EVALUATION OF HORIZONTAL DRILLING TECHNIQUES IN COAL BEDS

FOR

UNITED STATES DEPARTMENT OF INTERIOR

BUREAU OF MINES

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FOREWORD

This is a study to evaluate methods and techniques for drilling small diameter horizontal boreholes in coalbeds for the Bureau of Mines, United States Department of Interior. It has been performed by Jacobs Associates of San Francisco, California.

The purpose of this study is to provide guide lines for meaningful research leading toward improved drilling devices and techniques.

The evaluation of the technology has indicated clearly that those techniques, now in use by the Bureau of Mines, represent the most advanced state of the art, currently available, for the Bureau's purposes and conditions. It also shows that much of the advance, to the current state of the art, in technology has been the result of the Bureau's activities. It indicates that further advances can and should be reached through research by the Bureau and provides guidance for such activity.

The first section of the report describes the conditions under which a drill must work. The second section discusses the state of the art of drilling as it relates to the problem. The third section describes the problem.

Several possible approaches to a solution, including thirty-six concepts, and their evaluations, are presented in Section 4. Details of research programs are given in Section 5 for the most promising research projects selected by the evaluation in Section 4.

Section 6 presents: a Summary; Conclusions; Recommendations and Invention Disclosures, resulting from this study.

Information, herein, is not to be published by others than the government or revealed to others than representatives of the Contracting Officer without his written approval.

1.0 PHYSICAL CONDITIONS - IN MINES

Most U.S. coal production is bituminous coal. Some 90% of current production comes from a geographical area enclosed in a circle with a 300 mile radius and its center at about Huntington, West Virginia. There are important underground coal production areas in the western parts of the United States as well.

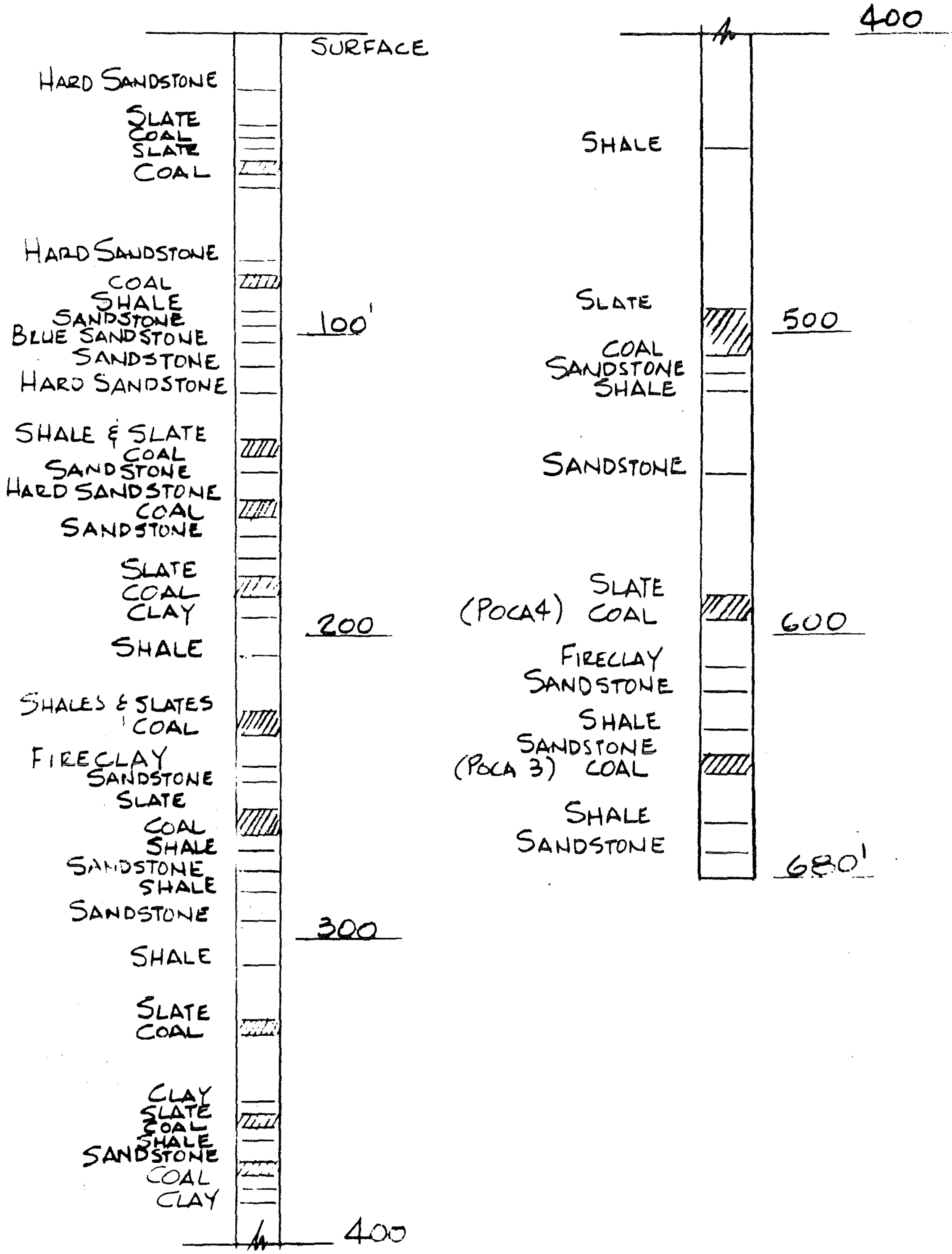
Most U.S. coal production comes from fairly level seams, many of which pitch rather uniformly only a few feet per mile. Usually there will be several overlying seams of varying thicknesses, separated by several tens of feet. Fig. 1.1. Seams have minor local undulations but these are small enough not to be a major consideration in a horizontal drilling research program.

In order to establish the mining conditions for which the technology must be evaluated, some data was assembled for some rather typical bituminous coal mines, of moderate size. These data are shown in Figure 1.2. Many of today's mines will be operating for a few decades but production after or during the first quarter of the next century, will be from mines not now in operation. The width of entries and breakthrough varies from about 17 to 20 feet. The thickness range may show rather large extremes in any one mine, but in an average mine 80% or more of the coal will vary in thickness no more than 4 to 6 inches.

Most of today's mines have 440 volt, 60 cycle, 3 phase power at the face but this is not universally consistant. Many mines will transmit the power to the working section at a higher voltage and reduce it there.

A typical mine has about five development sections which vary widely in advance per week from 30 to 160 feet at different mines. This usually means advancing about five headings on about 80 ft. centers in each working section and includes driving lateral connections or breakthroughs every 80 to 100 feet.

Water is produced in some coal mines but will not be a serious problem to drilling as flows seldom exceed those which can be handled easily at a drill site with a small pump. There will not be enough water made to be used as a circulation medium so drill water will have to be piped to, or carried in cars, to the drill site. Most mines will have a water supply at the section at 100 to 200 psi. This water is used for dust suppression for mining. It usually has a wetting agent, normally some form of detergent, added at its source. The wetting agent and water mixture with methane creates a very large volume of foam which



TYPICAL GEOLOGICAL SECTION IN COAL

FIG. 1.1

TYPICAL COAL MINE DATA

	Mine 1	Mine 2	Mine 3	Mine 4
Tons/Day	550	1900	3000	1800
Mine Life left - yrs	40	30	30	18
Coal thickness - in.	34 - 38	38 - 50	36 - 84	66 - 168
Width entries - ft.	20	20	20	20
Partings - thickness - in.	3	3	-	-
Average depth - ft.	800	650	600	800
Haulage	Belt	Rail	Belt	Rail
No. sections dev.	5	4	5	0
No. men underground	160	250	82	32
Advance/week - ft.	30	65	160	NA
Max. Mi, to portal	1	2	1.25	NA
Power (3/60) Voltage	550	440	440	440
Gas, 1000 cu.ft./day	367	1080	198	187
Fan. cap. million cu.ft./day	360	1075	540	374
Fan hp	600	1050	400	250
WG - In.	11	4 to 8	3.5	4.1

Fig. 1.2

can be a serious nuisance at the drill site. This foam may be dissipated by sprinkling rock dust on it. At the same time, there is some feeling that the foam may be an aid in cuttings transport and this must be examined in the research program.

Dust will not be a problem in the drilling rig's atmosphere. Drills normally will be working in areas where other activity, which cause dust problems, will not be operative. The drilling will be done wet so that the drill will not create dust.

Unless diluted, or otherwise controlled, methane emission from a hole being drilled may create concentrations which will require stopping of the drilling operation. The hole being drilled may add about 25 to 30 cu.ft. of gas per minute to that which normally is being released by the coal ribs and face. Some thought is required for directing supplemental ventilation air to the edge of the drill hole with brattice cloth on timbers or an air duct from a fan in good air, or to contain the gas for safe disposal away from the working area.

According to Bureau of Mines reports, methane pressures in the drill hole can reach 900 psi. in some situations and a few hundred psi. in many situations.

Most coal seams being mined are fairly uniform in non-coal inclusions. Some may have one or two shale or slate partings. These are uniform in thickness, of usually not much more than two inches, and consistent in their vertical location within the seam. These partings are harder and somewhat more abrasive than coal and can present some difficulties to the drill.

Other inclusions in coal which cause difficulties to drilling are pyrite balls or streaks. These can be very small-sized nodules of walnut size or larger ones of football shape and size. They are extremely hard. Fortunately, pyrite inclusions are not common, but can be very troublesome in the few seams in which they occur. One of these is in the Pittsburgh Seam in Northern West Virginia and Western Pennsylvania. The occurence of such inclusions must be recognized but should not become a major parameter for consideration in drilling research.

Coal, compared to most other mineral deposits, is extremely easy to drill. It can be compared to an imaginary laminated plaster of paris. Rotary drilling with drag bits is perfectly satisfactory. Vertical well drillers, when drilling in coal areas, find that their bits seem to "fall through" any coal seam encountered. Hand-held and manually rotated, breast plate, type of coal auger drills were used historically for very easy drilling of about 2-inch diameter blast holes eight to ten feet deep. Electric or air powered rotary (drag bits) drills frequently achieve penetration rates of 3 to 5 feet per minute.

The coal mining companies have done a very thorough job in physical and chemical analysis of their product. Nearly all seams in each location will have been tested for BTU, carbon, moisture, ash, sulphur, volatiles, coking qualities and grindability. It may be possible to correlate some of the drilling parameters with such things as volatile content or grindability.

Depth of coal seams from the surface is, in most cases, less than 1,500 feet and will have little direct effect on the drilling operation. The few, but probably increasing, numbers of deep mines may present some problem of lateral working space as entries may be driven narrower to minimize overburden pressures on pillars and resulting bottom heaving. The effect of greater depths on hole stability also may need some consideration. Most U.S. coal mining is at depths of less than 1,000 feet as compared to 2,000 to 3,000 which is common in Europe. A few of the new mines either in operation or projected in the Southern Appalachian area will be under more than 2,000 feet of cover as are some of the older mines in the western part of the United States, notably in Colorado and Utah. There is some indication that holes in the deep Colorado mines are unstable and this may be due in part to this weight.

The stability of the hole will vary with coal seams. Drilled drainage holes in some seams will stand indefinitely while elsewhere some special consideration must be given to techniques which will provide stability without excessively degrading the hole's ability to drain the gas. Hole stability may be influenced by the strength and structure of coal, hole size and shape, erosion by drill fluid or drilling tools, or by the gas pressure.

The temperature of the air surrounding the drilling operation will be fairly uniform in most cases. Temperature extremes, therefore, will not be an operating problem to the drill.

2.0 STATE OF THE ART

2.1 U.S.A. HORIZONTAL DRILLING TECHNIQUES

Most of the American horizontal long hole research has been done by the Bureau of Mines. Coal mining companies have done some experimental work using modified coal face drills (Fig. 2.1). Most of the Bureau's activity has been in the field of basic fundamental research to analyze the nature and behavior of methane in the coal measures. Much of the drill development has been incidental to getting good reservoir data fast and with a small crew. Their work has been designed to be performed at a minimum inconvenience to the mining operation, at which they are guests. This has required that their drilling activity be performed on weekends or on the midnight, or non-working shifts, in most cases. The drills they have chosen (or developed) are the best available from the existing technology for these purposes.

The above limitations have required the Bureau to design their equipment for very high mobility and compact size for ease of transport and storage. With these restrictions, they have incorporated the best features of current drilling technology, sometimes having to miniaturize concepts from such drilling fields as the highly developed oil well drilling industry and mine exploration drilling.

A crew of five men from the Bureau's Pittsburgh laboratory drilled a small diameter hole to record depth, horizontally, in coal on Sunday, July 19, 1970. This 3-inch diameter hole was drilled 503 feet deep in the 50-inch thick Pocahontas No. 3 seam at the Occidental Petroleum Company's Island Creek Coal Company Division's Beatrice Mine at Keen Mountain, Virginia. The hole produced approximately 40,000 cu.ft. of methane per day a week after it was completed. It is interesting that these holes increase production for a few weeks after being drilled. A detailed description of the drilling of this hole is given below, as it will describe the current state of the art and its problems, which a research program can use as a base from which to start.

The horizontal hole was drilled at 10 degrees from a straight ahead projection of the left wall in Number 1 entry. The drill rested on a leveled-double two-inch pipe rack with the pipes on about 2 foot centers. Fig. 2.2. The 15-foot long rack rested on adjustable height pipe pedastals on 4 to 5 foot centers to the rear and on a horizontal cross bar clamped between two Simplex mechanical roof jacks set up at the front of the rack. A third Simplex jack held a

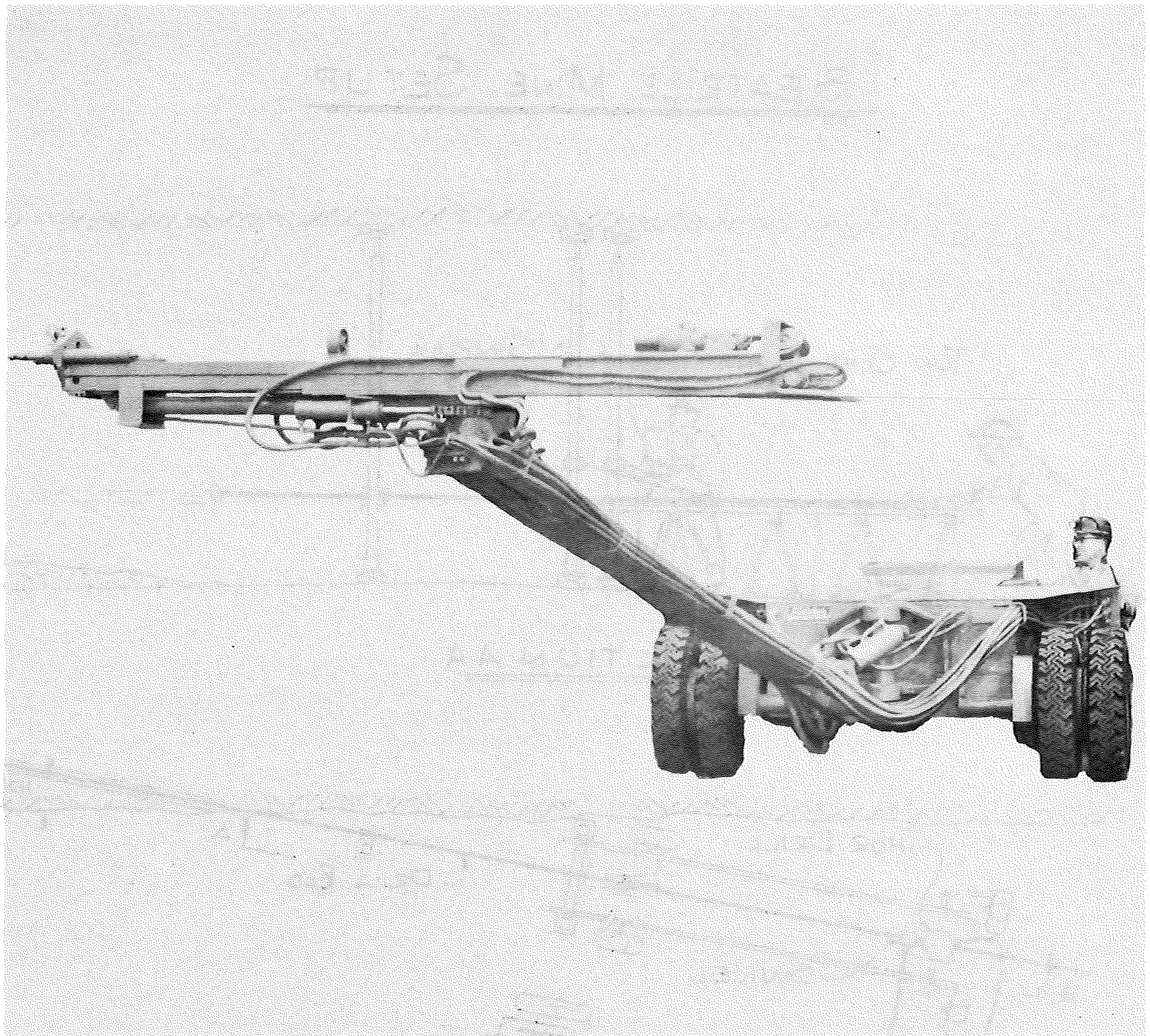


Photo
Courtesy J.H. Fletcher Co.
Huntington, West Virginia

COAL FACE DRILL
Fig.2.1

BEATRICE MINE SET UP

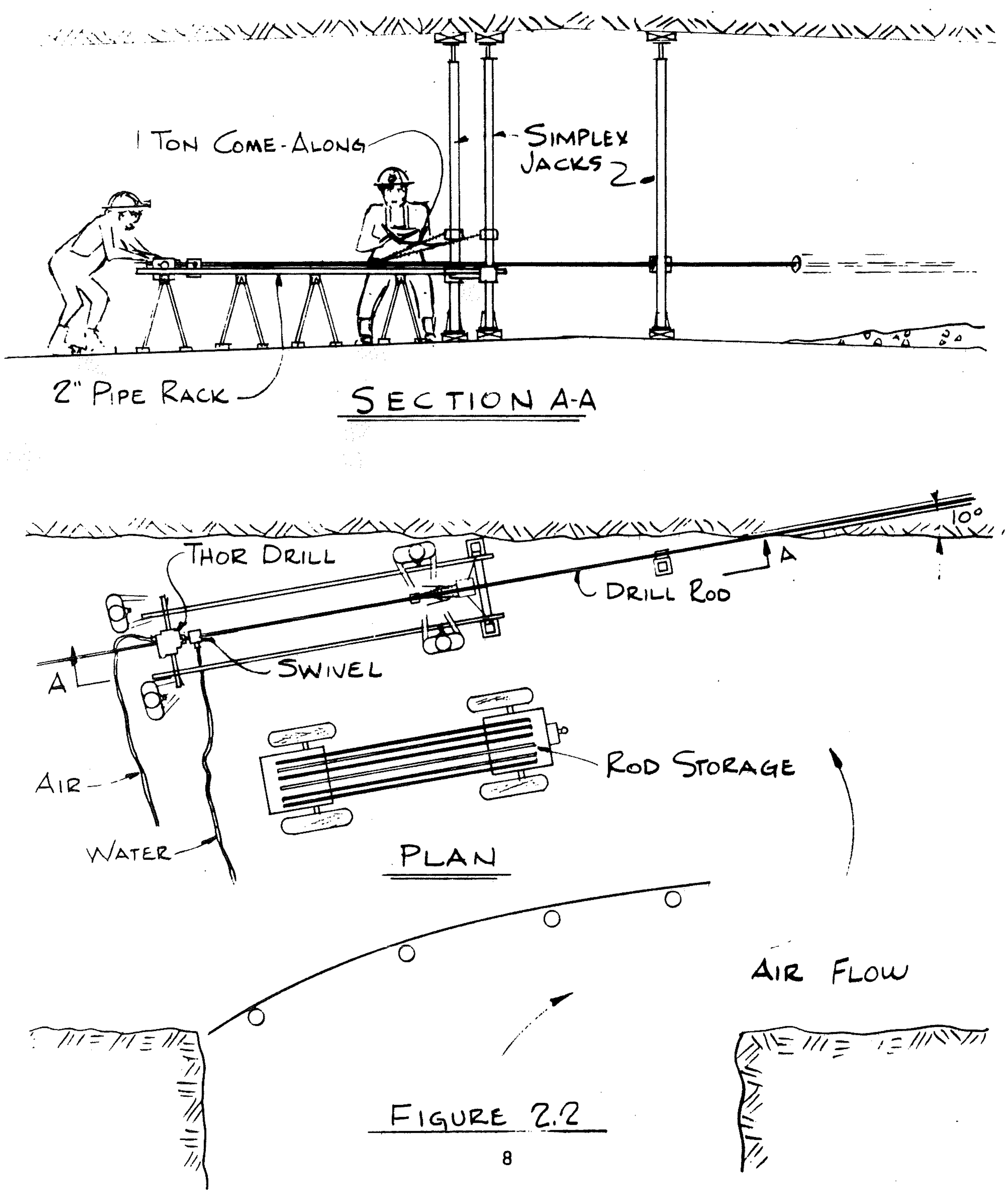


FIGURE 2.2

short tubular steady rest for the drill pipe about mid-point between the front of the pipe rack and the mouth of the drill hole some 12 feet away.

The air drill used at Beatrice was a Thor 56 pound, 8 horsepower, Model 09609A, Code 8L. The manufacturer says this drill consumes 200 CFM of 100 psi air. Mine air supply was used, coming from the section pipe line, through about 200 feet of one inch hose. The drill is a straight (non-percussive) rotary, turning the bit at 500 rpm, under no load, and about 425 to 450 rpm under load.

A swivel, just ahead of the drill, transmitted approximately 10 gpm of mine water from a one-inch hose into the E.W. 1-13/16 inch flush OD diamond drill casing. Each rod was 10 feet long. The square threads of the connections were four to the inch and the connections could be broken out by two men using a pair of 18 inch pipe wrenches. During make-up, pins were wire brushed and greased with regular machinery lubricating grease. The clear mine water used is normally used for dust suppression and, therefore, contained a wetting agent, presumably an unidentified detergent, added at the source. The estimated pressure of the water at the swivel was 200 psi.

The mouth of the hole was open so that a mixture of cuttings and water flowed onto the floor and surges of gas were released intermittently to the mine air. Ventilation in the place was good and a high velocity of at least 250 ft./min., of air swept the drill site at all times. The wetting agent, water and methane mixture created a heavy foam which became one to two feet deep, about the drill site, for the last 200 feet of drilling. This foam was a nuisance to the drill operation (and perhaps to subsequent mining) and it would be interesting to know if it was formed in the hole or only as the gas and fluid left the hole. If it forms in the hole, knowledge of the foam's effect on cuttings transport, hole erosion and hole wall conditioning may prove of some value.

Cuttings were about 1/32 x 0 inches from the start of the hole and no drastic reduction in percentage of the larger, approximately spherical, particles could be determined from a crude "feel" test as the hole got deeper.

The drill was set at the crest of a small anticline so that the seam sloped about 2 degrees to the face from the site. There was a down slope of about the same magnitude from the site in the opposite direction. The setup was such that most of the water flowed to the 20 foot wide face, which was approximately 15 feet in front of the drill hole. There was a breakthrough opposite the drill site. The drill was on the left rib of the left (or number one) entry. Some of the discharge water flowed through this breakthrough into the second and third entries of the 5-entry section. Water was never more than a few inches deep at the forward end of the drill work area. There was none at the rear end.

The five entries were on 80-foot centers except Numbers 4 and 5 which were 95 feet apart. Ninety degree breakthroughs were driven on one-hundred foot centers and track was laid to the second breakthrough in the second entry. Air was split in the center of the section so that both outside entries (1 and 5) were return airways.

The coal was mined with a Lee Norse continuous miner on a two-shift basis. The five headings are each advanced about 100 feet per week so that with the breakthrough approximately 1,000 feet of new openings are made weekly. Roof was supported by roof bolts on about 5 foot centers and there was no evidence of bad roof or bottom heaving.

The drill was set level about 12 inches off the floor and, due to the pitch of the coal seam, entered the rib at about 14 to 16 inches from the floor. There was a thin slate parting about 4 inches below the roof. There was some high torque at 160 feet, and the cuttings changed from black to dark grey, indicating that the bit went into either this parting or the roof. The 3-inch x 12 inch long stabilizers with four straight fingers had been used at each end of the first drill rod at the bit for straight hole. They were taken off at this point. Torque then went down and the high drilling rate resumed so that apparently the bit deflected back into the coal as a result of the maneuver. Black cuttings, from that point on, indicated that the bit stayed in the coal to the 503 foot depth.

When the stabilizers were removed at 160 feet, the three blades of the Hawthorne Blue Demon bit were replaced, as insurance against having to pull the tools again before completing the hole. The sintered tungsten carbide tips brazed on to the pointed head blades, were not dull but showed only a few chipped edges. Even a few chipped edges at the gage points of such bits will slow them down.

Thrust was applied for the first 80 feet of drilling by two men pushing on the drill so that it probably was less than 200 pounds. At 80 feet it became difficult to push and a one-ton come-along was attached to the front roof jacks and connected to the drill with a 1/8 inch wire line. Two men cranked the come-along and two men continued to push for the rest of the drilling. Probably 2,000 pounds thrust was needed toward the end of the drilling and some of this was to propel the pipe rather than a need by the bit.

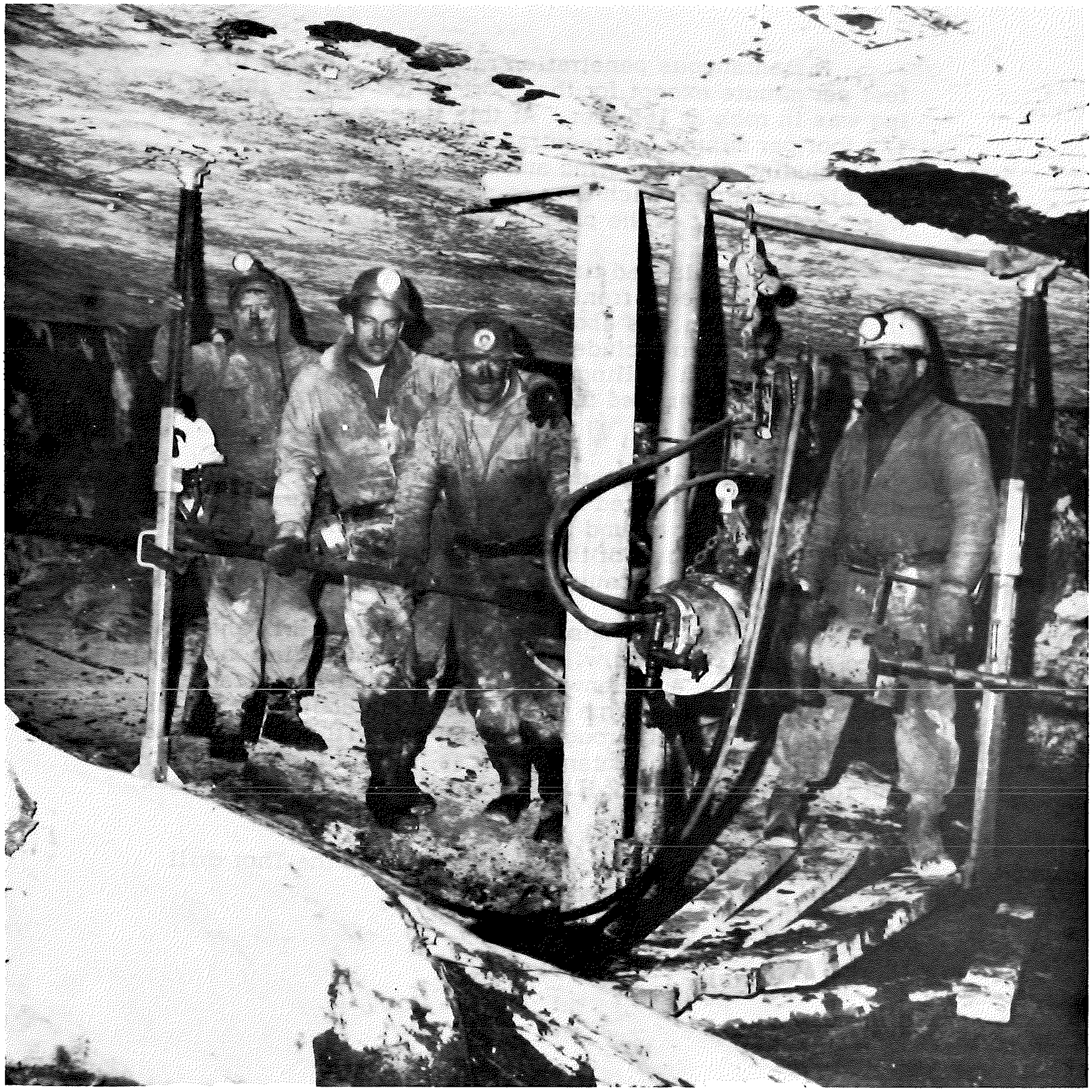
Instantaneous penetration rates varied from 2 to 4 feet per minute except for the short period of time the drilling was in rock at 160 feet. At this time it slowed to about 1/2 foot per minute. It required 4 to 8 minutes to add a rod including disconnecting and reconnecting the swivel and about a minute each time to regain circulation as water drained out of the pipe and hole during this operation.

The total elapsed time, portal to portal, was 15 hours including three hours transportation both ways to and from the section which was about three miles from the shaft bottom. That also included tearing down so that about eight hours was used in drilling. This was very hard work and should not be attempted frequently with a single crew in a single shift.

At completion of the hole, 30 feet of open-ended drill rod was re-inserted in the mouth of the hole and packed off with wet paper around the pipe. This is necessary to protect the loose part of the hole, near the surface, from erosion and collapse caused by the high rate of flow of gas.

The Bureau of Mines is building a larger drill than that used at Beatrice. This will be a post mounted diamond drill made by Sprague and Henwood of Scranton, Pennsylvania. Fig. 2.3. It is their type "B" swivel head drill. It will take a 1-13/16 O.D. rod through the drill and will apply thrust hydraulically and the rotary power is hydraulic. It is being put together as a 7-1/2 H.P. unit but a 20 H.P. power pack will be provided later.

This will be a more powerful unit than the Thor drill and will also have heavier components.



BUREAU OF MINES' SPRAGUE & HENWOOD DRILL

Fig.2.3.

2.2 FOREIGN DRILLING TECHNOLOGY

2.2.1 European Drilling

Lateral drilling for methane drainage in European coal mines has been given quite broad acceptance. As early as 1960, the English had a few tens of drills underground. Similar drills were in use in Germany and other continental coal mines at the same time.

Most of the drainage holes are drilled in rock and usually at some angle from the horizontal. Much of the drilling is done from the haulage road. This rock tunnel provides room for larger drill mounts than would be useful here. Most of their drill holes are capped and connected to the outside.

They have drilled an angle hole up in rock, as deep as 600 feet deep but nearly all of the holes are less than 300 feet on about 60 foot centers. A 250 to 300 foot deep hole in rock is completed in two to three shifts. We must plan to drill smaller holes, in the much softer coal, to three times their normal depth in one third the time.

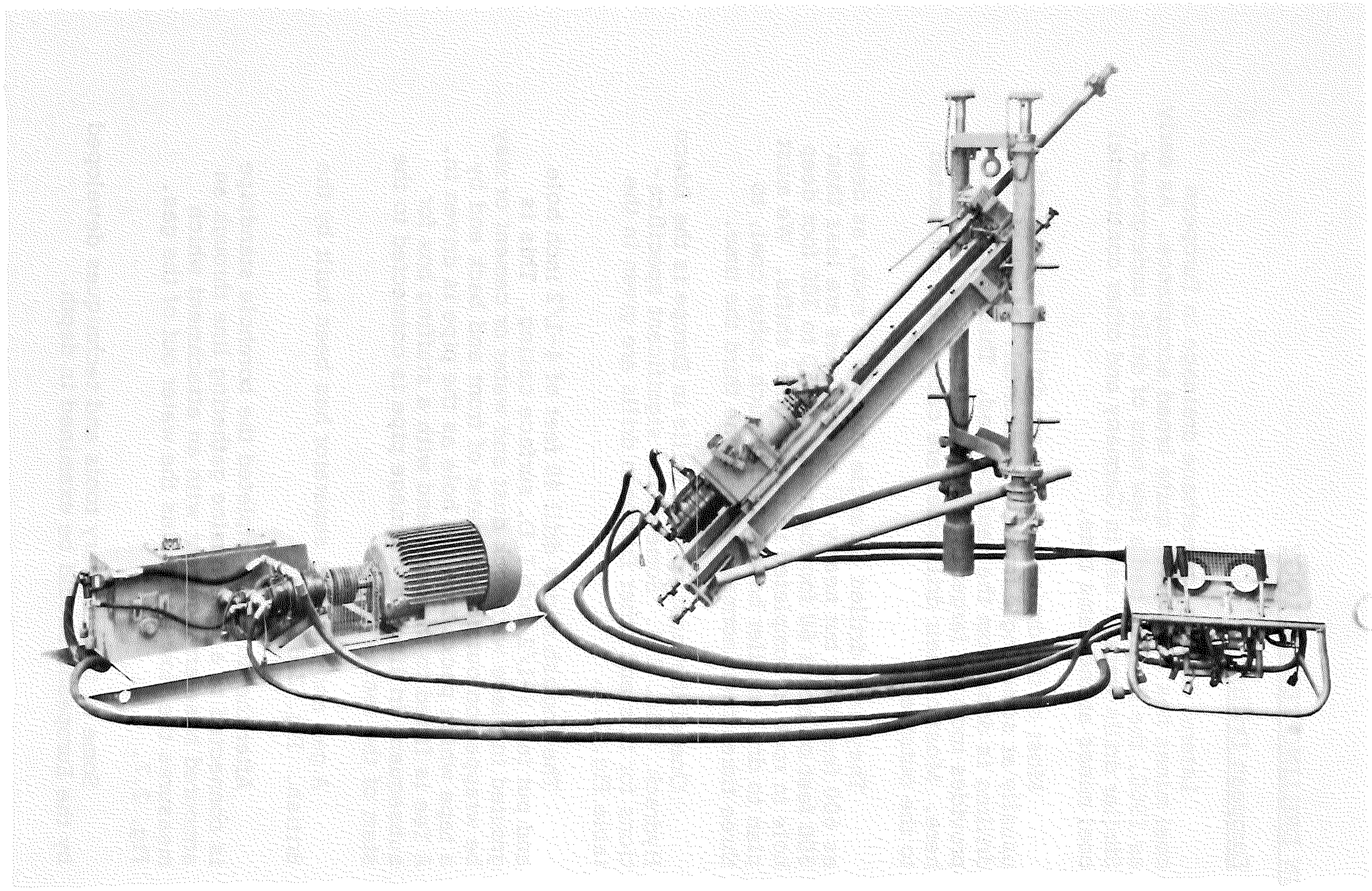
One of the most popular drills in Europe is the Edeco Hydrack. Fig. 2.4. Some of the significant specifications for this and other European drills are given in the table Fig. 2.5.

The English mines drill 40 feet of 4-1/2 inch hole and put in a 3-1/2 inch I.D. surface casing. This is grouted in place with rock dust and water or cement or may be wrapped on outside diameter of front and back end by a tape which packs into the hole as the pipe is driven in. A Tee is fitted to the outer end with a stuffing box for subsequent drilling. A drainage pipe is connected to the stem of the tee.

A gas and cuttings separator has been built by the British. Fig. 2.6.

After the hole is completed the borehole standpipe is connected to a 6-inch mine gathering line through an armoured hose arrangement with an attachment which measures the flow and drains the water out of the gas. Fig. 2.7.

Some of the auxiliary tools and techniques developed by the Europeans should be examined in depth.



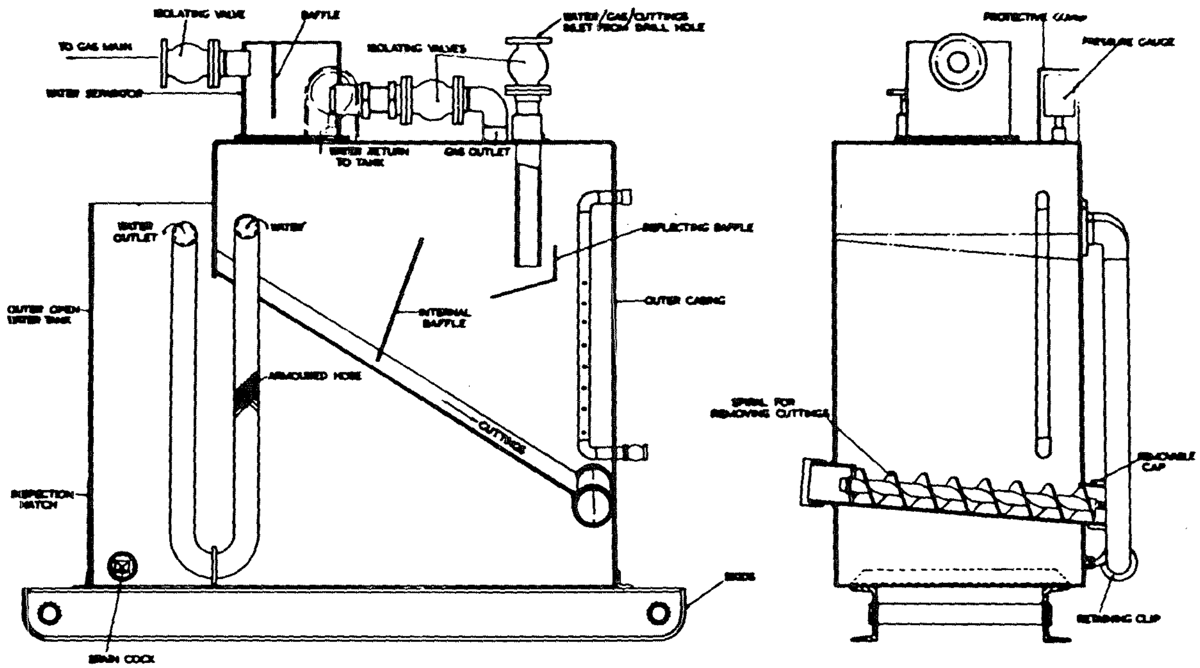
BRITISH METHANE DRILL
Fig. 2.4.

Photo
Courtesy English Drilling Eqpt.Co.
London, England.

<u>EUROPEAN DRILLS</u>

Model	Hydrack	P IV/6	DK 9/51	KD 9/68
Manufacturer	Edeco	Turmag	Hausherr	Hausherr
Motor Type	Hyd.	Air	Air	Air
H.P.	-	6	9	9
Thrust Method	Hyd.	Rac. & Pin	Screw	Screw
Thrust Mot.Type	Hyd.	Air	Air	Air
Thrust Mot. HP	-	2	4	4
RPM (No load)	680	550	160	150
Thrust tons	2.75	4	6	-
Drill type	Rot.	Rot.	Rot.	Rot.Perc.
Length-Ft.	9.25	10.5	10.0	10.0
Weight - lb.	2616	1000	900	1500
Rod. diam. - in.	2-3/8	2-1/16	2	-
Rod length - in.	60	66/48	63	-

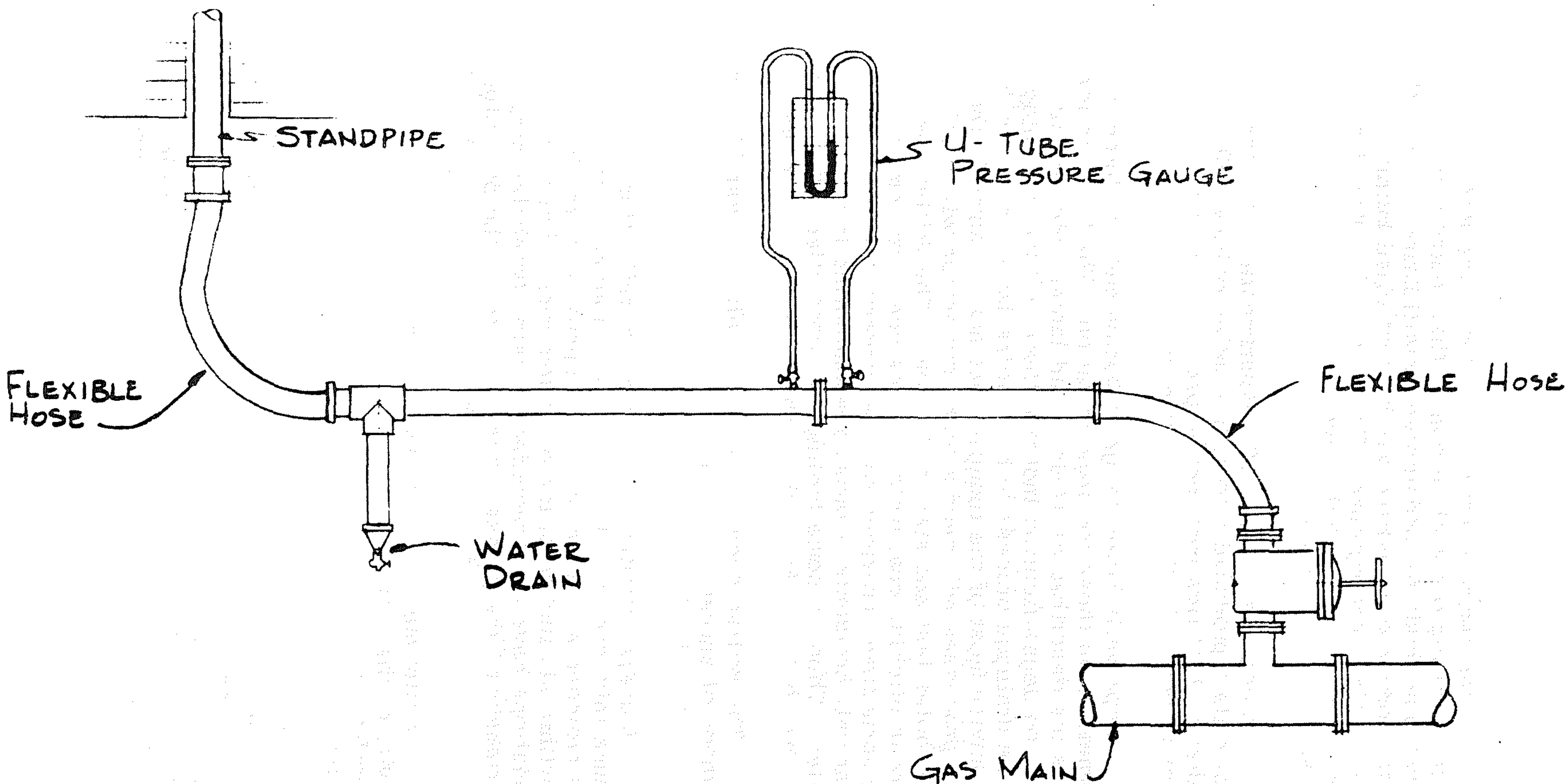
Fig. 2.5



From National Coal Board Report Ref.16 After Edeco drw

BRITISH CUTTINGS SEPARATOR

Fig. 2.6



After National Coal Board Report
Ref.16

BRITISH CONNECTION OF HOLE TO MANIFOLD

Fig. 2.7.

In the period starting about 1957, the British conducted drilling research in coal. Their purpose was to develop methods for underground gasification of coal, that is to produce combustible gas by controlled burning of coal in place underground. Techniques for Directional Control of horizontal holes over 300 feet deep were part of the purpose of this work. (Ref. 2.)

In one year's time, 185 experimental holes through coal pillars produced a total of 4 miles of hole. Electric hydraulic test rigs were developed which provided variations in power for thrust and rotation.

Apparently holes for gasification must be larger in diameter than those for degasification. The holes in these tests are described as 14-inch and larger, whereas limited tests on degasification indicate there is little advantage in the drainage process to have holes larger than 3 inches. Otherwise most of the requirements are the same in that both processes will need a technique which will produce deep holes fast and stay in the coal. The British tests were in pitching coal which causes some problems and at the same time, provides some advantages over drilling in relatively horizontal seams, predominating in the United States. There is some feeling that controlled lateral deviation may be more desirable in the degasification process.

The British spent considerable effort in establishing methods of surveying hole direction without the time-consuming operation of pulling drill rods.

A gieger counter measurement of reflections of gamma rays from an iridium source, injected in the hole, has provided an indication of the approach of the bore hole to within six inches of top or bottom rock. Slight vertical deviations have been recorded in rising boreholes simply by measuring the pressure head of water in the drill pipe and comparing this to what it should be for a straight hole.

A third method described is to measure specific gravity of the cuttings. These are compared to a chart of specific gravities made earlier, of coal from various vertical sections of the seam.

Either of these techniques is striving for more vertical direction accuracy than may be required in the United States methane drainage technology of the near future. The water head measurement would not work in flat seams with slight undulations. There is evidence drill bits will deflect back into the seam from hard top or bottom, especially when a rather flexible drill rod with satisfactory radial clearance is used.

British experiments to overcome the usual tendency of a bit to drill downward, at great depths, should be examined in the United States program. One of these is to have a three-longitudinal fingered wedge just back of the bit. The flat lying drill rod behind this wedge naturally sags, and using the wedge as a fulcrum, urges the bit into an upward attitude.

Directing the bit to a more declining attitude can be accomplished by cutting a groove in the bottom of the hole behind the bit. Such a groove can be cut by radially mounted cutters on the drill rod at a point where the pipe rests on bottom. The pipe is worked in and out of the hole at the desired location until the downward bit direction is achieved.

An interesting observation is made on one cause of accelerating a change of direction when such a change has been induced. A hole curved sufficiently to cause a bend in the rod will curve more rapidly in the same direction with increased thrust on the rod.

The British found that a "flat nosed", four finger, drag bit drilled a straighter hole than a "Rose" (apparently a pointed nose) bit.

A very brief description of line surveying instruments indicates that those used in England are similar to commercial in hole compasses described elsewhere in this report. (Fig. 2.20).

Using all of these techniques the British were able to control deviation in 260-foot deep holes to within 2 inches of target.

2.2.2 Japanese Exploratory Drills

The Japanese have described long hole rock drills used to explore ahead of the Seikan Undersea Tunnel. This approximate 25' diameter tunnel will be driven for 22.5 mi. and will be the longest transportation tunnel when completed.

The breccia, siltstones, shales, etc. to be encountered, by the Wohlmeyer Tunnel borer, is of less than 8,000 psi compressive strength. Some are almost as weak as coal. The boring machine makes 30 to 45 feet per day, for a 13 ft. pilot bore.

Some data is available on these drills (Ref. 11). The original drill, used, drilled 2,000 foot long approximately 3-inch diameter holes at a rate of slightly less than 5 feet per hour. It used a non-coring bit of unspecified type. Pictures indicate that it is a straight rotary drill with hydraulic cylinder feed. It has a chuck drive. They do not discuss cuttings removal methods.

Their reports say they now have made a 400 H.P. drill capable of drilling 16,000 feet horizontally. They do not give any underground performance figures but say surface tests produced 500 meter deep, 3.35 in. diameter holes in 56 hours. The first underground tests of the large drill were scheduled for October, 1970.

They mention Sperry Sun and Tro-Pari surveying systems. They also mention "electronic exploration" and "sonic prospecting" as methods to be tried, but give no details of any of these. They claim to have come within 8 inches of a target at the end of a 1,600 foot hole.

They are trying a Russian electric in-hole motor and a Dyna-Drill.

The new large drill is 35 feet long, 5 feet wide and 6 feet high. It has a 4-gear transmission with 1020 ft. lb. of torque with 800 rpm and 16,400 ft. lb. torque at 50 rpm. It has a 18.4 foot stroke and uses 16.5 foot long rods. It weighs 28,600 lbs.

This rig obviously is too large for U.S. coal mines. It is interesting that available drill rods are adequate for at least 1500 feet in 3-inch holes. It could be interesting to find out more about their surveying techniques and hole direction corrective measures, if any.

2.3. THE DRILLING ART

2.3.1 General

Drilling of small diameter holes of 6 inches and less in rock is done commercially by five general methods. Each of them has several sub-methods. The current commercial drilling methods are tabulated below with the major headings approximately in the order of their magnitude of use.

COMMERCIAL DRILLING METHODS

1. Rotary

   a. Blade bit (sometimes called "finger" or "fishtail")

   b. Replaceable blade bits - Figure 2.8.

   c. Diamond bit - Figure 2.9

   d. Rolling cutter bits - Figure 2.10

2. Percussion

   a. Out of hole machines - Figures 2.11

   b. In hole machines - Figures 2.12

   c. Churn drills (sometimes called "cable tools")

3. Rotary Percussion (a combination of 1 and 2)

4. Thermal

5. Hydraulic

All of the current drilling methods for small diameter holes have been tabulated on Figure 2.13. Those methods which might be affected by bit type were shown separately. In one situation, drag bits with unitized bodies and those with replaceable cutters, it was found the evaluation was unaffected and they were combined on subsequent tabular analyses.

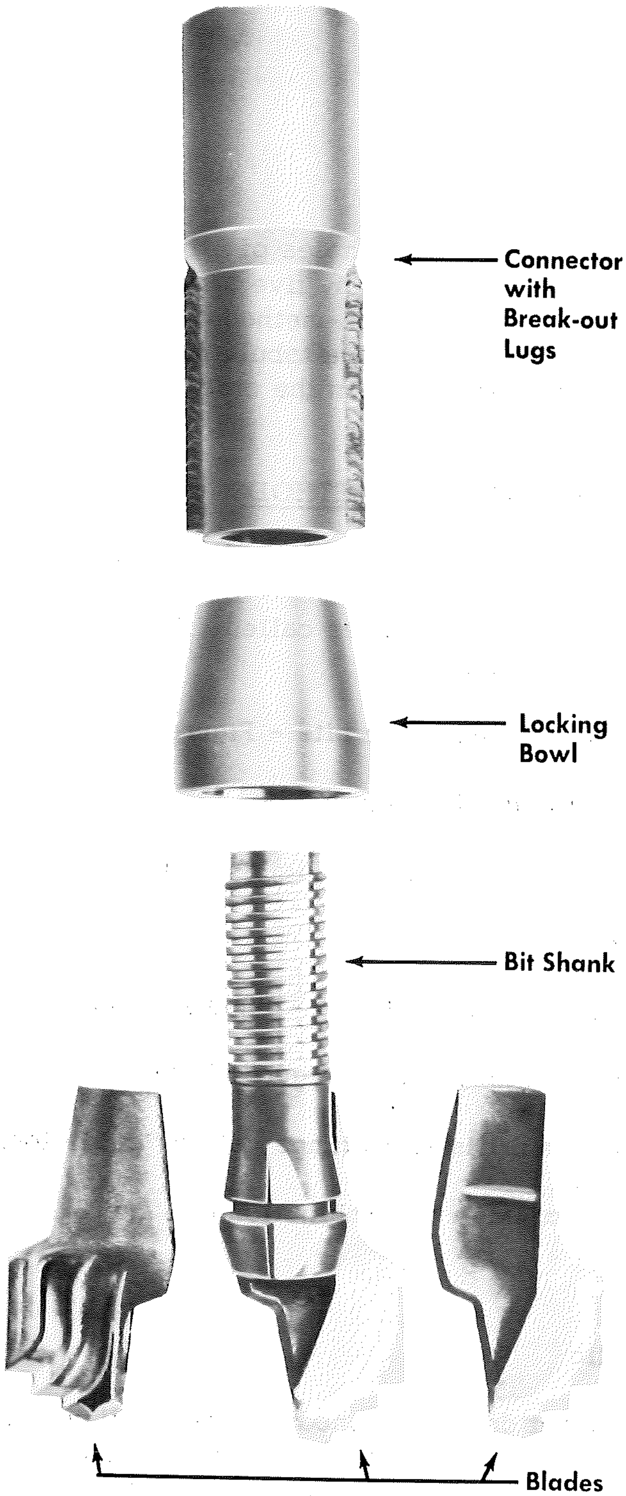


Photo
Courtesy Hughes Tool Co.
Houston, Texas

DRAG BIT - REPLACEABLE BLADES
Fig.2.8

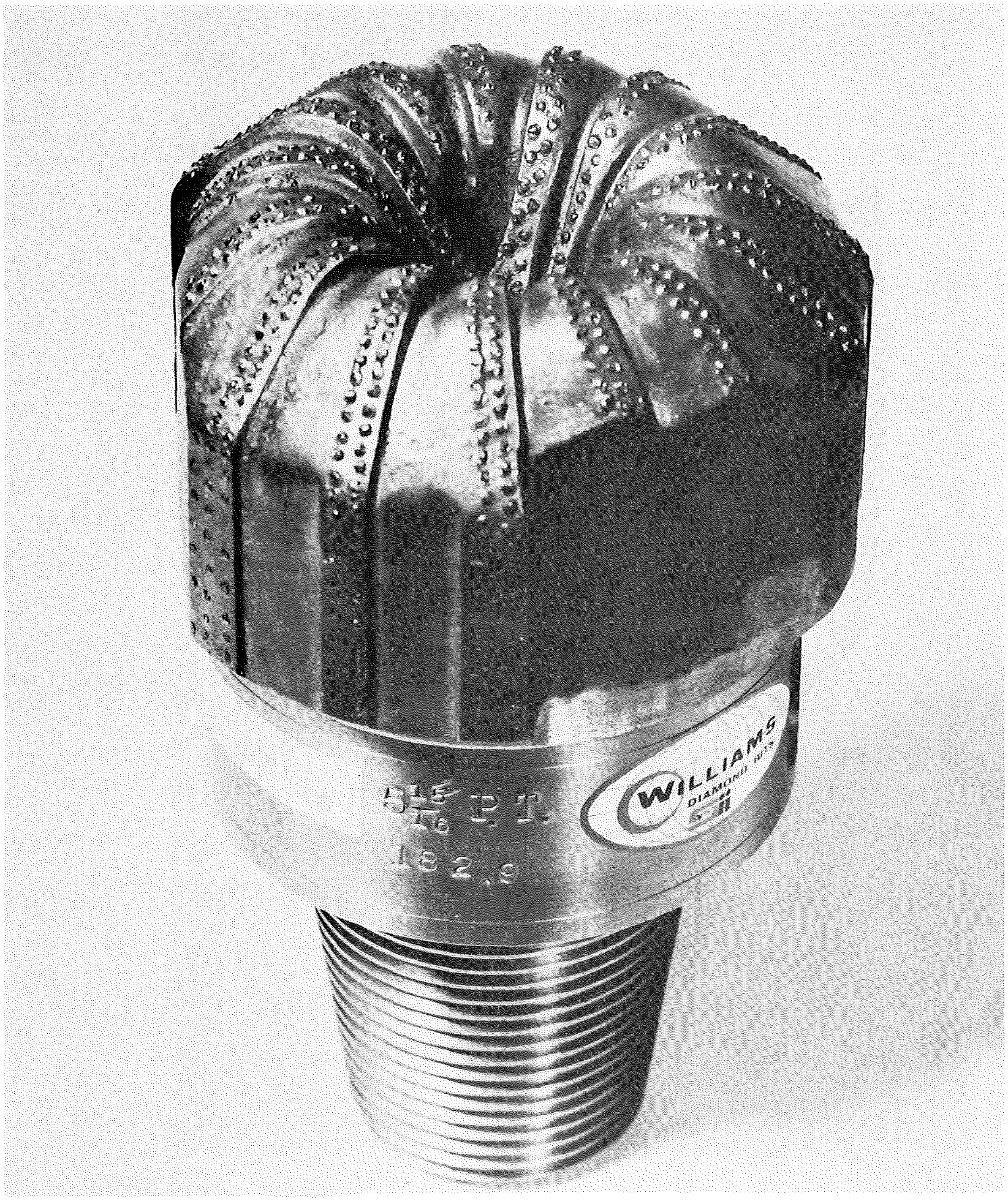


Photo
Courtesy Williams Bit & Tool Co.
Greenville, Texas

DIAMOND DRILL BIT
Fig.2.9.

Photo
Courtesy Smith Tool Co.
Compton, California

ROLLING CUTTER BIT
Fig.2.10

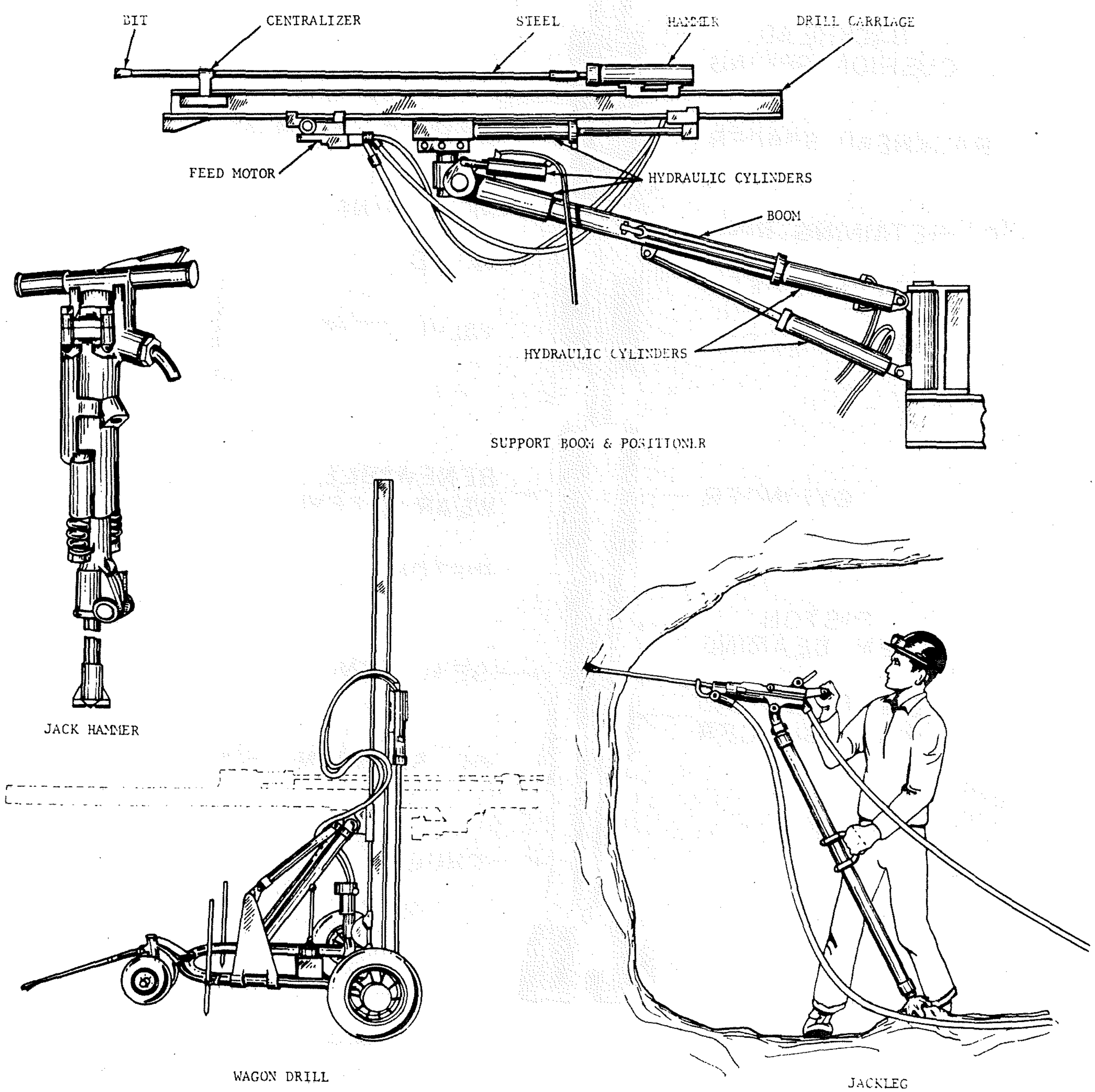


Fig.2.11 from Ref.12

OUT OF HOLE PERCUSSION TOOLS

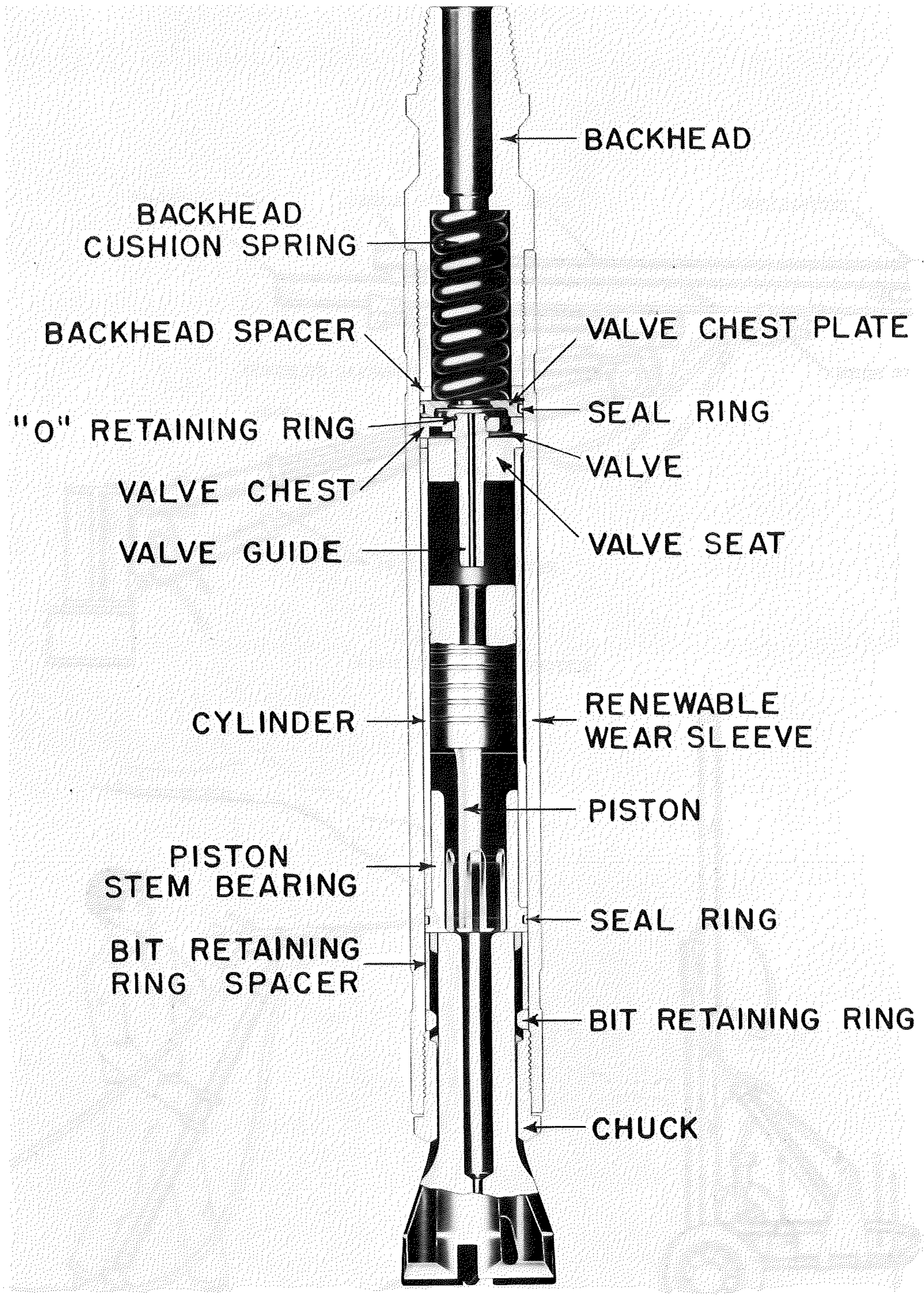


Photo
Courtesy Ingersoll Rand
New York City, N.Y.

IN-HOLE PERCUSSION
Fig.2,12

CAPABILITY OF CURRENT COMMERCIAL DRILLING TOOLS

		Compatability			
Drill Method	Bit Type	Coal Drill A	Deep Horizontal B	Environment C	Combined AxBxC = D
Rotary	Drag Unit.	10	10	10	1,000
Rotary	Drag Replaceable	10	10	10	1,000
Rotary	Rolling Cutter	6	10	10	600
Rotary	Steel Shot	2	0	10	0
Rotary	Diamond	6	10	10	600
Rotary Percussion	Rotary Percussive	10	2	10	200
Surface Percussion	Cross Type	10	2	10	200
Surface Percussion	Cyl. Insert	7	2	10	140
In-Hole Perc.	Cross	10	8	10	800
In-Hole Percussion Hydraulic	Cyl. Insert	7	8	10	560
Churn	Cable Tool	5	0	10	0
Thermal	None	2	10	0	0
Hydraulic	None	9	10	10	900
Turbine	Any Drag	10	10	10	1,000

Fig. 2.13

In Figure 2.13, an evaluation was made of the capability of the current state of the art of each system to be applied to the horizontal drilling problem. The value of 10 means most adaptable and declines to 0, which means not adaptable at all. It was assumed that for all drill methods water circulation could be provided through the tool or swivel either with or without an auger to assist in cuttings removal. Air will not be introduced into the hole because it could cause an explosive mixture with the methane.

In Figure 2.14, the best systems from Figure 2.13 were tabulated and evaluated from the standpoint of the adaptability to the mine methane drainage problem. These factors were multiplied together and the result multiplied by the current capability factor from Figure 2.13 for a combined factor of adaptability.

These same six systems were then evaluated in the table shown as Figure 2.15. This evaluation was based on the potential development of each of the systems, through research, to make an impact on the technology of horizontal drilling. Combining the sum of these factors of potential and multiplying it by the combined factors of the state of the art gives us a "combined potential" for each drilling method. From this combined potential factor and from the "research potential" factor of this table, we are able to designate certain guideline priorities for applied research and for fundamental or basic research.

It should be emphasized at this point that some 26 commonly called "novel", and occasionally called "exotic" methods of rock disintegration have been examined in detail in this study. Many of these methods involve high temperatures such as are produced by lasers, electron beams, etc. Any of these would be disastrous in the explosive atmosphere in a coal mine. Some of them deal with thermally cool methods such as pellet impingement, but are not considered applicable for the easy drilling coal, or are not adaptable, or would serve no very useful purpose to the small diameters required for the service of methane drainage.

POTENTIAL ADABILITY TO PROBLEM

OF SELECTED CURRENT DRILL METHODS FROM FIG.2.13

DRILL METHOD	Current Capability Fig.2.13 G	ADAPTABILITY TO MINE PROBLEMS-FACTORS					Combined Potential GxHxIxJxKxL ÷ 10,000 M
		Guidance H	Available Power I	Space J	Dispose Effluent K	Hole Size L	
Rotary - Drag Bit	1,000	5	7	9	10	10	3,150
Rotary Rolling Cutter	600	7	7	6	10	5	902
Rotary Diamond	600	6	7	9	10	8	1,814
Hydr. In-Hole Percussion	800	4	5	8	5	4	256
Hydraulic	900	5	6	9	4	8	785
Turbine	1,000	8	6	8	5	6	792

Fig. 2.14

RESEARCH POTENTIAL EVALUATION

POTENTIAL FACTORS

DRILL METHOD	Combined Factors of Capability & Adaptability Fig.2.14 M	Development from Present Knowledge N	Present Knowledge O	Research Potential P	Sum of Factors N + O + P Q	Combined Potential M & Q 1000 F	Research Priority	
							Applied	Basic
Rotary Drag	3150	6	6	3	15	47	1	3
Rotary Roll Cut	902	3	8	1	12	11	4	6
Rotary Diamond	1814	5	7	2	14	25	2	4
In-Hole Perc.	256	2	3	2	7	2	6	4
Hydraulic	785	1	3	5	9	7	5	2
Turbine (Motor)	792	2	4	10	16	12	3	1

Fig. 2.15

2.3.2 Drilling Methods

A. Rotary Blade Bits

Rotary with blade bits normally are used for soil and very soft formations of less than 1,000 PSI compressive strength. Coal would fall into this classification as most U.S. bituminous coal is of less than 800 PSI in unconfined compressive strength.

Rotary with blade bits is one of the oldest forms of drilling in the earth, but perhaps it is the system about which the least hard technical facts are known. There is little reliable published information on the effects of thrust and rotary speed or of bit configuration. Naturally, there is even less known about the change in combination of these parameters. Most drillers have arrived at a conclusion for operating conditions to suit their operation based on results of their own experiments.

Rotary speeds vary from about 40 to 500 RPM, but in small diameters normally are in the range of a few hundred RPM.

Thrust on the bit affects penetration rate directly. In coal drilling, thrust normally is provided to the limit of the system's ability to clean the hole or the limits of torque power of the drive motor, or both. A negative thrust or hold-back is sometimes required in cases where cuttings are removed by continuous flight augers. When these augers load up with cuttings, they propel themselves and the bit forward, frequently beyond the capacity of the rest of the system. There is very little knowledge available on the thrust requirements needed to propel, or advance, a long-horizontal-smooth walled drill stem with different diameter ratios to the wall of the hole, or in different kinds of rock and at different rotary speeds.

Blade bit designs of many configurations and with combinations of several materials are in use. The oldest one still in use is a two-finger bit of hardened steel, sometimes called a "fishtail" bit. Bits with three and four fingers with flat, pointed and stepped configurations are in use. Usually, but not always, the fingers are symetrically mounted. Most of the bits today have the wear edges of the fingers either hardfaced with cast tungsten carbide (torch applied) or, the most popular ones currently are those with sintered tungsten carbide tips brazed on the fingers. There is some very good evidence that a three-finger bit will drill a straighter hole than the two-finger configuration. There have been some reports of a flathead "plug" shaped bit in Europe, but little is known of such a shape in the United States, except for percussion drilling in hard rock.

Cuttings removal in rotary drag bit drilling is accomplished by circulating a fluid usually air or water or by continuous flight augers. The annulus velocity rate for circulation of air or water in a vertical hole has been well established by the considerable research done in vertical holes for oil well drilling. Less is known about the needs in a horizontal hole as is envisioned in this study. For example, there is no good data on the effect of the rotating drill stem in keeping cuttings in suspension where normally they would be expected to settle at a much lower velocity rate than in a vertical hole. There also is little known about the effect of the methane gas mixture with water, either as a gas or as a foam which appears to be formed by the methane with the wetting agent normally added to mine water. This foam may not form until contact with air or may be increased at that point on leaving the hole. In vertical holes, a minimum velocity of 125 feet per minute is desired to remove cuttings with clear water. The minimum annulus velocity needed for air in a vertical hole is 3,000 feet per minute. The ideal velocity is more in the order of 5,000 ft./min. The liquid velocities can be reduced somewhat if additives to the water increase its specific gravity. Limited laboratory tests indicate that the annulus velocity (the velocity between the drill pipe and the wall of the hole) in a horizontal hole may need to be three times that for a vertical hole. Empirical data with a drill stem rotating in the holes, and/or the foam effect, may reduce, substantially, the annulus velocity needs of the project under study. More needs to be known about the cuttings flow effect of a stationary non-rotating hose or pipe laying in a hole as may be required for some future drilling methods.

The use of rotary drills in the United States for deep horizontal holes have for the most part been adaptations of drills developed for other purposes. Some are driven by compressed air, some by hydraulic motors and some by internal combustion engines. Some were developed for blast hole drilling holes of a few feet or at most a few tens of feet in depth. Some have been used for horizontal exploration from tunnels or mines for minerals or water or for grouting for a few hundred of feet depth at most. There has been limited horizontal hole (small diameter) drilling by the Atomic Energy Commission for installation of instruments at the Nevada Test Site. In nearly all cases, the drilling has been done in material three to thirty times as hard or strong as coal. Most of these machines have been built from about 8 to 40 horsepower.

The horizontal earth drill made by Mobile Drill Company is representative of a family of such drills used for horizontal blast holes, drilling holes under highways and drilling water drainage holes in highway cuts (Figure 2.16). Most of these drills are powered by internal combustion engines and most remove cuttings by continuous flight augers.

Most of the existing machines were not built to operate in the confined vertical space found in most coal mines or were not designed for handling the extremely long drill stems required for deep methane drainage.

B. Rotary Diamond Bits

Most of the comments made on rotary with blade bits made in the preceding discussion would apply to rotary drilling with diamond bits. The principal difference would be in the bit configuration.

Traditionally, diamond bits have been used in formations harder or stronger than coal although they have been used to do nearly all of the vertical exploratory coal core drilling. Diamonds normally have been used for very hard rock drilling in metal mines and oil wells. They have been used for directional drilling where weights of sufficient magnitude cannot be put on a rolling cutter bit. They

Photo
Courtesy Mobile Drilling
Indianapolis, Indiana

UNDER ROAD BORER
Fig.2.16

have not been very effective in drilling open holes in coal because they provide slower drilling rates than drag or blade bits.

Recently, however, diamond bit manufacturers for the oil well drilling business, have made a concerted effort to improve the diamond bit performance in the softer formations. They have worked on such things as the shape of bit, matrix, size,orientation and projection of diamonds, and of design providing optimum conditions of fluid flow across the face of the bit. As a result, diamond bits are being accepted in some soft formation drilling which formerly was considered the domain of other drilling methods. Any research in long hole methane drainage drilling would be remiss in not taking a very careful look at the recent advances made in this field. Diamond bits would be more expensive per unit, but should last longer and could provide a wider variety of bit configurations, and formations drillable if penetration rates in coal can be increased satisfactorily.

C. Rolling Cutter Bits

Rotary drilling with rolling cutter bits is the most widely accepted method for drilling oil wells throughout the world. It has the advantage of drilling in all kinds of formations and of not losing gage or size of hole as the bit dulls as is the result to other types of rotary drilling bits. The rolling cutters, because of their geometry, present much more gage to be worn before the hole size is affected. This is important in deep oil wells, of several thousand feet, where several bits may be required to follow each other in the same size hole. Maintenance of precise gage is not as important in a methane drainage hole of about 1,000 foot depth.

In very soft formations, such as coal, rolling cutter bits will not drill as fast as a drag bit or would require a thrust of five to ten times as much to maintain comparable penetration rates. Rolling cutter bits in diameters of much less than 4-3/4 inches have never been made with very good life capabilities. Their life goes up just about as the square of the diameter from 4-3/4 to 9 inches and in the range from 6-3/4 to 9 inches they are superior to drag bits in life expectancy for most formations.

For these reasons, the rolling cutter bit does not seem to be a good candidate for research in small diameter methane drainage. This conclusion is reached in spite of the fact that more research has been conducted on this type of bit structure than any other and even though it will drill coal effectively. Limited research by the Bureau of Mines with rolling cutter bits of small diameter in coal support this adverse opinion of its capability for the task under consideration.

D. Percussion - Out of Hole Machines

The most common type of percussion drill is the pneumatic drill that does not go in the hole but pounds on one end of a drill rod on which a bit is attached to the other end. These drills are called jackhammers when hand-held and drifters, when mounted on an adjustable support. The principle of operation is the same. They are frequently classified by weight and sometimes by piston size. Again, they may be identified by method of mounting such as "wagon drills" or "stopers". They may be designed to strike 700 to 1,500 blows per minute and the energy per blow varies from 70 to 300 foot pounds. The reciprocating piston hits on an anvil connected to the drill steel. This piston has rifling incorporated in its design so that, acting through a one directional cam mechanism, it forces the drill steel holder and drill steel to rotate a fraction of a turn with each blow.

The normal bit is four point cross type, flat-faced shape with sharp sintered tungsten carbide inserts in each cross-face. A new configuration is a flat "plug" shaped face with small cylindrical sintered tungsten carbide inserts with hemispherical shaped ends protruding. Either of these bits will drill a few hundred feet of hard rock without dulling and should last several thousand feet in coal before being replaced.

Cuttings are removed by exhaust gases from the drill which are diverted into the hollow drill steel.

The lighter of these drills will consume slightly less than 100 CFM of 100 PSI air per minute and the heavier drifters will require in excess of 300 CFM.

The out of hole percussion is the most popular drill for small diameter holes in hard rock to shallow depth. It is universally used in rock blast hole drilling of holes of less than 4 inches (and sometimes 5 and 6 inches) to depths of 8 to 15 feet for hard rock mining and tunneling. It will drill the hardest rock at instantaneous penetration rates of more than two feet per minute. Production drilling rates of more than one foot per minute in hard rock tunnels are often attained. For shallow holes in coal, the drilling rate would be as fast as feed and cuttings removal could be provided and probably in excess of the three to four feet per minute now attained with rotary drills. This type of drill's difficulty in deep coal holes would be the same that it now is in holes more than 100 feet in rock, and that is that too much of the impact energy is absorbed by the drill stem and not felt by the bit. Out of the hole percussion tools are not effective and don't show much promise for drilling holes deeper than 200 feet.

There are out of the hole percussion drills driven by electric power and hydraulic mechanisms. They have the same disadvantages in deep holes.

Another disadvantage in the standard application of a pneumatic percussion tool is that the exhaust air is used to clean the hole. There is some fear, if air is used to clean a hole producing methane, that an explosive mixture could result. There is a possibility that a spark from the drill bit could ignite the mixture and cause an explosion.

E. Percussion - In Hole Machines

Beginning about 1960, research began to produce good results in field application of down-hole percussion drills. Several oil companies and their suppliers had spent a few million dollars each and about 15 years trying to develop a hydraulically operated percussion drill for down-hole use. This drill was to operate a reciprocating hammer by use of drilling mud flow. Other efforts were made, including a joint effort by a group of oil companies, to produce an electronically operated percussive device in a mud atmosphere. This work was done at

Battelle Memorial Institute. Some of these various effects were partially successful, but no mud tool lasted more than 30 hours and all of the efforts were abandoned. Some work also was done on this abroad, particularly in Belgium.

In the meantime, a few U.S. manufacturers were successful in producing a pneumatically operated down-hole percussion drill for vertical blast holes in hard rock and for drilling the surface holes in oil wells where hard rock was encountered near the surface and conventional rotary practices, requiring heavy drill collar weight, could not be applied. Most of these pneumatic tools were for holes of larger than 6 inches in diameter; were for vertical and not horizontal work; would not work in a water atmosphere; and discharged large volumes of air which would cause an explosive mixture with methane. Any one of these limitations would rule them out as far as a methane drainage drill was concerned. Researchers should not overlook the fact, however, that it may be possible to develop a hydraulically operated down-hole percussion tool but its chance of early success is less than some of the other propositions under consideration.

F. Churn Drills

Churn drills, sometimes called "cable tool rigs" are one of the oldest forms of water and oil well drilling. A heavy bit with a sharp point, a few feet long and almost the diameter of the hole, is raised a few feet and allowed to drop by gravity in a slurry filled hole. The cuttings are bailed out intermittantly. This drilling method depends on gravity and would not work in a horizontal hole. It is listed, but not considered seriously for this and several other reasons. It is slow. It makes an irregular shaped hole and is totally inappropriate for consideration.

G. In-Hole Motors

There have been many suggestions for the use of motors in the hole to provide the rotary motion to a bit. The patent literature shows many concepts of electric motors, air driven motors, and motors driven by water circulation. Those using water or mud have been advanced to the stage of wide acceptance for practical field application. An electric hole motor run on the end of a flexible drill stem has been developed by the Roy H. Cullen Research group in Houston. Several oil companies and Continental Emsco have continued this research for oil well drilling. The motor provides 30 to 1,000 RPM. The flexible pipe is a steel reinforced hose of 3-1/2 inch to 5-1/2 inch diameter. (Fig. 2.17 and 2.18) Ref. 14.

The first successful mud motor was a turbine introduced to this country from Russia in the early 1950's by Dresser Industries. This turbine drill is now being handled in the United States by Eastman Oil Well Survey Company.

One of the most popular in-hole motors is one using the positive displacement principle of the Moyno pump. It has been developed for well drilling and is distributed for that purpose by the Dyna Drill Company (Figure 2.19.)

There also is a 7-1/4 inch diameter, 80 HP, 500 RPM French tool and the Bristol-Sedley-Whittle English tool using the turbine principle.

Most of the mud motor tool's application in this country has been for directional drilling in oil wells. Bent subs can be put directionally into a non-rotating drill stem above the motor. They are used in some straight hole work, with diamond bits, where long bit runs at high RPM pay-off. Both applications are what may be called spot or limited applications but growing in popularity. The reliability of the tools has been increased tremendously over the past decade.

Of the two types of drills (that is, turbines versus positive displacement) it may be indicative of design limitations, for small hole drilling, that to date only those of the positive displacement principle have been able to make a commercial drill of less than 4-inch diameter. This may mean that only mud drills of the positive displacement type need be considered in methane drainage. Previous investigators have concluded there is little or no advantage of a hole larger than 3 inches. The possibilities of an electric motor drive should be investigated.

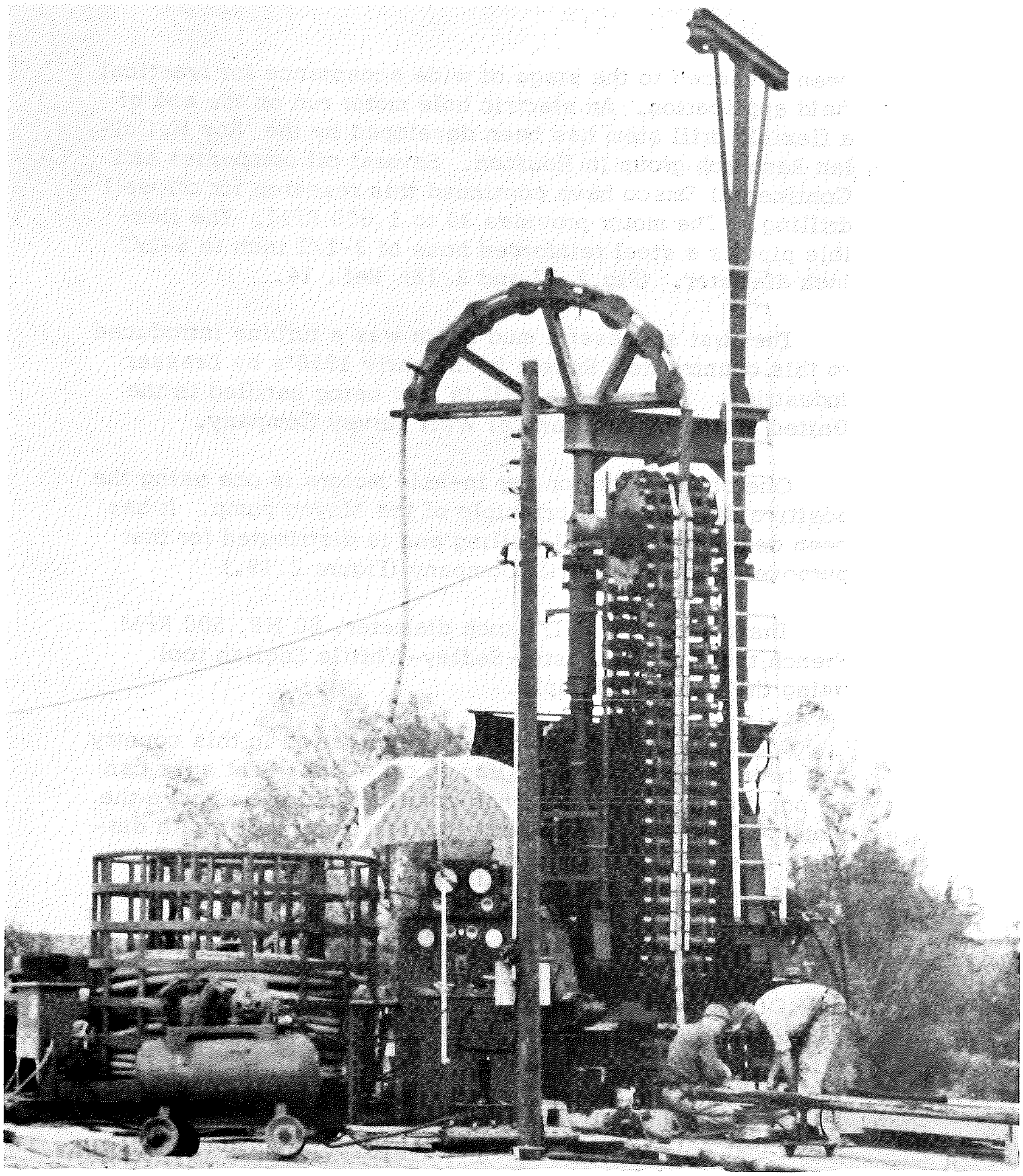


Photo
Courtesy Roy Cullen
Houston, Texas

CULLEN FLEXIBLE PIPE RIG
Fig.2.17

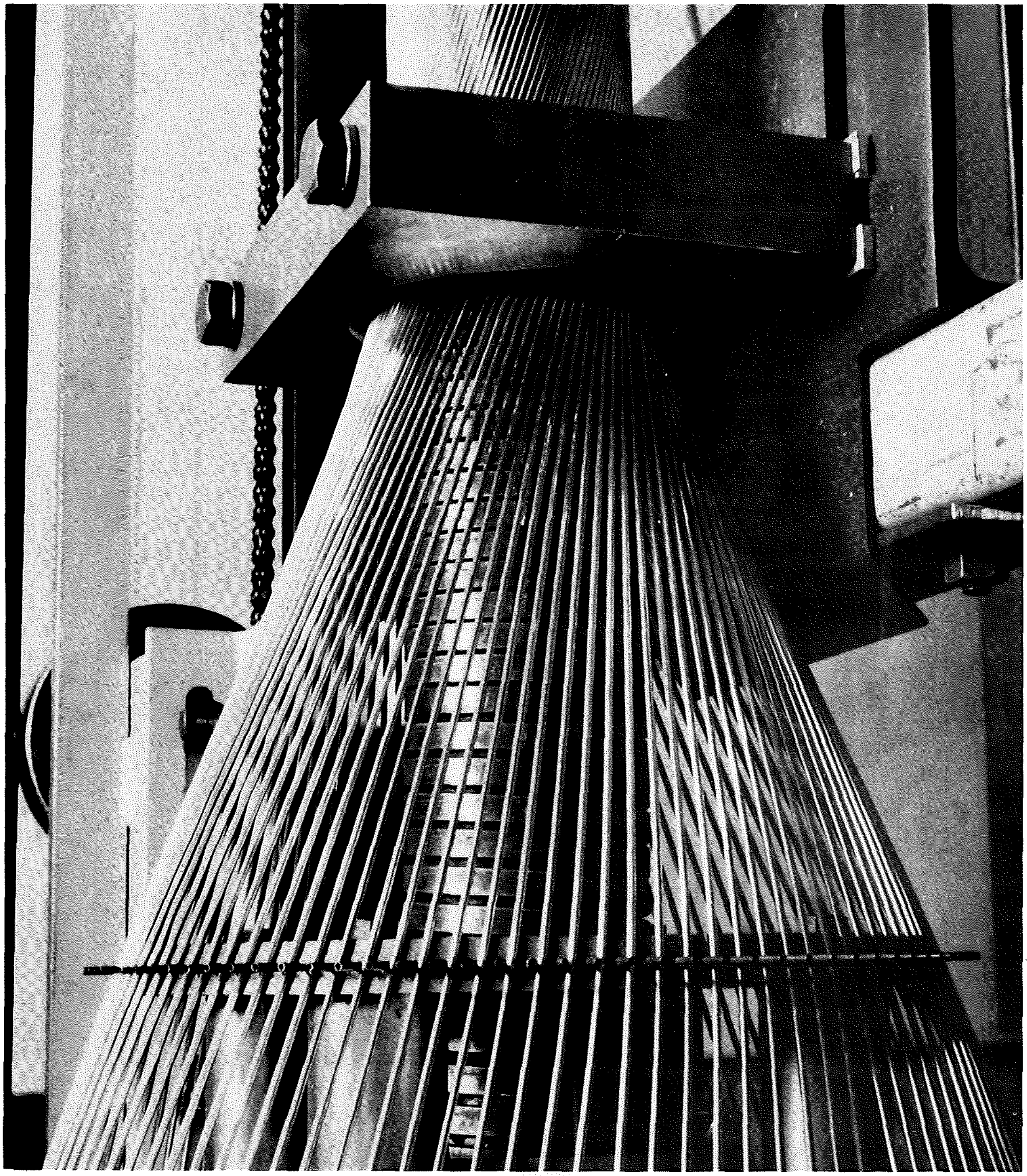
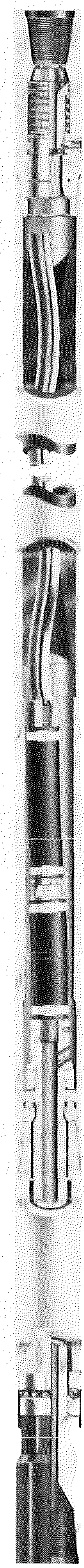


Photo
Courtesy Roy Cullen
Houston, Texas

MAKING FLEXILBE PIPE
CULLEN WIRE WRAP METHOD

Fig.2.18



IN HOLE MOTOR
Fig.2.19

Photo
Courtesy Dyna-Drill
Long Beach, California

In any event, it appears that the in-hole rotary motor is a principle, in all its types, which must be investigated in complete detail for the problem under consideration. It provides an opportunity for reduction in size of the major power package, some interesting possibilities in hole guidance, and a potential possibility of using a flexible or storable drill stem.

2.3.3 In-Hole, Non-Drilling, Devices

There are several in-hole devices in commercial application which should be considered in any research program. These include:

1. Various stabilizer (or centralizer) designs

   a. Rubber rotating
   b. Rubber non-rotating
   c. Square
   d. Spiral
   e. Straight finger
   f. Rubber - non-rotating
   g. Rolling cutter

2. Bit thruster

3. Surveying (directional) instruments

4. Hole calipers

5. Bent subs

1. Stabilizers

Stabilizers are a well recognized tool for a straight hole drilling in oil wells. Placement of stabilizers for maintaining straight holes has been given considerable high level research attention. Generally speaking, it has been found that a stabilizer right at the bit and one a stem away (or 30 feet above the first) is most effective. It is interesting that the Bureau of Mines researchers, quite independently, have found that the same methods can be applied for straight hole drilling in coal. The major differences are that in having stabilizers a stem apart, the Bureau's stabilizer spacing is 10 rather than 30 feet, but their holes and drill rod are also smaller.

Another major difference is that, in their much more limited drilling, the Bureau's investigators have not had a chance to try the many variable designs which have been available to oil well drillers. These include: different materials (rubber, steel, etc.), non-rotating stabilizers, straight blade type, spiral blade types, and those with perypheral rotating members.

In spite of the fact the Bureau's limited resources to date have allowed only one type (the straight blade type) to be fully tested, they have been extremely successful in maintaining a straight hole. As a matter of fact there is some indication they may have been too successful for some applications. When coal seams undulate vertically, there has been some tendency for the stabilized bit to go straight, which may mean into top or bottom. In these cases, stabilizers had to be removed to let the bit follow its natural tendency and "bounce" back into the softer coal seam where the hole was needed.

In-depth research is going to require a thorough investigation of all stabilizer types and placement for hole directional integrity.

2. Bit Thruster

An in-hole thruster (working on the principle of using circulating mud pressure differentials on pistons in a sub) to apply weight on or to redirect the bit has been in research at at least two facilities. They are at Drillco Company in Midland, Texas and Esso Production Research in Houston, Texas. These devices have had rather limited use in oil fields because thrust (or weight) can be obtained much easier in vertical holes simply by the usual practice of drill collars or thick-walled pipe just above the bit. In spite of the limited but successful use, in the much more severe oil well drilling environment, this technique has very intriguing possibilities in methane drainage drilling.

3. Surveying Instruments

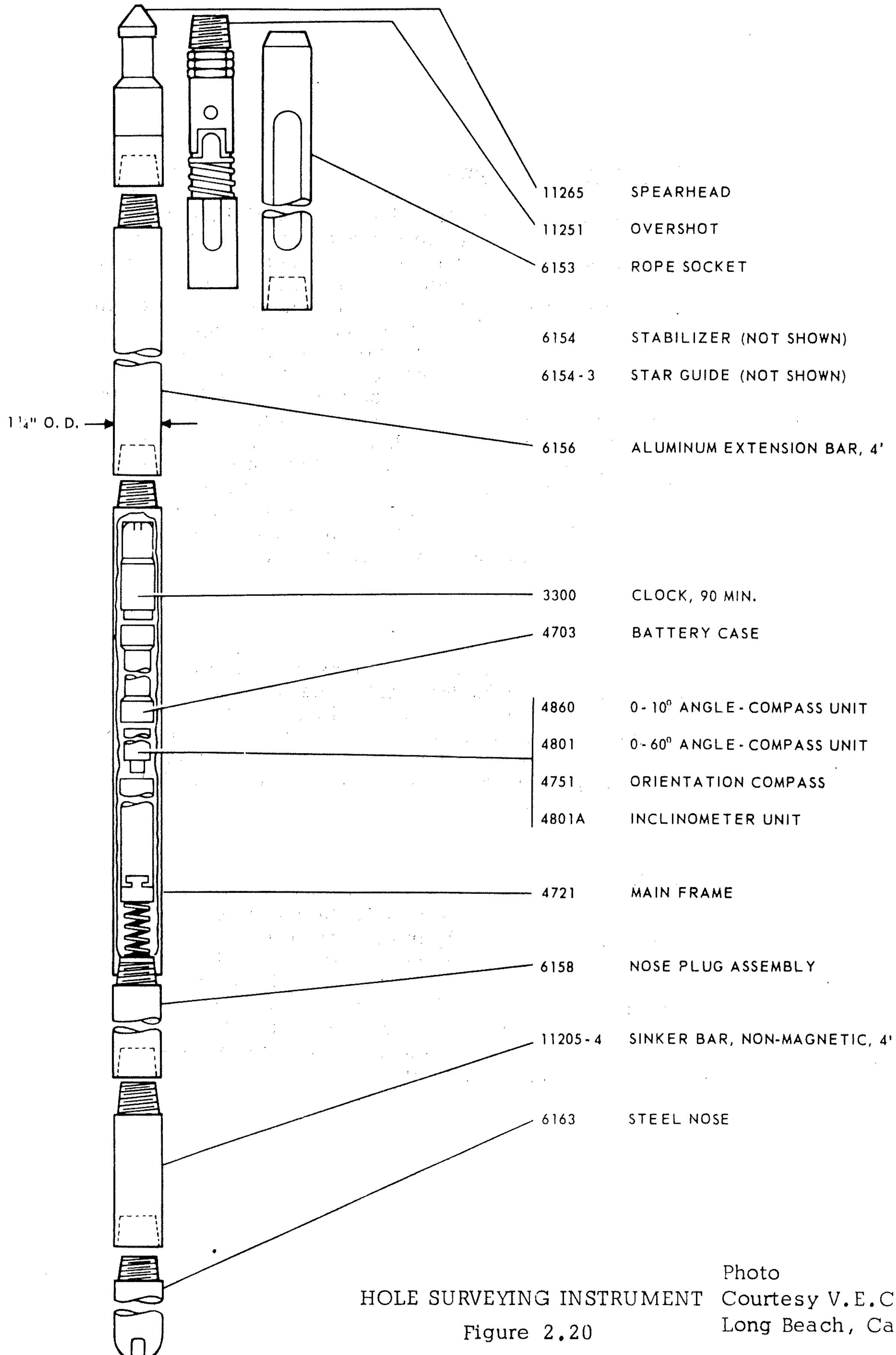
Again, in directional surveying of drilled holes, the most impressive work has been done by the oil well drilling business. In their drilled holes, normally, it is much more important to know where the bottom of the hole is than in mining, construction or water wells. There are several fine companies in the oil well surveying instrument field, but the most impressive early response to inquiries for this methane drainage problem came from the V.E. Custer Company of Box 7038 Long Beach, California 90807. This company makes a 1-3/4 inch O.D. tool which can be pumped in a horizontal hole with a piano wire attached, take a picture and be withdrawn (Figure 2.20). In any event, it appears that holes may be surveyed for direction with a slight extension to the surveying art and very little research.

4. Calipers

The need for calipers in methane drainage is primarily for the fundamental research because hole shape affects the placement of instruments. Slight deviations in hole shape has little or no effect on the rate of methane drainage. It will be quite simple to either buy or build a tool to show the profile of the wall of the hole.

5. Bent Subs

As has been mentioned, the use of the bent sub has been primarily in oil well directional drilling. It has been used with an in-hole motor such as a Dyna Drill where the drill stem back of the tool is not rotated. This seems to provide an exceptionally good opportunity to direct methane drainage holes into a desired course and should be investigated thoroughly.



HOLE SURVEYING INSTRUMENT
Figure 2.20

Photo
Courtesy V.E.Custer Co.
Long Beach, California

2.3.4 Directional Drilling Bits

The Battelle Memorial Institute has developed a bit which seeks to travel in a straight path. This work was accomplished under contract for the American Gas Association. Its purpose was to provide a method to emplace gas distribution lines in urban areas. Research was conducted on an approximately 6 inch diameter cutterhead. The goal was to maintain its deviation at less than one foot in a hundred feet of horizontal hole. Results in field laboratory work were favorable. (Bibliography Ref.1)

The automatic guidance was achieved by Battelle using a focused light beam with its source inside the pipe carrying the continuous auger flight back of the bit. The light source was 12 feet from the bit and was directed toward a photo cell mounted eccentrically or near one wall of the pipe at the bit. See Concept 28 in Section 4.

As the bit is deflected the drill stem is bent and the light fails to fall on the photocell for that part of its travel on the side toward which deflection is occurring. Through an electric circuitry, built into the bit head, this signals an hydraulic ram which extends a side cutting blade only for that part of the travel on the side of the hole to which re-direction is desired for straightening. (Fig. 2.21)

The system as developed by the AGA and Battelle has certain limitations for direct application to the methane drainage problem. It requires a dry drilling system for light and electronics and may not be explosion proof. Methane drainage holes in many cases do not need to be straight but must curve to follow the undulations of the seam.

It offers attractive possibilities for use of some of the techniques designed for the coal mine environment for programmed planned lateral hole direction changes.

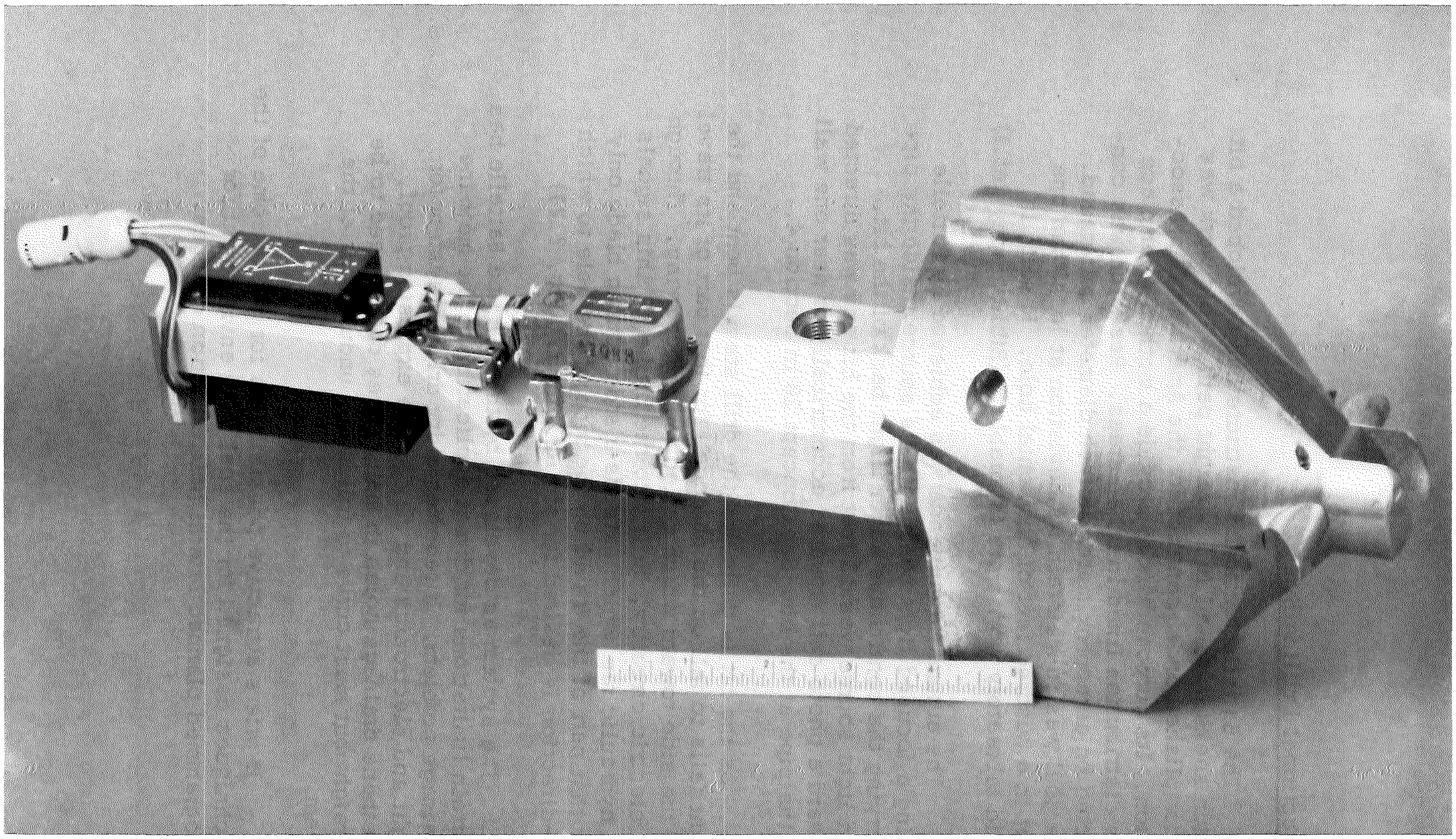


Photo
Courtesy Battelle Memorial Institute

BATTELLE BIT

Fig.2.21

2.3.5. Earth Screws

There are three developments in the United States of devices which either drive or screw themselves through soil.

The Schramm Company has an in-hole device which pneumatically drives itself through soil. It tows its own umbilical cord or air line and radially compacts the soil in its path to provide clearance for itself.

The Bell Telephone Laboratories have developed an earth screw with tapered section of three or four times its diameter. This is rotated by a steel drill rod. It radially compresses the soil as it advances pulling the rod behind it.

The Bell and the Schramm methods in their present form would not work in a material as firm as coal. The Ingersoll Rand Company has developed a rock screw in their Princeton New Jersey laboratory. The Ingersoll unit advances itself and cuts and removes the rock. It should be examined closely in this research.

2.3.6 Drill Pipe

The straight threaded hollow drill pipe used by the Bureau of Mines has been described. This EW Casing of 1-13/16 inch flush OD comes in 10-foot lengths. The straight threads require less radial space and are therefore more adaptable to the slim hole size than the faster tapered threaded connections normally used in oil and gas well rotary drilling.

Continuous flight augers will have limited application because of unreliability and high torque requirements at great depth.

Aluminum drill pipe has been fairly successful in oil well drilling tests. This pipe has to have steel threaded connections. It must be thicker walled than steel pipe to provide strength but the net weight is less. It is subject to a higher rate of erosion than steel.

Some very special pipe should be noted although it has no commercial application to date. The cullen wire wrapped flexible pipe has been mentioned. Mr. Cullen has another flexible pipe made in short joints, the connections between which can be made rigid either as the pipe is put in tension or as it is put in compression. This is revealed in Patent No.3,446,297 and Concept 32 Section 4 of this report.

The Brown Oil Tool Company of Houston, Texas has developed a flexible steel drill pipe of small diameter. This tubing of about one-inch diameter can be spooled on a coil of about 10 feet diameter.

Double walled drill pipe has been made by the Drilco Company of Midland, Texas. Its principal purpose to date is for use in sampling formations with reverse circulation to avoid contamination of the sample as it would normally move up the hole between the pipe and the hole wall.

3.0 PROBLEM DEFINITION

3.1 PURPOSE OF RESEARCH

The primary purpose of the research programs defined in this report is to improve horizontal drilling methods.

3.2 DRILLING TECHNOLOGY TODAY - HORIZONTAL HOLES

It has long been considered a possibility that the methane problem could be reduced substantially by a capability of drilling small diameter drainage holes into blocks of coal well in advance of mining. Even shallow blast holes of ten foot depth often exhaust perceptible volumes of gas.

The previously proposed horizontal hole drainage schemes generally call for drilling 3 or 4 inch diameter holes at a slight angle from the projected direction of development entries and from the outside wall of the two outside entries. This would be done only in those entries used for return air as, under existing schemes, the gas from the holes is released into the airway.

The Bureau of Mines principal efforts to date have been in the basic fundamental research field of determining the behavior of gas in the coal reservoir. This has meant that the rather novel drilling devices built by them have been directed toward drilling holes with a minimum of inconvenience to their host mining company and holes which would be receptive to instrumentation rather than as a primary purpose of drainage of the maximum amount of methane from blocks of coal of significant size in the minimum time.

Through the past research efforts the Bureau has been able to establish these conditions for the drilling of coal:

1. Holes in eastern coal seams are fairly stable and don't collapse but those of some western seams, presumable because of high weight of overburden pressure, may be rather unstable. This is even true for the more crushed (by nature) southern Appalachian seams, which are stable at some depth. None are very stable near the mouth of the hole where the coal wall has been disturbed by mining.

2. Three inch diameter holes can be drilled effectively in some bituminous coal with less than 1,000 pounds thrust, 500 rpm and a circulation of 5 to 10 gpm of clear water with a 1-13/16 inch drill rod. Perhaps 2 times as much thrust will be required to move the rods in horizontal drilling as will be required by the bit.

3. Drill rods of 1-13/16" (EW casing) type normally used for diamond core drilling are used. The rods have flush OD, and four square threads to the inch. They are satisfactory for at least 500 feet of hole. Such drill rods can be broken out by two men using a pair of 18-inch pipe wrenches.

4. Instantaneous drilling rates of 2 to 4 feet per minute are common.

5. A three-finger drag bit with tungsten carbide inserts should be good for at least 500 feet of hole in most coal seams. Such a bit will produce a smoother walled, truer diameter, hole than a two-finger drag or fishtail bit. Any blade type drag bit will drill faster than a diamond or a rolling cutter bit.

6. Eight horsepower is adequate to provide torque for the above drilling conditions at less than 500 feet, but considerably more may be required to reach 1,000 feet with conventional practices.

7. Drill rods of 500 feet length are fairly easy to withdraw, with about 1,000 pounds pull, if the rods are rotating.

8. Twenty gallons of water per minute can be an intolerable nuisance to ultimate mining if it is allowed to drain from a deep hole onto the floor. Some mine floors are more susceptible to water damage than others. Standing water is a problem regardless of floor stability.

9. Gas exuding from a hole being drilled does not interfere with a drilling operation using permissable equipment.

10. About 500 RPM appears to be an optimum rotary speed for a 3 inch bit.

11. Four men with a one-ton come-along can apply enough thrust to drill a 3 inch hole and propel 500 feet of drill rod. It is doubtful that this would be adequate for 1,000 foot deep holes.

12. Dust suppressants in the water create large volumes of foam when mixed methane.

13. One of the major drill set-up problems, with existing equipment, is dragging the usual 100 to 200 feet of air and water hose from the mine connection.

14. About 10 degrees is as small an angle that can be drilled into a coal rib from a straight ahead projection of a rib.

15. Handling long strings of drill pipe by hand is a very difficult task in coal of less than 60 inch height.

16. Drill rod threads are difficult to keep clean in a coal mine environment.

17. Stabilizers, sometimes called centralizers, near the bit tend to make the hole straight.

18. When stabilizers are removed the bit appears to deflect back into the coal seam when it might go if straight into hard bottom, or top, or slate parting.

19. No proven methods exist for surveying lateral direction changes of a bit in coal but some oil field tools look good.

20. There are no proven methods for calipering horizontal holes in coal.

21. There is very little precise information on the effects of changing drilling variable such as thrust, RPM and circulation volumes.

3.3 RESEARCH NEEDS

The goal of the research, in brief, will be to develop a compact self-contained drill which can be operated by two men. It should be capable of drilling a 3 to 6 inch diameter, 1,000 foot deep, horizontal hole in coal in 7 hours including setup and tear-down time.

Some of the things which need to be considered are:

1. Finding the best drill power mode.

2. Automation and mechanization of thrusting and retracting of tools.

3. Finding the optimum bit design for low power, high speed, directional control, hole integrity, and adequate bit life.

4. Automation of drill pipe or stem handling.

5. Self-contained power sources.

6. Effects of additives to circulation fluid.

7. Means to survey holes preferably with the tools in the hole.

8. Means to redirect the bit while drilling.

9. Optimum stuffing box design for controlling gas and water flow from the hole with minimum interference for drilling.

10. Effects on drilling and hole condition of changes in and optimum levels or combination of:

    A. Thrust
    B. RPM
    C. Diameter
    D. Fluid flow
    E. Stabilizers

11. Means to clean and reuse water.

12. Stimulating gas flow from completed holes.

4.0 RESEARCH POSSIBILITIES

This section includes a brief description of several suggestions for research. The description includes information on the goal, cost, chances of success and a summary evaluation.

The next section (Section 5) of this report deals with those ideas presented here which appear to have the greatest potential for achieving the goals of the Bureau of Mines. Some of these programs, selected for analysis in depth, are combinations of two or more of the ideas presented in summary form in this section.

Industry and literature sources have been searched for any concept which might contribute to a workable system for drilling horizontal holes rapidly. These sources included:

1. Drill component manufacturers (oil, water and mining).

2. Well drilling service companies.

3. Coal mine operators.

4. Mining exploration drillers.

The concept summary sheets used are an effort to concentrate all pertinent data for any idea on one sheet. In some cases, sketches are required in addition to that possible in the upper left-hand quarter of the summary sheet. In those cases the summary sheet shows that additional sketches follow.

The date on the summary sheet is the date the sheet was filled out and not the date of conception.

The number (No.) followed the sequence in which the sheets were filled out and has no other significance. The title and purpose of the concept are self-explanatory.

The time in months is the estimated time it would require to perform the research to achieve some meaningful results after the official start. In some cases, a two-step research program is suggested and a slant line divides the two-time intervals for each step. Normally, the second phase would not start until the first phase was completed.

Cost of research is estimated and, where there are more than one phase, the individual phase costs are divided by a slant.

The "Conclusion", "Description", and "Advantages" are self-explanatory.

"Disadvantages" in some cases indicates why the concept may not be readily applied to the problem with existing or projected knowledge. In some cases, difficulties in achieving the research goals are indicated in this space.

A list of the concepts by number and subject is shown as Figure 4.1.

INDEX TO CONCEPT SUMMARIES

Figure 4.1

CONCEPT SUMMARY

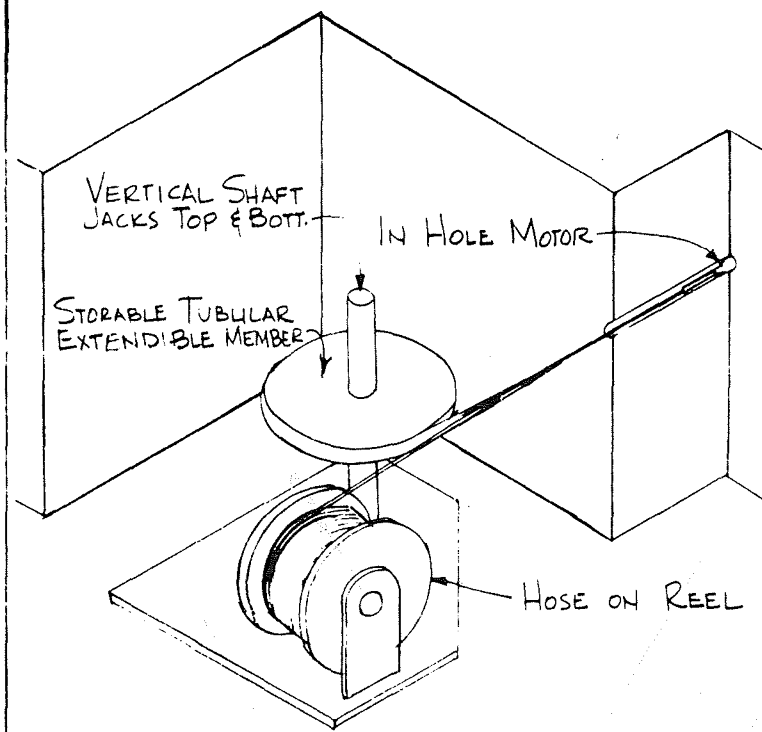
No Sketch	Date: 9-8-70 No: 1 Title: Fundamental Basic Research Purpose: Establish drill parameters for coal Time Months: 8 Cost: $70,000 Chance of Success: Good Patentability: None Conclusion: Must be done to establish a technological base for all methane drilling research. Absolutely essential Originator(s): Williamson

Description: Establish precise effects of variations in thrust, rotary speed, diameter, bit configuration, and circulation flow rates. Study variations in drilling fluid such as air, water, detergents, etc. Analyze effects of stabilizers. Tabulate data in graphs and charts for several coal seams. Attempt correlation of drillability and stability with grindability or chemical analysis.

Advantages: Essential data. Rather inexpensive (as compared to basic research in other fields). Most equipment is available, with slight modifications, to conduct the work.

Disadvantages: Test sites may be difficult to locate. No mechanical disadvantages.

CONCEPT SUMMARY



See Sketch 2 -- attached

Date: 9/8/70 No: 2

Title: Furlable Drill Steel

Purpose: Provide compact storage and handling of 1,000 ft. of drill tube

Time Months: 4/20

Cost: $15,000 / $400,000

Chance of Success: Fair

Patentability: Doubtful

Conclusion: Phase I is in conjunction with the following in-hole motor research. Phase II if justified. Prototype depends on Phase I results and results of in-hole motor studies.

Originator(s): Williamson

Description: Furlable steel can be rolled flat on spool and when released forms a tubular member. This may carry a hose and push or pull or be pulled by any in-hole drilling device not requiring torsional strength in pipe.
This technique developed by the De Havilland Corporation of Canada's SPAR Division has been proven in space applications.

Phase I: Try running turbine on end of 50' of furlable 2" steel with air or water hose enclosed. From results plan Phase II

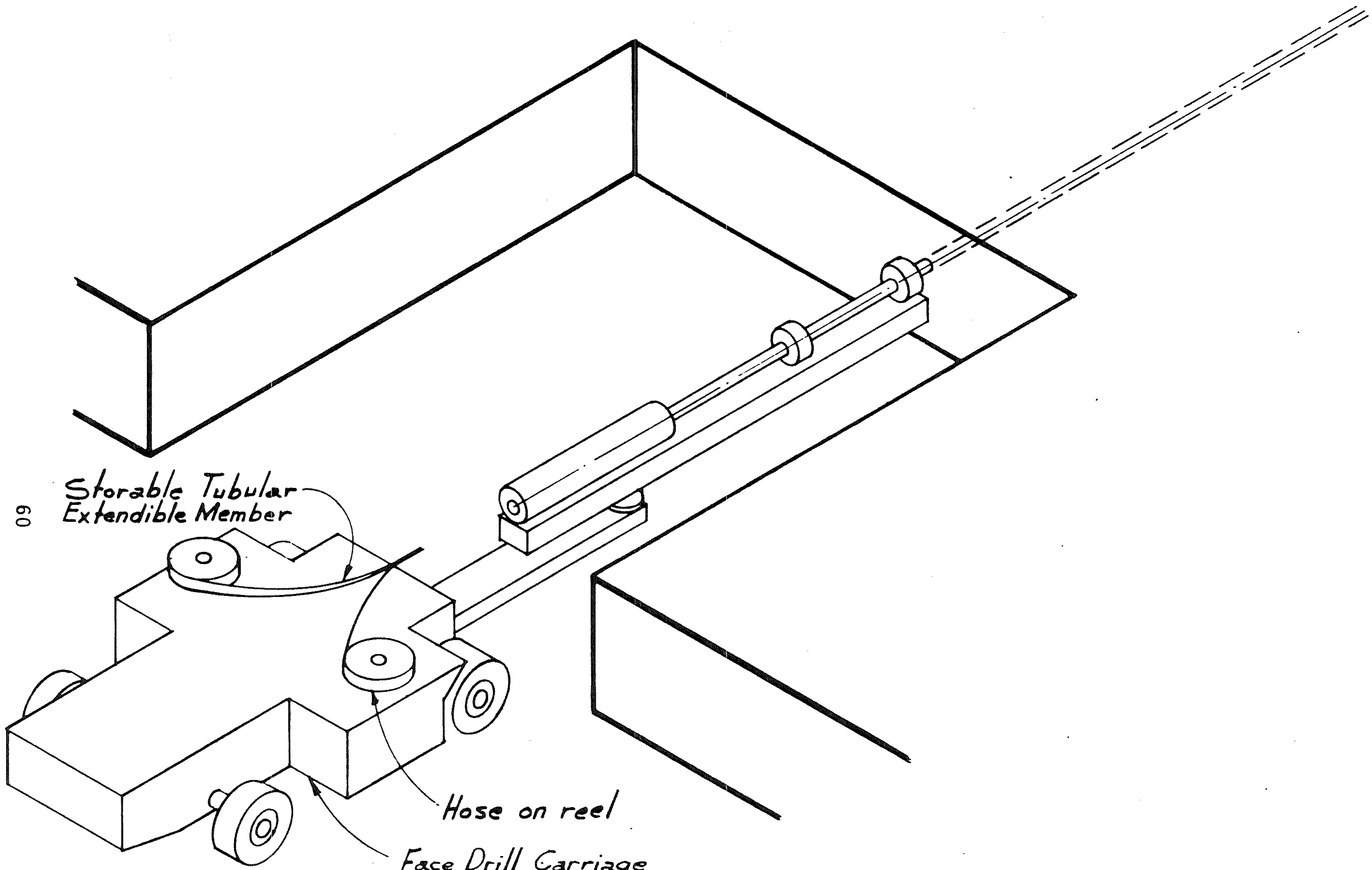
Phase II: Design and test prototype for deep hole drilling and test same for several hundred foot depths.

Advantages:

A single piece of drill rod could be stored in a reel less than one foot thick and perhaps five feet in diameter. Could be almost completely automatic saving labor, time and space.

Disadvantages:

No torsional strength, requires separate reel for hose; will require considerable development so that development cost will be extremely expensive.



SKETCH 2-a

9-8-70

CONCEPT SUMMARY

NO SKETCH	Date: 9-9-70 No: 3 Title: Auxiliary Methane Drainage Tool Purpose: Containment of gas and drill fluids Time Months: 6/18 Cost: $15,000/$60,000 Chance of Success: Excellent Patentability: Doubtful Conclusion: Equipment is essential for ultimate utilization of methane drainage but can be done combined with other programs at less expense. Originator(s): Several

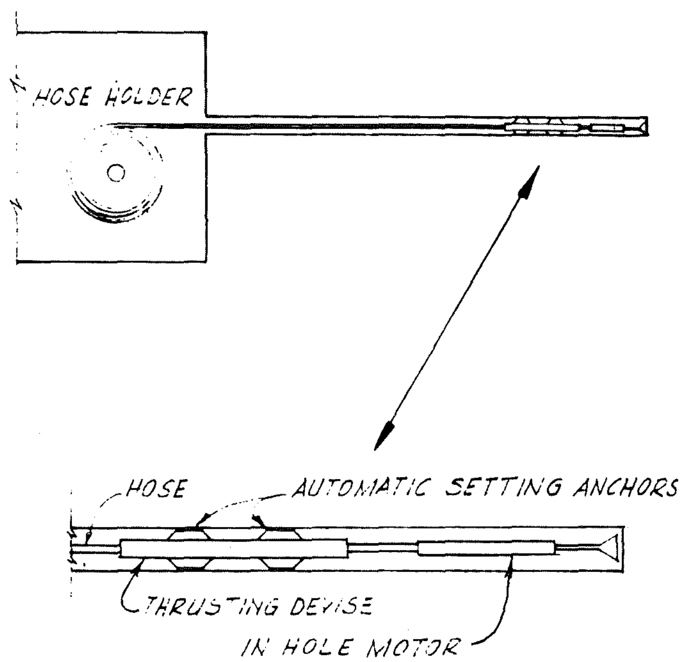
Description: Special plumbing and mechanical devices are to control methane drainage away from working areas. An oversize surface hole should be cased temporarily to permit attachment of stuffing box through which drilling will proceed to total depth. Fluids will be drained with cuttings to device which will separate water gas and cuttings for reuse or disposal.

Advantages: Protect mine environment, permit reuse of water, saves methane where usable, gives control for instrumentation and measurement.

Disadvantages:

Requires time and space.

CONCEPT SUMMARY



SEE SKETCHES 4-a AND 4-b ATTACHED

Date: 9/8/70 No: 4

Title: In-hole Thruster

Purpose: Water Pressure and flow advances bit

Time Months: 4/12

Cost: $20,000/$40,000

Chance of Success: Good

Patentability: Good

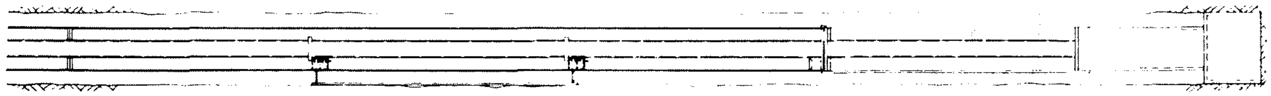
Conclusion: Preliminary tests should be conducted with modified available tools, then evaluate continuation

Originator(s): Williamson & Martinez

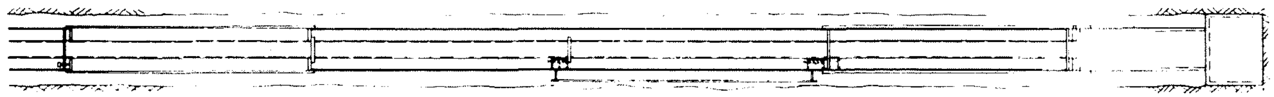
Description: A tubular piston with wall anchors will use some of drill fluid pressure and flow to push bit. This is a miniature tunneling machine.

Advantages: When used with turbine may eliminate rigid drill stem. Reduce bulk of machinery in entry. May have built-in guidance control. Some basic work has been done by others for vertical holes.

Disadvantages: Operator may lose "feel" of bit's activity. Requires starter hole (or tube). Abrasive fluids may damage many moving parts. Cyclic in operation and non-drilling time may be excessive.

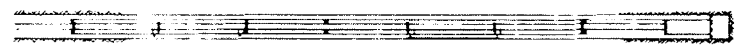


CHAMBER IN SET POSITION & TURBINE IN MAX. EXTENSION

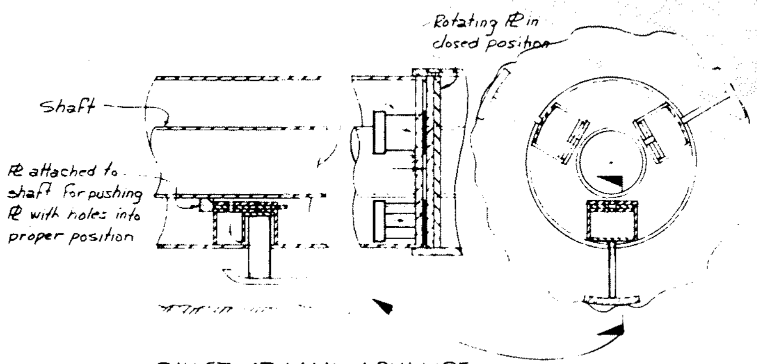


CHAMBER IN TRAVELING POSITION

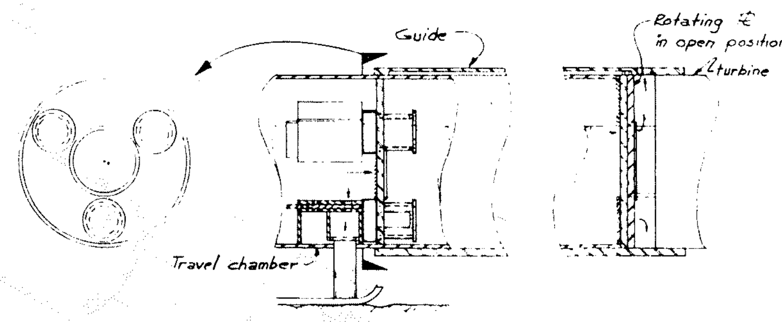
REAR CHAMBER IN SET POSITION



FRONT CHAMBER IN SET POSITION

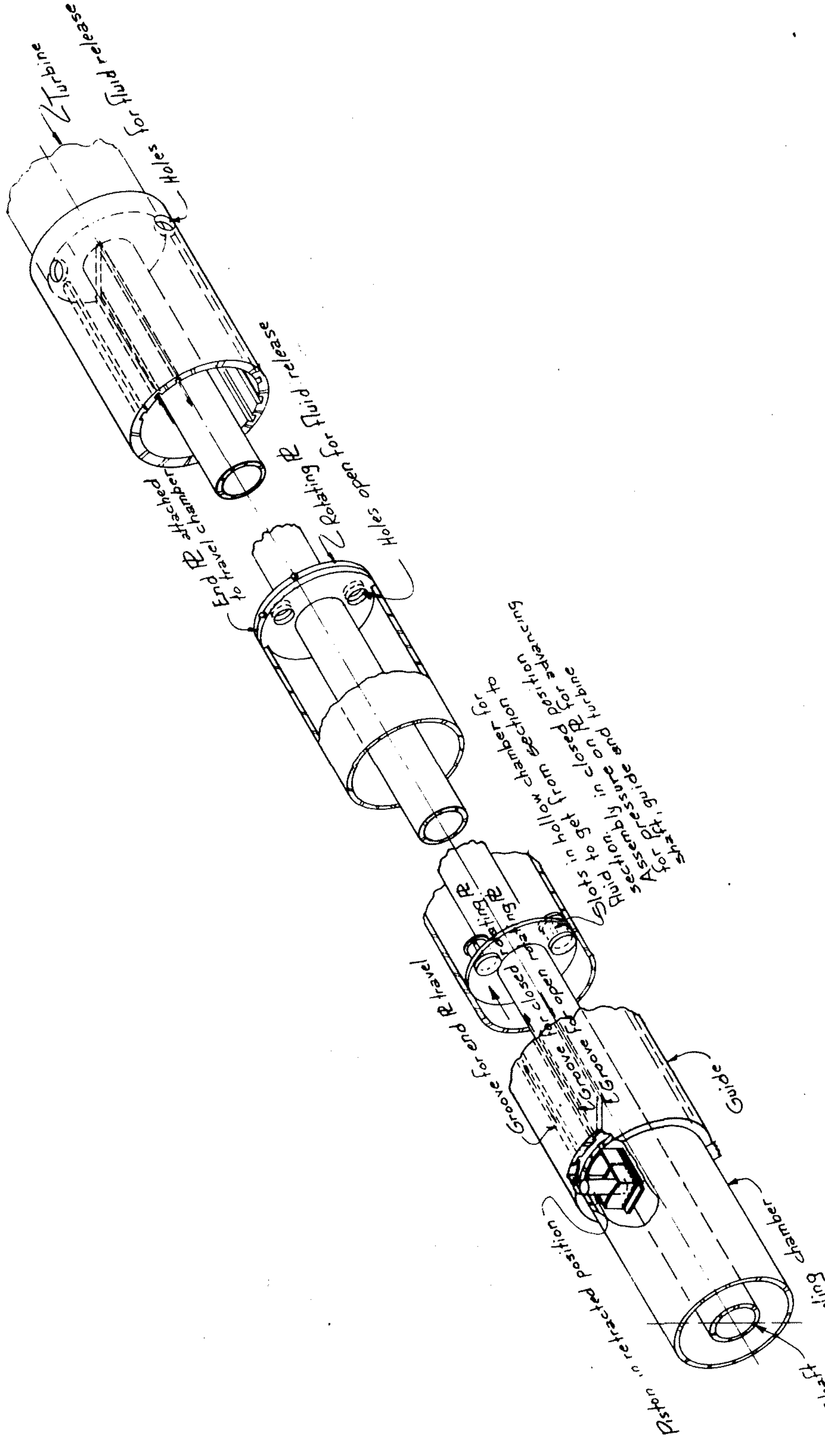


SHAFT AT MAX. ADVANCE



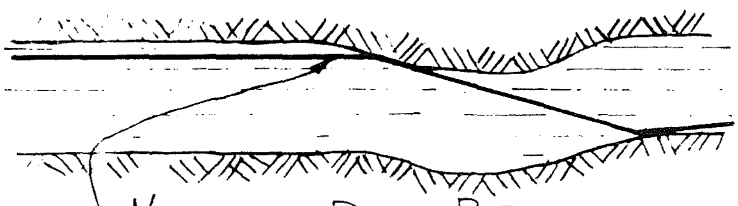
TRAVEL CHAMBER AT MAX ADVANCE

4-a


Turbine
Holes for fluid release
Holes open for fluid release
Guide
Traveling chamber
Shaft
Piston in retracted position

4-b

CONCEPT SUMMARY



— SEE 5A ATTACHED —

Date: 9/8/70 No: 5

Title: Coal Seeking Bit

Purpose: Bit to deflect from top and bottom into coal

Time Months: 3/12

Cost: $8,000/$20,000

Chance of Success: Fair

Patentability: Doubtful

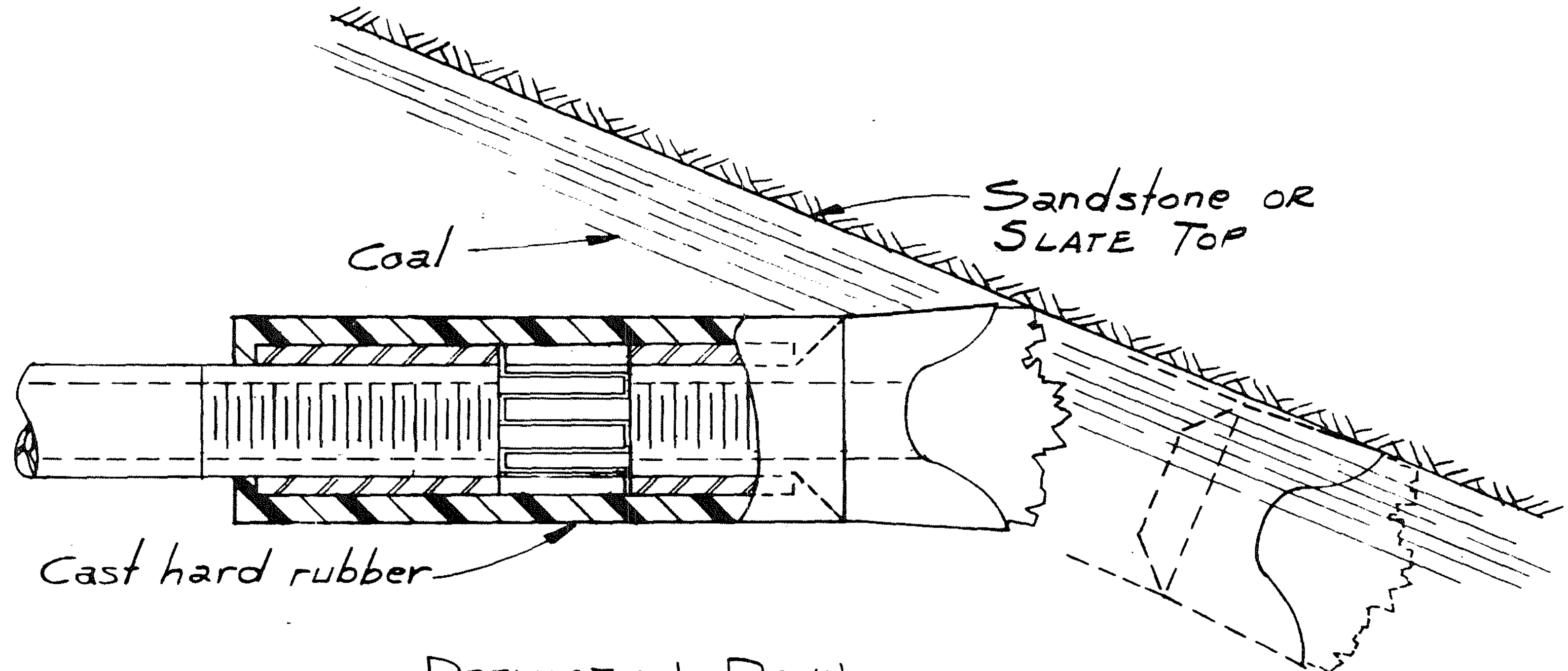
Conclusion: Miniature lab. 1st Phase - Test should be conducted, then decision made on making full scale prototype and field test

Originator(s): Williamson and Martinez

Description: Vertical undulations of coal seams will require bits which will follow coal and deflect from harder top or bottom. This may be accomplished by a semi-rigid universal joint connection at the bit, or in special attention to the bit design. This concept shows a hard rubber universal joint. Phase I Miniature Laboratory Test could use 1/4" drill in plaster of paris and concrete "sandwich". Results could provide guidelines for prototype design and test and the advisability of the larger subsequent expenditure.

Advantages: Bit should deflect from hard surface to soft. Sub would be inexpensive to build and try. Miniaturized version would be very cheap to try with 1/4" drill and plaster of paris with sandstone model of seam.

Disadvantages: Bit may be too unstable and permit excessive lateral deflection. Rubber failure could cause bit to be left and lose hole.



DEFLECTION - DOWN
DESIRABLE

5a

9-8-70
F.L. Martin

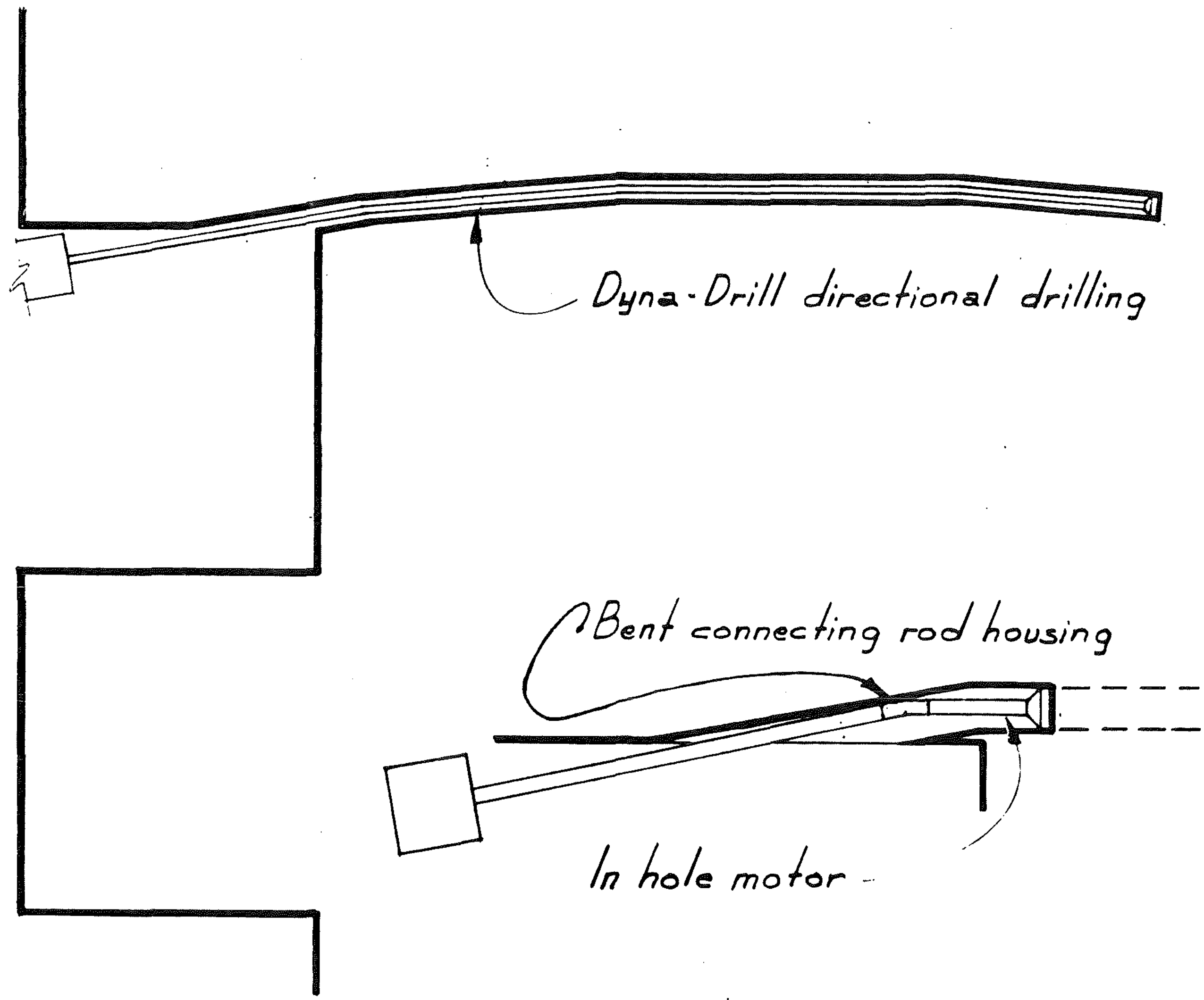
CONCEPT SUMMARY

SEE 6a ATTACHED	Date: 9-16-70 No: 6 Title: Bent Subs Purpose: Guide hole into desired direction Time Months: 4 Cost: $10,000* Chance of Success: Fair* Patentability: Poor* Conclusion: * The trial of this depends on success of in-hole motor research on which it depends Originator(s): From Oil Field Art

Description: After in-hole rotary motor has been proven then this program can start to design a bent sub to curve holes into path of projected mine operation.

Advantages: Puts hole where it is most effective - principle is proven in oil field practice.

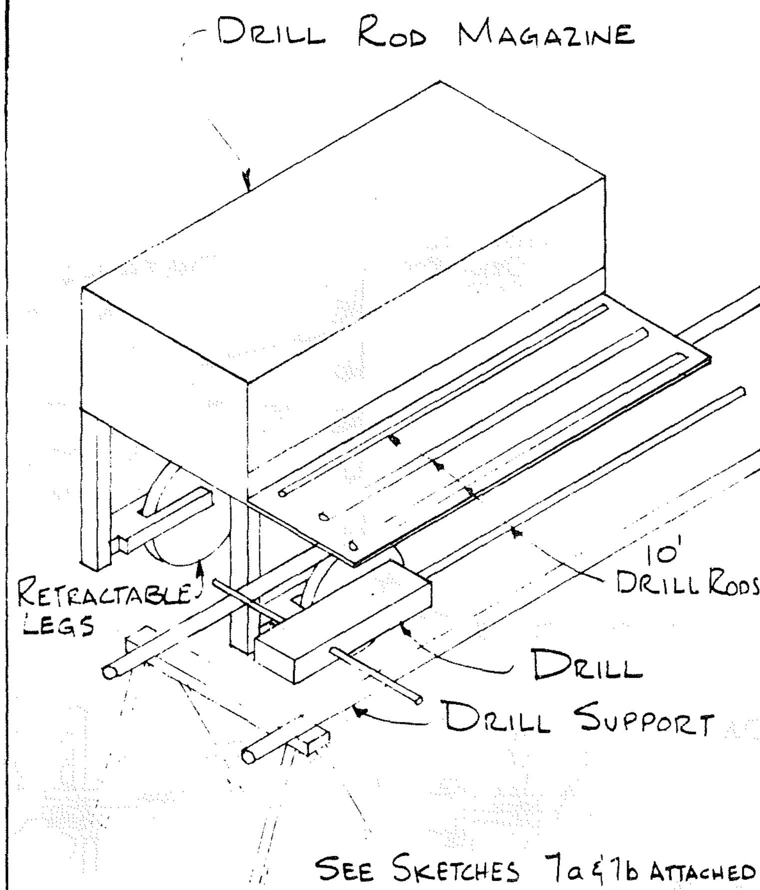
Disadvantages: Small diameter holes will keep kick off angle very small. Turbines or in-hole motors must be proven first for horizontal work in small size.


Dyna-Drill directional drilling
Bent connecting rod housing
In hole motor

6a

8-70

CONCEPT SUMMARY



Date: 9/11/70 No: 7

Title: Automatic Rod Handler

Purpose: Automated drill rod handling

Time Months: 4/12

Cost: $17,500 /$60,000

Chance of Success: Good

Patentability: Fair

Conclusion: It has a good chance of early applicability to problem. Do Phase I, then decide on II.

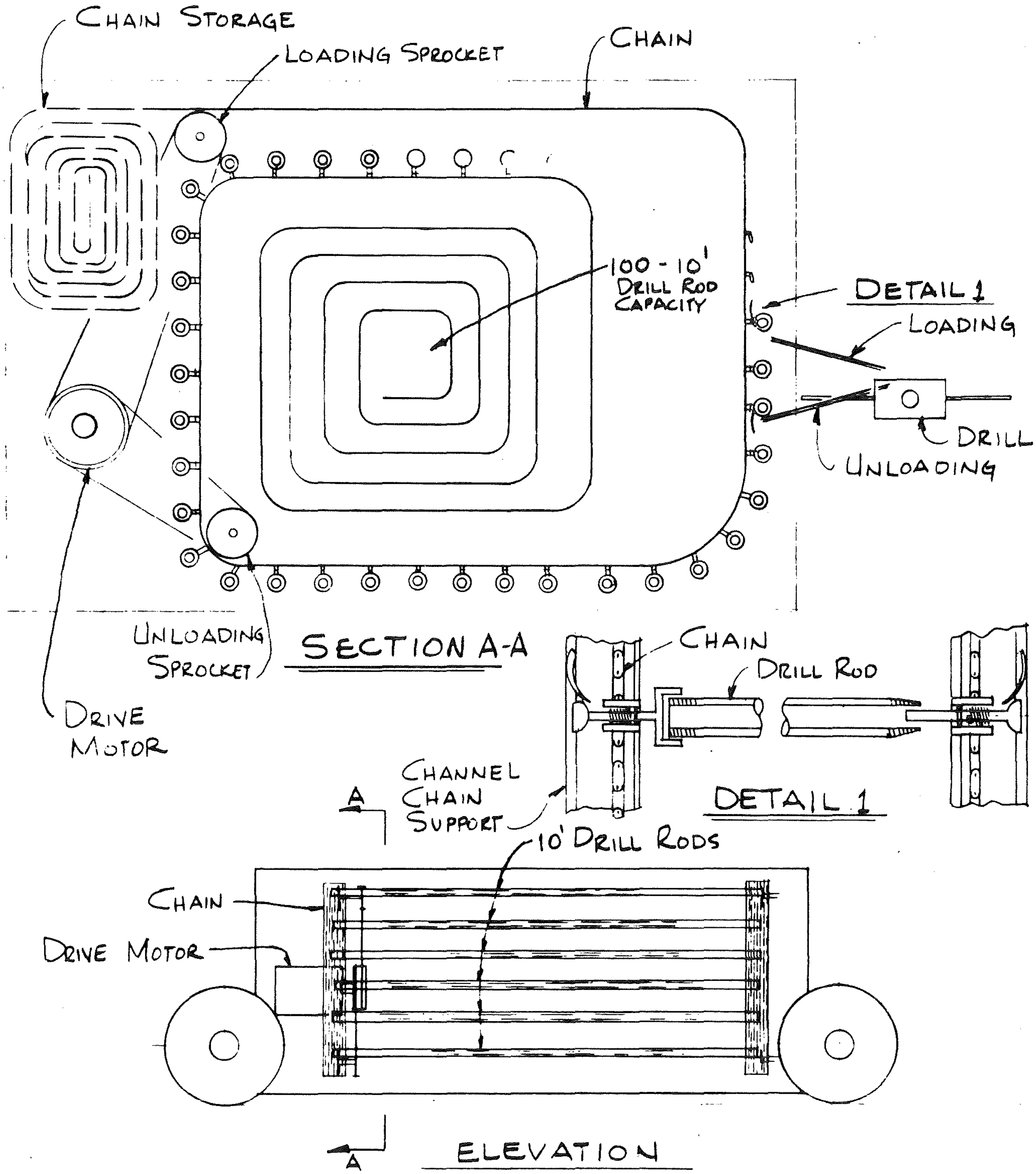
Originator(s): A. M. Petrofsky

Description: Automation of drill rod handling is essential for the application of existing techniques to deep hole drilling. The separate carriage will transport pipe to site, assist in breaking connections, deliver new rod to drill and helps thread it on. In withdrawal of tools, mechanizes removal and storage of drill rod.

Phase I - Design
Phase II - Build Prototype and Test

Advantages: Saves time, use less labor, use conventional drill pipe, keeps drill pipe out of dirt.

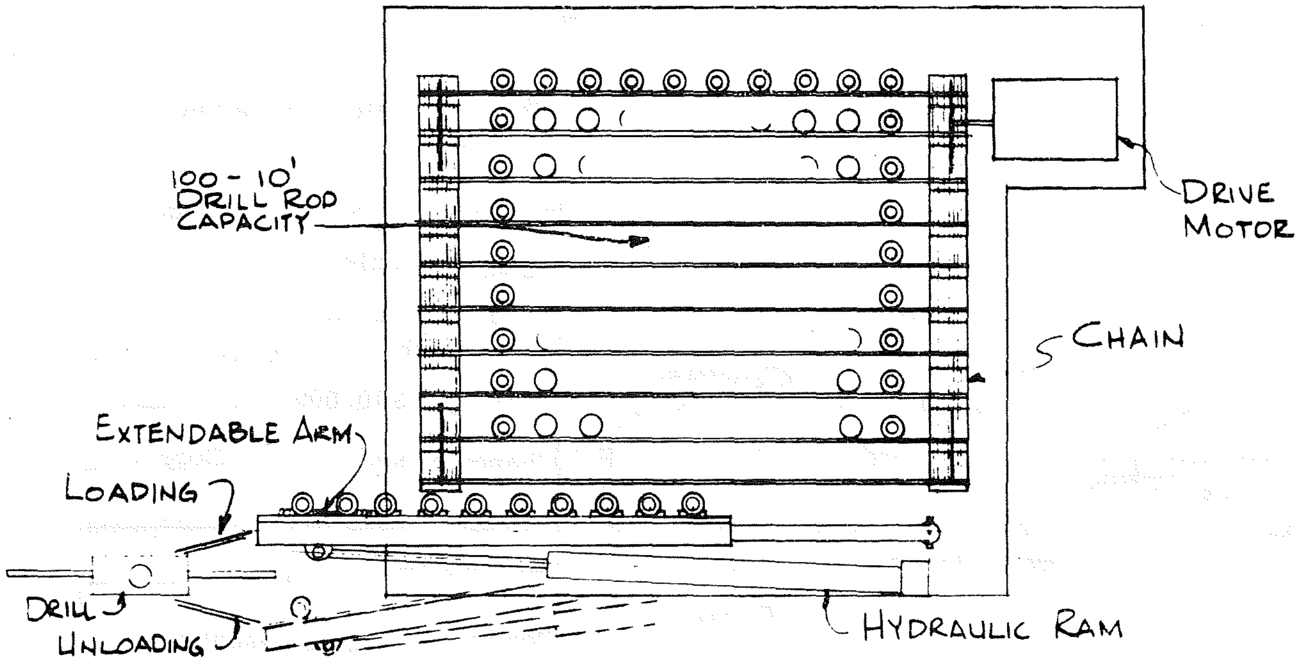
Disadvantages: Bulky, adds another piece of equipment, pipe requires more storage room than some other concepts.



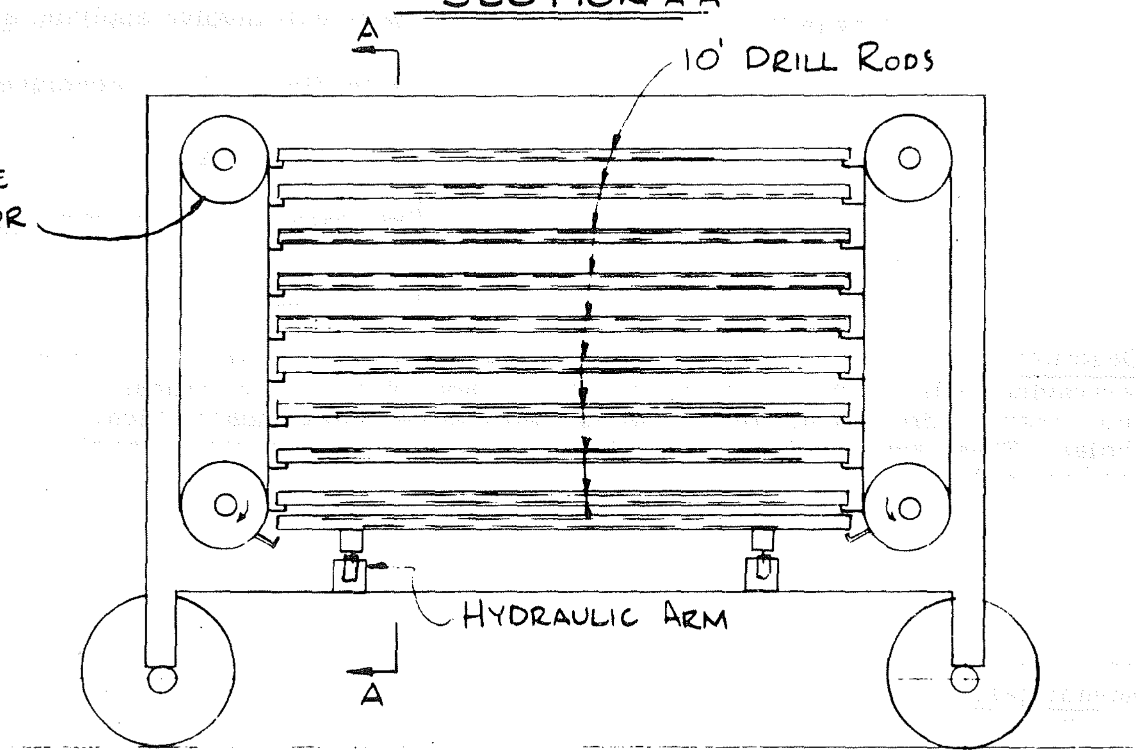
DRILL ROD MAGAZINE

SKETCH 7a

DNH
10/21/70



SECTION A-A



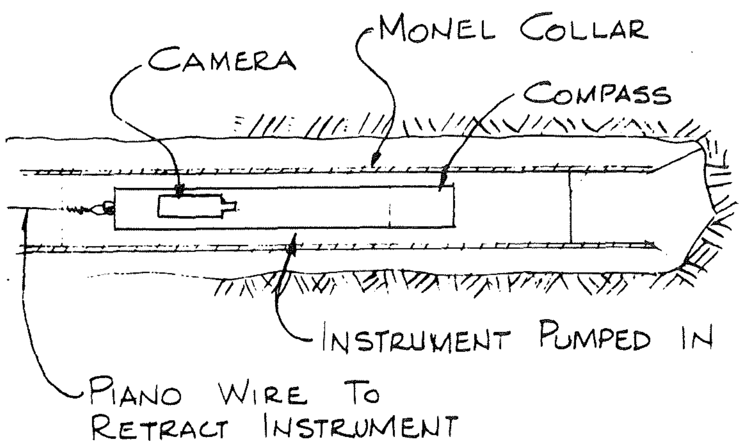
ELEVATION

DRILL ROD MAGAZINE

SKETCH 7b

A.M. PETROFSKY 10/21/70

CONCEPT SUMMARY



Date: 9/11/70 No: 8

Title: Hole Surveying

Purpose: Locate and direct holes

Time Months: 7

Cost: $30,000

Chance of Success: Good

Patentability: Poor

Conclusion: This essential work will involve applying and extending oil field techniques to coal drilling

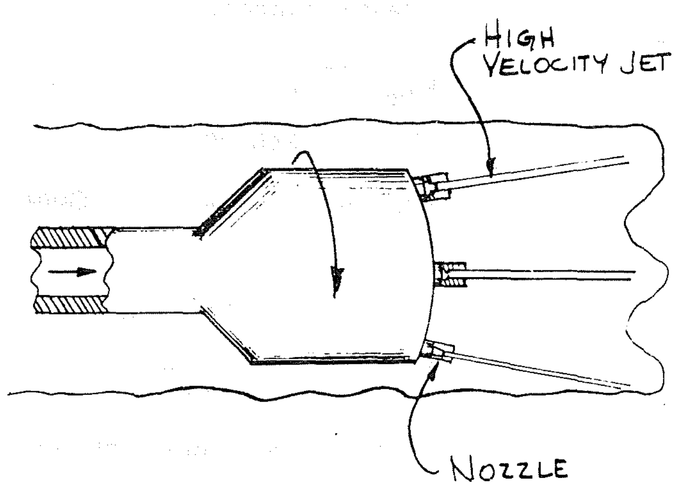
Originator(s): Several

Description: Oil well drilling service companies have perfected miniaturized surveying tools which, in effect, take one or more pictures of a compass in a non magnetic drill stem. These normally work in vertical or near vertical holes. These and such things as calipers can be converted to use in small horizontal holes.

Advantages: It's absolutely essential to the other research and development to know where the holes are and what their configuration may be.

Disadvantages: Time consuming. Electronic components may not be explosion proof.

CONCEPT SUMMARY



Date: 9/11/70 No: 9

Title: Hydraulic Drilling

Purpose: To cut coal without torque and with less thrust

Time Months: 14

Cost: $15,000

Chance of Success: Good

Patentability: Poor

Conclusion: This should be tried as it has most promise of "novel" techniques but probably not needed.

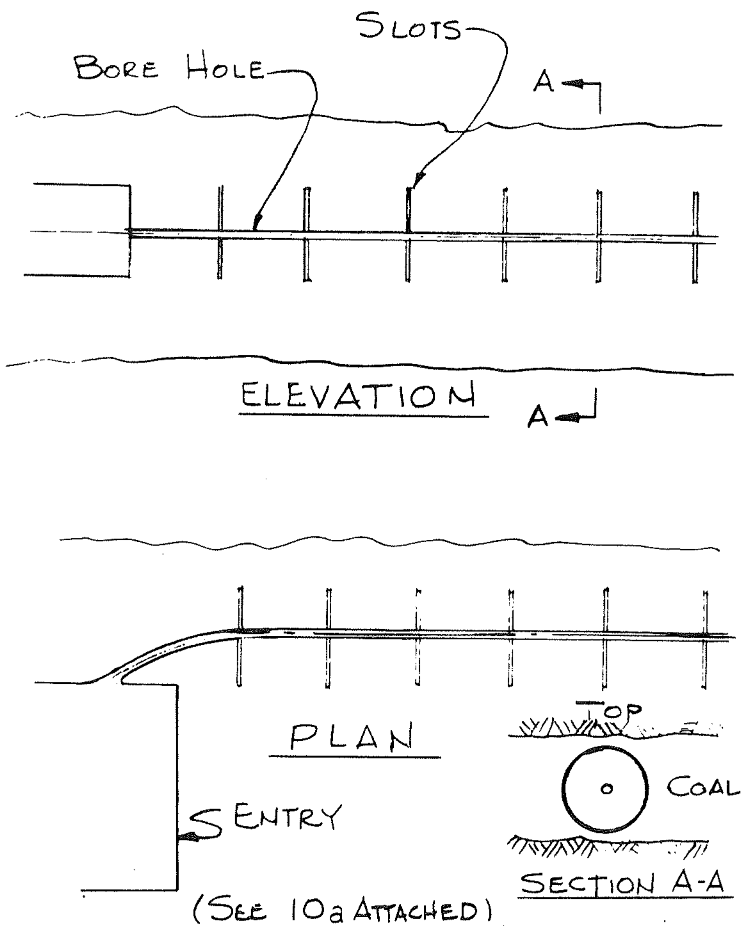
Originator(s): Several

Description: High pressure water jets will cut coal and remove all torque problems. Tests must be conducted to establish pressures and volumes as well as optimum nozzle configuration.

Advantages: No torque - No tool wear - cutting medium also removes material - may provide for elimination of pipe.

Disadvantages: Volumes of water may interfere with mining. May not drill any faster than or as fast as a drag bit.

CONCEPT SUMMARY



Date: 9/11/70 No: 10

Title: Hydraulic Jet Slotting

Purpose: Open reservoir for faster drainage

Time Months: 15

Cost: $40,000

Chance of Success: Good

Patentability: Fair

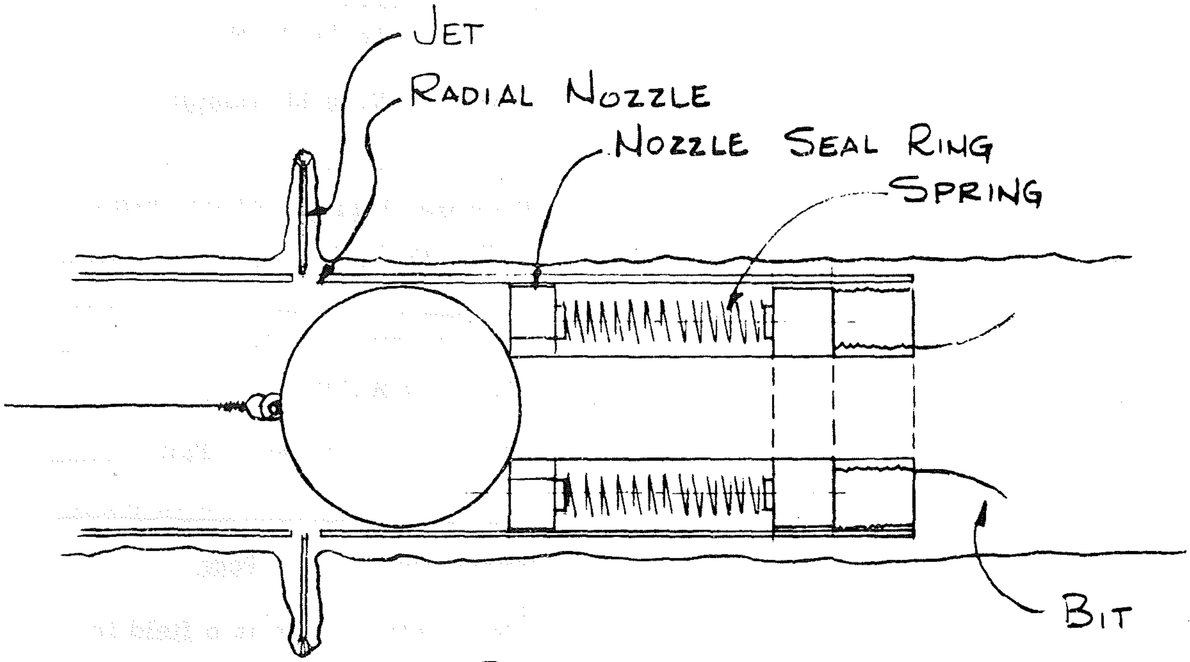
Conclusion: Reservoir channeling is desirable and this is an easy way with available materials

Originator(s): Williamson and Rudolph

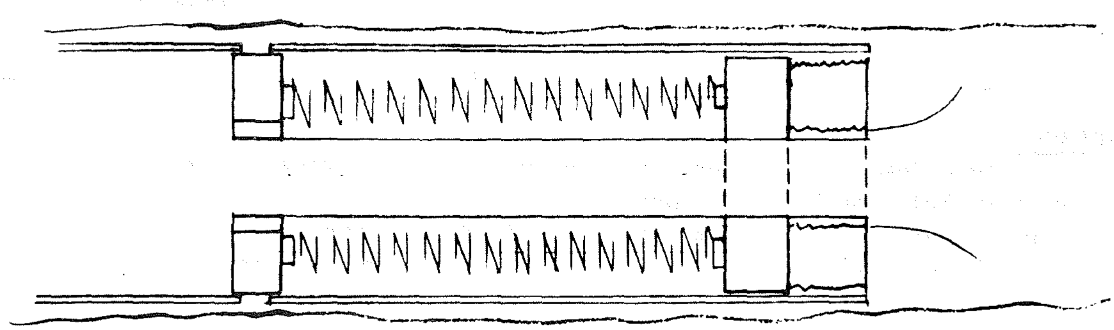
Description: Radially mounted jet nozzles will be activated by signal where desired to cut a radial slot across all the sections of a coal seam to permit gas to flow out faster. Signal device and effectiveness of jets to cut slot and effects of slots must be shown through research.

Advantages: Will provide much more effective drainage ahead of working section. It will be a fairly easy test to design and implement.

Disadvantages: Releases more water to mine. Could cause damage to roof (but this is doubtful). It may be difficult to evaluate results.



SLOTTING
ON RETREAT



DRILLING POSITION

10a

CONCEPT SUMMARY

No Sketch	Date: 9-16-70 No: 11 Title: Drag Bit Design Purpose: Improve drilling rate. Reduce torque Time Months: 12 Cost: $30,000 Chance of Success: Fair Patentability: Poor Conclusion: This is a field in which industry will carry the research burden. Suggest delayed Bureau participation Originator(s): Several

Description:

Analyze drag bit configuration to reduce torque, increase penetration rate, improve hole condition and lengthen bit life. Try different shapes (flat, plug, concave, convex and one, two and three blades)
Make theoretical analysis supported by miniature laboratory tests.

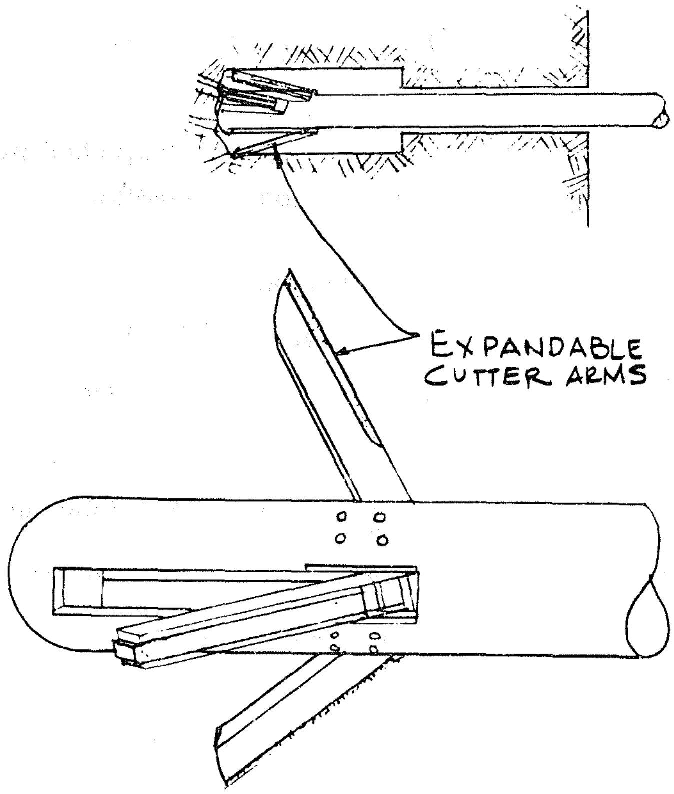
Advantages:

Reduce drill requirements and extend hole depth with existing drill stem.

Disadvantages:

This is a well-researched art by industry and chances of significant contributions at this stage are slim. When methane drainage can be proven by the Bureau industry will perform this research to gain competitive economic advantage.

CONCEPT SUMMARY



Date: 9/16/70 No: 12

Title: Mechanical Hole Opener

Purpose: Expose large coal cross section for drainage

Time Months: 7

Cost: $8,000

Chance of Success: Fair

Patentability: Poor

Conclusion: This is a most positive way to open wide sections of seam at depth at small expense.

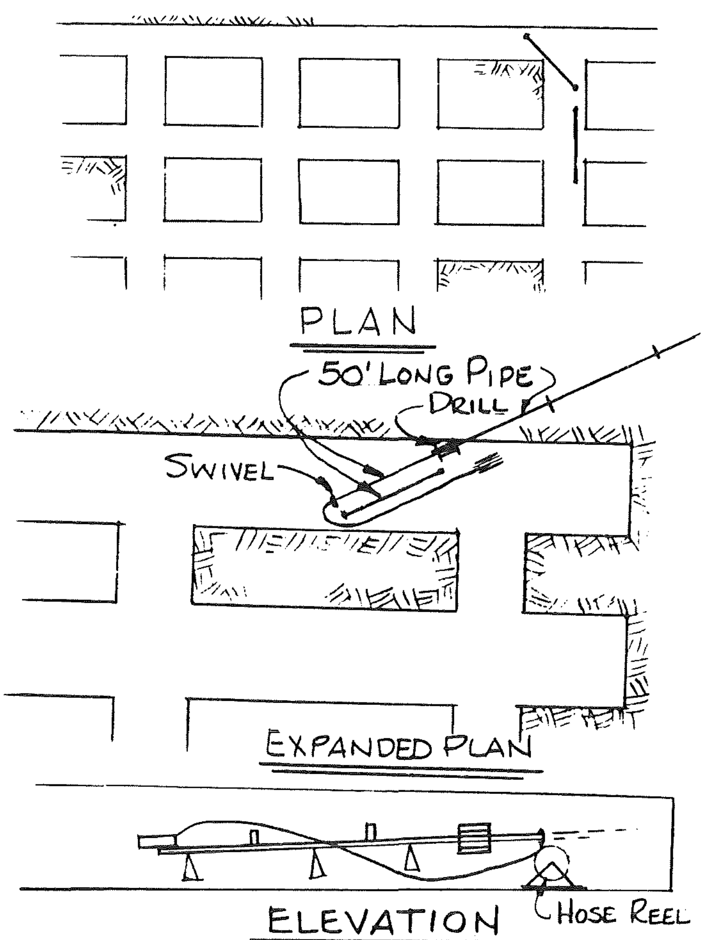
Originator(s): Williamson
Van Nolte (Servco)

Description: Minaturized version proven oil field hole openers or casing cutters can be adapted to methane drill stem. It can be activated by hydraulic pressure or mechanical leverage.

Advantages: Coal seam may have flow restricted between different layers which this would connect. General principles are proven in oil fields.

Disadvantages: May require a trip with tools; could cause stuck pipe. Tools have not been proven on this small scale or horizontally and many are activated by higher water pressure than will be available. Tools could cut into roof.

CONCEPT SUMMARY



Date: 9-17-70 No: 13

Title: Long Drill Rod

Purpose: Reduce Individual pipe connections & handling

Time Months: 6

Cost: $3,000/$10,000

Chance of Success: Good

Patentability: Poor (obvious extension of art)

Conclusion: Should proceed with Phase I

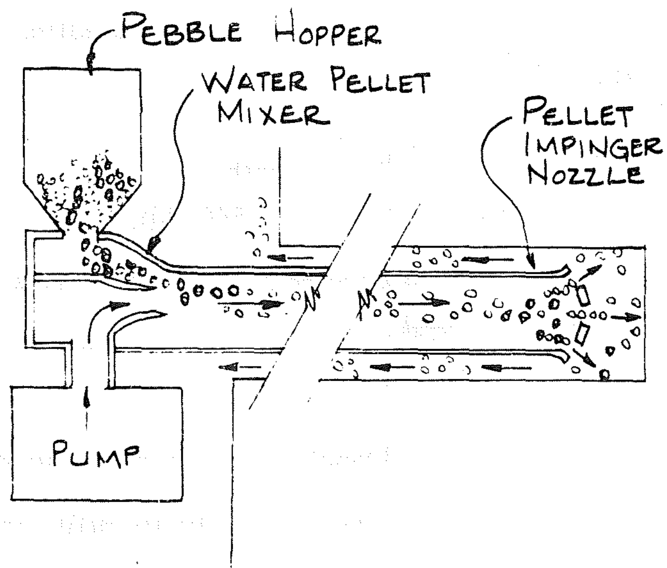
Originator(s): Daly/Williamson

Description: This concept requires a pull through drill such as the Sprague and Henwood diamond drill.
Phase I would be to design a simple guide and track for swivel and guard and guide for that pipe which is out of the hole. Also a hose handling reel to permit travel of swivel. The drill could be run in laboratory restraining forward end and 50 feet of E.W.pipe in 10 ft. sections turning free out tail end to measure restraints required.
Phase II if results of Phase I look good, proceed with Phase II

Advantages: This would reduce lost labor time in drilling of making eight out of ten connections, every 100 feet or 80 per 1000 feet at about 4 minutes per connection or 5 hours savings per hole less thread damage to connections. Pipe could be made in shorter sections of about 10 feet and 5 left coupled together.

Disadvantages: Could not be used in a mine with many timbers, because of difficulty of moving between entries - swivel connection and travel of 50 ft of hose from and to drill will be difficult - 50 ft of pipe back of drill turning at 500 rpm would be dangerous unless restrained and guarded. Cross section movement disruptive to other work.

CONCEPT SUMMARY



Date: 9-17-70 No: 14

Title: Pellet Drilling

Purpose: Improve jet penetration

Time Months: 3/8

Cost: $12,000/ $30,000

Chance of Success: Poor

Patentability: Poor

Conclusion: This is an interesting possibility but won't be needed to accomplish goal - no action recommended.

Originator(s): Williamson

Description: There is some indication in hard rock research that solid pellets impinging may be ten times as effective as water jetting.

Phase I design a system for mining quartz pebbles (large sand grains in a high pressure water circuit to impinge coal face)

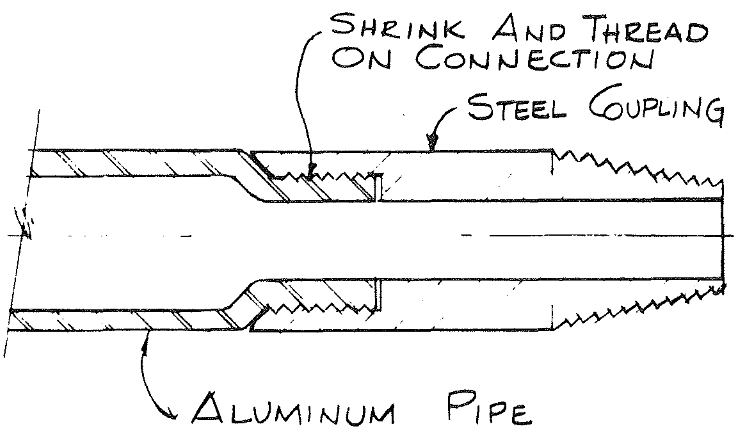
Phase II - build and test a prototype.

Advantages: Faster penetration - no torque system, compatible with bent sub hole deflection and some of flexible pipe ideas.

Disadvantages:

Requires supply of pellets and the penetration rate which could result probably would not be increased enough to justify the added expense and bother.

CONCEPT SUMMARY



Date: 9-17-70 No: 15

Title: Aluminum Drill Rod

Purpose: Ease handling of rod

Time Months: 12

Cost: $40,000

Chance of Success: Poor

Patentability: No

Conclusion: Not recommended because it limits drills and is subject to corrosion and erosion

Originator(s): Williamson

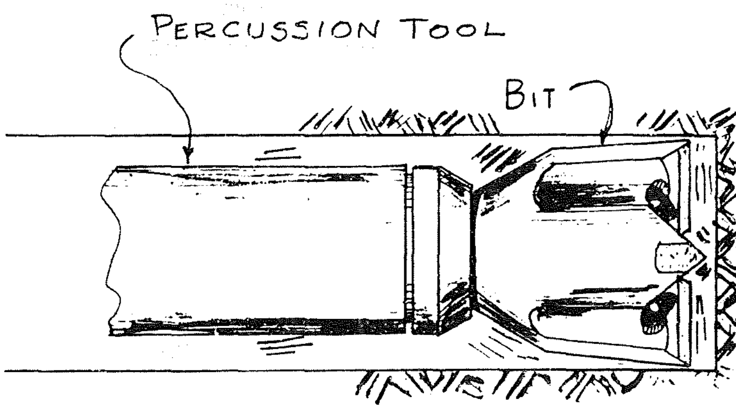
Description: Design would point toward a steel coupling shrunk on and threaded to aluminum pipe. Pipe would be larger O.D. to permit heavier wall required for strength. Weight of pipe could be reduced by as much as 30% including couplings.

Advantages:

Lighter - could help in handling longer rods, should that prove feasible.

Disadvantages: More expensive. Rods now are not too heavy in short lengths now used. Drills which grip pipe would gouge surface. Would require heavier wall section for equivalent strength and would either be detrimental to hydraulics or chance of getting stuck in hole. Corrosion and erosion.

CONCEPT SUMMARY



Date: 9-17-70 No: 16

Title: In-hole Percussion

Purpose: Faster penetration

Time Months: 6/20

Cost: $20,000/ $80,000

Chance of Success: Fair

Patentability: Poor

Conclusion: Since penetration rate is not the major problem, suggest delay of this research for more urgent needs

Originator(s): Williamson

Description: Phase I - analyze compatibility of in-hole percussive devices with hole diameter and methane environment. May consider conventional piston type actuated by air or water and mechanical or electrical devices such as those which roll bearings over bearings and electro-magnetic impulses.

Phase II - build prototype(s) and test.

Advantages: Reduction of thrust, faster drilling. Such a device can have built in rotary activator so that stem could be held stationary for guidance control.

Disadvantages: Drilling is fast enough without additional mechanical complications required. High maintenance costs. All proven methods require air which could cause explosive mixture and a spark could result from percussive action.

CONCEPT SUMMARY

No Sketch	Date: 9-17-70 No: 17 Title: Fluid Additives Purpose: Improve cuttings removal and wall support Time Months: 7 Cost: $20,000 Chance of Success: Fair Patentability: Poor Conclusion: This can be incorporated with other tests including that for fundamental research Originator(s): Williamson

Description: Analyze difference in fluid and volume flow requirements of plain water versus water with: detergents, air, bentonite etc. The effect should be gaged on cutting removal, hole stability and effect on mine environment.

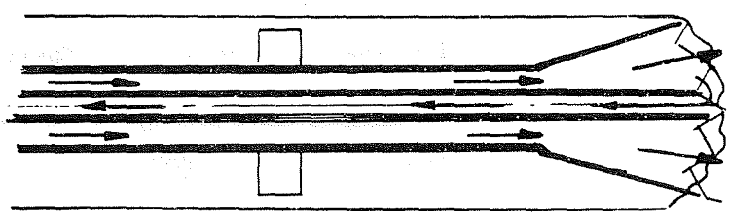
Advantages:

Use less water, keep holes from collapsing.

Disadvantages:

Expense, logistical requirements and doubt of need for advantages listed in most cases.

CONCEPT SUMMARY



Date: 9-17-70 No: 18

Title: Double Walled Pipe

Purpose: Reduce water volumes and wall erosion

Time Months: 3/12

Cost: $6,000/$35,000

Chance of Success: Poor

Patentability: Poor

Conclusion: Don't really need it at this time - no action

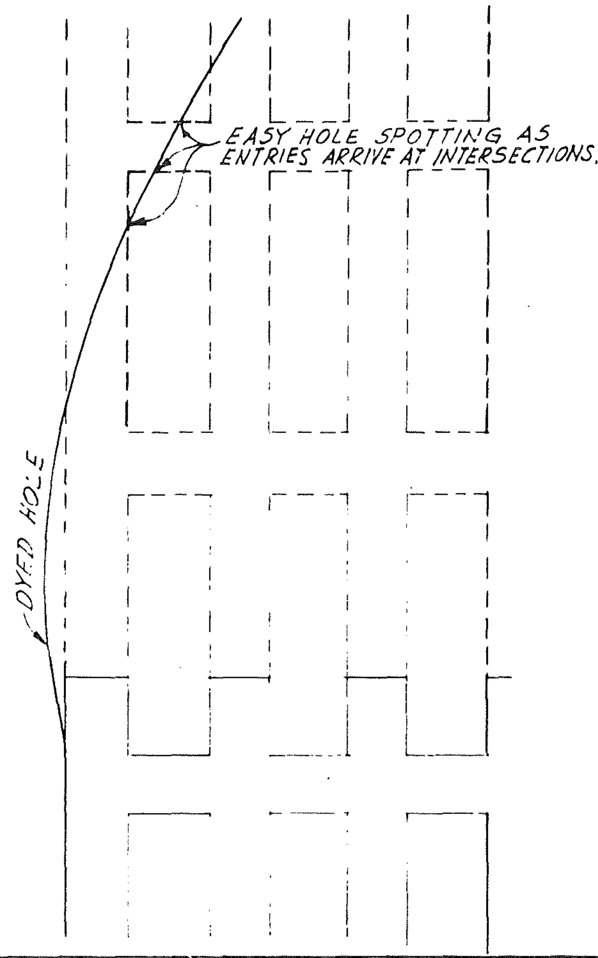
Originator(s): Williamson after Stanley Moore

Description: Double walled drill pipe has been developed by oil field drilling suppliers and has been used for vertical drilling in mine exploration for rapid uncontaminated formation samples through the central concentric drill stem. A test with this technique horizontally might provide turbulence to keep cuttings in suspension with a minimum of water flow. The first phase would be the design of a 3-inch system (3/4 inch drill rod)

Advantages: Reduce water flow requirements.

Disadvantages: Complications of drill stem. Doubtful of need as apparently drill rod turning 500 rpm in these conditions is more than adequate to remove cuttings.

CONCEPT SUMMARY



Date: 9-17-70 No: 19

Title: Hole Stainer

Purpose: Facilitate locating holes

Time Months: 3

Cost: $600 (with other tests)

Chance of Success: Good

Patentability: Poor

Conclusion: This test can be and should be run with others. No special program

Originator(s): Williamson

Description:

Inject a dye or paint in drilling fluid at completion of hole to help locate hole later when mining may cause surface hole to collapse. Dye may be of luminous material which will glow in dark.

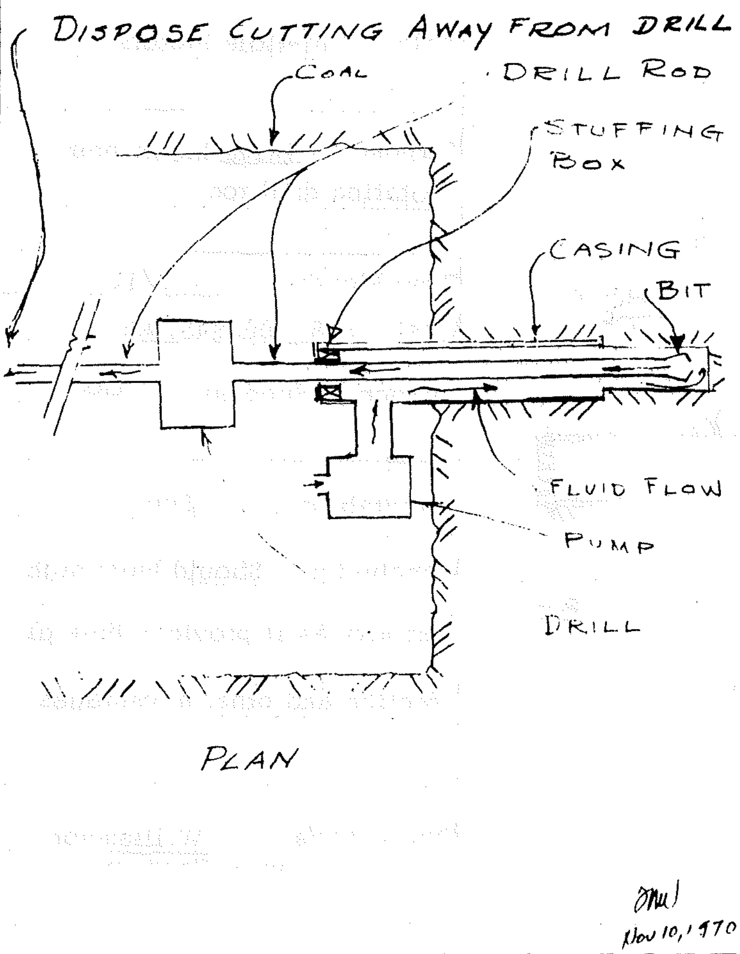
Advantages:

Locate collapsed or low producing holes in areas where mining will intersect and cause hole collapse. Help to check accuracy of hole direction control.

Disadvantages:

None

CONCEPT SUMMARY



Date: 11/9/70 No: 20

Title: Reverse Circulation

Purpose: Reduce Wall Erosion and Improve Drill Environment

Time Months: 6

Cost: $10,000

Chance of Success: Good

Patentability: Poor

Conclusion: Should be tried

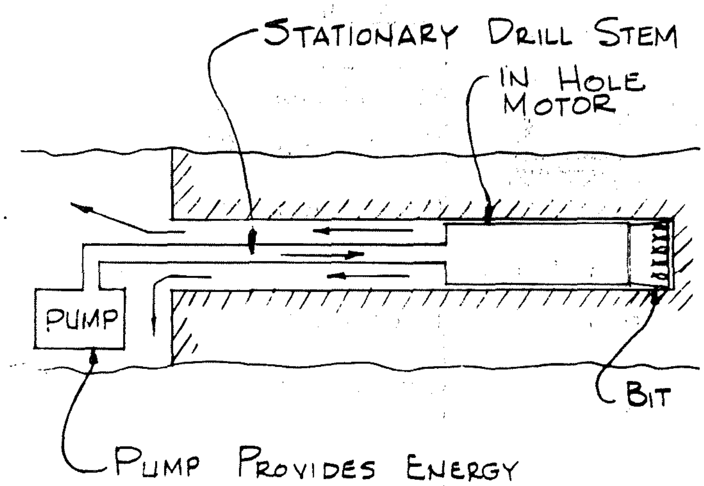
Originator(s): J.D. Hadden Jr.

Description: A short casing (3'to 5') will be installed into an oversize surface hole. It will have a stuffing box in its outer end through which drill rod will pass and rotate. The casing will have a tee to receive clear fluid from the pump into the hole annulus so that cuttings are picked up and returned through the drill rod. In Sprague & Henwood type drill, the rod carries them a convenient distance back. In a Thor type drill, fluid and cuttings would exit through a swivel and into disposal hose or pipe.

Advantages: Less fluid. Less hole wall erosion. Cuttings, used water and gas disposed conveniently away from drill site. Less chance of drill water damaging mine floor. Eliminates swivel when used with Sprague and Henwood drill.

Disadvantages: Can't use high pressure water for drilling. There is chance of lost circulation in badly fractured coal. (This might be overcome by deeper casing.)

CONCEPT SUMMARY



Date: 9/17/70 No: 21

Title: In-Hole Motors

Purpose: Drive bit without rotating drill rod

Time Months: 3/12

Cost: $15,000/$45,000

Chance of Success: Good

Patentability: Poor

Conclusion: Should have high priority as it provides hole direction and other advantages

Originator(s): Williamson with Garrison

Description: Several in-hole motors have been used in oil fields, including Moyno Pump (Dyna-Drill) and at least three turbines, all run by mud. Cullen Research has used an electric motor.

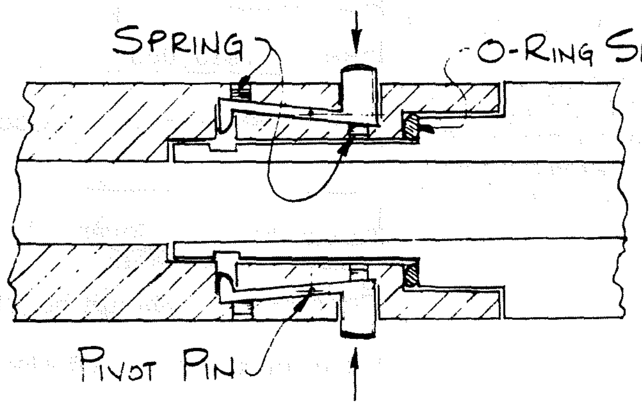
Phase I Study in detail all in-hole motors. Select best for this application and design system for its test.

Phase II Build and test prototype - first in strip mine, then underground.

Advantages: Reduces drill rig mass, reduces wear on pipe and hole wall, permits angle subs use for desired direction change. May permit use of flexible drill stem (hose).

Disadvantages: Use high volumes and pressures of water - maintenance costs are very high.

CONCEPT SUMMARY



Date: 9-17-70 No: 22

Title: Snap on Drill Stem

Purpose: Speeding drill connections

Time Months: 12

Cost: $35,000

Chance of Success: Poor

Patentability: Fair

Conclusion: Probable unreliability of such connection and possibility of other solutions dictate shelving this idea.

Originator(s): Williamson/ Hoadley

Description:

A push on drill stem connection secured by a pin or spring rather than threaded connection could save a minute at each time of adding or taking off drill rod.

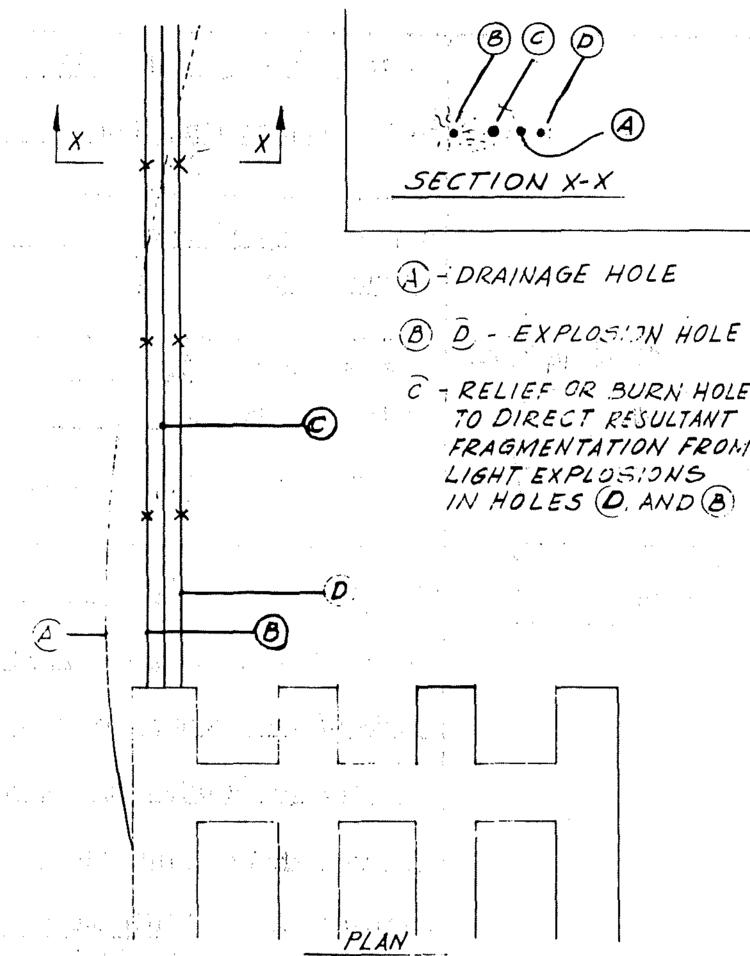
Advantages:

Save trip and connection time.

Disadvantages:

Such connections have been tried before and have always proven unreliable.

CONCEPT SUMMARY



Date: 9-17-70 No: 23

Title: Explosive Fracturing

Purpose: Stimulate gas flow by selective formation conditioning.

Time Months: 6

Cost: $15,000

Chance of Success: Good

Patentability: Covered but additions probable

Conclusion: Should be tried as it is inexpensive and almost within state of art.

Originator(s): Williamson

Description: Drill three (or more parallel holes in entry) These will be about 4 feet apart approximately in center of seam height; outer two holes will have about one stick of permissible explosive every 50 to 100 feet and center hole will be left open as a relief hole to cause explosive shock to go primarily in lateral direction. Enough of shock will go vertically to fragment coal seam but not enough to damage roof or floor. This will facilitate gas drainage and migration and also permit coal to absorb pumped in water for dust suppression.

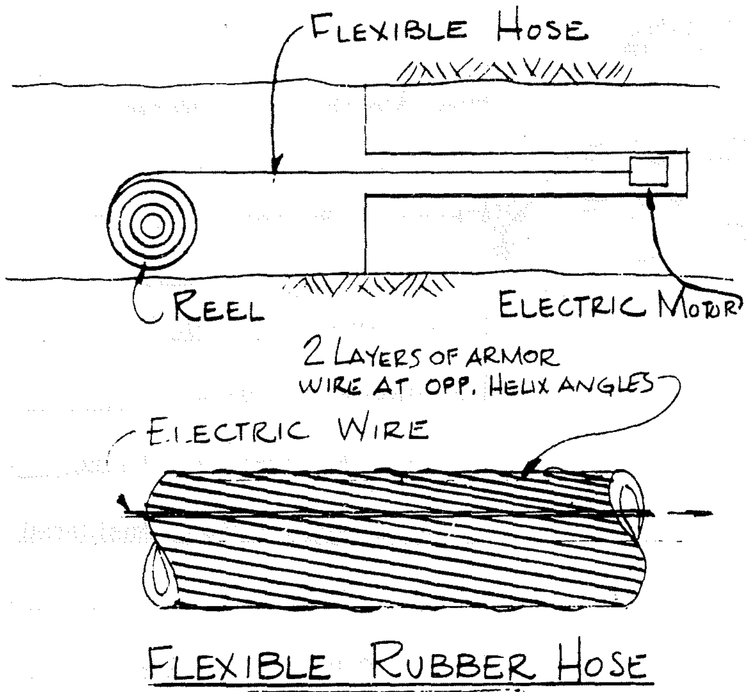
Advantages:

Speed up more complete gas drainage and help suppress dust.

Disadvantages:

Requires time - may be difficult to place explosives deep in holes.

CONCEPT SUMMARY



Date: 9-18-70 No: 24

Title: Cullen Flex Tube

Purpose: Make reelable drill steel

Time Months: 3/8

Cost: $6,000/$20,000

Chance of Success: Fair

Patentability: Poor

Conclusion: Phase I Investigation should be conducted to determine feasibility

Originator(s): Williamson (from published data)

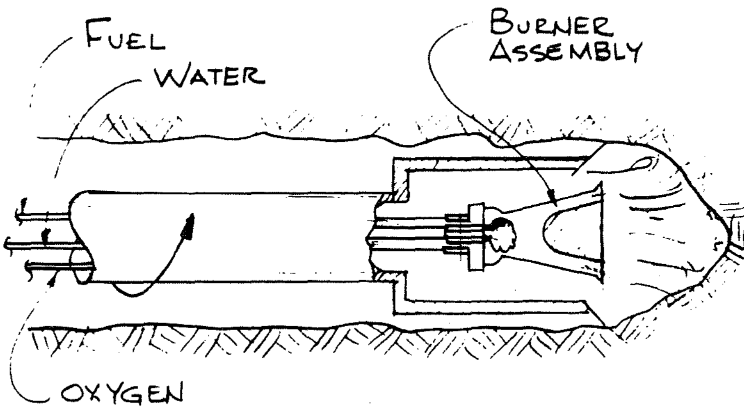
Description: Phase I: Investigate reelable drill steel developed for oil well drilling by Roy H. Cullen Research. Determine if this wire armored hose (including electric conduits) can be scaled down to small diameter and small space requirements of methane drainage in mines. Determine if wiring and motors can be made permissible. If answers are affirmative, design test rig and plan Phase II including possible test with such motor.

Phase II manufacture prototype and test

Advantages: Could lead to automated drill - compatible with direction change requirements.

Disadvantages: May be too bulky - probably very expensive - doubt that electric circuits can be made permissible (but pipe does not have to work electric motors)

CONCEPT SUMMARY



Date: ______ No: 25

Title: Thermal Drills

Purpose: Eliminate mechanism

Time Months: Never

Cost:

Chance of Success: None

Patentability: No

Conclusion: No - Hazard too great -- listed only to show it was considered

Originator(s): Several

Description:

Lasers and different torches and other thermal devices are being advanced as means of drilling rock.

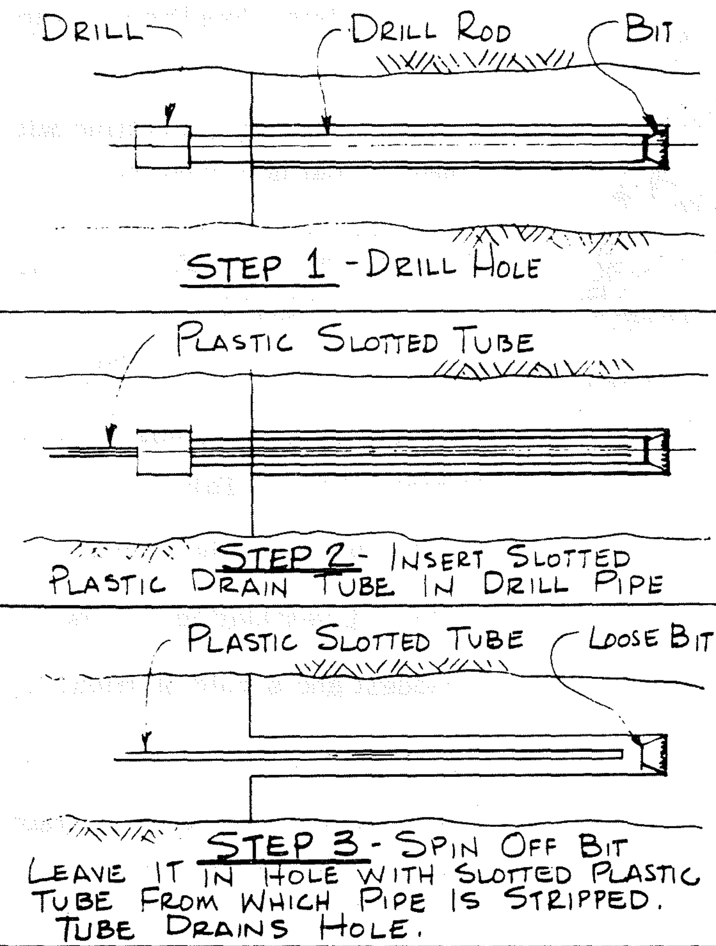
Advantages:

None - only possible use would be in the very remote possibility of success in mining in an inert atmosphere and then develop a drill to disintegrate coal by heat but it's not needed.

Disadvantages:

Cause explosion, cause fire, produce carbon monoxide -- too expensive probably slower than a dragbit.

CONCEPT SUMMARY



Date: 9-18-70 No: 26

Title: Plastic Drain Tube

Purpose: Tube in hole to protect against hole collapse

Time Months: 4

Cost: $7,000

Chance of Success: Good

Patentability: Poor

Conclusion: This should be tried in those areas such as Colorado where holes collapse

Originator(s): Harry Bingham
Pacific Hydro Corporation
420 Bryant St. San Francisco

Description:

Drill hole to total depth in caving or weak formations. Insert plastic tube with continuous slots at 120 degrees to permit methane to flow in. Reverse rotate and spin off bit. Pull drill stem from hole leaving tube in place.

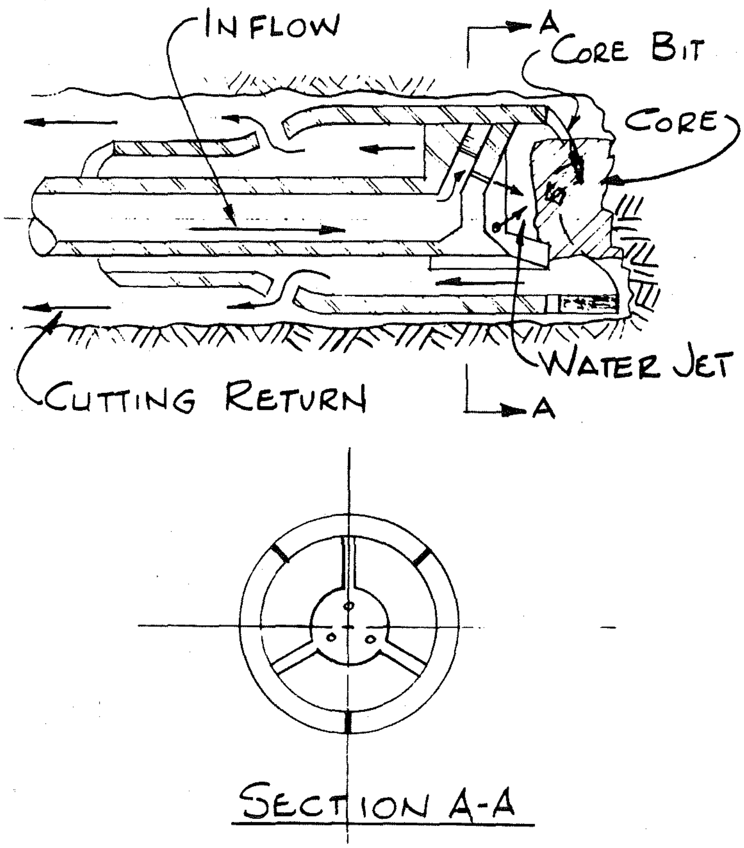
Advantages:

This is a rather positive way, proven in earth fill civil engineering construction, for maintaining hole integrity in weak formations. Will keep holes open for drainage.

Disadvantages:

Rather expensive at one to one and one-half dollars per foot for tube which may be destroyed in mining and not be reclaimable. Cost of abandoned bit must also be added to hole.

CONCEPT SUMMARY



Date: 9-16-70 No: 27

Title: Water Core Disintegrator

Purpose: Hydraulic cutting with mechanical hole shaping

Time Months: 4/8

Cost: $10,000 / $30,000

Chance of Success: Fair

Patentability: Fair

Conclusion: This is a novel idea - investigating cost is modest and should be tried.

Originator(s): Dr. Carl Peterson of Foster Miller Associates

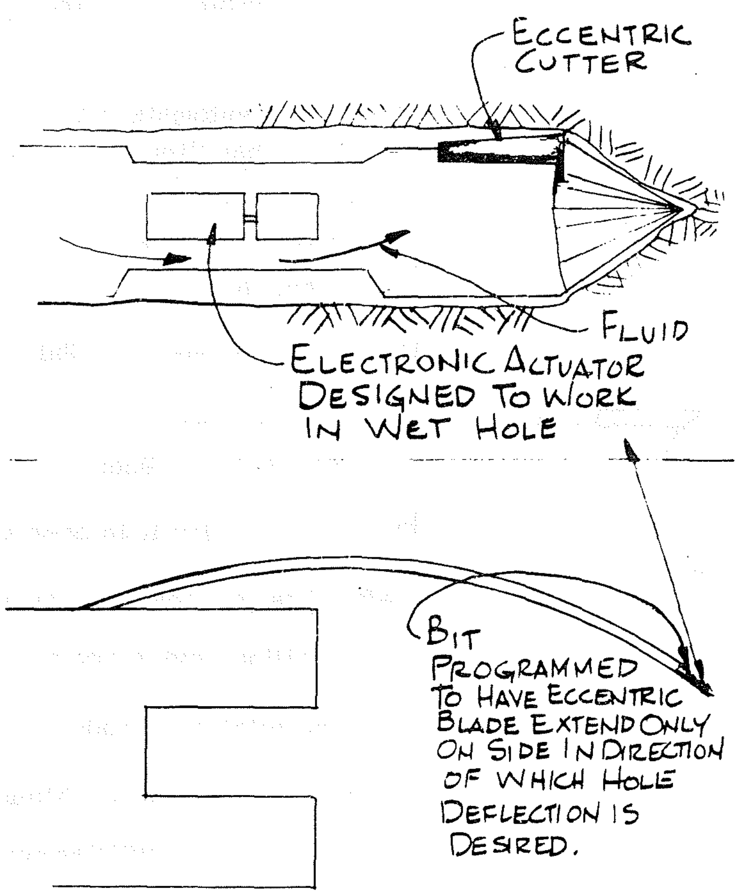
Description: Phase I design and plan manufacture of test devices and prototypes of a saw tooth drag type core bit within the body of which there will be one or more nozzles of 200 or more psi to break up core and transmit cuttings back into the annulus.

Phase II - build and test laboratory devices and prototypes out of the mine. Mine tests can be planned later as Phase III

Advantages: Less torque than full face bit - a well stabilized bit - less thrust than a full faced bit - smoothed wall hole for instruments when required.

Disadvantages: Bit may be difficult to remove in squeezing formations - bit may be less prone to deflect back into coal than a full face bit.

CONCEPT SUMMARY



Date: 9-18-70 No: 28

Title: Battelle-AGA Bit Director - "Sidewinder"

Purpose: Guide bit in pre-determined path

Time Months: 6/18

Cost: $15,000/ $35,000

Chance of Success: Fair

Patentability: Poor

Conclusion: Conduct Phase I analysis, then decide on Phase II.

Originator(s): Williamson from Battelle AGA Work

Description:

Phase I: Have Battelle or others analyze the Battelle-AGA straight hole (dry) bit to see if it can be programmed to guide a bit in a pre-planned horizontal camber. Also could it have water circulated by it? What is smallest size hole? Can it be made to work in explosive atmosphere? Can actuator be powered by 200 psi hole cleaning fluid system?

Phase II: Design, build and test prototype

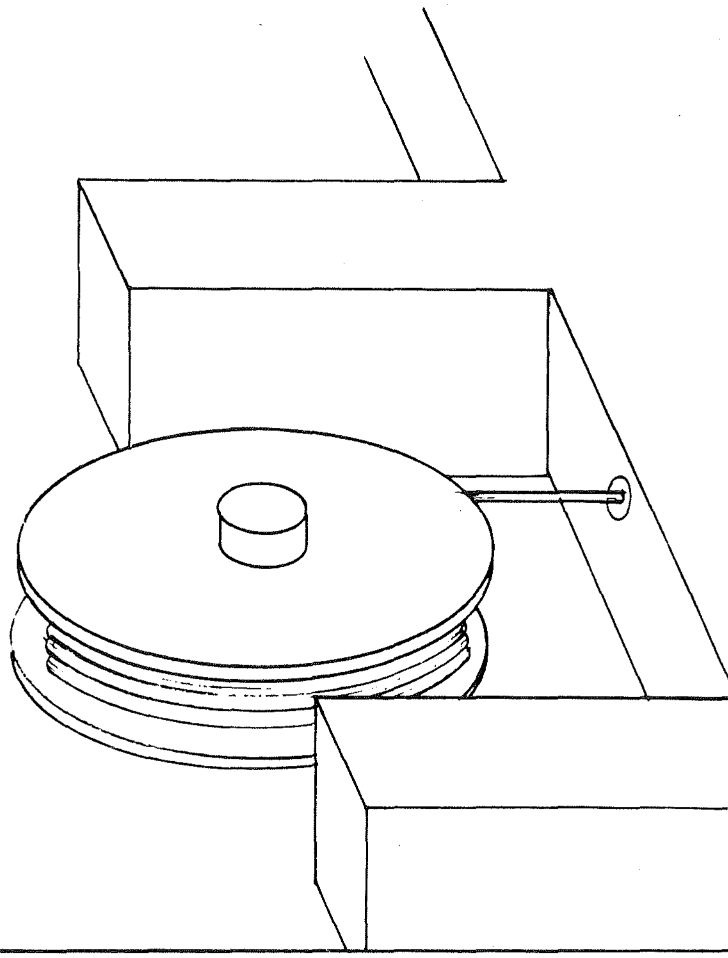
Advantages:

Could direct hole into desired zone without pulling tools and adding whip stocks or angle subs.

Disadvantages:

Difficult to get power to actuator - at high rpm (500) required for coal. Blade should operate in 60 $\div$ (500 x 4) = 0.03 seconds . May not be explosion proof.

CONCEPT SUMMARY



Date: 10/7/70 No: 29

Title: Flexible Steel Pipe

Purpose: Automate pipe handling

Time Months: 8

Cost: $20,000

Chance of Success: Fair

Patentability: Poor

Conclusion: Try it in open pit after first successful test of any drilling device not requiring rotation of rods

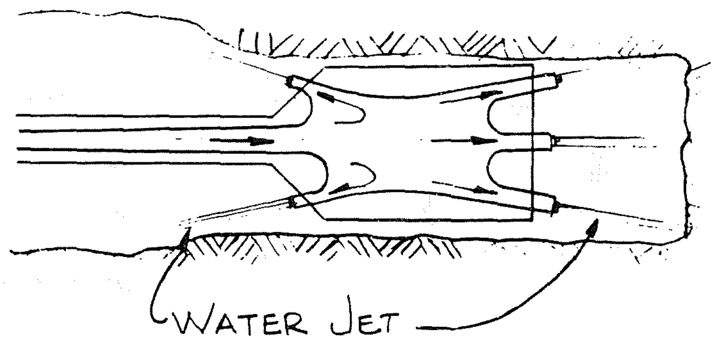
Originator(s): W.C. Mauer and Williamson

Description: One inch pipe that will reel on 10 foot diameter spool is a commercial product of Brown Oil Tool Company of Houston, Texas. A spool (or spools) may be designed to lie flat on a drill rig and tested in an open pit mine with a motor such as a Dyna-Drill.

Advantages: Eliminates time consuming pipe handling.

Disadvantages: Requires in-hole motor development. May be massive. Could be more difficult to control direction and flushing of cuttings may require more water.

CONCEPT SUMMARY



Date: 10/7/70 No: 30

Title: Water Jet Thruster

Purpose: Self propelling drill

Time Months: 6

Cost: $15,000

Chance of Success: Poor

Patentability: Poor

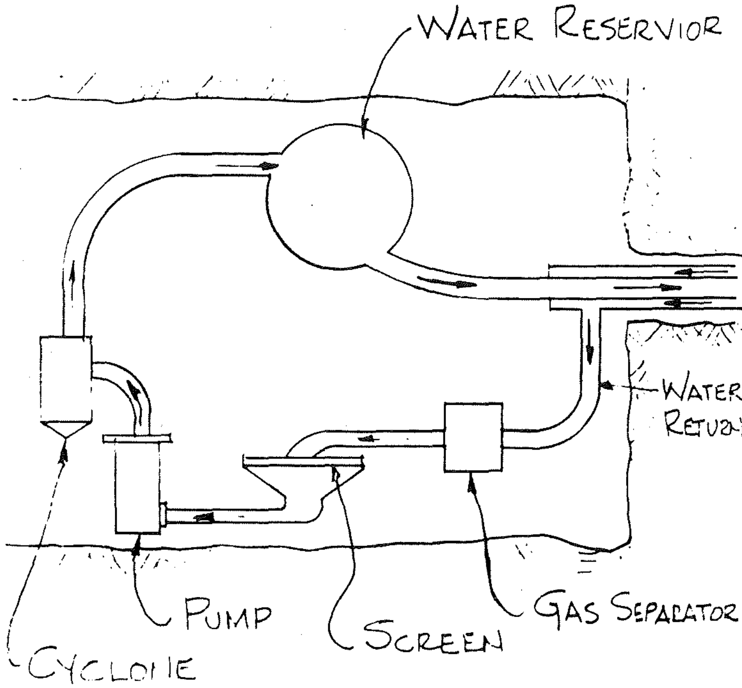
Conclusion: Possibility of developing effective thrust is poor. Discard for more promising possibilities.

Originator(s): W. C. Maurer

Description: Use several rearwardly positioned jets on the back face of the bit to assist in moving the bit forward.

Advantages: Reduction of thrust energy and mechanism on drilling machine for holes at some depth.

Disadvantages: Won't start hole. Holes will be irregular shaped where instruments are required. Irregular holes may interfere with good cuttings removal. Developed thrust will be undependable and difficult to control in power and direction.



Date: 10/8/70 No: 31

Title: Water Cleaner

Purpose: Reuse Drill Water

Time Months: 3

Cost: $10,000

Chance of Success: Good

Patentability: Poor

Conclusion: It should be tried in open pit mine but sized for underground.

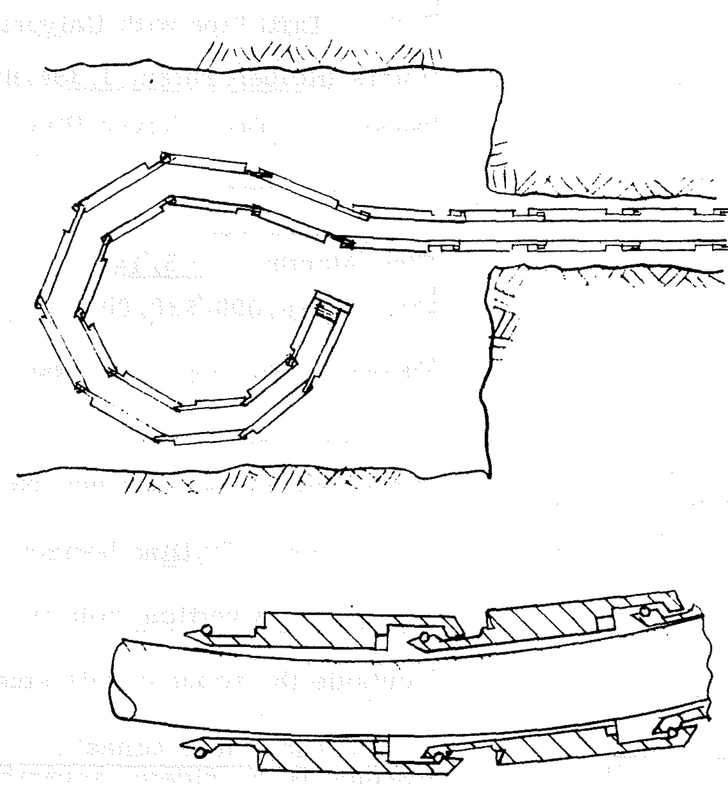
Originator(s): Haddan
Kloesel

Description: Commercial equipment is available to clean drilling mud. One system similar to sketch is sold by Drillco to clean mud and collect samples. This can be modified for underground size and permissability. Commercial unit may be rented for feasibility test.

Advantages: Less damage to mine environment by flooding. Drilling can be more independent of mine water system. If wetting agents normally in that system are an unnecessary insurance, by foam, they can be eliminated.

Disadvantages: None serious.

CONCEPT SUMMARY



Date: 10/8/70 No: 32

Title: Flexible -Stiff Drill Rod

Purpose: Easier storing and handling of rod

Time Months: 8

Cost: $35,000

Chance of Success: Fair

Patentability: Poor

Conclusion: This should be tried with rather low priority as lower cost alternatives may have better chance of success.

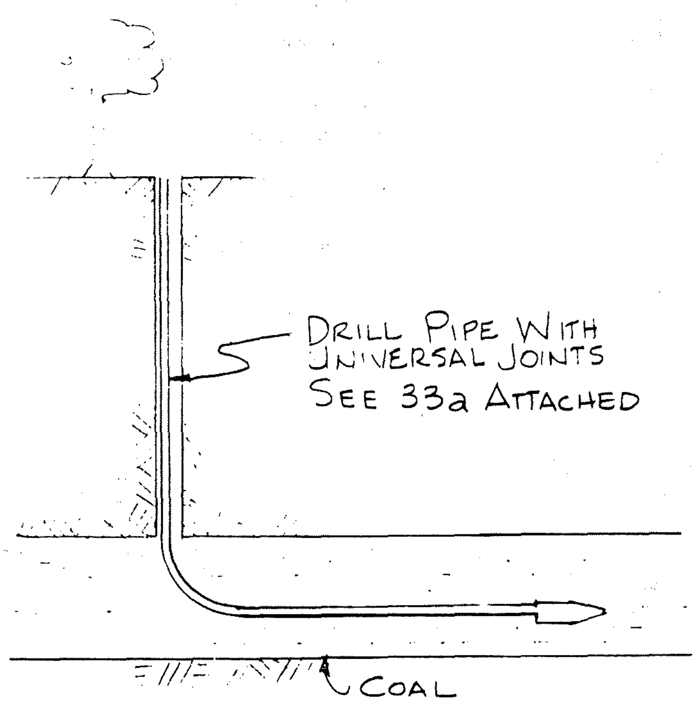
Originator(s): Roy Cullen

Description: Short sections of pipe may be joined so that when they are in tension, the joint is flexible but when in compression, they become rigid forming a straight pipe. There is similar experimental pipe in use described by Patent 3,446,297 to Roy Cullen et al. A fifty foot section for this purpose could be designed, built and tested in an open pit mine.

Advantages: Flexible pipe capable of taking torque and thrust.

Disadvantages: Difficult to manufacture. Costly. Maintenance costs could be high.

CONCEPT SUMMARY



Date: 10/13/70 No: 33

Title: Drill Pipe with Universal Joints (Holbert Patent 3,398,804)

Purpose: Drill Curved Hole

Time Months: 5/14

Cost: $6,000/$30,000

Chance of Success: Poor

Patentability: Poor, for new pat.

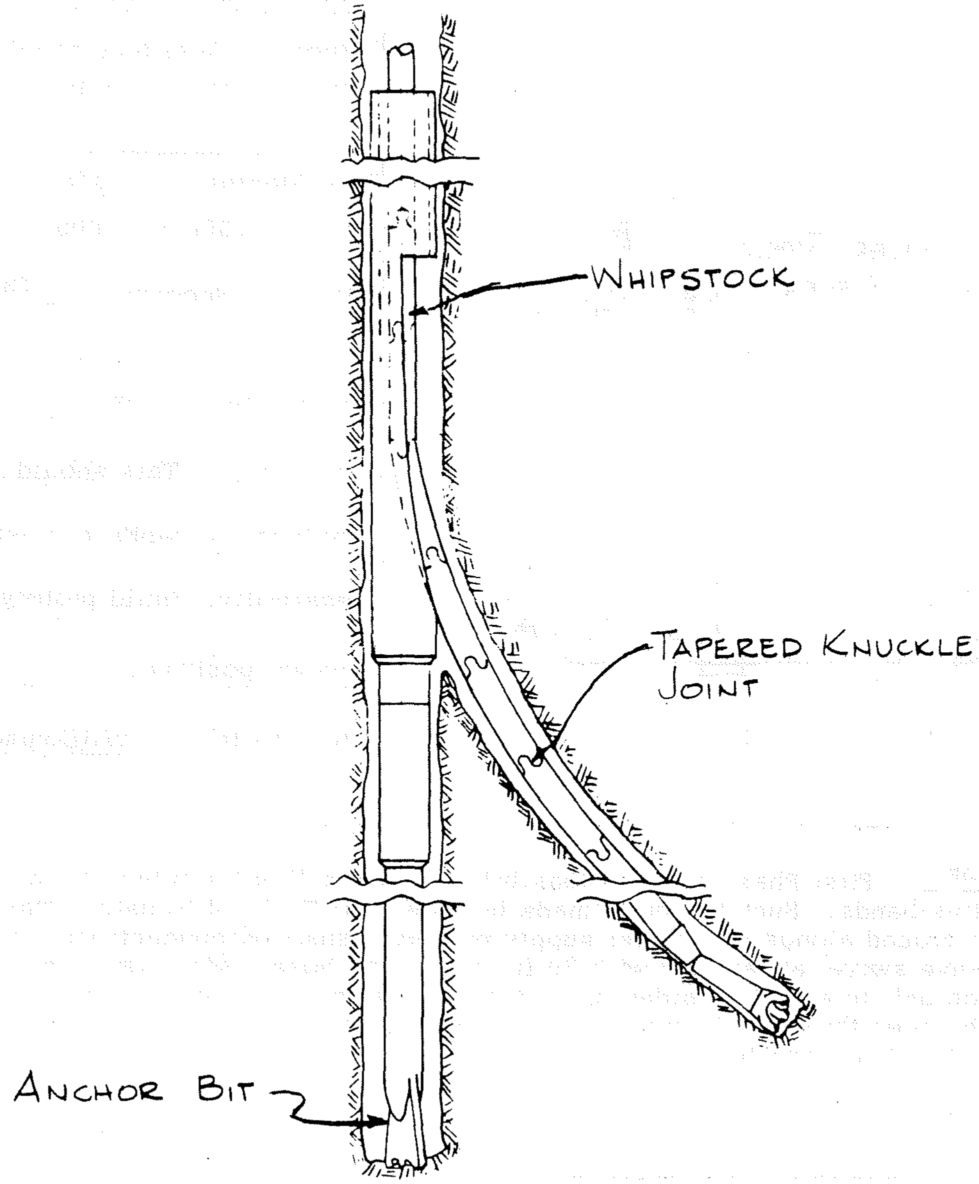
Conclusion: Drilling horizontally from a vertical hole is outside the scope of this study for drilling "from mines". Should be considered separately.

Originator(s): Palowitz

Description: Phase I study feasibility and II build and test prototype. Originally proposed to kick off a horizontal hole from a vertical hole into the coal seam. This contract covers only drilling in mines. The flexible pipe could be tried on a mine drill to accelerate desired lateral hole direction changes.

Advantages: Pipe will bend for 11.5 ft. radius. Permits torque transmission by pipe around a curve.

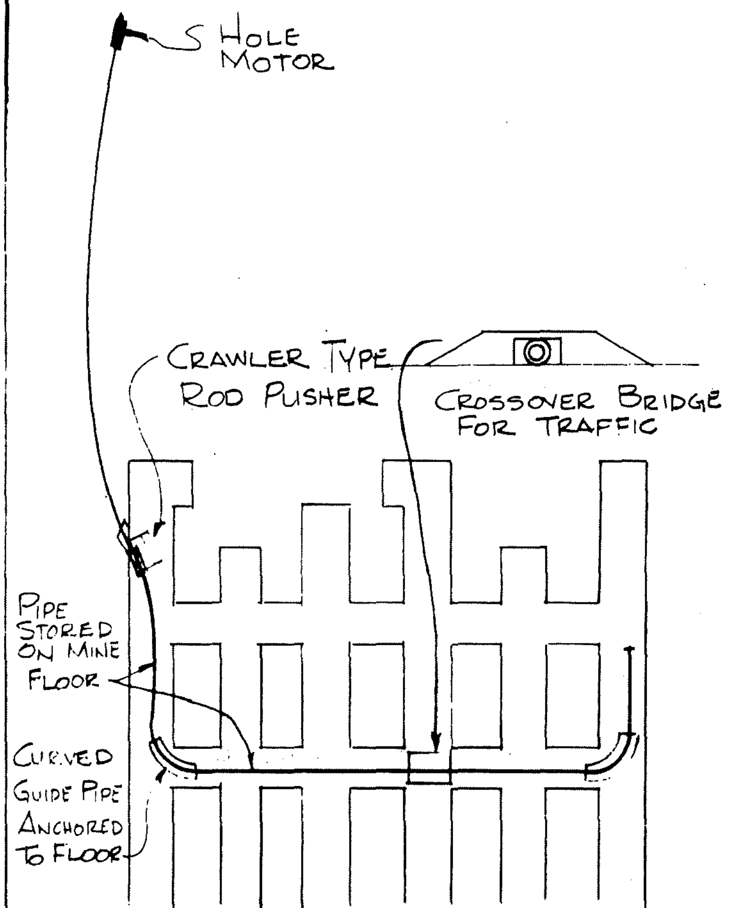
Disadvantages: Complicated joints may require high maintenance. Not flexible enough for coiled storage in 20 foot wide drifts. May be impossible to design small enough for mine drill.



CURVED BORE DRILLING

SKETCH 33a

CONCEPT SUMMARY



Date: 8/11/70 No: 34

Title: Ground Storage Dual Use Flexible Pipe

Purpose: Save pipe handling time - greater mobility

Time Months: 3/8

Cost: $5,000/$20,000

Chance of Success: Fair

Patentability: Fair

Conclusion: This should be analyzed in depth for cost and feasibility. Build prototype if answer positive.

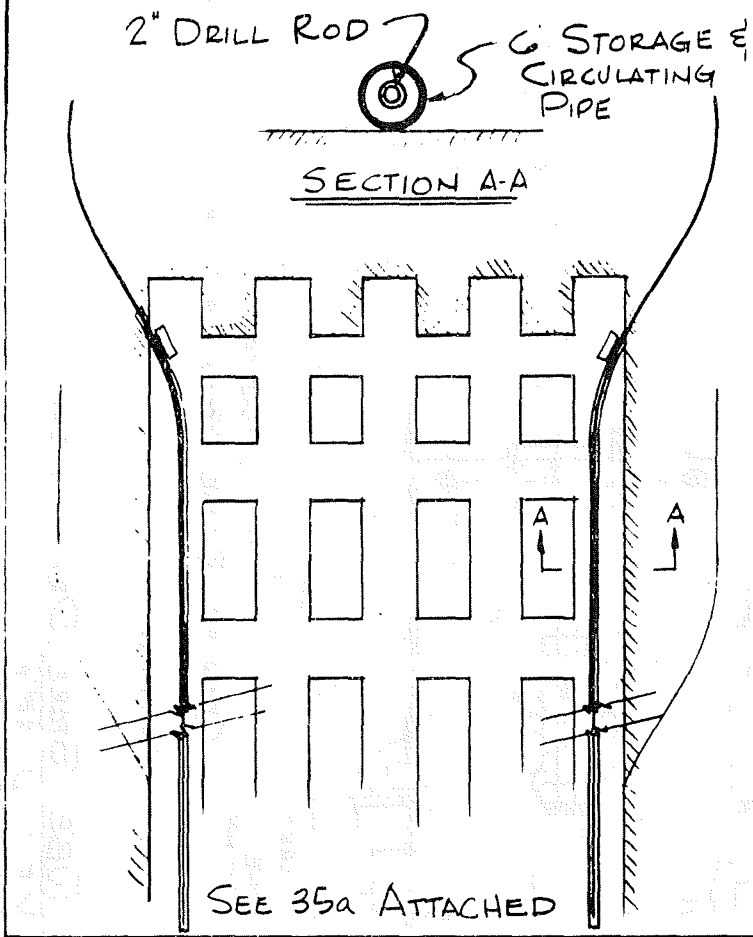
Originator(s): Williamson

Description: First Phase analyze feasibility of using flexible tubing for about 5 ft. radius bends. Such tubing is made by Brown Oil Tools of Houston, Texas. Lay it on ground alongside a water supply pipe with snap-on connections every 50 ft. Have swivel at tail end with 30 ft. of trailing hose. Move only drill propulsion unit to alternate sides of section, reversing direction of pipe. It can be threaded through advancing cross cuts on retraction as section moves ahead. Then build and test.

Advantages: Eliminates individual pipe handling.

Disadvantages: Depends on successful development of in-hole motor. Flexible tubing may not take compressive loading for thrust. Pipe will be in route of some traffic.

CONCEPT SUMMARY



Date: 10/14/70 No: 35

Title: Tube Store Drill Stem

Purpose: Simplify drill rod handling

Time Months: 4/8

Cost: $20,000/$40,000

Chance of Success: Excellent

Patentability: Good

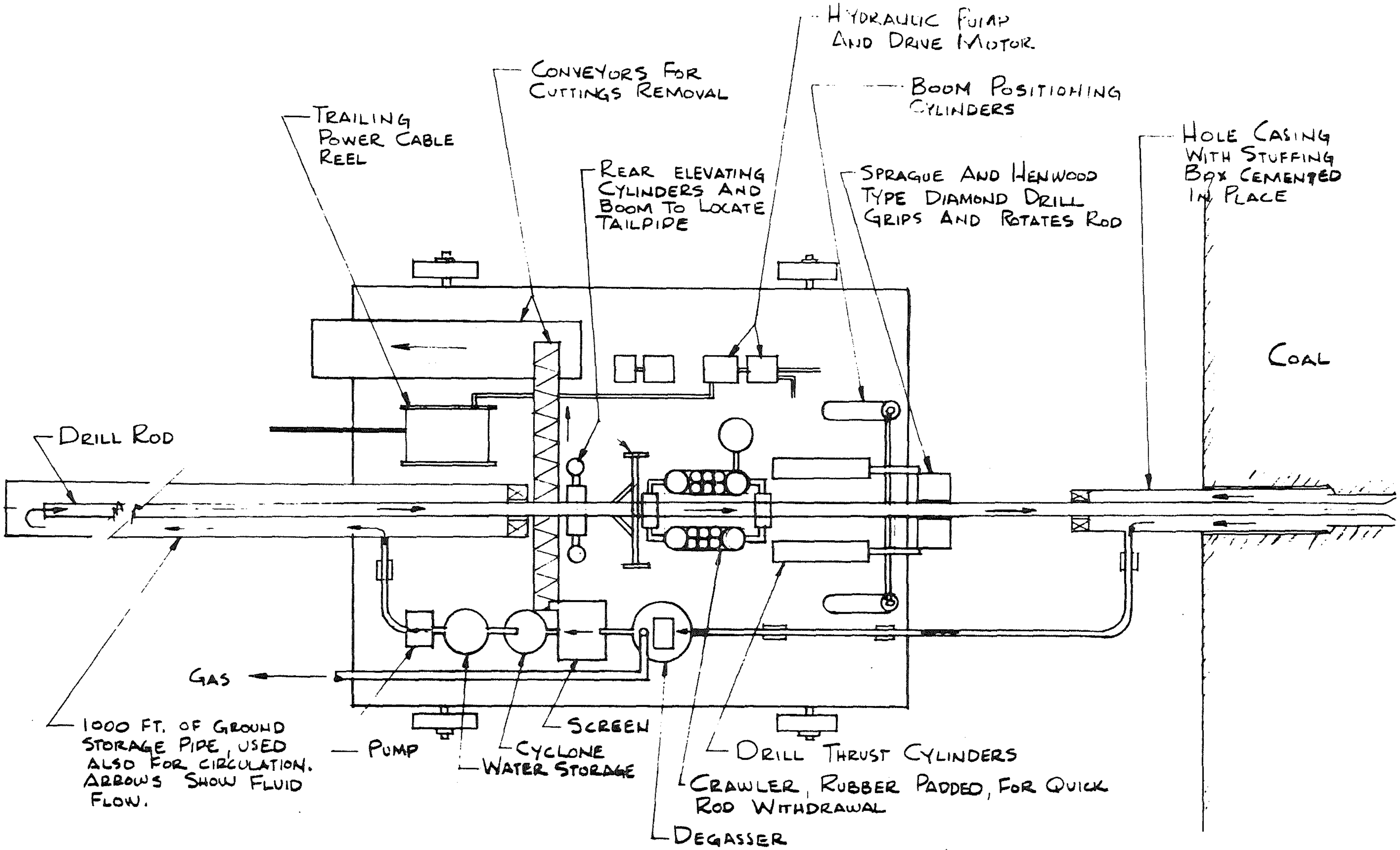
Conclusion: This is the best concept for providing a quick economical methane drainage system from underground

Originator(s): Williamson

Description: Phase I design detail of drill rig and support system in 4 months for $20,000 using for the main elements commercially available tools. Phase II build prototype and test. Use 1,000 ft. long 6-inch flanged pipe with rubber gaskets for flexibility for storing drill rod and to provide fluid circulation from cleaned fluid at drill rig. Diamond gripping and thrusting drill works between packers in hole and storage pipe.

Advantages: Two man operation. Eliminates connection time. Easy to advance. Out of way of traffic. Uses available technology in unique combinations. Available quick, inexpensive to buy and operate. Can be made safe. Adaptable to rotating rods or in-hole motors. Eliminates swivel.

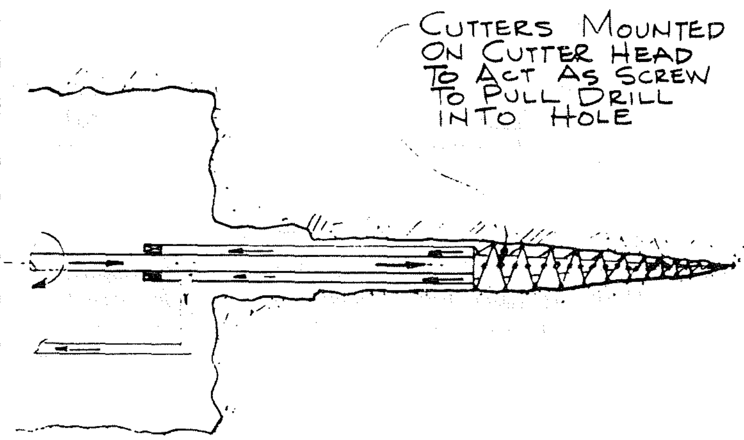
Disadvantages: Requires two drill rod. Cannot be used until 1,000 feet straight development has been made, except in shorter sections, for example 5-200 foot sections.



SCHEMATIC OF TUBE STORE DRILL STEM

SKETCH 35a

CONCEPT SUMMARY



Date: 10/18/70 No: 36

Title: Ingersoll Rand Rock Screw

Purpose: Eliminate thrust requirements from drill rig.

Time Months: 4/5

Cost: $10,000/$10,000

Chance of Success: Fair

Patentability: Poor (Patented)

Conclusion: Perform analysis and then decide whether field test be performed.

Originator(s): T. Holmes (Ingersoll Rand)

Description: A long tapered cutter head with cutters spirally mounted so that they pull their mounting and any trailing tube into the hole as it advances. Phase I study past experience at Ingersoll Rand Princeton Lab and apply it to coal for feasibility. If favorable, proceed to Phase II field test.

Advantages: Eliminates thrust cylinders and time delay for stroking such cylinders.

Disadvantages: None, if it will create sufficient forward thrust.

5.0 RESEARCH PLAN

The first four sections of this report have analyzed the background, the problem, the state of the art and some 30 concepts for improving the state of the art through research. This section describes how the concepts can be researched most effectively to achieve those goals of the Bureau of Mines.

The research plan, set forth herein, follows the philosophy of being in steps or phases. This will permit on-course evaluations of the research and a redirection, or abandonment, as may be desirable to accomplish the stated goals.

A tabulation of research possibilities, Figure 5.1, shows that the more than 30 concepts from Section 4 can be grouped for more efficient handling at less total cost. About one fourth of the concepts can be abandoned because they are impractical, too risky, too costly, or are not pointed toward an obvious public good.

Several facilities to perform the research are available for consideration in each of the research plans. Independent groups who are not manufacturers may be best qualified to conduct detailed method evaluation and test direction and analyses. These would include research or engineering companies. Manufacturers of hardware may be desirable to have as participants in prototype manufacture and tests. Some manufacturers are affiliated with independent research facilities so that in some cases, such a combination could play a dual role effectively.

Field testing in coal mines should present no labor jurisdictional problems. The predominant unions in coal mines are extremely safety conscious. Men performing tests for these purposes generally will not be required by such unions to be members of any group. The key individuals should have had coal mining experience, and arrangements must be made for fireboss inspection of work sites underground.

A review of this rather detailed analysis of the problem in the first four sections leads to certain conclusions necessary before establishing a research plan.

The horizontal drilling technology developed in the United States to date has been by the Bureau of Mines. Their principal purposes have been to provide mobility and holes for instrumentation leading toward fundamental knowledge of the coal methane reservoir. These drills and their application show a high level of drilling knowledge, ingenuity and the use of the best available techniques from the several earth drilling fraternities, including oil well, water well, blast hole, mineral exploration and utility distribution groups.

Fig. 5.1

CONCEPT-PROGRAM AND PRIORITIES

CONCEPT		PROJECT AND PRIORITY			
No.	Title	Basic Research	Drill Methods	Drill Stem	Hole Direction
1	Fundamental Research	A			
2	Furlable Drill Steel			C	
3	Auxiliary Tools	C			
4	In-Hole Thruster		B		
5	Coal Seeking Bit				B
6	Bent Subs				B
7	Automatic Rod Handler		B		
8	Hole Surveying				A
9	Hydraulic Drilling		C		
10	Hydraulic Slotting	B			
11	Drag Bit Design		D		
12	Mechanical Hole Opener	C			
13	Long Drill Rod			C	
14	Pellet Drilling		D		
15	Aluminum Drill Rod			C	
16	In-Hole Percussion		D		
17	Fluid Additives	C			
18	Double Walled Pipe			C	
19	Hole Stainer				B
20	Reverse Circulation	B			
21	In-Hole Motors		A		
22	Snap-on Drill Stem			C	
23	Explosive Fracturing	B			
24	Cullen Flex Tube			C	
25	Thermal Drill 3		D		
26	Plastic Drain Tube	C			
27	Water Core Disintegrator		C		
28	Battelle Bit Director			B	
29	Flexible Tubing (Brown)			B	
30	Water Jet Thruster		D		
31	Water Cleaning		A		
32	Flex-Stiff Drill Rod			C	
33	Universal Jointed Pipe			C	
34	Double Use Ground Stored Pipe			C	
35	Ground Pipe Rod Storage		A	A	
36	Ingersoll Rand Rock Screw		B		

The Bureau's drills will provide sufficiently fast instantaneous penetration rates with reasonable power. They provide a satisfactory hole shape in most cases for instrumentation as needed. The cuttings removal techniques are adequate for the drilling process.

The Bureau's drills are not adaptable in their present form to be accepted by the industry as production tools. This is because they have had to be developed on a limited budget and have had to be adaptable to the many variable conditions of the several host mines. They are not mobile enough. They require too much manpower. Drill rod handling is awkward. There is no satisfactory lateral direction control or means of surveying for it. Means are cumbersome for connecting on to mine systems to which they must be parasitic such as compressed air, water and electricity. Means of disposing of waste products, principally water, must be improved.

As has been mentioned, better means of lateral direction control appear desirable and within reach by extension of the art through research. Vertical direction control as developed by the Bureau's researchers may be adequate, as possible further improvements probably would be too expensive and add unnecessarily to the complications and unreliability of the system for production. The vertical control now used to follow undulations of the seam and stay in the coal is as follows. The first 150 feet is drilled as straight as possible using stabilizers or centralizers at each end of the first drill rod. Holes this deep can be drilled straight in most United States bituminous coal. This establishes the integrity or stability of the drill stem so that any further directional changes are likely to be gradual as are local changes in elevations in most coal in this country. The straight hole tools can then be taken off and the bit will deflect from the harder top or bottom rock and ricochet back into the coal seam.

Some work has been done by the Bureau leading toward the stimulation of gas drainage from coal seams. This has been primarily in the technique of water flooding from one hole to another. There has been some indication that water flooding helps allay dust in subsequent mining. Water flooding may be used also to provide a curtain within a block of coal to retard, temporarily, the flow of methane into working places. Research needs to be directed at water flooding and other means of gas flow control or stimulation. This would include locally slotting or fracturing the coal bed at some depth in the hole.

All of the above leads to the recognition that research can be grouped into four study areas as follows:

A. Fundamental Basic Research
B. Drill Mechanisms
C. Drill Stem Research

D. Hole Direction Control

There is a possibility that B, C and D are so inter-related that they should be combined into one large research project. They and the other lettered subjects are treated separately in 5.1 through 5.4 of this Section 5.

5.1 FUNDAMENTAL BASIC RESEARCH

The very highest priority must be given to fundamental basic research. This must be conducted to establish a base from which all other research and analysis can be directed and measured.

Nearly all horizontal drilling in coal has been done by the "seat of the pants" type of drilling skill. There is no reliable data in the literature on horsepower (torque), thrust or optimum combinations of these parameters and variations in RPM, fluid circulation, or bit configuration. This data is essential before any meaningful research can be planned in detail or conducted.

Much of the fundamental research can be conducted with available equipment. Many of the tests can be produced economically and speedily in strip mines with a minimum of interference with existing operations.

Those knowledgeable in horizontal drilling in coal claim that best performance, with a 3" drag rotary bit and 1-13/16" O.D. drill rod (EW casing) can be obtained at:

A. 500 rpm

B. 1,000 lb. thrust

C. 5 to 10 gpm - clear water - circulation

This is certainly not precise enough or reliable enough to use as a basis for any meaningful research but does establish a base for selection of equipment.

Laboratory research to obtain drilling data with miniaturized equipment would not be economical or reliable. It is much cheaper to haul the light drilling equipment and instruments to a mine site than to cut and haul blocks of coal to a laboratory and set them up. No good substitute rock for coal has been found, although for limited tests plaster of paris does provide some similarity. Later, some correlation may be established.

5.1.1 Analysis of Alternatives (Fundamental Basic Research)

The requirements of this research are to establish the basic criteria for drilling small diameter horizontal holes in coal. A series of tests will be conducted holding all variables except one constant. This will establish the effect of varying the parameter and the optimum range for each parameter or combination of parameters. Some of the variables which should be considered in such a test are:

A. Thrust

B. Rotary Speed

C. Circulation volume (or annulus velocity) of air and water

D. Additives to circulation fluid (such as foaming agents, air, etc.)

E. Auger flight removal of cuttings including measurements of pull of auger, varying with depth and drilling speed.

F. Depth of hole

The effects of changing these variables will be measured, tabulated and analyzed against such results as:

A. Torque

B. Drilling speed

C. Bit Wear

D. Hole direction

E. Hole shape

F. Hole stability

G. Hole friction characteristics (for measuring or determining anchoring ability in coal of such things as torque or thrust anchors, for some of the novel drilling concepts envisioned).

H. Correlation of drillability parameters and physical characteristics of coal such as grindability, strength, volatile content, etc.

Data from these tests must be presented in as detailed and analytical form as possible. Information should be made available, progressively, as it is developed, as other tests on advanced concepts depend on results of this test. These other developments should get underway prior to completion of the fundamental research.

5.1.2 Facility (Fundamental Basic Research)

There are several kinds of facilities which would be able to perform this task. In any event, the one chosen should have already had some experience in field test drilling, and drilling variable analysis. This would eliminate or reduce the training period for the key people to learn what the important variables may be and how to record and judge them. The group chosen should be one with an open mind, that is without too many prejudices or preconceived ideas as to limits of methods or parameters. It must be a group which recognizes that this is a data gathering task and variables will be extended well beyond the recognized practical limits in both directions. It is not a mission solely of determining an optimum relationship of variables although that should be one of the results. Many things must be tried which are known to be wrong to establish firmly and precisely what is right. Facilities which may perform this task would include any one or a combination of the following:

A. An engineering firm in this field.

B. A drill manufacturer (being sure it would fairly test and evaluate products other than its own).

C. A university.

D. A non-profit research organization.

E. A drilling contractor with horizontal small hole drilling experience and with analytical capability.

F. A Bureau of Mines team with or without advice or guidance from one of the above.

5.1.3 Hardware (Fundamental Basic Research)

The exact equipment selected for this test can be chosen from several alternatives. Those submitting proposals should be given some latitude to specify the exact equipment they intend to use to get the required results.

The following is a typical equipment list which could be used:

A. Test Equipment (purchased or rented)

1. Drill - Thor 45 pound air rotary drill

2. 100 feet of EW drill rod

3. Two stabilizers

4. 100 feet 2-1/2 inch auger flights
5. Specially designed and built skid mounted drill stand with hydraulic thrust cylinders with pressure gages
6. 60-pound jackhammer drill with 20 ft. of steel (primarily for anchoring drill stand)
7. 100 gpm, 200 psi. water pump
8. Cuttings settling tank
9. Reserve water tank, 1,000 gal.
10. Hydraulic pump for thrust jacks
11. A specially designed and calibrated torque sub.
12. Miscellaneous small tools, anchors, pipe wrenches, hammers, saws, pipe fittings, etc.
13. Assortment of bits

B. Major Tools - Rental

1. Pick-up truck
2. 315 cfm 100 psi. air compressor
3. Welder
4. Pit dewatering pump
5. Front-end loader--part time

C. Instruments

1. Stop watch
2. Tachometer
3. Air pressure gages
4. Tapes (measuring)
5. Hole caliper
6. Hole directional surveying instrument

7. Transit

8. Water flow meter.

5.1.4 Time (Fundamental Basic Research)

Two months should be sufficient, at the start, for lining up two test sites and arranging for regular commercial and special equipment. The time required for this data gathering program should not exceed eight months. Five months should be sufficient for final analysis and evaluation and reports.

The complete job can be done in 15 months.

5.1.5 Costs (Fundamental Basic Research)

The principal cost for this phase of testing will include: capital equipment (purchase or rental); engineering; field labor; and travel. Capital equipment costs should not be considered chargeable in full to these tests. Subsequently, it will be property of the Bureau and can be used on other research which must be conducted. Perhaps arbitrarily only one third of the estimated capital equipment costs should be charged to this phase of the program but funds will be required to be allocated for the full amount:

Item	Hours	$/Hour	Cost
Senior engineers	550	$25.00	$13,750
Jr. Engineers and technicians	1,100	18.00	19,800
Casual labor	1,200	12.00	14,400
Equipment ($36,000 x 1/3)			12,000
Travel, etc.			6,000
			$65,950

5.1.6 Test Plan (Fundamental Basic Research)

It is believed that tests can be arranged best at some of the larger strip mines in the Ohio or Illinois area or in one of the western mines in New Mexico, Colorado or Wyoming. The strip mines of West Virginia, Virginia and Kentucky are primarily contour strip mines with narrow and congested pits. In those areas, auger mining follows stripping so that drill sites will be limited.

Some drilling sites chosen may be desirable in abandoned areas of contour strip mines. There will be more of these seams in which gas is a problem. Arrangements must be made with land owners and any current lessees. Such site may have been backfilled, drained and planted in accordance with the local reclamation requirements. It will, in any event, require some site preparation. This should require only one or two days with a crawler type front-end loader. An area at the base of the coal 50 feet along the coal seam and a bench 25 feet wide should be adequate.

A site with a stable highwall is essential for safety. A site near a still usable haul road and one in which there is little water flow is desirable. The seam of coal chosen should be one that is mined underground for subsequent correlation of results in the two environments. The coal should be back far enough from the original outcrop so that it will not have been affected by oxidation or weathering. If auger mining followed the stripping, then the site must be one where at least 50 feet of exposed coal was not augered because of terrain (thin points, inside curves, etc.),

It may be determined with a few preliminary tests, that valid results can be obtained in an augered seam by drilling into the cusps at top and bottom between auger holes. This would open up many choices of test sites. It would eliminate one objection of the owner in that it uses coal that will never be recovered. It would eliminate cost of site preparation and reclamation after the test.

Reclamation costs must be included. These include backfilling and grading with connection to the planned drainage system. It also includes replanting.

Rather shallow holes are envisioned for most of these tests. Holes 25 to 50 feet deep should provide most of the data that is needed. Several holes can be drilled in each vertical plane, about one foot apart, and one foot from top and bottom. Shale or slate partings should be avoided for the coal tests but some tests for data in typical partings should be conducted as a part of the test. Following this pattern, some 100 test holes could be drilled in 50 feet of a 36" thick seam and 150 holes in a four foot seam. The owners or operators may prefer that the holes be more widely scattered. Since coal is uniform in any one mine and moves are easy, this is not objectionable.

Two sites are envisioned in the extremes of drillability for bituminous coal. For example, there may be one in an easy drilling coal such as that in southern Appalachian, and the other in a harder drilling coal such as that in the northern Appalachian area. One test may be considered in the Colorado mining area where hole stability problems may be more pronounced than elsewhere. Mid-continent Coal Company has a strip mine there.

5.2 DRILL METHODS

Present rotary drills can be improved, through engineering development, to drill 1,000 foot deep horizontal holes in coal. One problem is that the drills (to be as fast as they need to be) may have to be too massive for working in the confined space of coal mines. It seems apparent that some form of rotary drilling will be used. Percussive, thermal, high pressure water and the several so-called "novel" methods of drilling, show little promise of application to this problem.

Several alternative methods of providing rotational and thrust power to the bit with in-hole motor devices have been suggested. The research program planned is to investigate these various devices and select the best for prototype design, manufacture, and test.

5.2.1 Investigate Alternatives (Drill Methods)

The several rotary drilling systems should be evaluated in depth for:

A. Practicability

B. Economy

C. Efficiency

D. Reliability

E. Cost of Development

F. Chance of Success

These systems would include primary power selection of hydraulic, pneumatic, and electric. Rotary power applied through a pipe end chuck; square, hex or slotted kelly; pipe gripping chuck, or in-hole motor must be analyzed and compared.

The in-hole motor study must consider turbines, positive displacement motors, and electric motors.

More than one rotary power provider may be shown to have enough merit for detailed design and perhaps prototype building and testing.

Another part of the drilling system which must be analyzed is the cuttings removal. It appears that air cannot be considered because of the explosive hazard. Continuous flight augers may be used in a part of the system but not for all of it because they are weak, require too much torque in deep holes and generate too much thrust. Some form of water circulation seems essential.

Methods of controlling, containing and processing the water to remove gas and cuttings must be compatible with the system. Reverse circulation including double walled pipe should be a part of the analysis.

Thrust application techniques are an integral part of the system and must be evaluated. Thrust can be applied by hydraulics or wire rope. Attachment may be through a swivel, a pipe gripper or an in-hole thruster. A minimum delay time must be achieved for stroking a thrust system.

Mobility of the drill rig, pipe handling and minimum inconvenience to other operations, are other important considerations. All of the components of the method must be put together for operation with safety as a main goal.

The best combination or combinations of drill method components will be selected for detailed design, prototype manufacture and test.

Some experimental work may be involved to determine the characteristics of the components without building a complete system depending on that component. For example, it may be decided that an in-hole motor of positive displacement type shows great promise to be used with a non-rotating conventional drill rig to determine the support requirements, performance and reliability of the in-hole motor.

5.2.2 Facility (Drill Methods)

This project may be done as a whole divided into several projects. If consolidated, it should be administered by a research oriented company or university group without prejudices for any particular system component. If split into pieces, then those companies with expertise in the component under study should perform the task better at less expense.

In any event, the final evaluation should be done by an independent group.

5.2.3 Hardware (Drill Methods)

The principal hardware required for testing system components in this program is similar to that described for fundamental research in Section 5.1. It can, in fact, be the same equipment slightly modified.

The special components selected for test may be:

a. A Dyna-Drill or an electric in-hole motor, or both, at about $25,000 including parts and special design features for this application. (Concept 21)

b. An in-hole thruster at about $15,000, including design. (Concept 4)

c. Mud cleaner package at $10,000. (Concept 31)

Total hardware is $50,000.

5.2.4 Time (Drill Methods)

The selection process will require four months. Hardware design and procurement will require 8 months. Testing can be completed in 4 months. Total time is 16 months.

5.2.5 Cost (Drill Methods)

Analysis and selection	$ 30,000
Basic standard equipment	35,000
Special equipment	50,000
Testing	40,000
Final analysis	15,000
Total	$170,000

5.2.6 Test Plan (Drill Methods)

First, field tests should be in open pit strip mines for economy due to ease of access. Open pit testing also provides better scheduling without undue interruptions to the host mine's operation.

That equipment which appears to have real promise for advancing the technology should then be tested underground. This will provide knowledge of its application in the more confined space and in the ultimate environment of gas. It also will show any needs for supporting facilities.

Most underground miners with a methane problem will be pleased to have holes drilled for them. They will insist that the drilling operation not interfere with production. In many cases, this will mean weekend or third-shift scheduling of the drilling. There is, of course, the possibility that the drill components which evolve from this phase will be that ultimately needed which can, in fact, operate concurrently with the mining operation.

Tests will include measurements or recording of data which will provide a sound basis for establishing operating characteristics. Information will be required on the following:

a. Penetration rates

b. Depth capability

c. Compatibility to small space

d. Labor requirements

e. Power demands

f. Effect on mine environment

g. Maintenance requirements

h. Directional characteristics

i. Mobility

j. Set-up and tear-down time

k. Minimizing interference to other mine functions

l. Safety

The recorded data will include:

a. Details of all tools used

b. Coal physical characteristics

c. Penetration rates

d. Bit condition at various intervals

e. Hole configuration

f. Cuttings size

g. Effect of depth on penetration and power

h. Creation of foam

i. Water volumes and pressure

j. Thrust required

Progressive and test end reports will present this data in an orderly fashion. They will be provided at test end, or monthly, whichever is the shorter. The reports will give conclusions, extrapolations, where appropriate, and recommendations.

5.3 DRILL STEM RESEARCH

Perhaps the greatest potential for an early improvement to methane drainage drilling will come from attention to drill stem handling.

Field tests with existing equipment points out quite clearly that, in deep holes in coal, slightly more time is used handling drill steel than is used in drilling. A ten-foot long drill rod can be drilled in about 4 minutes and it frequently takes 5 or 6 minutes to add another rod. Time to pull the full string of tools at completion of the hole must be added to rod hauling, and this can amount to 15 or 20 minutes per hundred feet of rod.

Research in this area can be two-pronged and could be done simultaneously. First, research should look at improvements in handling rigid or stiff rod similar to that which has been found reliable for this use. One form of this rod is casing normally used for small hole diamond exploratory drilling.

The second and parallel effort should be to explore some of the novel ideas of flexible drill rod. The actual application of some of this novel rod will depend on the success of research for in-hole rotary motors, which do not require drill rod to deliver the turning power to the bit.

5.3.1 Investigate Alternatives (Drill Stem Research)

An analysis will be made of the best means of improving the handling of conventional-rigid or stiff drill rod. This will include means of handling longer sections and the overall advisability of such an approach. It will include an analysis of different means of storing rod as well as putting it in or out of the string in the hole.

The above may require: creation of new magazines for racking pipe, new concepts of make-up and break-out wrenches or new concepts of connections not requiring torque.

The most promising method of handling rigid rod is that revealed in Concept 35, Section 4 of this report. That is for ground storage in a pipe which also becomes a part of the circulating system. This eliminates the swivel and does away with all rod handling chores except at the beginning and end of each hole.

At the same time, an analysis will be made of some of the new flexible drill rod ideas, including:

a. The Cullen Flexible Rod
b. The DeHaviland Furlable Steel (STEM)

It is generally assumed that these flexible rods will not transmit rotary power to the bit. They will be examined to determine which may be best suited to:

a. The limited space of a coal mine

b. Applying sufficient thrust to an in-hole motor

c. Dependability in pulling all tools out of a thousand foot deep horizontal hole

d. Diameters required

e. Withstand abraision of wall and erosion of drill fluid

f. Resistance to torque as required

The method or methods will be selected which provide the greatest chance of contributing to a real advance in the art. Work can proceed into engineering development of a prototype of the ground storage method in advance of the study on the other method as this has been given enough consideration to indicate a high degree of success probability. It can be put together, for the most part, with components which are commercially available.

Alternatives which should be considered in rigid rod, from Section 4, are:

Concept 7 - Automatic rod handler
Concept 13 - Long drill rod
Concept 15 - Aluminum drill rod
Concept 18 - Double walled pipe
Concept 22 - Snap-on drill stem
Concept 35 - Ground storage of pipe in pipe

Concepts for flexible drill rod which must be considered are:

Concept 2 - Furlable drill steel
Concept 24 - Cullen flexible pipe
Concept 29 - Flexible tubing
Concept 32 - Flexible/stiff rod
Concept 33 - Universal jointed pipe
Concept 34 - Ground storage double use flexible pipe

It is suggested that these projects be considered. One would be for analysis only of Concepts 7, 13, 15, 18, 22 and any other handling rigid rods which might be provided by the project team.

The second would be for analysis only of Concepts 2, 24, 29, 32, 33, 34 and any new concepts on flexible pipe.

The third and most promising would be for the immediate design, and prototype manufacture and test of Concept 35. Results could be produced within six months and in the unlikely event they are unfavorable, results from the first two projects described above will have provided a back-up method or methods on which to proceed.

5.3.2 Facility (Drill Stem Research)

The facility for handling the three proposed projects should be an independent engineering group without a normal conflicting product line. It should be groups with some knowledge of the drilling art and with proven mechanical improvising.

5.3.3 Time and Scheduling (Drill Stem Research)

Each of the three projects described in Section 5.3.1 should require about 6 months. Final testing of hardware prototype of Concept 35 in the third project could run this one into an 8 month schedule.

Should it be necessary or advisable to proceed into a second phase of work in projects one and two, 12 months would be required for engineering, prototype manufacture and preliminary field tests.

5.3.4 Costs (Drill Stem Research)

The cost of each of the first and second projects, which is the analyzing phase of rigid and flexible drill rods respectively, is estimated to be about $30,000. If the second phase of either of these projects materializes, then the cost would be about $60,000 and long range budgeting should include a consideration for one such continuing project.

The third project, which is considered ready for engineering design prototype manufacture and field test, will cost approximately:

Engineering	$18,000
Manufacture	40,000
Field Test and Report	15,000
Total	$73,000

5.3.5 Test Plan (Drill Stem Research)

The first two projects are paper studies only and will not have field tests unless Phase II of either project is required. Should Phase II be required, it would be a matter of building the special rod and rod handling equipment to be tested on or with one of the Bureau's rigs in a mine. Any revolutionary new design would require: torque and fatigue tests; test for handling time; tests to check out fluid handling characteristics; tests of abraision effects; and tests of compressive and tensile qualities in long-hole work.

The test plan for the third project would involve a first test with as long a tail pipe as could be accommodated in an open cut mine. Hopefully, such a mine with nearly a thousand feet of exposed cut in a fairly straight line might be found. The tail pipe could be layed along the pit parallel to the high wall. The drill could be bent to attack the face at about 10 degrees as it would in a mine.

Measurements could be made on torque, speed of penetration, effectiveness of fluid cleaning system, wear and security of pipe stuffing boxes, operating characteristics of pipe, effectiveness of circulation system, and speed of pipe handling. When the device has received any mechanical corrections required, it can be taken underground for environmental tests in the real situation.

5.4 HOLE DIRECTION CONTROL

It probably will require a long range research effort by the Bureau to develop hole direction control techniques. Better lateral control, particularly, will be required for an effective methane drainage operation.

The method used by the Bureau's researchers for vertical direction control may be adequate for seams of six feet and less in thickness, which predominate today. This method is simply to stay within the seam by letting the bit deflect from the harder top and bottom. In 6 foot and thinner seams, it is unlikely that more precise vertical control would be of enough benefit to warrant a very elaborate control mechanism by an operating mine. More knowledge needs to be gained on causes and effects on vertical attitude in the event either thicker western seams of the future or other drainage technology demands better control.

The principal directional control effort should be applied to learning more about lateral deviation causes and effects. Most of the pre-mining drainage schemes now call for holes fanned out from the two outside entries in developing coal. As these holes are extended to a thousand feet, the end of the hole may be 170 feet from the edge of the block of coal to be mined immediately. This can put it some 400 feet from the center of the block in the path of the developing entries. Obviously, it could be beneficial if these holes could be directed to be at least parallel or even to intersect that block at some depth.

Some of the fracturing techniques suggested rely on the relatively close spacing of two or more parallel holes which are to be connected by some rupturing process. Naturally, such a system would require rather precise control.

Some knowledge can be gained on directional characteristics of different bits and drilling techniques in the fundamental tests described in Section 5.1.

5.4.1 Investigate Alternatives (Hole Direction Control)

Lateral direction control can be analyzed including such techniques as:

1. Use of whipstocks and existing boring tools.

2. Use of bent subs and in-hole motors.

3. Use of different bit configurations as bits with non-concentric cutters may have a tendency to wander more in one direction than another. Flat bits may wander more than pointed bits.

4. Use of a special bit with directional control built in such as the Battelle-AGA bit shown in Concept 28.

5. Use of an in-hole directional urger similar to the thruster in Concept 4.

This analysis of alternatives also must consider the best methods for continually surveying the direction of the hole. This can be by intermittant surveys with pumped in and withdrawable instruments such as the V.E. Custer tool described in Section 2 or continuously by the Battelle-AGA method described in Section 2.3.4 of this report. The Battelle method will require a drilling system which permits continual electric power transmission to and from the vicinity of the drill bit through the drill pipe. This may not be an insurmountable obstacle with some of the concepts under consideration. For example, the Cullen electric motor idea requires a power source at the bit. The ground storage of a continuous flight of drill rods, as proposed in Concept 35, overcomes one of the electrical power transmittal problems of making connections through many drill stem connections.

After alternatives have been analyzed, then design, manufacture and tests of the various prototypes must be accomplished as Phase II.

5.4.2 Facility (Hole Direction Control)

The facility for conducting Phase I, investigation of alternatives could be an independent laboratory or engineering group with some knowledge of the drill survey or hole direction art. It could be a joint effort including firms with hole surveying expertise such as Eastman Oil Well Surveying or E.V. Custer.

The operational test phase could include the same groups and those who are knowledgeable in whipstocks, bent subs and other directional tools for oil wells. It is believed, however, that this is one of the projects which is best suited for field testing by one of the Bureau of Mines' teams. It is a long range testing project. It must be fitted in with convenience of mining plans to be done effectively. It is just not as good a project to contract out as are some of the others.

5.4.3 Hardware (Hole Direction Control)

The major drilling hardware to be used in this project should be that which has been provided for other tests. The fundamental research drill and/or drills provided for drilling method research can be modified to accept instruments and techniques evolving from this study.

The need for some very special hardware will most certainly evolve from the analysis of alternatives. In other words bent subs for use with in-hole motors may be indicated. Conventional whipstocks are an almost certainty to be needed. Surveying or monitoring instruments will be required. Special bits may need to be designed. The know-how exists to make these special tools and instruments as soon as the problem has been defined.

5.4.4 Time and Scheduling (Hole Direction Control)

The Phase I investigation of alternatives and specifications of a plan should be done by a knowledgeable group within 5 months. Preliminary field tests will require 15 months but this is a program which will require a continuing effort by subsequent jobs. Directional drilling research for this effort is so much in its infancy and is so important that at least five years' effort is envisioned.

5.4.5 Costs (Hole Direction Control)

Phase I, investigation of alternatives and recommendations for immediate action can be accomplished for about $30,000. The first phase of prototype testing will require an expenditure of approximately $100,000.

5.4.6 Test Plan (Hole Direction Control)

The principal drill equipment will be borrowed from those other drill projects for instrumenting reservoirs, testing new drill methods, or drill stem research. This is a continuing program which will extend on beyond most of these projects which hopefully can be turned over to the private sector within about two years.

This means, therefore, that a very careful scheduling program may be required.

As in other projects, much of the preliminary tests can be conducted in open pit mines. Some results will be obtainable through surveys, but even these must be confirmed by ultimate observation of dyed holes as mining progresses.

The directional tools must be tried with various combinations of drill methods. The effects must be measured on penetration rates, hole direction, hole stability, and tool wear.

This is clearly a project in which only the Bureau can schedule in the tests with other tests, using expertise from industry but providing the direction, scheduling and details of purpose as they go.

6.0 CONCLUSIONS, RECOMMENDATIONS AND INVENTION DISCLOSURES

6.1 CONCLUSIONS

1. The Bureau of Mines should conduct research in methods of horizontal drilling.

2. The Bureau's technique for hole direction control in the vertical plane probably will not be significantly advanced by research. That technique is to start the hole straight, then depend on gradual deflection of bit from harder top and bottom.

3. Horizontal or lateral hole direction control can and should be improved through research.

4. There is a lack of knowledge of basic drilling parameters for horizontal holes in coal.

5. Little improvement can be expected in drilling rates by research and are not needed.

6. In-hole motors may be used in this application. Their use will be limited to special applications such as directional control as their maintenance costs will be too high for routine drilling.

7. Drilling economy must be achieved to get industry acceptance.

8. The best way to achieve greater drilling economy is an improvement in the drill system by providing more efficient drill rod handling.

9. Research must provide means of reducing the environmental deterioration such as flooding caused by present drill technology.

10. Better means of accelerating or stimulating gas flow from coal beds can be achieved.

6.2 RECOMMENDATIONS

1. First priority must be given to fundamental basic research as described in Project 1, Section 5.

2. A high priority should be given to research in rod handling, particularly to that described in Concept 35, Section 4.

3. Research for lateral directional control should be started immediately. This will include or be supported by separate projects analyzing such things as in-hole motors with bent subs, whipstocks and surveying techniques.

4. Approximately $250,000 should be budgeted for supported research in this field over a two-year period.

6.3 INVENTION DISCLOSURES

There appear to be five ideas which have evolved from this study which may be patentable. These are:

1. An In-hole Thruster which operates on pressure of drilling fluid on a piston in a cylinder. This is described in Concept 4, Section 4 of this report.

What is claimed that is new is two such thrusters mounted in series. One acts as an anchor for the other so that it can retract and prepare for a new stroke on an in-hole motor.

Valves are opened and closed by the longitudinal motion of the piston which positively set or release the radial wall anchor jacks at the appropriate times.

Other valves in the piston head are opened at the forward end of the stroke causing the housing to become the effective piston so that it advances and lets the piston head return to a rearward position in the housing in preparation for another stroke. At this point, the valves in the piston are closed by the motion and it again becomes an effective piston.

The piston rod in this arrangement acts as a thrust rod on the drill motor and also transmits fluid to that motor to operate it if it is a mud-driven motor, but in any event to clean the hole.

Inventors are:

A. Thomas N. Williamson
318 West Poplar Avenue
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B. Fred L. Martinez
2345 Washington Street
San Francisco, California

C. Joseph D. Hadden
U.S. Bureau of Mines
Mining Research Center
Pittsburgh, Pennsylvania

2. A Coal Seeking Bit is provided for vertically maintaining a hole in horizontal coal beds. This is described in Concept 5, Section 4 of this report.

Several flexible subs or pipe have been invented for vertical holes where considerable tensile loads can be expected. These are all rather complicated mechanical joints.

What is claimed that is new is a rather simple flexible joint for drill pipe consisting of mating longitudinally disposed jaws held together by a surrounding tube of tough rubber or other flexible material.

Inventors are:

A. Thomas N. Williamson
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B. Fred L. Martinez
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3. Hydraulic Slotting for stimulating drainage of methane. This invention is described in Concept 10 of Section 4 of this report.

If all of the vertical section of a coal seam can be connected to a drainage hole at fairly close spacing longitudinally, the drainage rate of flow should be increased substantially.

What is claimed that is new is a sub with radial high pressure water jets blocked during drilling by an internal sleeve held in place by a spring. When hole is finished, a ball can be pumped through the drill pipe which will force the protecting sleeve foward blocking water flow through the bit and opening the radial jets for cutting a vertical slot at any desired position along the hole.

Inventors are:

A. Thomas N. Williamson
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4. Piped Ground Storage of Drill Rod can be provided which will eliminate rod handling during the drilling of a long hole underground. This is described in Concept 35 of Section 4 of this report.

What is claimed that is new is drill rod storage within a pipe in which that storage pipe also becomes a part of the circulating system. The storage pipe is capped at the rear end and is fitted with a stuffing box at the forward end to permit the pipe to be withdrawn.

Connection on the outside of the forward end of the storage pipe to the pump provides circulation through the open ended stored drill rod, thus eliminating the swivel and long trailing rotary hoses.

Inventors are:

A. Thomas N. Williamson
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5. Magazine Storage for Drill Rod can be provided in a compact package for automated handling of drill rod. This is described in Concept 7, Section 4 of this report.

What is claimed that is new is two systems of multiple rod storage chambers that will, through a system of chains and/or hydraulic cylinders, feed individual rods into a drill string as required. This system or systems will also remove rods when coming out of the hole.

Inventors are:

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