/5-second) burst of random noise which is amplified and transmitted to the speakers located in the mine. The sound travels through the seal and is picked up by the microphone-preamplifier. This received signal is transmitted through the microphone cable to the signal processing module. This unit processes the signal and indicates the strength of the noise which



Operational Block Diagram - Acoustic Seal Checker

Figure 33

reached the microphone. The special electronics in the unit "listens" only to the sound which passes through the seal and ignores any sound which reached the microphone by traveling through other passageways which have not yet been sealed.

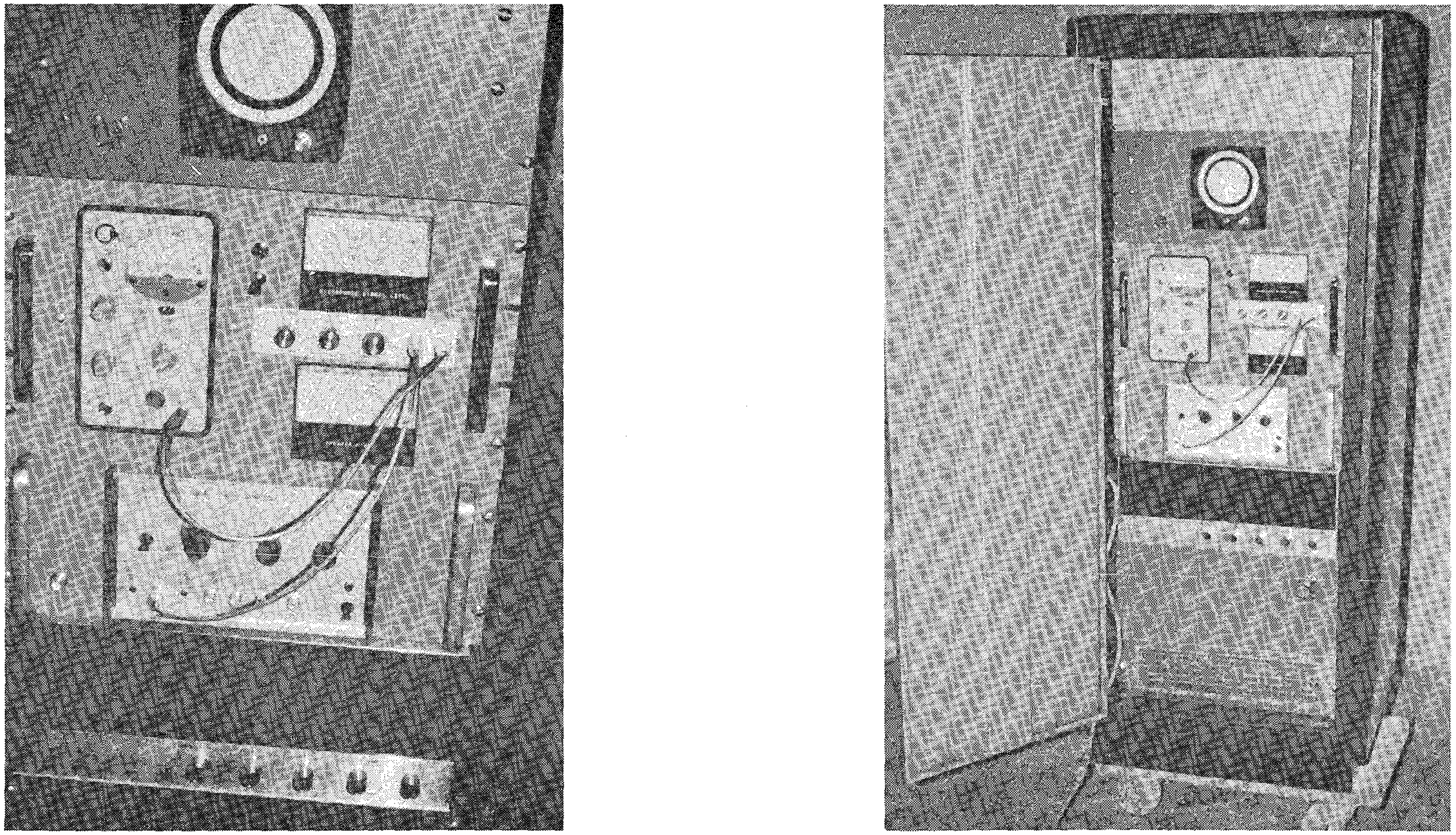
10.1.2 Readout Unit

All of the above-ground electronics are housed in one cabinet, shown in Figure 34. The readout unit displays the strength of the acoustic signal in decibels (db). The percent seal completion can be determined by comparing the db level before sealing started to the db level measured as the seal is constructed, as shown in Figure 35. Note that the closer the seal is to completion, the bigger the change in db level, which means that the system has the desirable characteristic of being the most sensitive as the seal nears completion.

10.1.3 Deployment System

The operation requires some method of locating monitoring equipment on each side of the seal to be checked. This may require special boreholes unless the series of holes planned for the sealing operation can be used before they, in turn, become holes for material pouring.

The speaker module, shown in Figure 36, is lowered into the mine utilizing surface towers previously discussed in Section 7 on sonar checking. Again, aluminum poles are connected to provide a stable suspension so that the speaker unit can be oriented toward the seal. Special couplings are used to provide support for the electric cable at 20-foot intervals down the borehole.

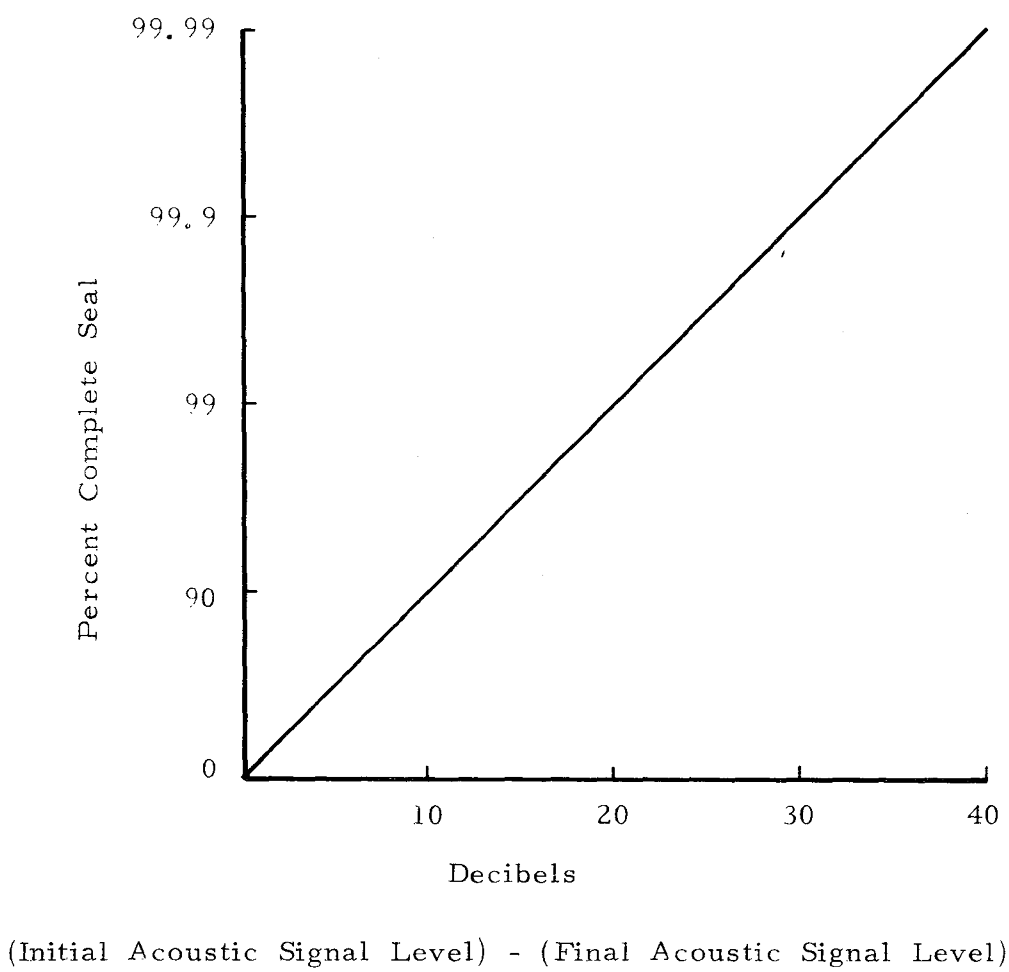


(a) Signal Processing Module

(b) Electronics Cabinet for Sonar Probe and Acoustic Checker

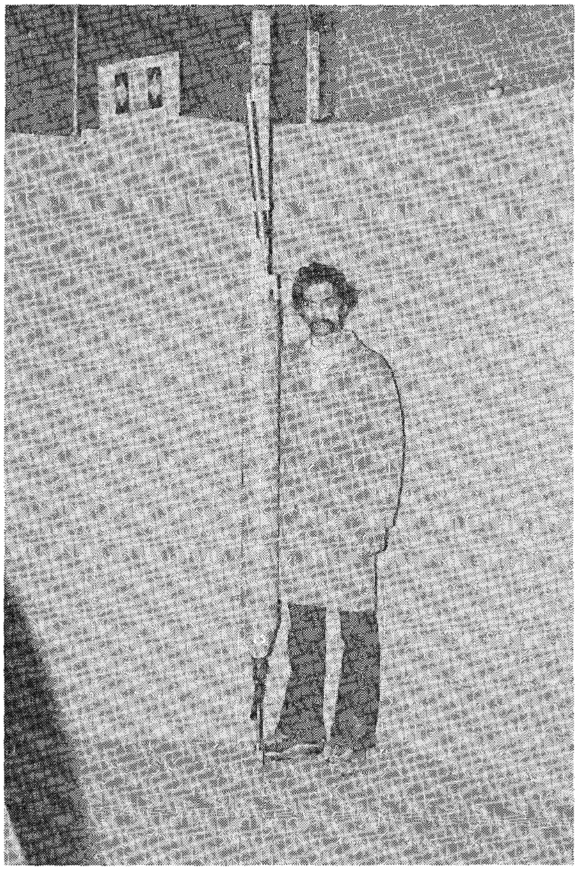
Electronics Components

Figure 34

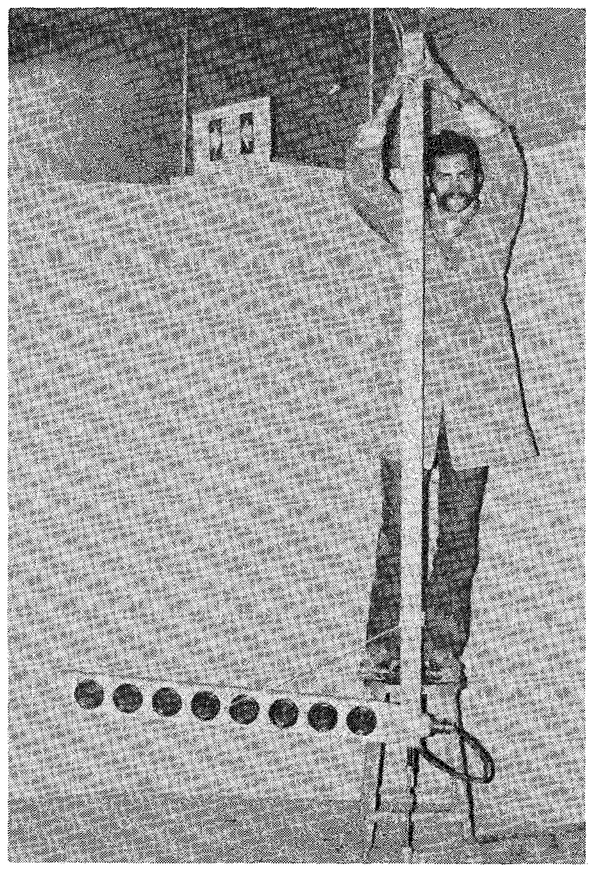


Calibration Curve for Acoustic Seal Checker

Figure 35



(a) Linear Acoustic Array in "Cocked" Position for Lowering Through Borehole



(b) Linear Array Deployed Horizontally

Linear Acoustic Array Deployment

Figure 36

The microphone module, shown in Figure 37, is light-weight and has a small cable and does not require rotational orientation. Therefore, a small winch is used to cable-lower this unit.

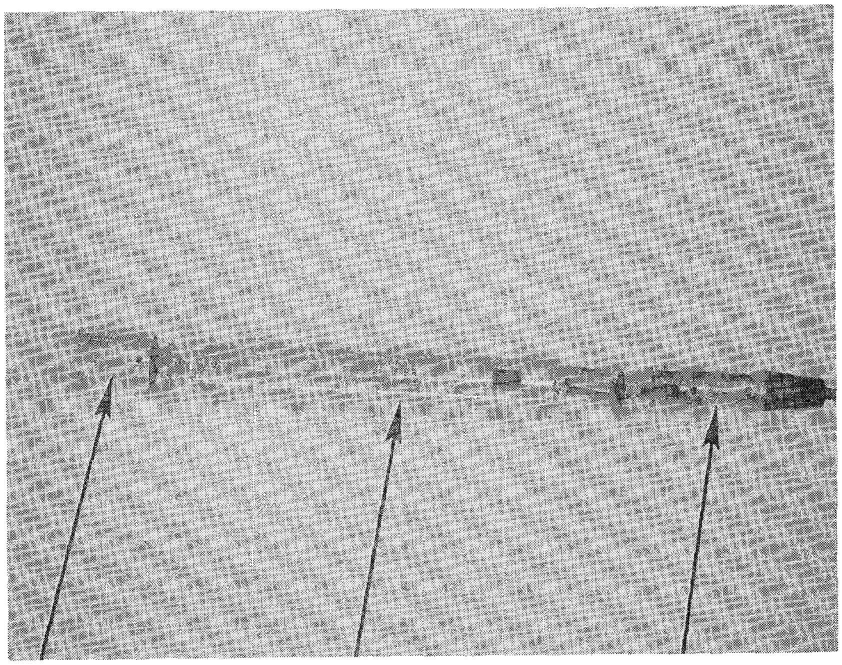
10.2 Effects of On-Site Variables on Acoustic Seal Checker System

Table IV summarizes the effects of on-site variables on acoustic seal checker performance. The primary factors affecting the seal checking operation are borehole depth and the presence of water flow down the borehole or along the passage. Borehole water flow in the microphone hole creates noise which will mask the reduced speaker signal as the seal nears completion. It is therefore required that the microphone borehole be cased if ground water is present.

The most time-consuming portion of the seal-checker operation is the lowering and subsequent retrieval of the speaker module. Borehole depth increases the equipment and time required for this operation. The actual monitoring of the seal is conducted during seal emplacement and does not therefore slow down the sealing operation. Figure 38 shows the total time required for the seal checker operation, including downhole deployment and subsequent retrieval of the instruments.

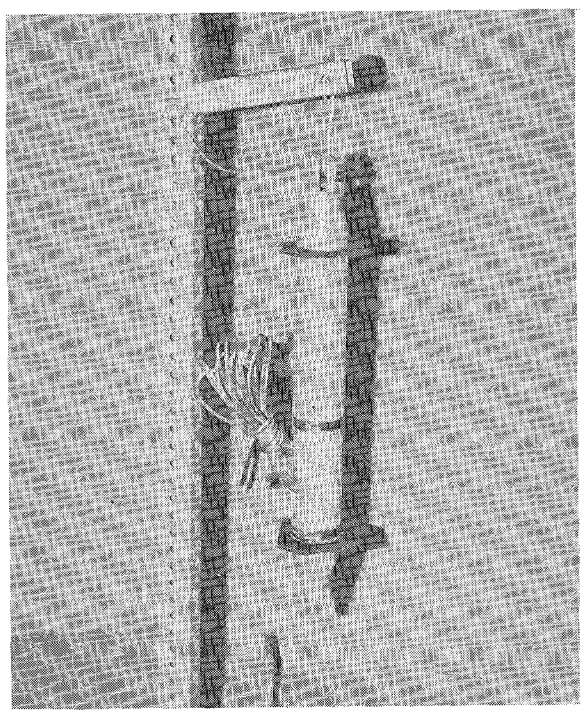
10.3 Operating Procedure

1. Attach the large electrical cable to the speaker housing and lower the unit into the mine using the equipment and technique outlined in Section 7.3. Orient the pipe string so that the speakers will face the microphone position.



Microphone Preamplifier Cable Connector

(a) Microphone and Preamplifier



(b) Microphone Preamplifier Module

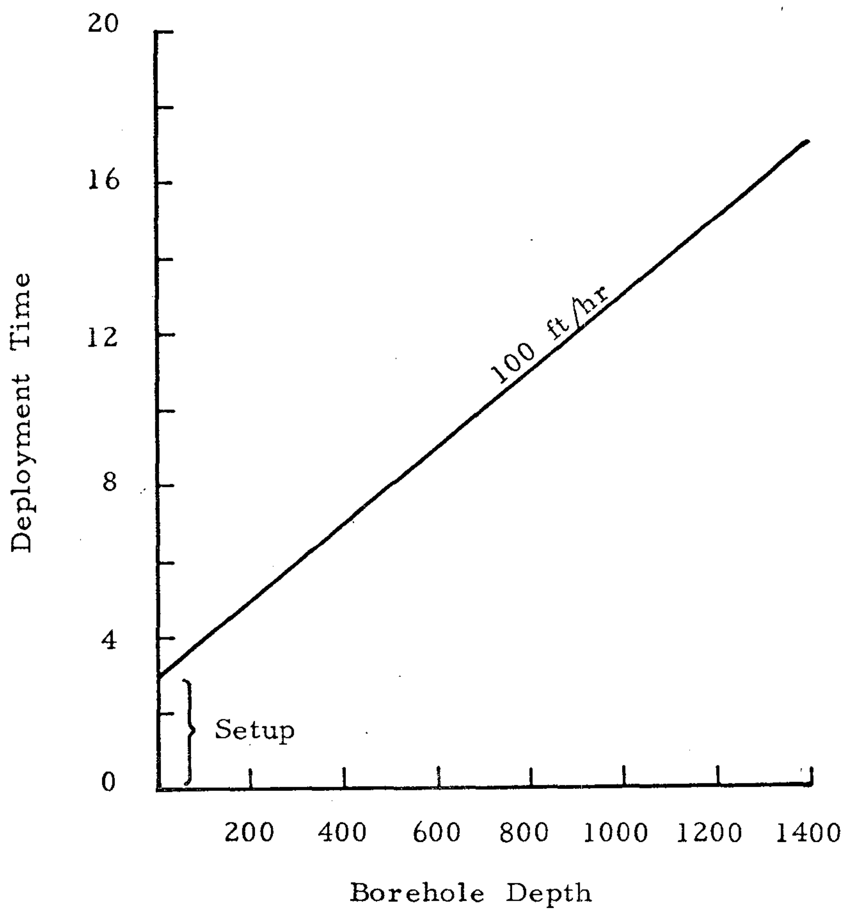
Microphone and Preamplifier Module for Acoustic Seal Checker

Figure 37

TABLE IV

EFFECT OF ON-SITE VARIABLES ON SEAL CHECKING

Parameter	Effect on Remote-Seal Checking Operation
Passage Width Passage Height	No effect on individual seal checker reading. More readings may be taken due to additional material required to fill larger passages.
Passage Blockage	May affect sensitivity during initial pouring slightly. No significant effect on final results.
Water Flow in Borehole	Water flow down microphone borehole will reduce sensitivity by increasing the background noise level. Water flow down speaker borehole has only minor effect on system.
Water Flow Down Passage	System is sensitive to passage water flow only to the extent that the water flow increases the ambient noise level.
Borehole Depth	Borehole depth increases electrical resistance of cables and the time and equipment required for deployment.
Borehole Diameter	Microphone module could easily be adapted to smaller boreholes. Speaker system would require major redesign.



Time for Deployment of Speaker Module

Figure 38

2. Attach the microphone cable to the microphone housing and lower it into the mine with the small electric winch and 1/8 -inch wire rope. Tape the mike cable to the wire rope at 20-foot intervals.

3. Turn on all the electrical components on the operator console. Set the "rep rate" to 5 seconds, the "window size" to 160 milliseconds, and adjust the mike-speaker distance to the actual distance between the microphone and speaker boreholes.

4. The system is now ready for operation.

5. Adjust the "db Level" dial on the Sound Level Meter until the "Signal Level" meter reads between zero and + 10 db. The actual signal level is then the number on the Sound Level Meter dial plus the indicated value on the Signal Level Meter. Record this number.

6. After the initial reading has been taken, the seal building may commence. Additional readings may then be taken 5 minutes after a truck has completed pumping fly ash. The percent of seal completion may then be determined by subtracting the latest db reading from the initial db reading and using Figure 35.

7. When the seal is complete, retrieve the speaker and microphone modules.

11. Summary of Remote Mine Sealing Operations

The time required to emplace a single seal depends largely on the depth of the mine passage from the surface and the dimensions of the mine passage. Passages at greater depths require deeper boreholes with considerable increases in the time required for drilling and casing. In addition, the deeper boreholes require additional deployment time for the sonar probe, for the seal checker speaker and microphone modules, and for the foam equipment, if required. The additional time and cost required for the drilling and casing operations overshadow the other effects.

Tables V, VI and VII compares the required seal completion times for a variety of conditions. Considered in these tables are:

(a) borehole depths of 100, 400 and 1500 feet

(b) passage dimensions of 4 x 13 feet and 7 x 20 feet

(c) 100 percent fly ash seals and foam-topped 95 percent seals

(d) the effect of multiple drill rigs.

Each table presents the information for a single borehole depth and two passage sizes. The effect of borehole depth on the drilling and casing times and the several downhole deployment operations may be determined by comparison of similar operations on the three tables. Note that the drilling and casing time for a single borehole increases from about 13 hours to 110 hours as the depth increases from 100 to 1500 feet.

The effect of multiple rigs may be determined by comparing the completion times for the 1, 2 and 3 drill rig situations presented on each table. Adding one or two drill rigs does not proportionally reduce the time before fly ash may be poured because holes drilled sequentially may be used for probing and deployment of the seal checker modules while additional holes are being completed. In general the second drill rig provides greater incremental benefit than does the third. For boreholes of 100-foot depth the addition of a second drill rig reduces the elapsed time until fly ash is poured from 40 hours to 27 while the third drill rig further reduces it to 16-1/2 hours. For extremely deep passages like that of Table XII, the drilling and casing times are so long that using a single drill rig has not been considered.

The effect of passage size and seal type are presented for each borehole depth. The dimensions assumed for the small passage are 4-feet x 13-feet and for the large passage, 7-feet x 20-feet. From Figures 25 and 26 the small passage requires 46 tons of fly ash for a 95 percent seal and a total of 76 tons for a 100 percent fly ash seal. The large passage requires 213 tons and 343 tons respectively. The filling times, determined using a 20 ton/hour fly ash delivery rate, are presented on the tables. The time required for a 100 percent seal is the sum of the time for a 95 percent plus either the incremental time for the last 5 percent of fly ash or the time for the foam topping.

The time required to pump fly ash is independent of borehole depth but a strong function of passage size. Foam topping time, on the other hand, is affected strongly by deployment time through the long borehole and only to a minor extent by the size of the passage. Consequently, foam topping is generally more attractive for large passages and shallow boreholes, while 100 percent fly ash seals are more suitable for smaller passages of greater depths.

Tables similar to those discussed may be preapred for any combination of borehole depth and passage dimensions by using Figures 10, 25, 26, 32 and 38 to determine the appropriate times.

In general, the following conclusions may be drawn:

(a) Multiple drill rigs are desirable in all situations. Their desirability increases in direct proportion to the borehole depth.

(b) Foam topping is generally more attractive for large passages at shallow depths, while 100 percent fly ash seals are more suitable for smaller passages at greater depths.

TABLE V

MINE PASSAGE SEALING SCHEDULE

BOREHOLE DEPTH ~ 100 FEET; PASSAGES: 4' x 13' and 7' x 20'

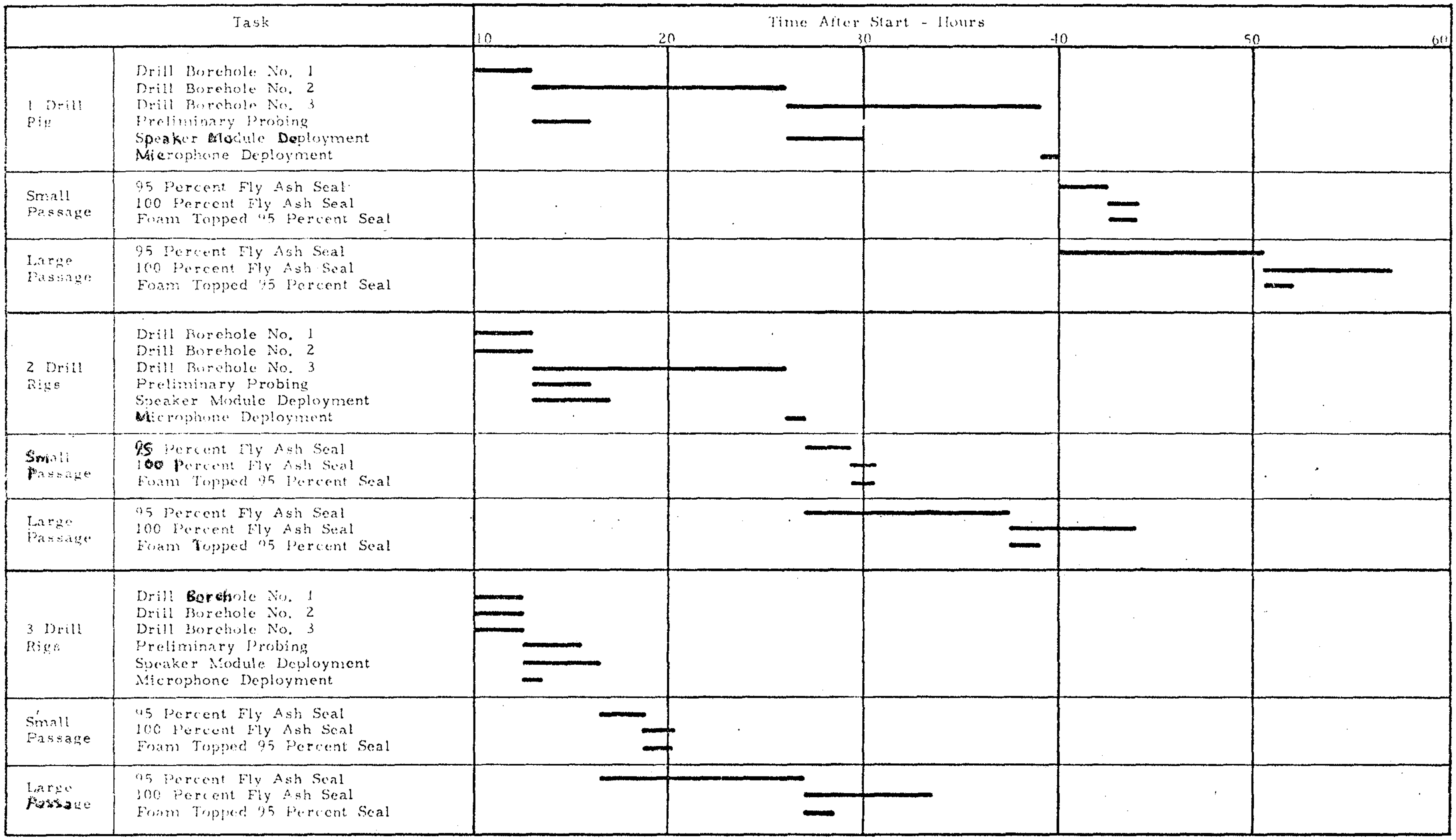


TABLE VI

MINE PASSAGE SEALING SCHEDULE

BOREHOLE DEPTH ~ 400 FEET; PASSAGES: 4' x 13' and 7' x 20'

Task	
1 Drill Rig	Drill Borehole No. 1
	Drill Borehole No. 2
	Drill Borehole No. 3
	Preliminary Probing
	Speaker Module Deployment
	Microphone Deployment
Small Passage	95 Percent Fly Ash Seal
	100 Percent Fly Ash Seal
	Foam Topped 95 Percent Seal
Large Passage	95 Percent Fly Ash Seal
	100 Percent Fly Ash Seal
	Foam Topped 95 Percent Seal
2 Drill Rigs	Drill Borehole No. 1
	Drill Borehole No. 2
	Drill Borehole No. 3
	Preliminary Probing
	Speaker Module Deployment
	Microphone Deployment
Small Passage	95 Percent Fly Ash Seal
	100 Percent Fly Ash Seal
	Foam Topped 95 Percent Seal
Large Passage	95 Percent Fly Ash Seal
	100 Percent Fly Ash Seal
	Foam Topped 95 Percent Seal
3 Drill Rigs	Drill Borehole No. 1
	Drill Borehole No. 2
	Drill Borehole No. 3
	Preliminary Probing
	Speaker Module Deployment
	Microphone Deployment
Small Passage	95 Percent Fly Ash Seal
	100 Percent Fly Ash Seal
	Foam Topped 95 Percent Seal
Large Passage	95 Percent Fly Ash Seal
	100 Percent Fly Ash Seal
	Foam Topped 95 Percent Seal

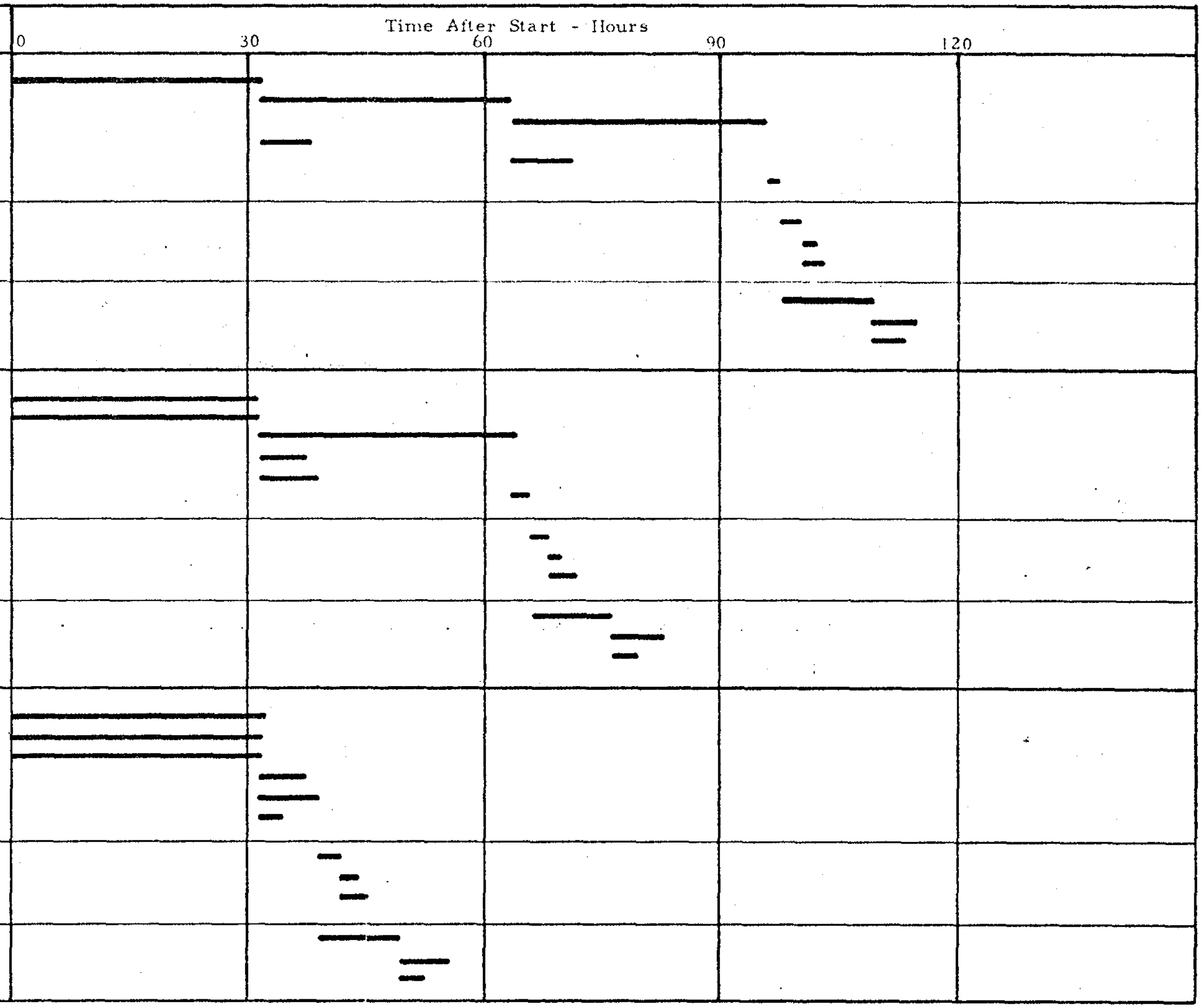
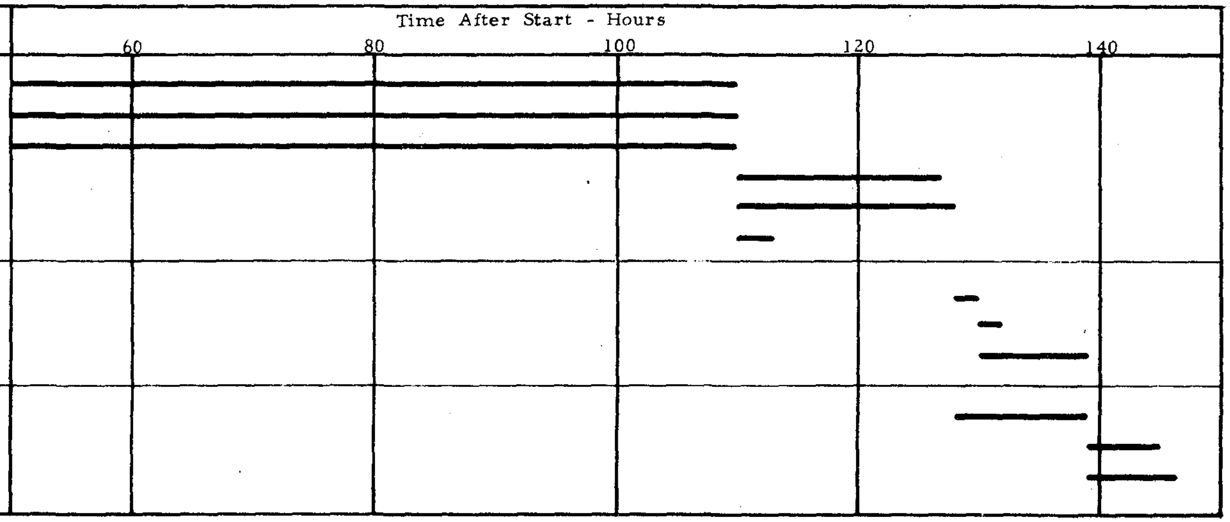


TABLE XIII

MINE PASSAGE SEALING SCHEDULE

BOREHOLE DEPTH ~ 1500 FEET; PASSAGES: 4' x 13' and 7' x 20'

Task	
3 Drill Rigs	Drill Borehole No. 1
	Drill Borehole No. 2
	Drill Borehole No. 3
	Preliminary Probing
	Speaker Module Deployment
	Microphone Deployment
Small Passage	95 Percent Fly Ash Seal
	100 Percent Fly Ash Seal
	Foam Topped 95 Percent Seal
Large Passage	95 Percent Fly Ash Seal
	100 Percent Fly Ash Seal
	Foam Topped 95 Percent Seal



Note: For holes of this depth, multiple drill rigs are essential

12. List of Do's and Dont's

12.1 List of Do's

1. Set up a capable and efficient emergency mine sealing organization with detailed plans and assigned responsibilities including, Officials of the Mine Corporation, the United Mine Workers of America, the District Office for Mine Safety, U. S. Bureau of Mines, the State Mining Department and Consultants familiar with mine disaster recovery and remote sealing operations.

2. Draw up a primary and secondary plan for remote sealing, taking into consideration both underground and surface conditions.

3. Select suitable sealing locations to minimize sealing time and maximize ease of operation. Select a seal location at an entry midway between two cross cuts of as small a passage size as possible and having a minimum of overburden.

4. Plan site preparation to provide adequate access of heavy equipment and trucks to borehole locations.

5. Check conditions of water table and case and grout boreholes if required to eliminate borehole water flow.

6. Make sure that access roads and bridges can support the massive fly ash trucks, gross weight about 35 tons.

7. Prepare a fly ash truck off-loading platform to support fly ash trucks when pumping fly ash.

8. Locate platform at a central location to service maximum number of boreholes but not greater than 300 feet from auxiliary blower.

9. Select one or more drilling contractors who have both the equipment and expertise required; preferably local drillers who have done previous work for the coal company.

10. Drill 3 boreholes per seal, one primary borehole for sealing and a secondary borehole for seal checking on either side of the primary hole, 30 to 40 feet inby and outby of the primary hole. The primary borehole and one of the secondary boreholes must have a 6-inch I. D.; the other secondary hole a 4-inch I. D.

11. Purge fly ash hose with air for one minute before and after pumping off a truck load of fly ash.

12. Use fly ash with foam topping to seal large passages at shallow depths and fly ash alone to seal small passages at large depths.

13. Use fly ash with foam topping for air-and water-tight seals.

14. Sonar probe the main borehole to determine location of borehole with respect to ribs, intersections, cribs, roof falls and passage obstructions.

15. Sonar probe the acoustic seal check hole containing the speaker assembly to determine borehole location in passage and define speaker assembly orientation.

16. Continuously monitor fly ash buildup and subsequent foam topping with acoustic seal checker.

17. Locate adequate sources of fly ash supply and trucking contractors with sufficient number of trucks to maintain an adequate and continuous supply of fly ash.

18. Schedule fly ash trucks to maintain a continuous flow of fly ash. Provide standby parking space for waiting trucks and ample room for turn around without interfering with work.

19. Purchase adequate supply of foam, preferably in 20,000 lb quantity (10,000 lb each tank).

20. Provide equipment to unload tanks and locate at a central location to the boreholes to be sealed.

21. Maintain foam tanks at a constant 75° to 80°F temperature by providing a heated enclosure if the weather so requires.

22. Purge foam system and lines with methylene chloride immediately on stopping the foaming operation.

23. Cable lower the foaming head and hoses using a diesel-operated, mobile hydraulic crane with a telescopic boom. Tape the hoses to the cable at 3-foot intervals.

24. Make sure that there is sufficient foam in the tanks to complete foaming of seal in one continuous operation.

25. Make sure that there is a bulldozer with chains and cables, if access of heavy equipment is required over unimproved terrain.

12.2 List of Dont's

1. Do not pump water into the fire zone during the sealing operation.

2. Do not pump fly ash through a borehole with water flow.

3. Avoid sealing at passageway intersections, 3-way or 4-way, if possible.

4. Do not use fly ash alone to make a water-tight seal - use fly ash with foam topping.

5. Do not skimp on access roadway for handling fly ash trucks.

6. Do not allow the urgency of the operation to override caution when drilling holes. The driller must be allowed to proceed at his own pace if the drill is to stay on course.

7. Do not locate fly ash trucks more than 300 feet from auxiliary compressor.

8. Do not locate fly ash truck to pump uphill more than 15 feet vertically.

9. Do not locate auxiliary blower more than 150 feet from borehole.

10. Do not operate the fly ash truck pumping system at any time unless the auxiliary blower is running.

11. Do not operate the auxiliary blower with the bleed valve closed.

12. Do not attempt to pump off the fly ash truck unless the compartment pressure is maintained at a minimum of 16 psi.

13. Do not operate the foam system if the two foam components are at a temperature less than 75°F.

APPENDIX

EQUIPMENT REQUIRED FOR MINE SEALING SYSTEM

I. Drilling Operation

The borehole drilling operation is best conducted under contract to a local drilling contractor. Typical equipment required and to be supplied by the drilling contractor include:

1. Mobile drill rig.

2. Flat bed truck containing the necessary length of drill pipe.

3. Auxiliary compressor.

4. Bulldozer for moving heavy equipment.

5. Specified length and diameter of threaded casing for 6-inch diameter cased borehole.

6. Drill bits, stabilizer units, cutting and welding equipment, other miscellaneous tools and supplies.

7. Ready mixed cement grout.

8. Water supply.

II. Sonar Probing Operation

The sonar probing operation requires the use of the special remotely operated sonar probing system developed by Foster-Miller Associates under this contract. The system includes.

1. Remote sonar probe with transducers, electronics and housing.

2. Sonar readout unit, including signal processing and display.

3. Sonar probe deployment and scanning system.

III. Fly Ash Sealing Operation

The fly ash sealing operation requires the use of the special, dilute phase, pneumatic transport system developed under this contract. The system includes:

1. Fly ash delivery truck.

2. 300 feet of 4 inch diameter flexible fly ash hose with couplings.

3. 5000 scfm, 10 psi capacity, diesel driven, positive displacement type, rotary blower, such as, Series 3200 Sutobilt, Div. of Fuller of Fuller Company, Compton, California. Or - Inert Gas Generator presently under development by Foster-Miller Associates under contract to the U. S. Bureau of Mines for use in fly ash sealing.

4. Dilute phase, pneumatic transport system, consisting of a fly ash ejector-mixer, 10-inch and 8-inch diameter pipe, valves, tees, reducers, elbows, etc. as required.

5. Flow instrumentation including, pressure transducers, solids flow meters and air flow meters.

IV. Foam Topping Operation

The foam topping operation requires the use of the modified "Puff Grout" system developed under this contract. The system includes:

1. Olin Autofroth supply tanks.

2. Isocyanate and polyol component metering and blending control system.

3. Downhole mixer assembly and packer system.

4. Component delivery system including hoses for the isocyanate and polyol components, hoses for methylene chloride and nitrogen lines for the flow control valves.

5. 1 Truck mounted hydraulic crane with at least 600 feet of 3/8 inch diameter wire rope - on winch - generally rentable from local construction company.

6. Methylene chloride cleaning system.

7. Nitrogen bottles and freon bottles.

V. Acoustic Seal Checker Operation

The seal checking operation requires the use of the special acoustic seal checking system developed by Foster-Miller under this contract. The system includes:

1. Linear acoustic array and deployment module.

2. Microphone - preamplifier module.

3. Signal generating and processing console.

4. Acoustic array and microphone downhole deployment system.

5. Specified length of acoustic array and microphone signal cable.

VI. Availability of the Remote Mine Sealing System

The various systems comprising the remote mine sealing system, such as the sonar probing system, the fly ash sealing system, the froth-foam seal topping system and the acoustic seal checking system are all special systems developed by Foster-Miller Associates and as such should be procured on a system rather than a component basis.

A number of these systems are presently undergoing design modifications to miniaturize component size, improve performance sensitivity and simplify overall operation. Three units each of the improved sonar probing system and the acoustic seal checking system will be supplied by Foster-Miller to the U.S. Bureau of Mines, Bruceton, Pa. by June, 1974. It is understood that two of these systems will be transferred to Mine Enforcement Safety Administration (MESA), Technical Support Center, Pittsburgh, Pa. An inert gas generation system for pumping fly ash and for subsequently inerting the sealed fire zone is presently under development by Foster-Miller for subsequent delivery to the Bureau during 1974. Extending the capability of the fly ash delivery system to deliver a predetermined mixture of fly ash and cement in order to ensure the development of air- and water-tight seals, is presently under consideration.