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LONGWALL IGNITION SUPPRESSION

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16. Abstract

This report describes the results of a study of longwall ignition hazards and specific suppression systems to minimize each of the major hazards. The major ignition hazards were identified by conducting a literature search and conversing with knowledgeable individuals in the United States mining industry.

Three classes of potential ignition suppression systems are discussed: triggered suppression systems for face ignition, passive suppression systems, and control of ignition hazard in the gob. The triggered suppression systems included protection for the shearer, head and tail gates, welding equipment, and the shearer power cable. Passive systems include improved ventilation and water sprays, and charges in the shearer head. Gob protection can be improved by isolating the gob from working areas and by introducting inerting agents into the gob.

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FOREWORD

This report was prepared by Foster-Miller Associates, Inc., Waltham, Massachusetts, under USBM Contract Number J0357099. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PM and SRC, with Dr. David Burgess acting as the Technical Project Officer. Mrs. Pearl A. Shapert was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period of April 1975 to September 1976. This report was submitted by the authors in September 1976.

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SUMMARY AND CONCLUSIONS

A survey of U. S. and British statistics on the occurrence of ignitions in longwalls and conversations with U. S. mine industry personnel shows that the ignition hazard on the longwall face could become serious as the number of longwalls in this country increases. Even though normal ventilation of the longwall face is much better than ventilation of a continuous mining section and methane concentrations is normally maintained below explosive concentration levels, sudden release of large methane pockets can lead to dangerous methane levels which could ignite and lead to an explosion hazard.

The survey showed that the principal hazards are:

1) Methane ignition at the cutterhead caused by frictional sparking of the cutter teeth with rock.

2) Gob ignition caused by either frictional sparking from secondary roof falls or by spontaneous combustion.

3) Electrical short and arcing caused by failure of the power cable, leading to methane or coal dust ignition.

4) The use of a welding torch during normal maintenance near an unventilated area, such as under the pan line, where methane can accumulate can lead to a methane ignition.

In most cases, because of good ventilation at the face, such methane ignitions do not propagate. However, because of the large amount of coal dust normally present on chocks and other machinery at the face and the absence of rock dusting there is always a definite hazard that the methane ignition could initiate a coal dust explosion. Such an explosion could result in a significant loss of life.

This study has been devoted to developing and evaluating concepts for controlling the ignition hazards defined herein. These control techniques have included systems for preventing ignition as well as systems for sensing and suppressing an ignition once it has occurred. Development programs have been outlined for the most promising concepts. The principal results and conclusions from this study are summarized.

1. Triggered Suppression System for Face Ignition

A. Shearer Mounted Ignition Suppression System

This triggered ignition suppression system is designed to sense an ignition occurring at the cutterhead and to release an instantaneous spray of water behind the cutterhead sufficient to inundate the area and prevent a flame from propagating through. Approximately 8 gallons of water released at a peak flow rate of 5,000 to 10,000 gpm should provide a curtain lasting 50 to 100 milliseconds, long enough for flame quenching.

The system uses water, as it was found to be as effective for this purpose as most other chemical extinguishants. The system can use the same general piping used for the dust control water spray system on the shearer head with some modifications.

Because of the very severe space constraints on the shearer, the primary extinguishant storage, sensor and trigger electronics have to be mounted remotely. The remote sensor views the location of potential ignitions through fiber optic flexible light pipes. This enables sensing of a large area around the cutterhead. Keeping the light pipes clear of coal and operational will be the major problem with this system.

Development of such a system will involve a high risk. However, it is one system which could suppress an ignition at the cutterhead after it occurs. Success will depend on detailed engineering and suitable packaging of the equipment. The necessary system components have been developed.

B. Explosion Barrier at Gates

An exploding container type of triggered barrier system would be placed at the end of the chock line designed to prevent the explosion from propagating up the entries. 4 to 5 cu. ft. of dry chemical extinguishant would be timed to release when the flame reaches the barrier. The same type of optical detector system as with the shearer mounted system could be used, with fiber optics and convenient remote location of electronics. Timing the release of the extinguishant to coincide with the arrival of the flame front will be a major problem with this system. Success will depend on detailed engineering and packaging.

This is a high risk development.

2. Passive Systems for Ignition Prevention at the Cutterhead

A. Sprays for Local Inerting

It is unlikely that sprays could be used for inerting. Estimates indicate that it is very difficult to obtain a high moisture concentration in the air (18 percent by weight) with a fine enough spray required for inerting because of the air entrained by the sprays.

B. Auxiliary Ventilation

The same air moving capability of the sprays can be used for improved face ventilation behind the cutterhead. The Hollow Shaft Ventilator (HSV) is one such concept developed and presently being evaluated by the British. These improved spray systems can be developed to dilute the methane at the cutterhead. Recent work by Foster-Miller Associates for the U. S. Bureau of Mines has shown that face ventilation can be significantly improved with an optimum spray system on a continuous mining machine.

Air jets suitably located along the cowl and diffuser fans such as used with continuous mining machines could be used for auxiliary ventilation of the cutterhead. Results show improved performance over the HSV system.

Work in this area is not presently on-going in the U. S. and it is recommended that such a program be initiated as it could lead to a high payoff at a low development risk. The program should include design features for improved reliability of the spray system, such as non-clogging sprays and interlocks to prevent shearer operation when the spray system is not functioning.

C. Methods to Reduce Frictional Ignition

Modification of the cutter design to reduce cutter speed and make deeper cuts have resulted in a reduction in frictional sparking. Also changing the pick design to use non-incendiary materials can result in a reduction in sparking and cutter ignitions.

Work in this area is presently in progress though not specifically for longwall mining. A design, development and demonstration program to test an improved cutterhead design should be undertaken.

3. Gob Ignition Suppression

The gob represents a major area of concern to the U. S. mine operators surveyed in this study. Conditions in the gob are difficult to predict and control.

Trickle dusting of the gob with a dry chemical extinguishant such as sodium chloride or potassium bicarbonate has been conceived to be one of the primary methods for control of ignition in the gob. Trickle dusting equipment is readily available so that a demonstration program can be conducted relatively easily and at low cost. This represents a low risk effort which is more than likely to provide a tangible benefit.

Salt water spray, directed at the gob from nozzles at the rear of chocks is another possible technique for inerting the gob. However, as with most sprays, achieving a droplet size fine enough to remain in air suspension long enough to achieve a significant distribution in the gob could be a problem. The system appears to be more complicated than dry chemical trickle dusting and should be given secondary consideration at this time.

4. Power Cable Suppressant System

The electrical power cable represents a distributed line source of ignition at the longwall face; arcing could occur at any point along its length. Hence an ignition suppression system for the cable must be distributed along the cable length.

This concept would utilize a modified power cable which contained one or more lengths of tubing in addition to the electrical conductors. The tubing is filled with Halon, fed from a reservoir. Damage to the cable would rupture the tubing, enveloping the failure zone with Halon gas. The release of the suppressant material provides the initial protection and allows the circuit breaker time to trip.

The technology for the manufacture of pressurized gas filled electrical power cables exists and could be applied with some modifications to the specific longwall application. The development of such a self-inerting, incipient failure detecting, electrical power cable system could also have application for the trailing cable of a continuous miner.

5. Self-Inerting Welding Torch

The self-inerting welding torch concept has been developed to protect against the hazard of ignition of a methane pocket from propagating. As conceived, the torch has a canister of Halon which would be released by the sensor sensing the explosion pressure. Because the source of ignition is known, a localized triggered ignition suppression system can be developed. Success depends on detailed engineering and packaging to minimize weight, and assure reliability of operation. It is likely that such a development would have a more general impact on the safety of normal maintenance practice in mines.

6. Miscellaneous

A. Washing of the chocks by sprays suitable mounted on the shearer should help in reducing the hazard from dust accumulated on the chocks by wetting the coal and washing some of it away.

B. Dust scrubbers on the shearer would also reduce the dust hazard. The Bureau of Mines is doing considerable work in this area at the present time.

1. Introduction

1.1 Objective

Extensive preventive measures taken over the years have markedly reduced the danger from fire and explosion in coal mines. Nevertheless, a finite risk of dangerous ignition continues to exist. Fires and explosions, when they occur, are sufficiently costly in their consequences to justify continued intensive efforts aimed at eliminating them. This program is aimed at the conceptual designs of systems and procedures to further reduce the hazard on longwall faces.

Ventilation of longwalls is more positive than in conventional room and pillar mining, since air is swept across the face in relatively unbroken flow.[(1)] However the flow effectiveness may be reduced by leakage to the gob area.[(2)] Obstructions on the face, such as mining machinery, may cause local disruptions in ventilation effectiveness and flow between the face and gob. The possibility of ignition always exists when pure methane is being diluted to under 2 percent by means of ventilation; it must somewhere pass through the ignitable concentration range. Furthermore ventilation may be disrupted temporarily or large pockets of methane released, momentarily allowing the formation of an explosive gas concentration.

Water sprays are helpful in reducing the visible dust level. However, water sprays, even with wetting agents, are not effective against very fine dust particles.[(3, 4, 5)] The finer particles are the most easily ignitable and violently explosive if present in sufficient density.[(6)]

Rock dusting, which is helpful but not always effective in arresting explosions, is impractical on the longwall face.

Existing preventive procedures have therefore been unable to completely eliminate the ignition hazard.

This program is devoted to the development of conceptual designs of ignition suppression or prevention systems to counteract the ignition hazard at the longwall face. The program includes an analysis of the hazard to define potential ignition sources, concepts to suppress ignition in the gob, face and those caused by electrical failure and finally an evaluation of the impact of these concepts on the productivity and safety of the mining cycle.

1.2 Background

1.2.1 Rock Dusting to Limit Explosions

Disastrous explosions, spreading through and engulfing large areas of a mine, were common before 1920. Since that time general rock dusting has become a universal practice. This has served to limit the extent of explosions.[6] Rock dusting has its limitations, however, and has never been absolutely effective. It extinguishes a flame front by absorbing sufficient heat energy to prevent further ignition of coal dust. To be effective in this function the rock dust must be uniformly mixed with the flammable coal dust.

1.2.2 Explosion Actuated Barriers

The introduction of conveyor coal transport in the 1930's provided a path for explosion propagation that could not be protected with rock dust. This led to the development of explosion barriers which drop inert material into the path of an advancing flame front. The barriers are shelves or troughs laden with the inert material. The barrier is made so that it will release its material when disturbed by explosion generated forces. Its operation depends on the shock front preceding the flame front in a propagating explosion, by a roughly predictable distance. The inert material is blown from the barrier and should ideally fill the entire passageway cross section. When the flame front reaches this dispersed cloud it loses enough heat to be extinguished.

Inert materials most commonly used in these unpowered barriers have been rock dust and, in some European countries, water.[7,8]

The explosion actuated barrier must be emplaced a specific distance from the expected ignition source. If too close:

(a) The explosion may not have built up sufficient strength to activate the barrier.

(b) The flame front will follow too quickly behind the shock front and the inert material will not have time to properly disperse.

The minimum distance that such barriers can be placed from an ignition and be effective is determined experimentally and is generally in the order of 50 to 100 yards.[9] Thus if the barrier performs flawlessly, men and equipment in the first 50 to 100 yards will still be exposed to the explosion before it reaches the barrier and is extinguished. Further, the barriers cannot be counted on to extinguish an explosion flame front reliably.[9]

If placed too far from the ignition source, there is too long a time between shock front and flame front and the inert material, having been dispersed, may settle out and be ineffective. The maximum effective distance is a less critical parameter than the minimum distance since it is desirable to arrest the explosion as close to its source as possible.

1.2.3 Triggered, Powered Barriers

In recent times, increasing mechanization of coal mining has resulted in the creation of more and finer dust in mines. As a result, improved methods of protecting against coal dust explosions have been able just to keep up with the increasing hazard. British records, which have been comprehensively kept for a long time, indicate that there has been a decline in serious gas explosions since 1945, largely due to improved ventilation. However there has not been any significant decrease in explosions involving coal dust. Explosion experience in U. S. mines has been very similar to the British experience despite differences in mining methods.[6]

Advances in technology have led to the development of active, triggered barriers which do not rely on explosion forces for their actuation. They sense the flame using high speed thermocouples or radiation detectors, and the signal from the sensor is used to trigger the forced dispersion of an extinguishing agent. Pressurized gas is generally used as a propellant, released on command by a valve or by some form of rupture disc and explosive arrangement. Results with such systems indicate that they can be extremely effective, depending on the type and amount of extinguishant used. (10, 11, 12) As originally conceived, they are useful only as more reliable replacements for the passive barriers. Because they are activated by the flame front they are not sensitive to the variation in time delay between the pressure and flame fronts and can always disperse their extinguishant at the optimal time. However their reaction time is such that they must still be placed some distance away from the point of ignition, 50 yards or more. (12) The long reaction time is due primarily to the limited rate at which a large quantity of extinguishant can be dispersed. A large quantity is necessary to stop a fully developed explosion.

1.2.4 Triggered, Powered Ignition Suppression Systems

Triggered ignition suppression systems provide the ultimate in suppression capability. They can stop an explosion at its point of ignition virtually before it has taken place. This capability is in part a disadvantage, since it requires that one know in advance precisely where an ignition will take place. Specific systems have been developed to suppress ignitions at the cutter head of a continuous mining machine.[13, 14]

In the context of a longwall mining system an ignition can occur from various causes anywhere along the face (though most frequent occurrence is at the cutter head) which may be hundreds of feet long, or it may be initiated in the gob area.[16] Recent developments in triggered, powered ignition suppression systems[13, 14, 15] have been sophisticated and relatively expensive. They are bulky and often specialized to a degree which limits their effectiveness. To date, such systems have not been developed for longwall mining.

2. Ignition and Explosion Hazard in Longwall Mining

2.1 Methane Ignitions in Longwall Mining

2.1.1 Possible Sources of Methane Accumulation in Longwall Mining

There are several possible mechanisms for methane accumulation in a longwall mine:

1) Gas is liberated from fresh face, especially in mining high volatile coal such as the Pittsburgh seam. [3]

2) Gas can accumulate in the gob area under pressure. [1,17]

3) Seepage from the floor can accumulate in enclosed volumes under mining equipment. [1]

4) Methane accumulates by layering in open entries behind the gob. [1]

5) Accumulations of gas can develop in pockets between chocks and roof. [1]

6) Gas is generated by piles of freshly cut coal, particularly high volatile coal. [18]

The relative importance of different methane sources varies among different mines and seams.

2.1.2 Causes and Development of Methane Ignitions

Methane can be ignited by:[19]

1) Spark, frictional or electrical, with at least 0.3 milli-joule energy.

2) A hot surface.

3) An open flame.

Gob fires such as the ones at Pocahontas No. 3 were initiated by frictional sparking of falling roof.[17] Ignitions can also occur due to friction between cutter bits and inclusions in coal, or hard strata.[1,18] Ignitions of electrical origin are generally due to arcing of a faulty circuit, e.g. connectors pulled apart, short circuits, broken cable.[18]

Methane ignitions can develop as incipient explosions if:[19]

1) The gas-air mixture is near stoichiometric, and

2) The ignition takes place in a confined area.

Ignition in an unconfined area, even if stoichiometric, may be relatively slow burning.[20] Experiments in mines have indicated variation in peak gas explosion pressure from 1 psig to 47 psig, depending on the degree of confinement of the ignition, with the same amount and concentration of gas.[19] This mitigating effect of relatively open space around an ignition may help explain why most ignitions on longwall faces, which are less confined than room and pillar entries, do not propagate or ignite coal dust.

The case of methane ignition igniting local coal dust and subsequent developments is described in Section 2.2.

2.1.3 Limitations of Controlled Ventilation for Ignition Suppression

The range of ignitable methane concentration in air is approximately 5 percent to 15 percent, with about 9.5 percent being the stoichiometric and most dangerous mixture.[19] Pure methane is generated by gassy strata, including coal, and is normally diluted to less than 2 percent concentration by means of ventilation. In being diluted, there is inevitably a region where gas passes through the ignitable concentration range. This represents a limitation to ignition suppression by controlled ventilation. Other limitations associated with ventilation in longwall mining are:

1) The gob area is an uncontrollable and non-uniform medium for ventilation flows. Channeling of ventilation within the gob, combined with a natural methane concentration gradient around the gob perimeter, may produce an area up to several square miles with ignition potential.[21]

2) Ventilation directly under the cutter head is generally poor. However, small ignitions at the cutter head generally die out and do not propagate if ventilation around the cutter head is good, coal fines are wet, and suspended dust is minimized.[1]

3) Ventilation is subject to local disruption at the face due to mining machinery and the nearby semi-open space of the gob.[2]

4) Methane can accumulate in pockets at the roof or under machinery, out of the direct path of ventilation flows.[1,19]

Thus, though normal ventilation in longwall mining is much better than with room and pillar type mining, a potential ignition and explosive hazard exists. Statistics for such an ignition hazard are provided in Section 2.3.

2.2 Coal Dust Ignitions

Coal dust is the major fire and explosion threat in underground mining.[3] Ignition of coal dust may result in fire or explosion, depending on conditions discussed below. Coal fines may accumulate in the following locations in a longwall operation:[1]

1) On chocks and other machinery, as float dust.

2) In gob, as float dust.

3) On or under conveyors.

4) Along face.

2.2.1 Coal Dust Fires

Coal dust fires can be started virtually anywhere there is coal dust. In 1973, a typical year, there were 51 recorded fires in British mines. Of these, 36 occured at or near a working face. Major causes were:[18]

1) 24 fires ignited by frictional heating of mechanical equipment. This includes bad bearings, excessive friction due to poor maintenance, and hot conveyor brakes.

2) 12 fires ignited by faulty electrical equipment.

Experience in U.S. mines is similar.[16] The statistics indicate that the major causes of coal dust fires are associated with conveyors or other powered mine machinery. These potential fire hazards are located continuously along the entire length of a longwall face.

2.2.2 Coal Dust Explosions

Several conditions must exist simultaneously for coal dust to ignite explosively: [16]

1) There must be an intense source of heat initiating the combustion.

2) A large portion of the dust must be in the form of fines.

3) There must be very little inert material mixed with the coal dust.

4) There must be a high concentration of airborne dust, or,

5) Settled dust must be readily dispersable, and raised into suspension by the source of ignition.

A hot surface, such as a bad bearing, may cause a coal dust fire but not an explosion. Some kind of spark or flame is necessary for explosive ignition. [16] In principle, any flame or spark with sufficient energy including a gas ignition can cause a coal dust explosion. Coal dust can ignite explosively without gas. [3] In practice, however, gas ignitions are the most likely cause of a coal dust explosion. [22] At or near the face a gas ignition of less than 15 ft^3 methane can cause explosive ignition in coal dust. [6,23]

As a general rule, a large portion of coal fines must be smaller than 240μ for an explosive ignition to take place. Finer coal dust results in easier ignition and more violent explosion.

Fineness of coals in U. S. mines is well into the explosive range. Fifty percent of float dust on ribs and elevated surfaces and 40 percent of dust on the floors of return airways, is below 74μ.[24] Fortunately, average coal size along the face and conveyors is not this fine. However, the advance of chocks and passage of mine machinery tends to produce more fines in these areas, as does the grinding of chocks against roof coal. Float dust on chocks and machinery is very fine along the face as well as in return airways.[1]

The potential hazard for a coal dust explosion at a longwall face is extremely high due to the possibility of a large accumulation of fines on equipment surfaces, such as the chocks and the shearer. Rock dusting used in conventional room and pillar type mining is not used on a longwall face; therefore that inert material is not available to suppress a coal dust explosion from propagating. Proper dust control with a longwall shearer is a difficult problem which is receiving considerable attention at the present time. The use of dust scrubbers on longwall shearers should help in reducing dust accumulation on equipment and consequently the dust explosion hazard.

2.3 Survey of Ignition Hazard in Longwall Mining

A limited survey of available information and statistics and telephone interviews with mining personnel involved in longwall mining was conducted to assess the magnitude of the ignition hazard problem in U. S. longwall mines. Because the use of longwalls in the U. S. is relatively recent, U. S. experience has been very limited Hence, British statistics were reviewed, to obtain an estimate of the hazard that may develop with extensive use of longwall mining in the U. S.

2.3.1 Statistical Information on Ignition Hazard

2.3.1.1 Reported Data on Ignition in U.S. Longwall Faces

Statistics compiled by HSAC in Denver for the years 1972 through 1974 indicate 14 ignitions in U.S. coal mines that resulted in injury in the three year period. All 14 ignitions, resulting in injury, on U.S. longwalls in that period. Statistics from 1971 and earlier were not available.

Information provided by Mr. J. Nagy of MESA at Bruceton, Pennsylvania indicates two frictional ignitions in caved areas, which resulted in gob fires.

2.3.1.2 Ignitions on U.S. Longwalls, Described in Conversations With Coal Industry Personnel

Discussion with coal industry personnel are detailed in Appendix A; results are summarized here.

1) Fire in lead entry, which spread toward face.

1) Electrical insulation fire in machine at headgate. Coal or gas were not involved.

1) Small dust explosion at face, due to cloud raised by roof fall. Explosion fortunately did not propagate far.

3) Gob fires. Exact cause unknown. Spontaneous combustion or frictional ignition are among possible causes.

1) Methane pop under face conveyor.

2) Methane pops at cutter head.

Total identified: nine ignitions on U.S. longwalls since 1971.

2.3.1.3 Recent British Experience

This section is based on statistics in reference (18), with additional information provided by Mr. D. Wilde of SMRE.

Very few fires occur on the face in a longwall mining operation. Typically over half of all fires occur in intake airways; 20 to 25 percent in return airways, 10-15 percent in surface facilities, and less than 10 percent occur at or near the face.

There were 18 explosive ignitions on British longwalls in 1973. Of these, 17 were caused by frictional ignition of methane at cutter heads. There was one fire at the face of a British mine in 1973. It was caused by arcing of a defective cable.

Also in 1973 there were two fires in chock hydraulic supply pumps due to lubrication failures. These pumps are often classified as face equipment, though not physically located at the face.

While these fires in 1973 are typical, there have been certain other types of fires which are less common. For example, in 1971 there was a fire caused by frictional ignition at a cutting machine.

2.3.2 Face Ignition

Friction between the cutters and rock is the most frequent single cause of ignitions at the face area of a longwall. In 1973, 17 ignitions occurred at the cutter head of longwall mining machines in British mines[(18)] and in 1974 there were 16 such ignitions.[(25)] They now appear to be occurring at an average rate of about one per month.[(26)] At least two ignitions at shearer drums are known to have occurred in U.S. longwall mines which employ essentially the same kind of equipment as those in Britain. In the great majority of cases these ignitions are harmless, but they have the potential to ignite methane or coal dust and propagate explosively.

2.1.3 Positive Displacement Metering Systems

The foam component metering system is shown in Figure 10. The heart of the system is a high pressure, variable displacement, radial piston, Bosch pump driven by a 5 horsepower electric motor. Boost pressure to the Bosch pump is supplied by the component circulation pump which circulates each component through the temperature conditioning system. A positive displacement flowmeter is plumbed to the low pressure inlet of the Bosch pump. The digital readout for the flowmeter is located on the wall behind the Bosch pump. The large crank wheel on top of the Bosch pump changes the effective displacement of the Bosch pump and can be adjusted continuously while it is running. The operator adjusts the Bosch pump setting while looking at the flowmeter readout. The crank wheel dial calibration provides a check on the set flow rate.

Also visible in Figure 10 is the pressure gauge on the output of the Bosch pump and a pressure switch that is connected to a safety control circuit. The safety circuit will shut down the Bosch pump and switch all metering pumps from dispense mode to recirculate mode if an overpressure condition arises. This will prevent damage to hoses or critical downhole components in the event of a plug. The temperature controller with its readout is visible on the back of the temperature conditioning package.

The metering pumps for the catalyst and blowing agent are mounted below their respective storage tanks. The catalyst pump, shown in Figure 11, is a Zenith gear pump which is driven by a variable speed DC motor. A rotometer, visible in the photograph, is placed on the inlet to the pump. A pressure gauge and pressure switch are included in the outlet piping of the Zenith pump. The blowing agent is metered with a high pressure, variable displacement, piston actuated, diaphragm Lapp pump shown in Figure 12. The output of the pulsafeeder

Such frictional ignition of methane under the cutter drum is caused by friction of the cutter picks on rock or hard inclusions leaving a trail of extremely high temperature "hot streaks" on the rock surface. This, rather than the spectacular sparking which sometimes occurs, ignites the methane-air mixture.[27]

These cutter-induced ignitions generally self-extinguish due to a fortuitous combination of factors:

a) Face ventilation is sufficient so that methane concentration surrounding the cutter is too low for propagation of a methane explosion.

b) Nearby coal fines are too wet or coarse, or both, to be ignited by the methane flash.

c) Suspended coal around the cutter does not contain a sufficient density of fines to produce coal dust ignition.

These ignitions are potentially hazardous and are cause for concern. Methane can be released from the face at instantaneous rates of several hundred CFM.[28] While such high liberation rates are transient, due to cutting into local gas pockets, they may temporarily overwhelm the capacity of face ventilation and create a hazardous methane concentration beyond the immediate vicinity of the cutter. A methane ignition of any significant size has the potential to ignite coal fines on the floor or on nearby machinery.

Ignitions can and do occur anywhere along the face, though not as frequently as at the cutter. Typically, ignitions are due to (see Appendix A):

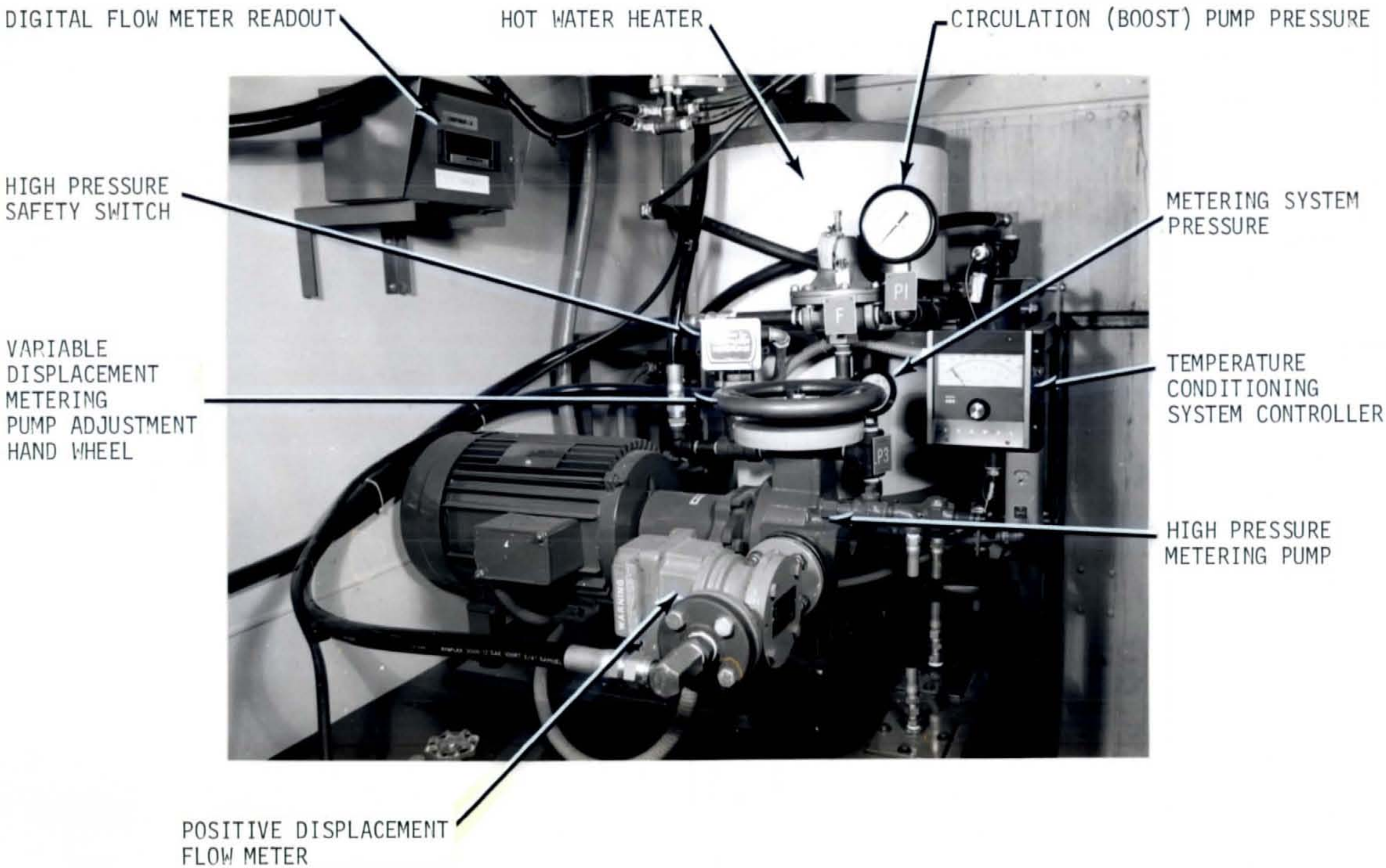

Figure 10. Foam Component Metering System

a) Methane accumulations under the pan line.

b) Electrical damage or fault.

c) Other "freak" occurrences, such as mishaps in welding operations.

The nature of freak occurrences is by definition difficult to predict. However it is predictable that they do occasionally occur and can lead to potentially serious ignitions. The results of a sample survey of U. S. mine operators reported in Appendix A support these conclusions.

2.3.3 Gob Ignitions

Gob ignitions are more likely to occur in coal seams where the overlying strata are very gassy, for example, in the Pochahontas seam. Drainage holes to Pocahontas No. 3 produce up to 7,000,000 ft^3 of methane per day, from strata below 800 ft. The nearby Beatrice mine produces up to 16,000,000 ft^3 per day. Mines in the area are from about 1,400 to 2,600 ft deep.(17) The major ignition hazard in these mines is therefore in the caved areas, after mining. Pocahontas No. 3 has had two recent gob fires, in separate panels.

The survey of U. S. longwall mining personnel itemized in Appendix A indicate their greatest concern to be the gob. It is inaccessible and conditions inside are difficult to control. There have been several gob fires in U. S. longwall mines caused by frictional heating due to roof falls or spontaneous combustion. A brief summary of the results of Appendix A follows.

1) Regulations, requiring methane concentration under 2 percent in all

8-180

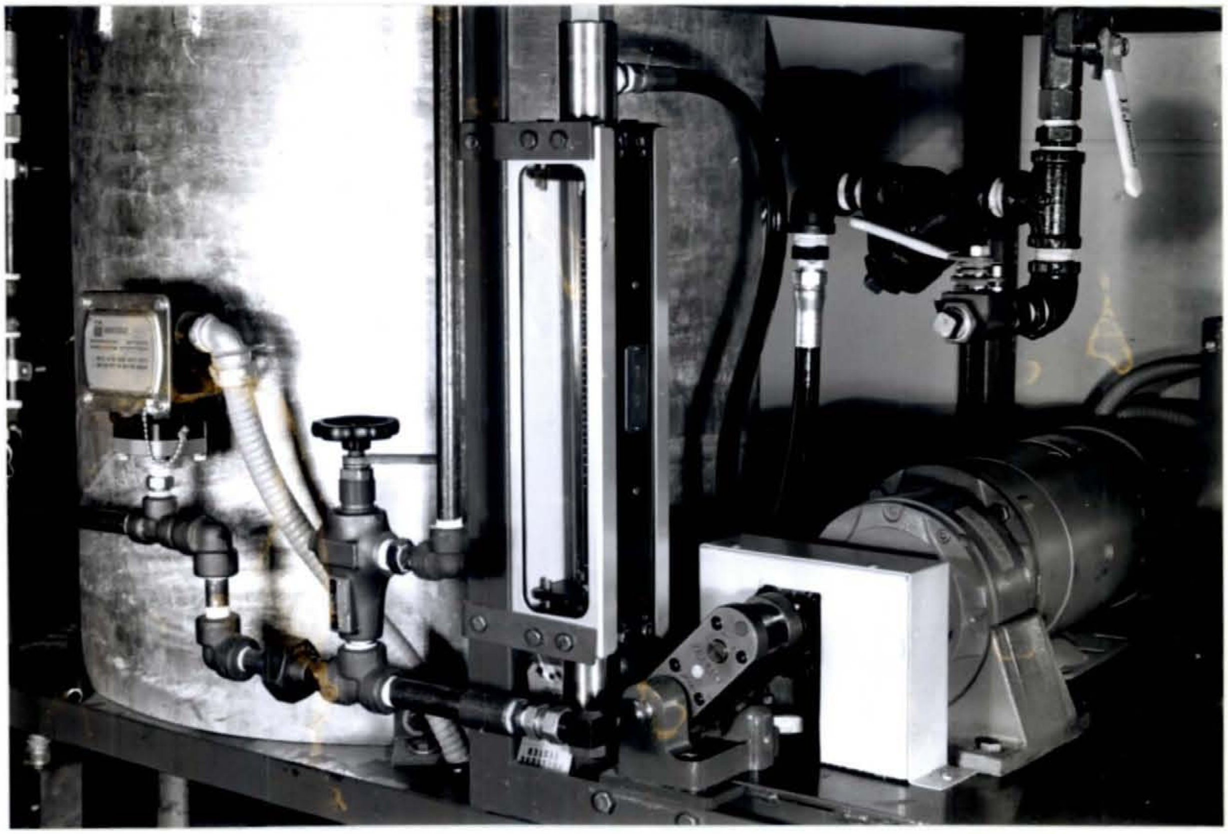

Figure 11. Catalyst Metering Pump

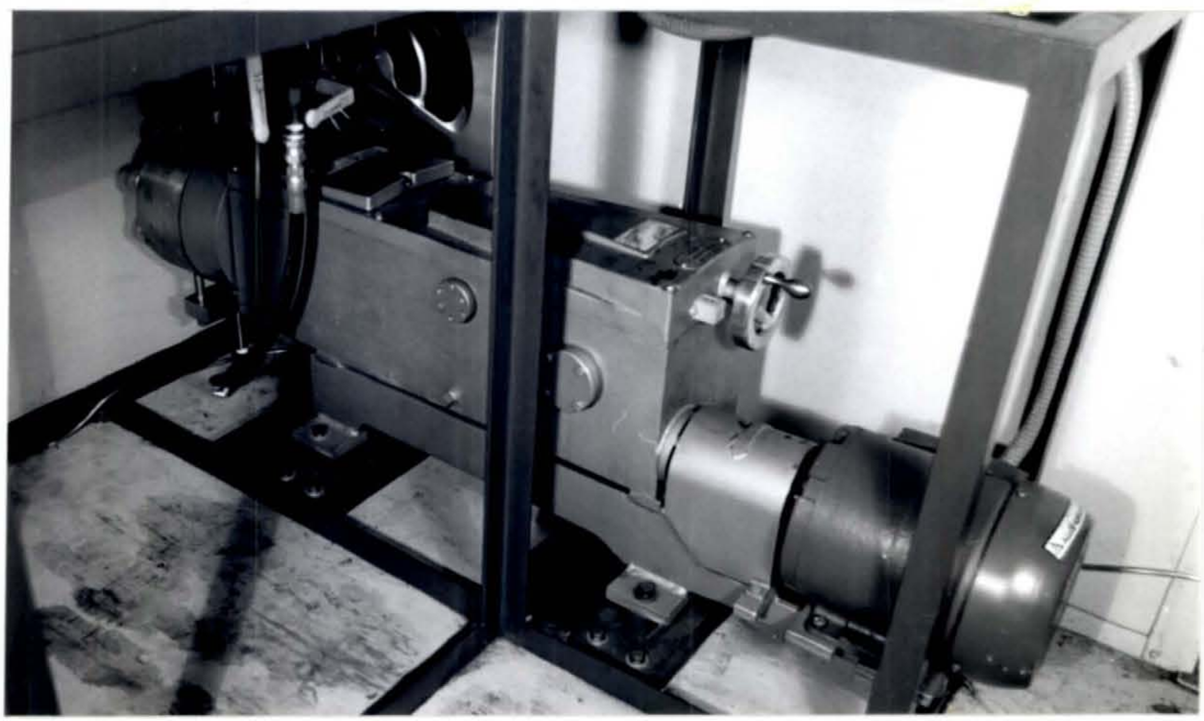

Figure 12. Blowing Agent Metering Pump

bleeder passages, aggravate the gob hazard. In diluting to this level, large portions of the gob contain methane in ignitable concentration. It might be preferable to develop a controlled ventilating system that extracts methane from the gob at over the ignitable concentration, and dilutes it at a controlled locality.

2) Vertical methane drainage through boreholes to the surface is a necessity in mines with gassy gobs. Well regulated division of ventilation flows to face and gob areas would allow better methane control within the gob as well as around it. Some means of inerting the gob, or at least reducing its flammability, would be helpful if it could be made practical.

3) Gob ventilation and peripheral bleed-off as practiced cannot make the gob area immune to ignition. Channeling of ventilating air within the gob may produce large areas of methane concentration gradient through the ignitable range, in addition to the perimeter area. A gassy gob area, properly ventilated, may contain millions of cubic feet of ignitable methane-air mixture.

pump is delivered to a static mixer where it is blended with the B component (polyol). The output of the Lapp pump also contains a safety pressure switch.

2.1.4 Mixing System for B Component and Blowing Agent

The mixing head and static mixer that make up the mixing system for the B component and blowing agent are shown in Figure 13. They are mounted on the ceiling of the trailer. Also visible in Figure 13 is a valve that will direct solvent and compressed air into the B component line to purge the hose line after a foaming operation.

2.1.5 Solvent Pumping and Automatic Flush System

The variable displacement pump for the solvent is shown in Figure 14 mounted below the solvent storage tank. This is the same type pump as used for the blowing agent, but with its pressure rating downgraded to 350 psi. The output of this pump is used to fill the hydraulic control lines which flow into the downhole package, to purge the component lines after a foaming operation is complete, and to supply the solvent flushing system.

The solvent flushing system will automatically sequence a flush cycle by cycling solvent with high pressure nitrogen to the mixing system in the downhole package. The complete flush cycle can be adjusted up to an 8-minute flush. The solvent is on for 20 seconds and off for 10 seconds during the flush cycle. The pressure to dispense the flushing agent is provided by nitrogen pressure in the accumulator, giving a flush capability even if electrical power is lost. Sequencing in the automatic solvent flush cycle is provided by pneumatic logic driven by compressed nitrogen. A photograph of the solvent flushing system is shown in Figure 15.

4) Degasification via surface boreholes permits better control of methane buildup in previously inaccessible gob areas. Methane is drained, with drillholes from the surface, at almost 100 percent concentration. This is in addition to normal gob ventilation. The only significant region where an ignitable concentration exists is therefore around the fringes of the gob.

2.3.4 Electrical Ignition

Fires are often electrical in origin. In particular, the most frequent cause of electrical fires is damage to cables supplying power to face machinery.

Ignitions originating from damaged power cables have occurred regularly in British longwell mines[25] and at least once in a longeall mine in the U. S. A. (see Appendix A for relevant experience). Since U. S. longwalls utilize essentially the same kind of equipment, the same type of hazard is to be expected. Arcing of damaged cables may cause ignition of methane or coal dust leading to localized fires or explosions. Ground fault protection of modern day cables has resulted in a significant reduction in the hazard. Each current carrying conductor in the shearer power cable is provided with a protective braided shield and the cables' ground wire will trip the circuit breaker and de-energize the current carrying conductors. Thus, theoretically in case a cable is cut, the braided shield would be cut first, tripping the circuit breaker prior to breaking of the live circuit. However, due to the long time delays involved in circuit breaker operation up to 100 m-sec this type of protection may not be always adequate to suppress the initial arc from occurring.

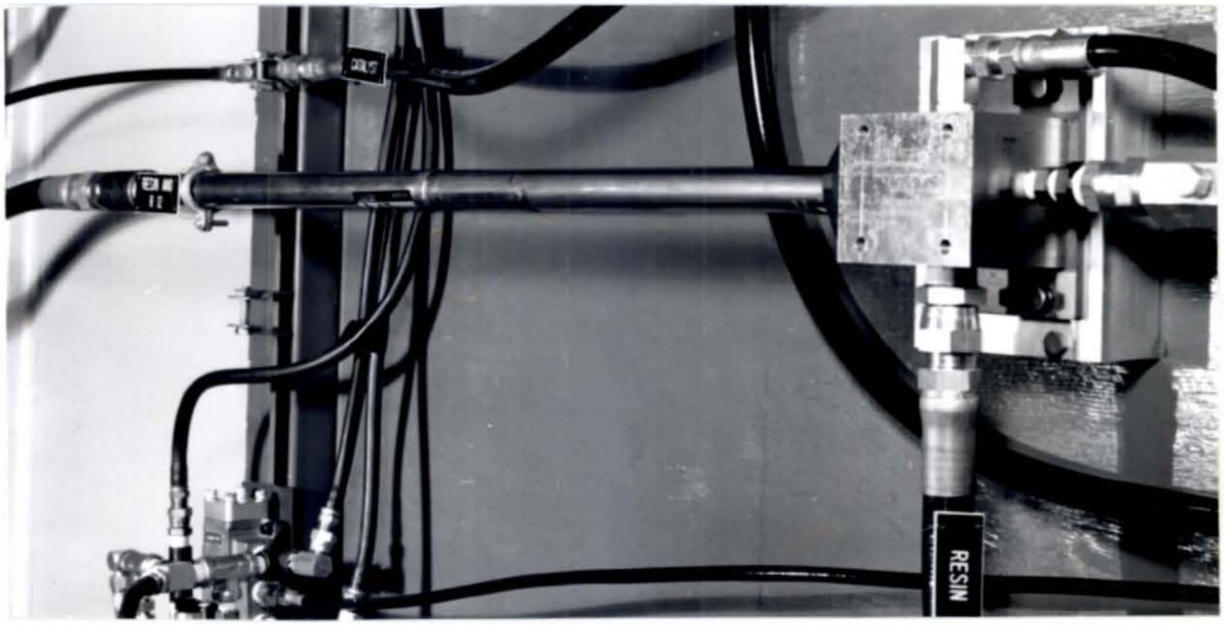

Figure 13. Mixing System for Blending the Blowing Agent with the B Component of the Foam

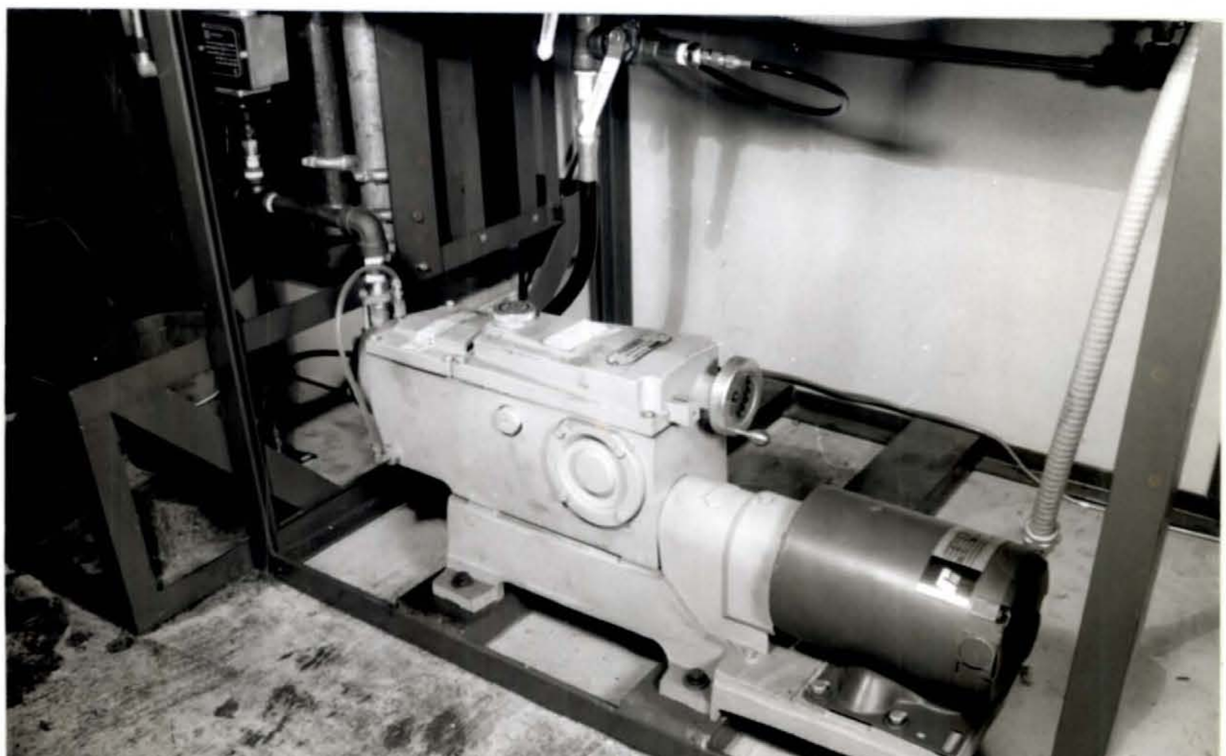

Figure 14. Solvent Metering Pump

In many other cases because of the long length of cables involved and the large impedance drops in the lines, a short circuit may not result in a significant increase in the current. In this case arcing would occur but the circuit breaker would stay closed. This type of a failure might be protected by the ground fault protection system.

In summary, it can be stated that there is no absolute fail-safe way of preventing the occurrence of an arc due to cable shorting. An improved braided shield system, or even thicker and heavier insulation will help to reduce the risk, however, an additional suppressant system would appear helpful in providing protection against the possibility of an arc initiated fire or explosion.

2.3.5 Miscellaneous Ignitions

One small explosion occurred when falling roof behind the chock line raised a dust cloud while maintenance workers were using a cutting torch. The explosion propagated only about 100 feet and there were no fatalities.

One mine reported a minor ignition in their longwall, a "pop" under a conveyor. Methane accumulated there due to seepage from the floor and was ignited, during a maintenance shift, by a welding torch. There was no propagation. The potential hazard was corrected by cutting ventilation and drainage holes at the top of the volume.

2.4 Summary of Critical Locations for Ignitions and Ignition Protection on a Longwall Face

In a normally operating longwall mine, with adequate ventilation, the most serious hazard of explosive ignition exists at the cutter head. Gas ignition there can potentially ignite coal fines on the floor or face, or float dust on chocks and other machinery. Other, less critical explosion hazards are:

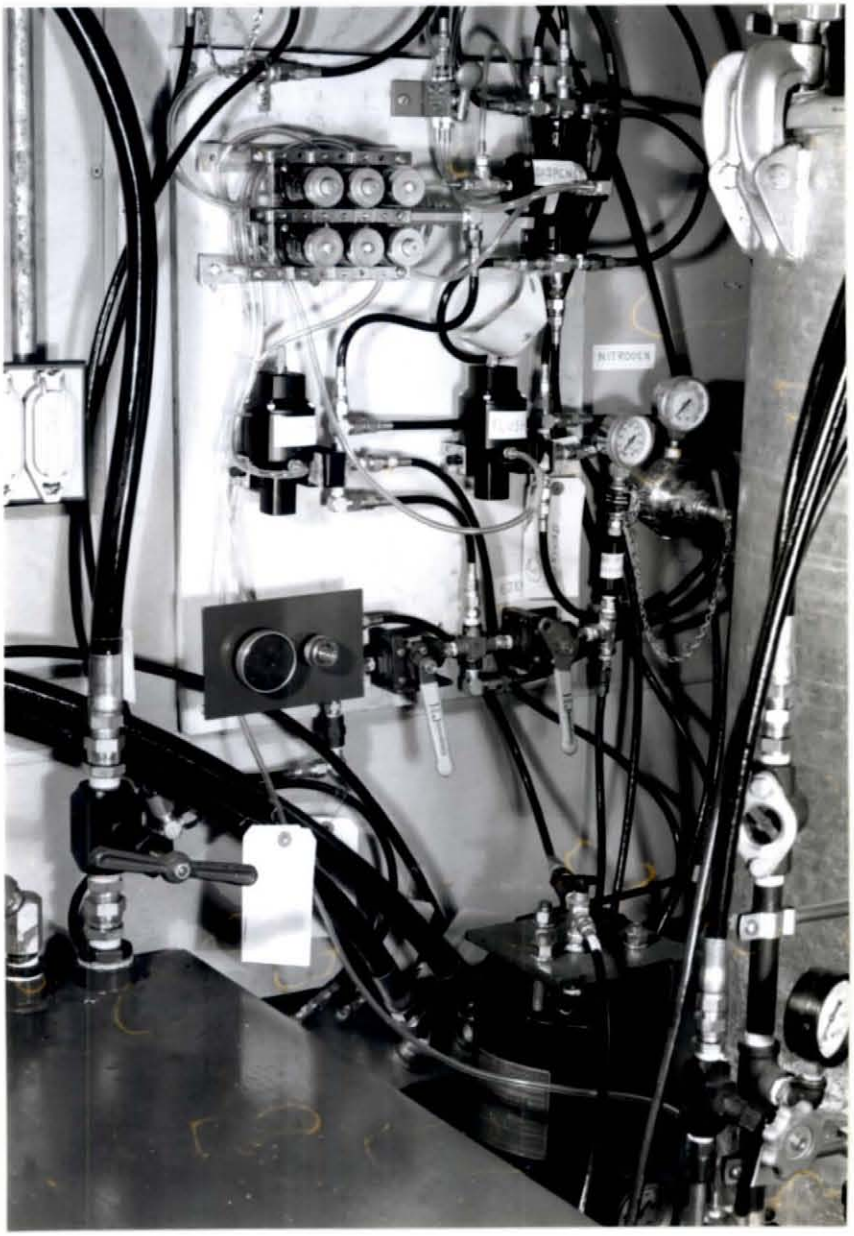

Figure 15. Automatic Solvent Flush System

1) Wherever gas may accumulate in closed volumes under machinery, cut off from ventilation flows, a spark or flame, such as a carelessly used welding torch, can cause ignition. Such trapped spaces should be eliminated, if possible.

2) Wherever faulty electrical equipment may arc and ignite coal dust directly. This is in essence anywhere on the longwall.

3) In the gob, where float dust may create the potential for explosion. Statistically, however, this has not proven to be a major hazard. The gob may act as a packed bed in dissipating explosion force and absorbing heat from incipient explosions. As a result, fire in the gob is a greater hazard than explosion.

If there is a failure of ventilation the entire longwall and adjoining passages may be explosion hazards.

Probable locations for non-explosive fire are:

1) Anywhere along the face. Local hotspots on machinery may ignite coal fires. Hotspots may be caused by electrical or mechanical malfunction, or by conveyor brakes. Arcing at faulty cable or equipment can ignite coal fines non-explosively. Coal fines accumulate everywhere along the face; e.g., on or under conveyors, on the floor.

2.1.6 System Control Panel

The complete system control panel is shown in Figure 16. On the left panel is the main power on-off switch and the control buttons to start the A and B component pumping loops. On the right hand panel are three on-off buttons to control catalyst, blowing agent, and solvent pumps; speed adjustment to the catalyst pump motor; pump overpressure alarm indicators; and master dispense control button. An audible alarm is included with the pump overpressure safety circuit.

Inside the control panel are all motor starters, the 110 volt transformer, all control relays, the DC motor controller, and the digital flow meter signal processing units.

2.2 Deployment System

The deployment system is composed of six major subsystems. These are:

- Hydraulic power supply
- Hydraulic crane
- Hydraulic winch
- Hydraulically driven hose take-up reel
- Skid and outriggers
- Hose bundle and support clamps.

A picture of the complete system is shown in Figure 17. Subsystems are described in the following sections.

2.2.1 Hydraulic Power Supply

Two independent sources of power are available to operate the deployment system. The system shown in Figure 18 is driven by a 4 cylinder gasoline engine, while the system in

2) In the gob. Gas may be ignited by frictional sparks from falling rock. Fire may be sustained by gas, float dust and head coal left in the gob.

Based on the above, explosive ignition protection should be provided at least:

1) At or around the cutter head.

2) At the ends of the face, or at intervals along the face defining "blocks" of protection.

Although the threat of an explosion originating in the gob is not a major one, protection may be provided:

3) To contain explosion effects in the gob area and prevent propagation to the face. True quick-reaction ignition suppression in the gob is not practical.

Protection against non-explosive fires should be available everywhere on the face and along conveyor lines. However, automatic reaction in milliseconds is not required, and equipment to provide this protection may be less sophisticated and expensive.

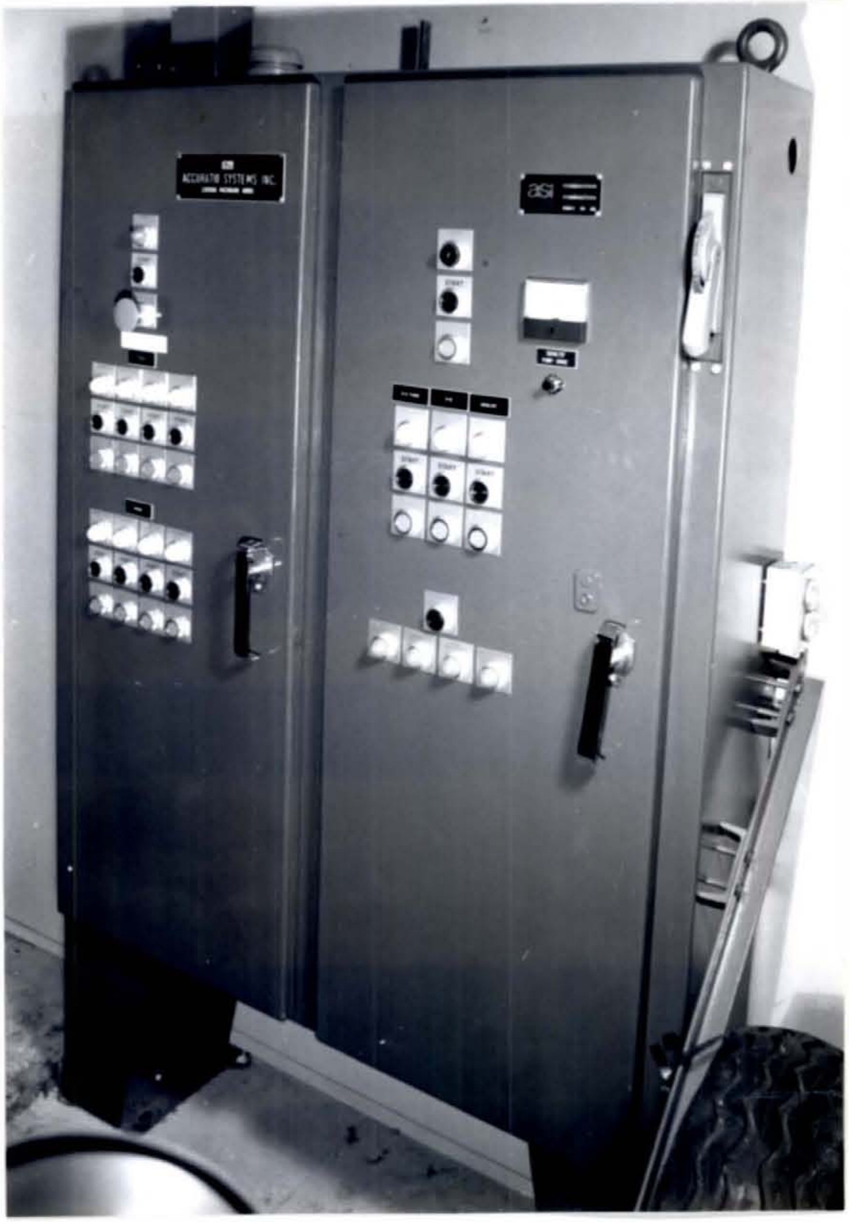

Figure 16. Control Panel

3. General Discussion of Ignition Suppression and Prevention in Longwall Mining

3.1 General Ignition Suppression Techniques

Combustion can be extinguished or prevented by the following means:[29]

1) Remove fuel

2) Remove oxygen

3) Remove heat energy

4) Interfere with chemical reaction of combustion.

Removing fuel is difficult once an ignition has taken place and is more properly a preventive measure. Gas is removed by ventilation, as much as possible. Means of binding coal fines with pastes or water,[6] or salts,[30] have been proposed. Such binding would help to prevent dust being dispersed and forming an explosive cloud.

Removal of oxygen from a fuel smothers flame. CO_2, stored under pressure as liquid and released as a gas, has been used for this purpose. Combustion is effectively stopped if enough CO_2 is added to comprise 30 percent or more of the atmosphere locally. In this quantity the CO_2 acts also as a coolant, since the gas is cold when released. Foams, or water with foaming agents such as "Light Water",[31] are very effective in extinguishing fires by smothering, but are not appropriate against an explosive ignition.

Removal of heat by putting inert material in the flame path has been the most common way of suppressing combustion. Rock dust functions in this manner, as does water. Dry chemical, such as

Figure 17. Froth Foam Deployment System

ABC, normally extinguishes flame by chemical action in part, as discussed below. However, when used for ignition suppression and exposed to flame only for milliseconds, it appears to function primarily as a heat absorber.[14]

Some materials are used to extinguish flame primarily by chemical action. The dry chemical extinguishing agents are in this category as normally used. When exposed to high temperature they liberate inert vapors.[32] Halon extinguishants also disrupt combustion chemically. When exposed to high temperature they form decomposition products which preferentially combine with intermediates in the combustion process.[33]

Both dry chemical[13, 14] and Halon[15] have been used effectively in extinguishing incipient explosions. Water is also known to be effective in suppressing ignitions.[7, 18, 34]

3.2 Classes of Ignition Suppression Concepts

Approaches to reducing the ignition hazard on longwalls are categorized in three classes:

1) Passive suppression measures.

2) Triggered, explosion actuated systems.

3) Triggered, powered systems.

Passive measures are equipment or procedures intended to prevent or extinguish ignitions without responding to the occurrence of ignitions. Ventilation and water sprays are common examples of passive measures. Section 5 describes several passive appraoches to ignition protection at the cutter head and Section 6 describes concepts for passive suppression of gob ignition.

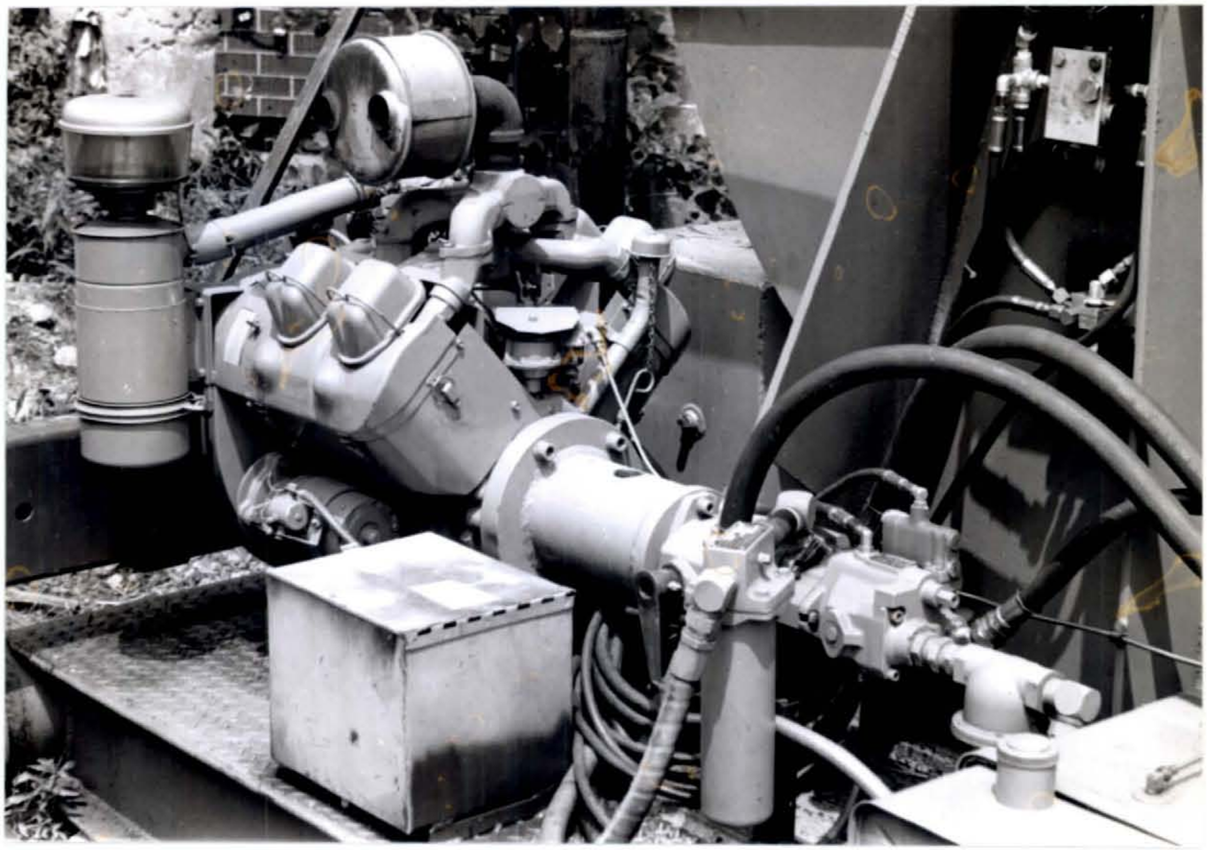

Figure 18. Deployment System Power Supply, Gasoline System

Figure 19 is powered by a 40 horsepower explosion-proof electric motor. Both power sources are coupled to two tandem mounted hydraulic pumps. One hydraulic pump is a pressure compensated variable volume pump used to power the hose take-up reel and the crane. The second pump is an uncompensated variable volume, reversible output pump used to drive the hydraulic winch.

The hydraulic reservoir is common to both hydraulic pumps systems. The supply lines and return line to all hydraulic systems are connected to the pump systems with quick disconnect couplings. The hydraulic hoses are simply disconnected and moved to the other pump system when the mode of operation is changed.

Triggered systems release an extinguishing agent in response to the occurrence of an ignition. In explosion-actuated systems, release and distribution of the extinguishant is accomplished by explosion generated forces. Powered systems distribute their extinguishant with a propellant upon receiving a signal from an explosion sensor, and are faster and more reliable. Triggered systems are discussed in Section 4.

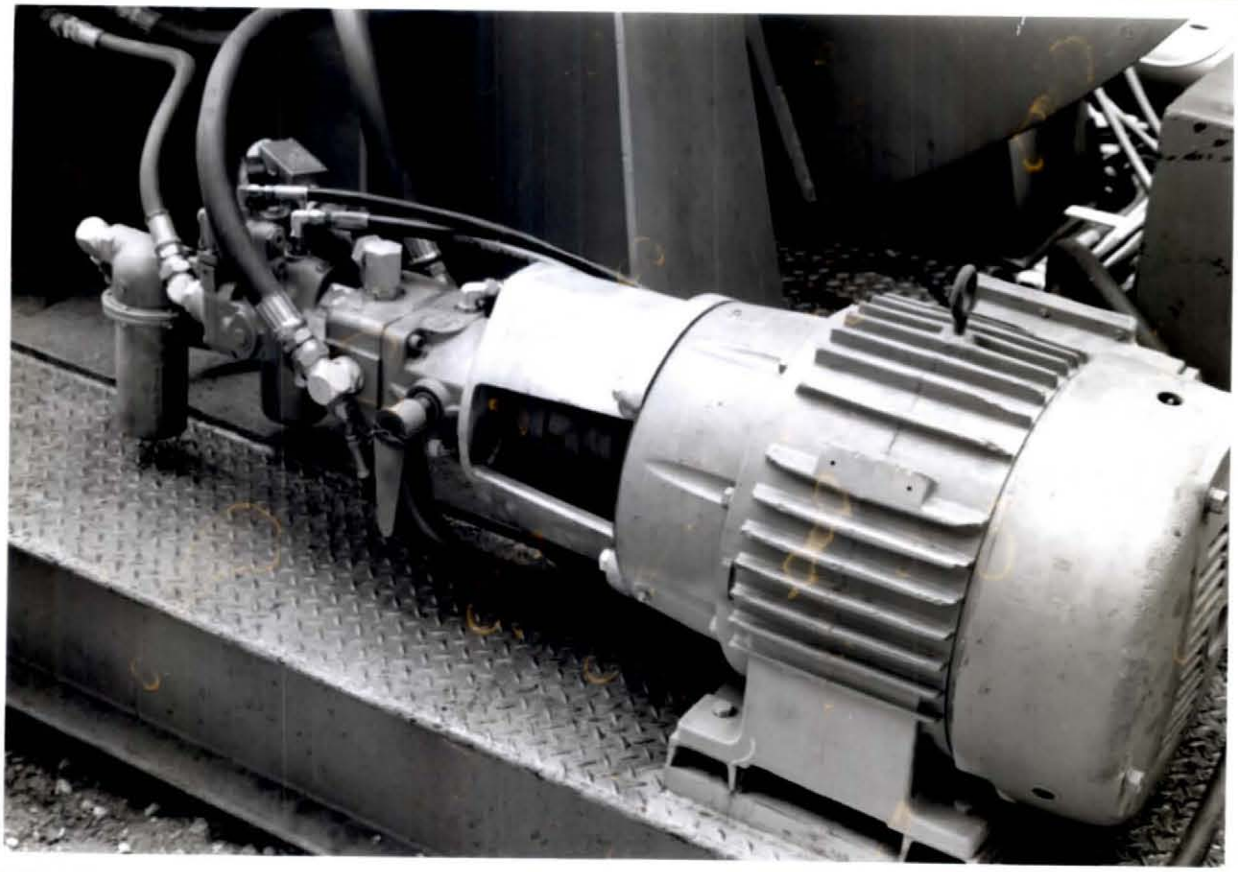

Figure 19. Deployment System Power Supply, Electric System

2.2.2 Hydraulic Crane

The deployment system crane is pictured in Figure 20. It is hydraulically driven for boom lift, boom extension, and boom rotation. The general capabilities of the crane include:

- 370 degree boom rotation
- Boom lift from -40 to +85 degrees
- Side reach of 26 feet
- Maximum height of 35 feet

4. Triggered Suppression Systems for Face Ignitions in Longwalls

4.1 General Description of Triggered Suppression Systems

The nature and extent of the face ignition hazard in longwall mining was defined in Section 2.3 of this report. This section describes the development of triggered suppression systems which respond actively to the occurrence of an ignition by dispensing an extinguishing agent directly into the flame. By contrast, other passive systems which operate continuously and are designed to either prevent or automatically quench an ignition are described in Section 6.

The operation of a triggered suppression system is illustrated schematically in Figure 1. These systems include:

(a) An ignition sensor to provide a trigger signal;

(b) An actuator to dispense extinguishant upon receipt of the command signal;

(c) An extinguishant agent which is dispensed to suppress the ignition.

In the context of a longwall face, two types of triggered suppression system are envisoned.

(a) Explosion barriers. This type of suppression system is intended to prevent propagation of an explosion beyond its location in a passageway. It does not prevent explosions but limits them. An explosion which may initiate anywhere along the face, or in the gob, can thus be limited by barriers placed around the face area.

Figure 20. Deployment System Hydraulic Crane

- Lift capacity of 14,000 pounds at 6 foot radius and 3,000 pounds at 26 foot radius
- Dual controls.

The crane has a modified boom to accommodate two sheaves with 20 inch pitch diameter. One sheave is for the wire rope; the other handles the foam material hose bundle.

2.2.3 Hydraulic Winch

The hydraulic winch provides the power required to raise and lower the downhole package and the hose bundle. It was designed to hold 1600 feet of 1/2-inch wire rope. The winch is pictured in Figure 21, mounted on the aft end of the crane boom.

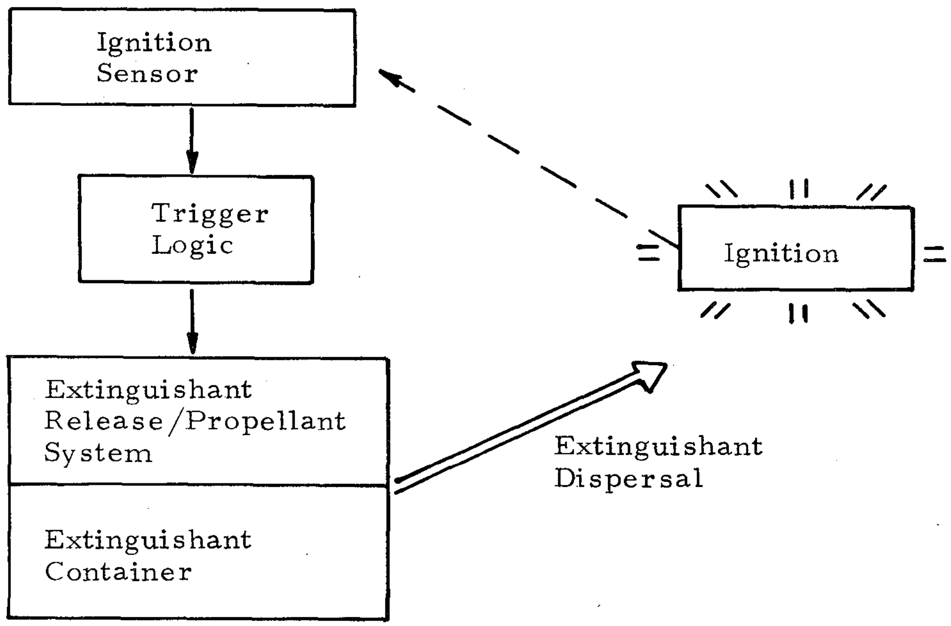

Figure 1 - Schematic of Powered, Triggered Suppression System Operation

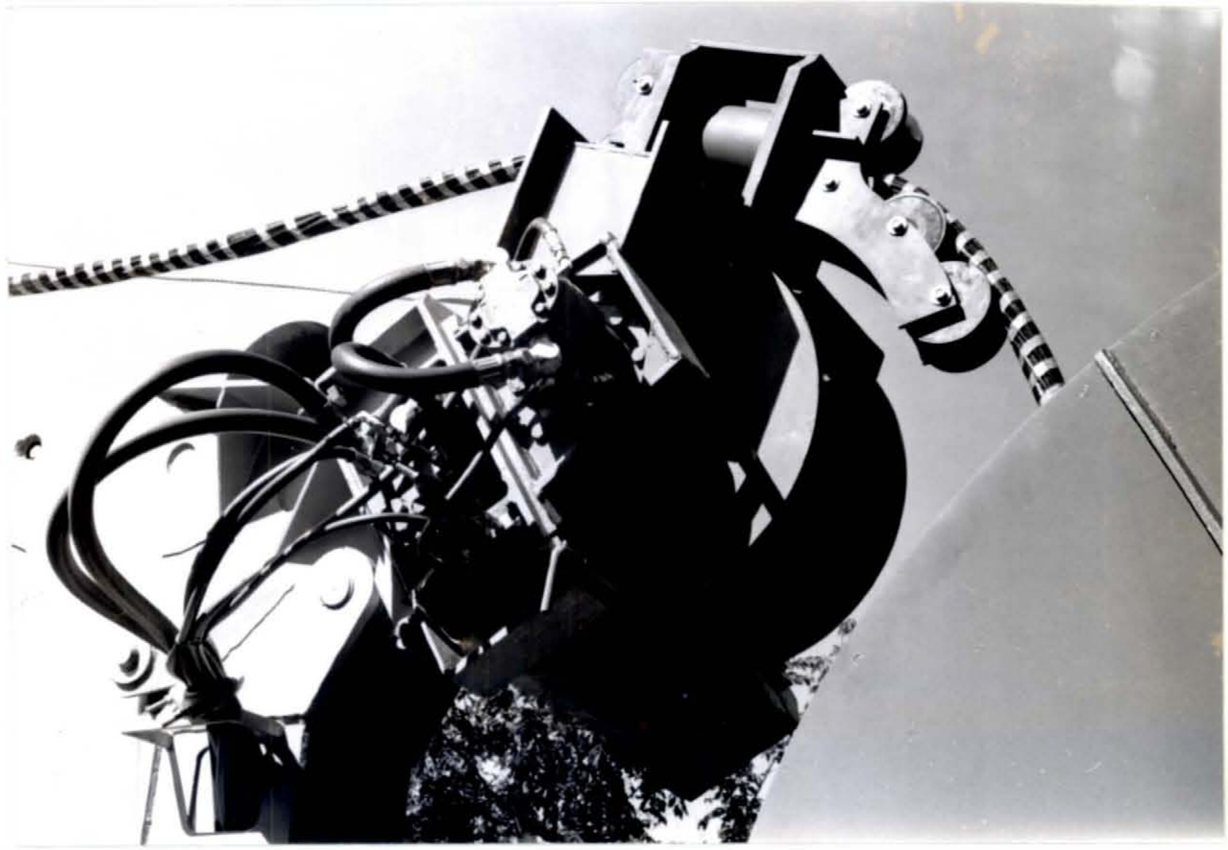

Figure 21. Deployment System Hydraulic Winch

To minimize the size of the hydraulic system, the hydraulic motor on the winch was designed only for normal operating loads of the deployment operation. In the event that the downhole package or hose bundle becomes lodged in the borehole, the winch can be locked and tension applied to the wire rope with the boom lift cylinder. The winch is locked using a ratchet and pawl arrangement, visible in Figure 21.

The winch is hinged to the crane boom and is designed to fold down against the crane mast to minimize the total height of the system for shipping. In stowed position, the high point on the deployment system is 10 feet 6 inches.

(b) Point protection ignition suppression system. Being a point protection device with limited range, a powered ignition suppression system should be located near and aimed at a site of relatively high ignition hazard. On a longwall face this is the cutter, primarily. Since this is the most cramped location on the face, the suppression system must be designed for minimum volume and must be integrated smoothly with the shearer. Bolt-on appendages to existing machinery are very vulnerable to abuse and damage in underground operation[35] and should be avoided wherever possible.

The following functions are important to system effectiveness:

(a) Ignition detection. Very fast acting sensors must be used to detect either the flame or pressure disturbance of an ignition.

(b) Timing. In suppressing an ignition at its source (point ignition protection), the detection signal should be used to trigger release of extinguishant as fast as possible. However, an explosion barrier in a passage or roadway should have its discharge timed so that extinguishant is dispersed directly into the flame front.[36]

Capabilities of the winch include:

- Maximum line speed of 130 fpm
- Maximum lift capability of 2300 pounds with all the cable on the winch and 5000 pounds with the winch empty
- Integral, spring set/hydraulically released brake
- Stows itself by lowering itself with the wire rope.

2.2.4 Hydraulically Driven Hose Take-up Reel

The hose take-up reel is shown in Figure 22. It carries 1600 feet of nominal 2-inch diameter hose bundle. The reel is designed with a narrow width to prevent winding problems that might result in kinked hoses. Minimum diameter of the hose reel is 24 inches, which is 50 percent above the minimum bend radius of the hose bundle.

The hose reel is driven by a hydraulic torque motor with adjustable torque control. Torque control is adjusted to provide sufficient tension in the hose bundle to maintain snug wrapping on the drum and negligible sag in the borehole between hose bundle clamps.

The hose reel also contains a spring set, hydraulically released brake that is coupled to the winch brake during deployment or retrieval operations. A single control lever raises or lowers the hose bundle and downhole package.

Connections to the hose bundle from the metering system are made with self-sealing, quick disconnects on the hose reel flange. Hose connections from the metering trailer must be disconnected before deploying or retrieving the downhole package.

(c) Extinguishant release and dispersal. A dense cloud of extinguishant should be dispersed quickly and uniformly to encounter the entire fireball or flame front of an ignition. Any nonuniformity in the dispersal may allow a propagation path for flame, and therefore cause failure in suppressing the ignition. The amount of extinguishant required is largely a function of the type of extinguishant used. However, the means and uniformity of its dispersal may have a strong effect on apparent extinguishant effectiveness.

(d) The potential ignition hazardousness should be clearly defined and both the sensor and extinguishant agent dispersal system directed at these areas.

Triggered suppression systems have been under development for several years, both in the U.S. and abroad. Results of development efforts were summarized in recent papers by USBM personnel.[37,38] The bulk of the past work has been devoted to obtaining reliable suppression by refining the functions described above. Results with regard to technical feasibility and reliability have been generally successful. At least one program also addressed the problems of practical industrial design of suppression equipment for survival in a mine environment, with field testing. The results of these tests were discouraging.[35] A need for further miniaturization and survivable packaging appears to be the major difficulty in applying triggered suppression systems.

The overriding advantage associated with triggered systems is that, if all normal precautions fail to prevent an ignition, they may be

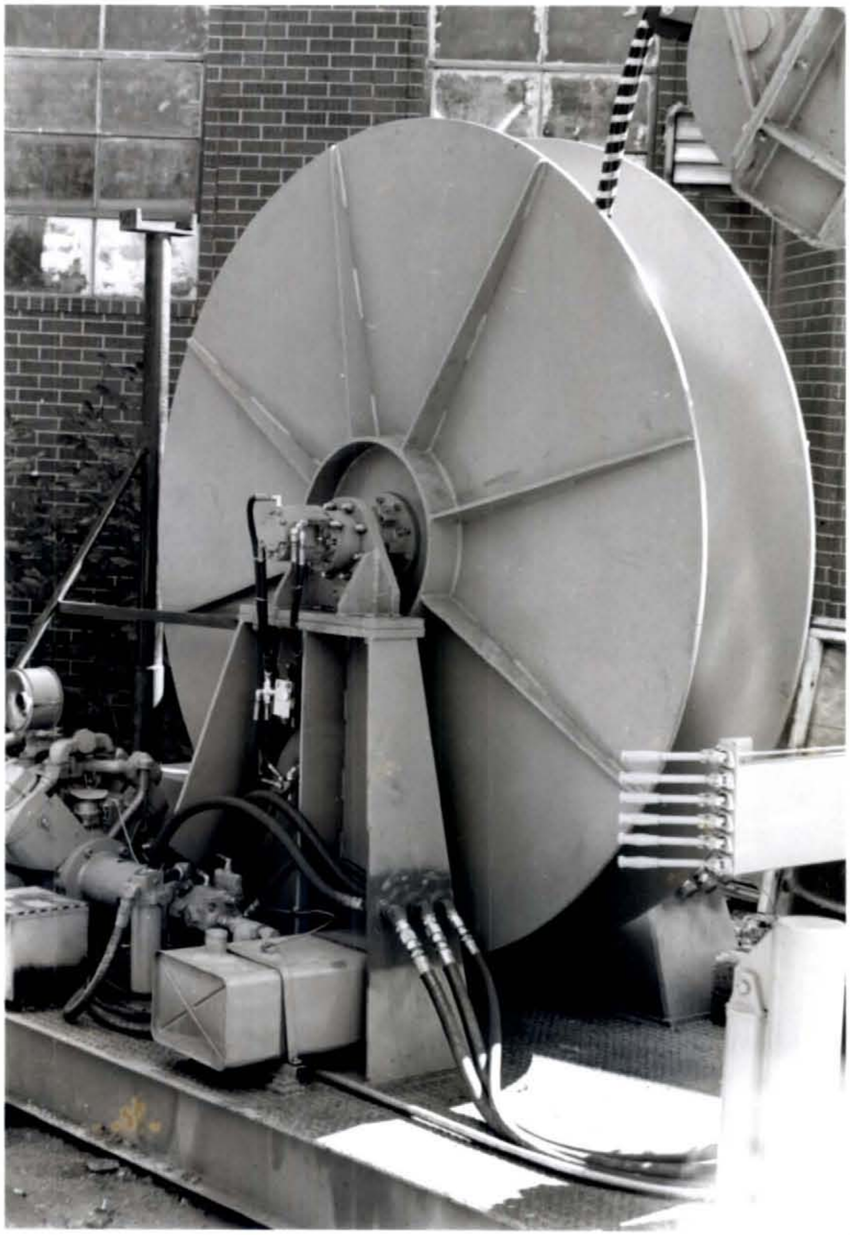

Figure 22. Deployment System Hose Take-up Reel

the only reliable "last ditch" defense against explosion propagation at some locations. In the context of a longwall these locations are primarily the face and conveyor haulageways, where large quantities of coal are present that have not been inerted with rock dust.

Limitations associated with the systems are:

(a) Large system size may not permit installation in the cramped environment at the face and in the entries.

(b) Highly vulnerable to damage if added as an appendage and not integrated into the system.

(c) The system is limited in range and can provide protection only at a very specific location.

(d) Development models of suppression equipment have been extremely expensive.

(e) Equipment in place cannot be completely tested for operation.

(f) Layout of the longwall mine may diminish a system's effectiveness.

Being a local protection device with limited range, ignition suppression equipment will be located at or near a critical location. These are:

2.2.5 Skid and Outriggers

The deployment system skid is pictured in Figure 23. It is 8 by 15-1/2 feet and is built around four 10 inch "I" beams, with cross bracing and a complete 3/8-inch plate on top and bottom. The forward edge is tapered to ride over ground irregularities.

The skid is leveled and stabilized with outriggers, also shown in Figure 23. The outriggers at the crane end of the skid move out manually and down hydraulically. The rear outriggers are manual for both out and down movement. The outriggers can be extended to provide an effective skid width of 13 feet.

Figure 23. Deployment System Skid and Outriggers

(a) The cutter, primarily, where most face ignitions occur;

(b) At head and tail gates and possibly other passages leading from the face area;

(c) Small, portable suppression equipment adjacent to welding or cutting operations.

Thus, of all the objections which may be raised against powered suppression in the longwall, only two are really significant:

(a) Can the equipment be effective at critical locations in the longwall layout?

(b) Can the equipment be made sufficiently small, rugged, and unobtrusive for the mine environment?

These questions are discussed further in subsequent sections.

4.2 System Locations

Possible "permanent" locations for triggered suppression systems are illustrated in Figure 2 . These are:

(a) A dedicated system mounted on the shearer to suppress ignitions which may be induced by friction of cutter picks on rock.

2.2.6 Hose Bundle and Support Clamps

The hose bundle is composed of eight individual hoses. The quantity, size, and purpose of the hoses are:

- Two 3/4-inch hoses for A and B foam components
- One 3/16-inch hose for the catalyst
- Two 1/4-inch and one 3/16-inch hoses for pneumatic control signals and high pressure pneumatic flush
- Two 1/4-inch hoses for hydraulic control signals and solvent flush.

The cross-section of the hose bundle is shown in Figure 24. The bundle is cabled with a full twist every 5 feet. A total of 1560 feet of hose bundle are provided with the froth foam system. The total length is divided into seven sections to allow assembly of hoses in any length up to 1500 feet in 100 foot intervals. The lengths provided are:

- Three 400 foot lengths
- Three 100 foot lengths
- One 60 foot length.

Molded polyurethane pads are placed on the hose bundle at 50 foot intervals and near the end of each section. Clamps lock into a groove in the polyurethane pad and grab the wire rope with a grip cast to fit the spiral grooves in the wire rope. The hose bundle pad is pictured in Figure 25. A complete hose clamp assembly is shown in Figure 26.

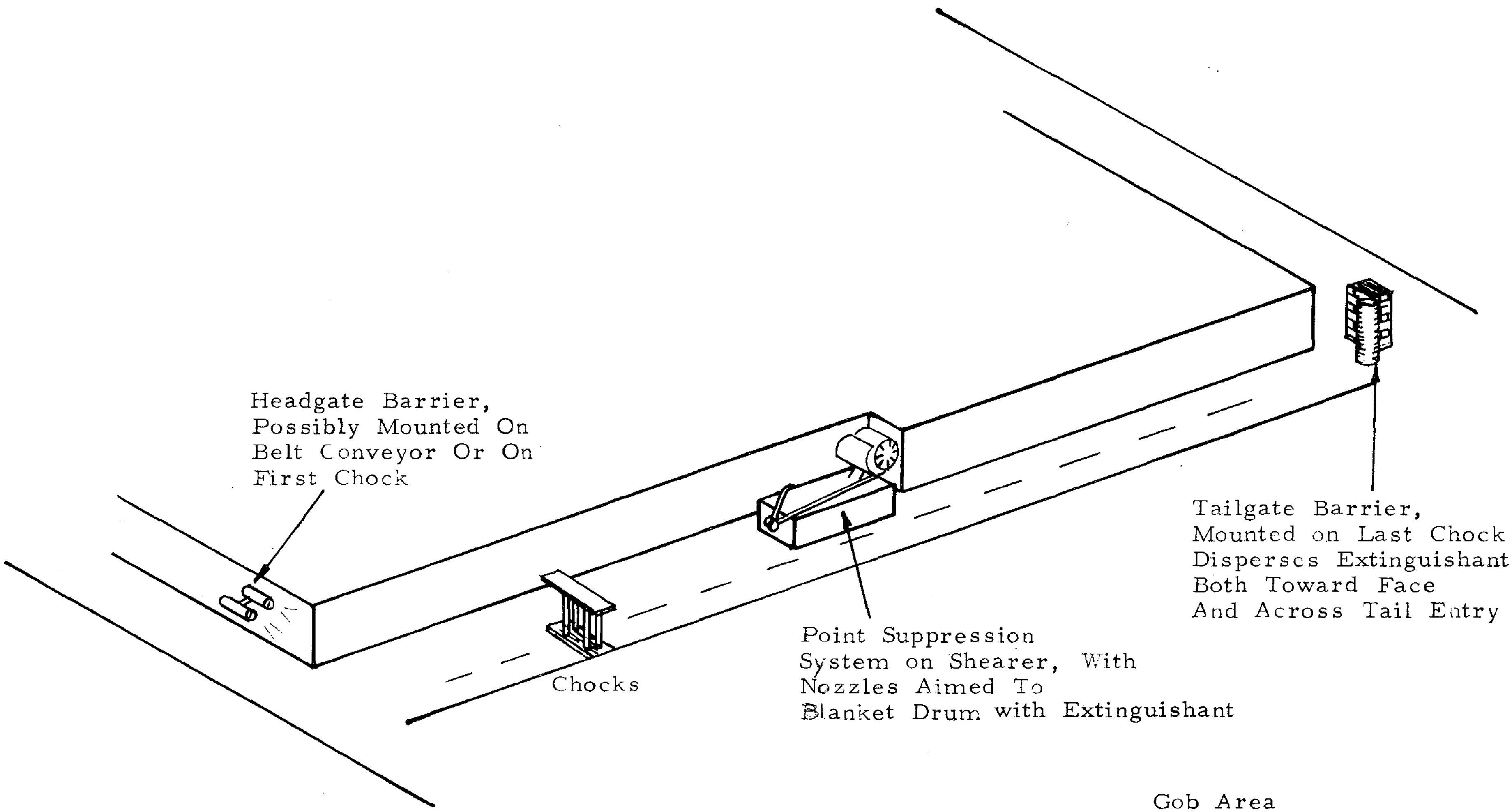

Figure 2 - Locations For Powered Suppression Systems On A Longwall Face

Figure 24. Cross-Section of Hose Bundle

(b) Nominally stationary explosion barriers at head and tail gates.

(c) A portable suppression system to be used in conjunction with welding equipment, provided such a system can be made small enough.

4.2.1 Shearer-Mounted Suppression System

This is a point protection system intended to extinguish "pops", or incipient explosions, before they can grow into explosions. In this respect, it is similar to systems previously developed for continuous miners.[14] Several extinguishant nozzles are required, and possibly several flame detectors, to obtain complete coverage of all possible flame paths from an ignition source behind the cutter.

These components will be in inhospitable locations near the cutter. Therefore, design and placement of the nozzles and miniaturization and packaging of detectors are important design problems. The extinguishant storage and discharge mechanism can be located farther back on the shearer, away from the cutter and flying coal.

A shearer with two drums will require two sets of nozzles and detectors. Extinguishant may then be stored on the shearer somewhere between the two drums.

4.2.2 Explosion Barriers at Gates

Barriers at the ends of the gates are intended to provide a secondary line of defense against the further spread of explosions

Figure 25. Support Pad on Hose Bundle

Figure 26. Complete Clamping Assembly

The hose bundle clamp assembly, shown in Figure 26, was designed to transmit a 1000 pound force from the wire rope to the hose bundle. Extensive laboratory testing was conducted to evaluate the effect of the geometry of the polyurethane pad and the clamp on transmitted load capability. The final clamp was tested and the 1000 pound load capability was verified.

2.3 Downhole Mixing System

A simplified schematic of the downhole mixing system is presented in Figure 27. Flow of the three foam components to the mixing head is controlled by three 3-way ball valves that are actuated in unison by a hydraulically driven actuator. The components are mixed in a Kenics* static mixer and delivered to the mine passage through a dispersion tube. When a dispense

*Trade Name.

which may originate anywhere along the face. These barriers will be a conceptual outgrowth of powered barrier development work which has been in progress both in the U.S. and abroad. However, the design of barriers for use at gates is further complicated by:

(a) A need for limited mobility, so that barriers can follow retreat of the face.

(b) Operation at an intersection.

(c) A need for extreme compactness since the headgate, in particular, is very crowded.

Precise timing of extinguishant discharge will be more critical for these barriers than for point ignition suppression, as illustrated in Figure 3[39]. Timing should be such that extinguishant is dispersed directly into the moving flame front. Location of the barriers will complicate efforts to achieve precise timing, as will the variable distance from the explosion initiation and unpredictable explosion strength at the barrier. Explosions propagating along the face are likely to be weak due to:

(a) The relatively short distance involved,

(b) Absence of confinement for pressure buildup,

(c) Presence of the gob as a dissipator.

However, weak explosions may be as difficult to suppress as strong ones.

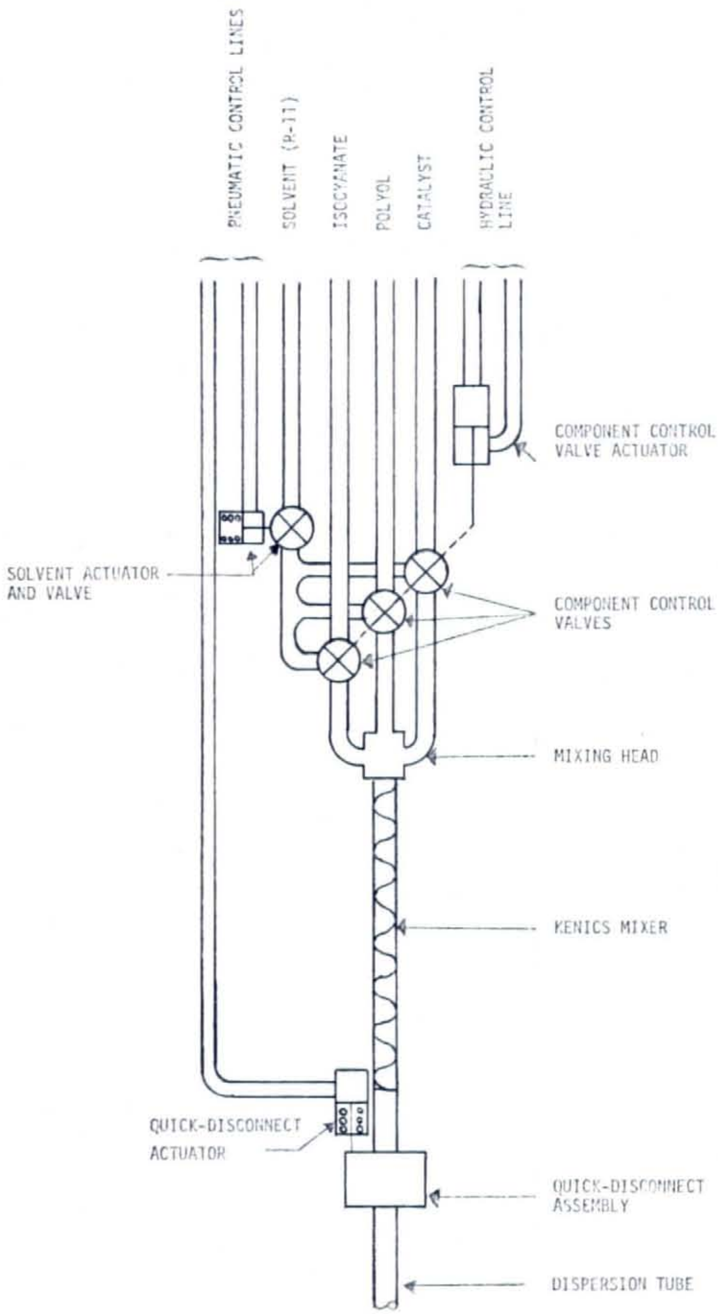

Figure 27. Simplified Schematic of the Downhole Mixing System

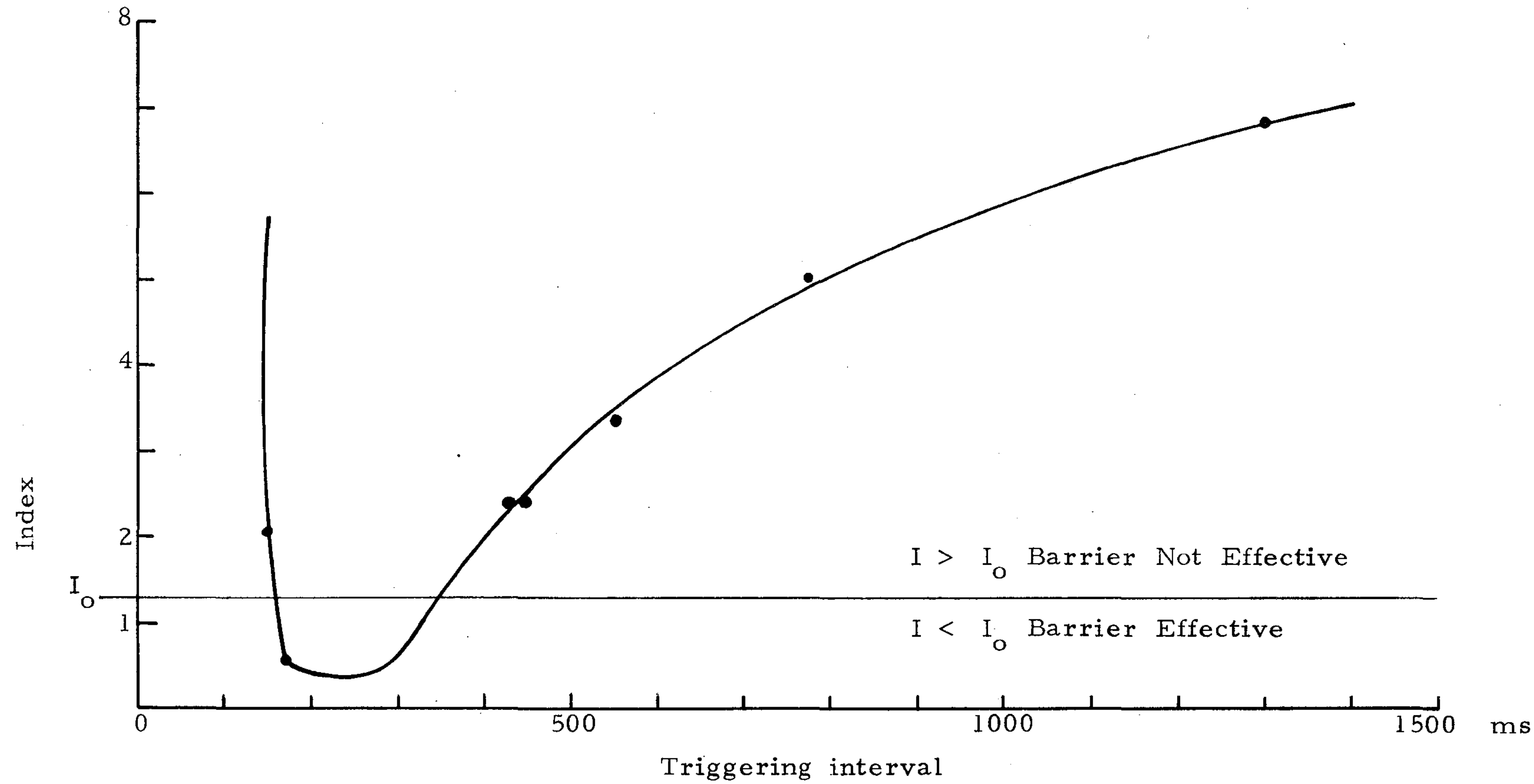

Figure 3 - Desired Index of Effectiveness Treatment for Triggered Barriers

cycle stops, components are shut off and solvent lines to the component control valves are opened. The flush sequence is then controlled by the solvent actuator and valve. A quick disconnect assembly and actuator is provided to separate the downhole package from the dispersion tube in the event the dispersion tube becomes trapped in the borehole.

Each part of the downhole mixing system will be discussed in more detail in the following subsections. A picture of the complete downhole package is shown in Figure 28. The complete package is 9 feet long.

2.3.1 Downhole Component Filtering System

Filtration is provided for each component in the downhole package. Several of these filters are shown in Figure 29, near the top of the downhole package. The filters are used to trap any dirt particles that might enter the hose bundle during the assembly or disassembly of various lengths of hose. Downstream of the filters are restriction valves to maintain adequate back pressure on the system. These are susceptible to clogging if dirt is present.

Figure 28. Froth Foam Downhole Mixing System

4.2.3 Portable Suppression System with Welding Equipment

This system is intended to suppress incipient explosions initiated by the flame of a torch used in welding or cutting. At least one small coal dust explosion in an American longwall has been initiated in this way. The special requirements of this system will be:

(a) The greatest requirement for miniaturization of any suppression system type,

(b) Detailed detector design to eliminate any possibility of the system being triggered by the normal flame of welding, or by hot metal,

(c) A means of automatically turning off welding equipment if the suppression system is triggered.

Achievement of these requirements is facilitated because the location of explosion initiation is well known in advance, i.e., the welder. Therefore:

(a) A relatively small quantity of extinguishant is required to extinguish flame in the small predetermined volume.

(b) Detector design is simplified by knowing precisely where to look for the ignition.

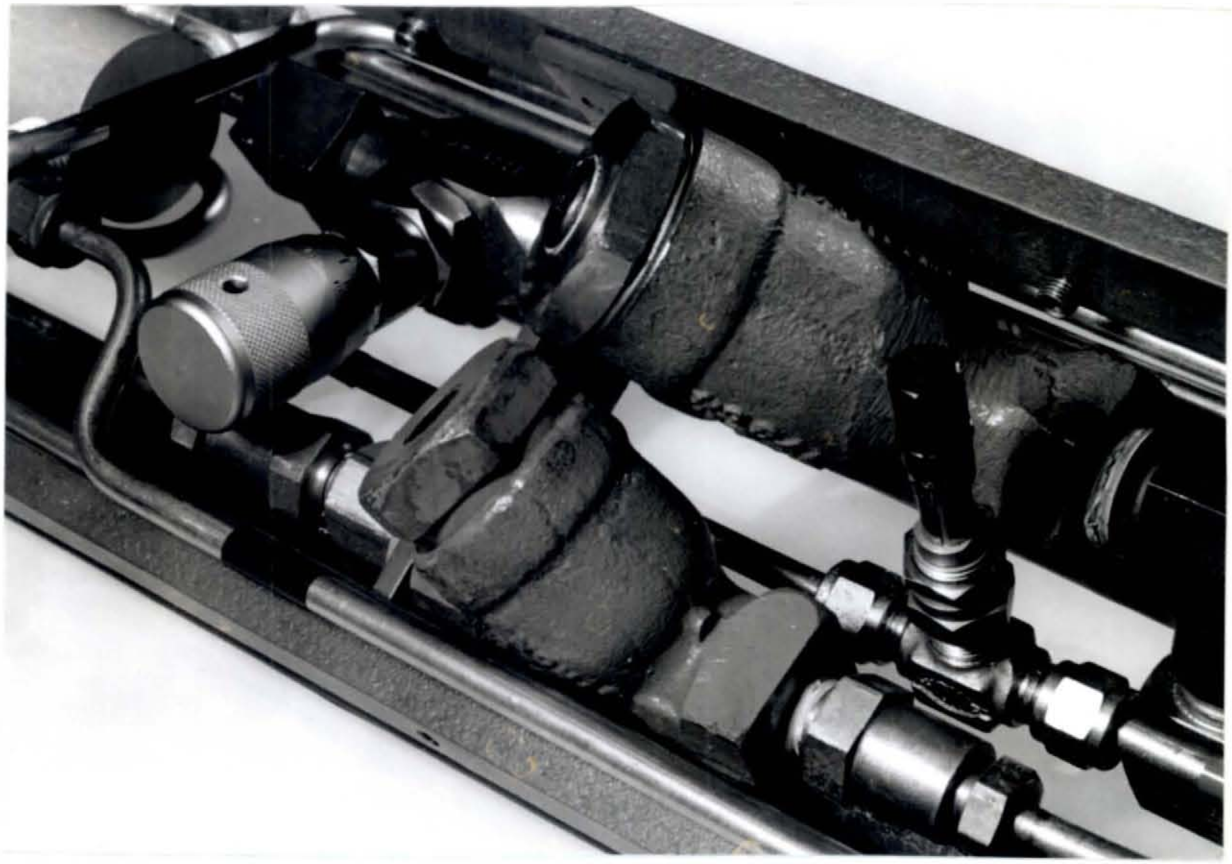

Figure 29. Component Filters in Downhole Mixing System

2.3.2 Downhole Component Control Valves

As discussed in the introduction of Section 2.3, the component control valves are 3-way ball valves that port either foam component or solvent to the mixing head. The three component control valves are linked to a common actuator. This assembly is shown in Figure 30.

The actuator is hydraulically driven with solvent used as the hydraulic medium. Solvent is used to avoid working with fire-retardant hydraulic oils and because solvent is available in the downhole package as the mixing head flushing agent.

2.3.3 Downhole Component Mixing

The three foam components are brought together in a custom designed mixing head that introduces the small catalyst

4.3 Ignition Sensors

A powered suppression system includes one or more detectors to provide a triggering signal when an ignition occurs. A detector should have the following characteristics for use in a longwall explosion suppression system:

1) It should be functionally reliable, being able to detect any ignition while minimizing the probability of false alarms.

2) The sensor should be rugged enough to withstand the abuse of mine conditions.

3) Means by which the detector can be fouled with dirt should be minimized.

4) Exposed profile of the detector should be small and it should occupy minimum volume.

5) Means for periodically testing the detector should be incorporated in its design.

6) Very fast reaction is required. Therefore, a remote detector may be preferable to one which operates on contact with flame.

Following sections describe several approaches to detecting ignitions in suppression systems.

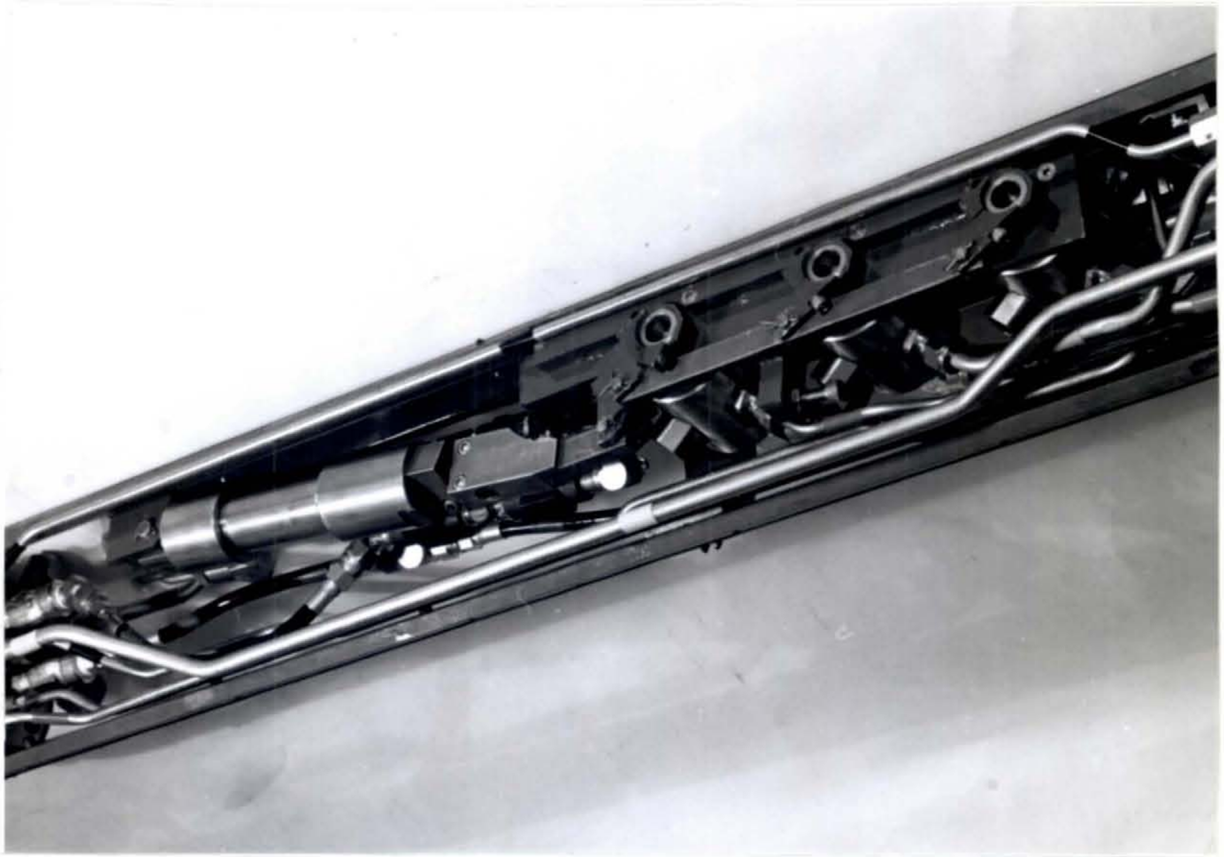

Figure 30. Component Control Valve Assembly

flow into the center of the A and B component flows. The combined flow then enters the top of a six stage Kenics* mixer where it is continually split and turned until all three components are thoroughly mixed. A photograph of the mixing head and Kenics* mixer is shown in Figure 31.

After the components have entered the mixing head, the back pressure on the components is less than the vapor pressure of the blowing agent. The blowing agent, therefore, starts mixing action in the static mixer.

*Trade Name.

4.3.1 Ultra-Violet (UV) Detectors

Radiation sensors can remotely detect light from an ignition. Detectors sensitive to UV radiation have been found to be most adaptable to mine conditions in the U.S. as well as France and Germany.(41) Detectors sensitive to some UV bands can give false alarm signals due to stray light from sources other than flame.(32) However, UV sensors in the band 1,850 to 2,450 Å have been found to give excellent functional reliability. They are sensitive only to ignitions and welding torches in a mine.(14)

UV sensor tubes are generally available off-the-shelf. However, proper selection is important since some sensors have too long a rise time for a very fast reaction ignition suppression system.(42) The line of UV sensors made by Honeywell has been proven to be reliably fast and effective in several series of close-in ignition suppression tests.(13,14)

Some problems were anticipated due to contamination of detector windows with resulting serious attenuation of UV signal strength.(37) However, a cleaning system using a low flow rate water film (14) has been developed and tested for keeping UV detector optics clean in a mine environment. There have been some problems in the past due to the bulk and vulnerability of a sensor module protruding from mine machinery. However, this may be primarily a packaging problem.

4.3.2 Pressure Sensitive Detectors

One of the first operational explosive ignition suppression systems, developed for RAF aircraft fuel tanks, employed a fast

2.3.4 Dispersion Tube

The discharge from the mixing system passes out of the downhole package and into the foam dispersion tube. This tube is used to allow the downhole package to remain up in the borehole while foam is being dispensed into the mine passage. The top of the dispersion tube has two packer assemblies which block the passage of foam up the borehole, preventing the downhole package from becoming encased in foam. A picture of the dispersion tube is shown in Figure 32. It is 10 feet long, which is the maximum length that will easily clear the borehole without detaching the dispersion tube from the downhole package.

2.3.5 Mixing Head Flush System

The mixing head flush system is controlled by the automatic solvent flush system, located in the temperature conditioning and metering system and described in Section 2.1.5. The solvent is supplied to the downhole package through one of the two hydraulic control lines that actuate the component control valves. Compressed nitrogen to control the flush sequence and to blow out the mixing head is supplied through two of the pneumatic control lines. The automatic solvent flush system initiates the flush cycle at the termination of any dispense sequence. The flush cycle can be adjusted up to 8 minutes in duration and involves blowing nitrogen through the mixing chamber and adding solvent to the nitrogen in a 20 second on, 10 second off sequence.

2.3.6 Dispersion Tube Quick-Disconnect Assembly

In the event that the dispersion tube becomes lodged in borehole debris or encased in foam to the point where the deployment system cannot extract it, the dispersion tube can be discarded by a quick-disconnect assembly. This is a standard response pressure sensitive switch as the trigger. Since then, pressure detectors have often been used in ignition suppression systems to prevent industrial explosions.[15]

The pressure detector is generally sited remotely from the point of ignition. It performs remotely because a pressure pulse caused by an ignition propagates away from its source at the speed of sound.[43] Propagation speed of the flame front in its incipient stage is only 15 to 20 ft./sec.[14] The pressure pulse therefore can reach a remote sensor and be detected before the ignition or explosion has grown to that extent.

The rate of pressure rise due to an ignition depends in part on how enclosed and constrained the ignition is. Pressure rises more slowly, and sometimes to a lower peak, in a large volume than in a small one.[44] When explosive ignition takes place in a large volume, such as a mine passage or longwall face, pressure rises gradually at first. During the first 50 msec a rise to about 2 psig is typical.[15] This is mild enough to not cause great damage if stopped immediately, but strong enough to trigger a pressure sensor and not to be confused with normal sound transmission. The RMS sound pressure of a 140 db noise is only about 0.03 psi.

A pressure sensor, used in conjunction with an infra-red detector, has performed satisfactorily in tests of a powered barrier system for coal mines.[12] This experience combined with industrial explosion protection experience indicates that appropriately packaged pressure sensors alone may be adequate for longwall point ignition protection. Pressure detection is attractive for the application because:

Figure 31. Mixing Head and Static Mixer

Figure 32. Downhole Mixing System Dispersion Tube

1) The sensors are small.
2) They are relatively low in cost.
3) They can be made immune to dirt and other adverse conditions of a coal mine.

Use of pressure sensors may be inappropriate for use in barriers at the head and tail gates due to the different times of arrival of the pressure and flame fronts of an explosion. From the point of view of suppression, the flame front is of interest. However, since the pressure front arrives first, pressure detection can be used to arm a flame detector such as a UV sensor, thereby guarding against false alarm firings of the flame sensor.

4.3.3 Other Detector Types

The following sensor types have also been considered or used for fire detection. However, they are not as appropriate to the ignition suppression application as the UV or pressure sensors.

1) Ionization sensors are widely used in mines and in general commercial automatic fire protection systems.[32] However, they are too slow acting for use in ignition suppression.

2) High speed thermocouples, often used for fire protection, can be made with response time barely short enough for ignition suppression.[15] They have been used in this application industrially but are marginal

1 inch Bruning* quick-disconnect connecting the dispersion tube to the downhole package. It is actuated by a pneumatic cylinder driven by compressed nitrogen. Quick-disconnect assembly and actuator are shown in Figure 33.

Actuation of the quick-disconnect is a last-resort procedure. Every effort should be made to extract the complete package from the hole. The main frame of the downhole package will transmit up to 12,000 pounds of force to the dispersion tube. The quick-disconnect was successfully tested to 20,000 pounds.

The dispersion tube and packer assembly is fabricated from standard 3/4-inch pipe. It is a low-cost item in the event that it must be left in the borehole.

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*Trade Name.

since the extreme high response speed of other sensor types, even if higher than necessary, provides a welcome safety factor. Thermocouples are activated by direct contact with a flame and therefore cannot be remotely located. They are adaptable to small, rugged packages, however, and can be placed around high ignition hazard areas if necessary.

3) Infra-red (IR) sensors have been used instead of UV sensors in one system developed for ignition suppression in coal mines, because IR sensors offer faster response times in some configurations.[42] However, IR sensors can also be activated by bright lights or other stray radiation, leading to undesirable false alarms.[32] To avoid this problem, IR was used in conjunction with pressure sensors in one powered barrier program. The IR sensor circuit reacted only after receiving a pressure pulse to arm the system.[12] That development was aimed at suppression of developed explosions. Pressure sensors could not be used alone because of the large and unpredictable time lag between the pressure and flame fronts. In ignition suppression, this lag presents no problem and the IR sensor would be extraneous. Other more elaborate IR detectors have been developed by the USBM to

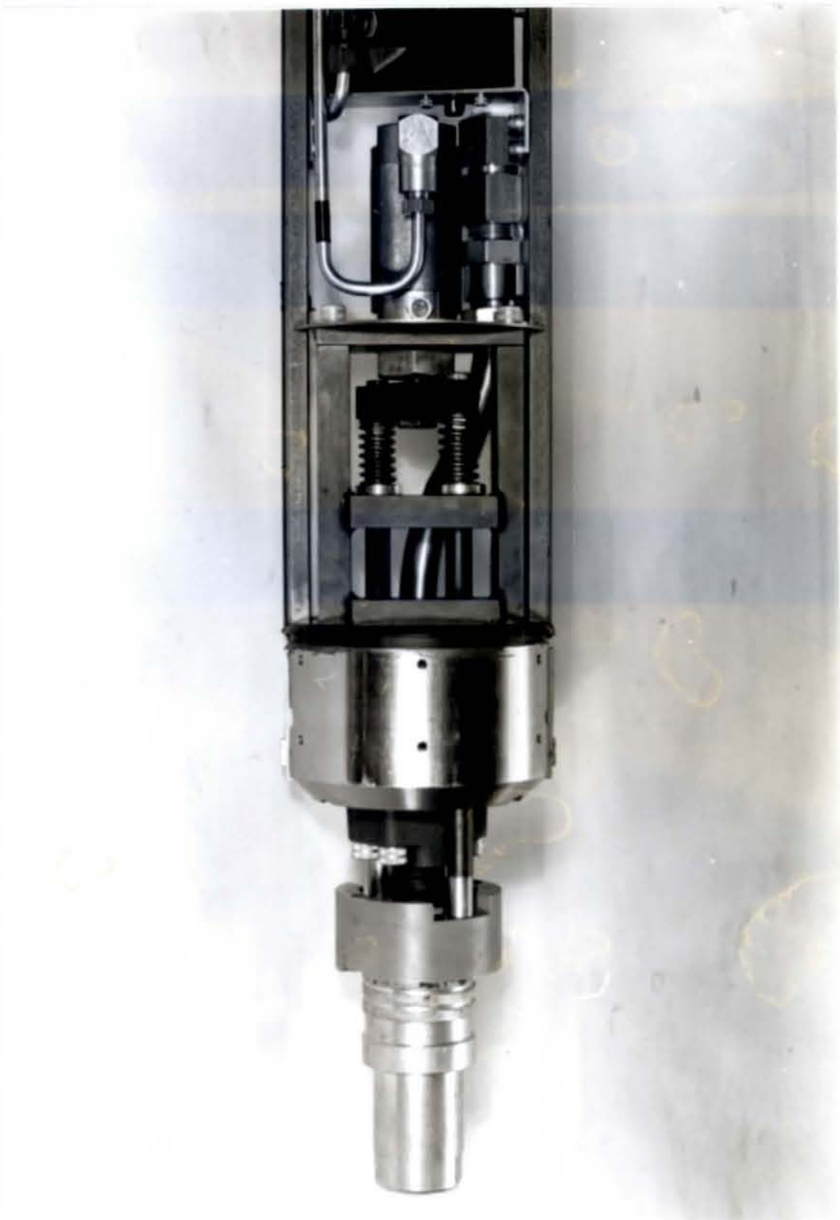


Figure 33. Downhole Package Quick-Disconnect Assembly

eliminate false alarms. These include several sensors in a bridge circuit to respond only to radiation in specific bands such as the CO_2 or H_2O radiation bands. The complexity of these devices has been a handicap and they have not been successfully tested in the field. With very fast UV detectors now available, IR sensors offer no strong relative advantages and give more false alarms.[14]

4.4 Extinguishing Agents

In principle, almost any extinguishant can be effective against combustion. In practice, however, the following factors influence effectiveness in ignition suppression in mines:

1) The amount of a particular extinguishant required, since it must be very quickly dispersed,[12]

2) The ease with which it can be uniformly distributed in the ignition vicinity, since the ignition can propagate through even a small gap in the dispersed extinguishant,[22]

3) The influence which the extinguishant may have on design of the triggered actuator.

The amount of extinguishant required is also critical for a practical reason not directly related to technical performance of a suppression system. Extinguishant storage may be a major portion of the bulk of a system. Size and awkwardness of ignition suppression equipment are the primary obstacles to acceptability in a mine environment. Therefore extinguishant effectiveness is a very important parameter. A practical suppression system will incorporate an extinguishant with high effectiveness, thereby minimizing the amount of extinguishant required and size of the equipment.

Most sources indicate that two types of extinguishing agents, water and dry chemicals, have the best combination of desirable properties. These properties are:

a) effectiveness
b) low cost
c) availability
d) ease of handling.

Following sections describe some commonly used extinguishing agents with potential for use in ignition suppression on longwalls.

4.4.1 Water

Where water is available it is generally the least expensive extinguishing agent.[32] It works primarily by cooling a flame and has been applied by deluge or by coarse or fine sprays.[29] However, to minimize the amount required to stop a flame front, it is most effective when applied as fine droplets.[6,43]

The presence of water in a volume with otherwise explosive conditions is known to reduce the frequency of ignitions.[18] There is some feeling within the mining industry that water can cool an ignition and, under the right conditions, extinguish it.[1,3] Experimental work with water in a fast reaction ignition suppression system yielded uniformly successful results.[34] Mist curtains are also used in Russia for ignition protection in shot firing.[7]

There is more background information about water as applied to developed explosions than to ignitions. Explosion actuated water barriers have been completely effective in some test conditions, even with very little water used,[44] but were ineffective against strong explosions in other conditions.[9] Water in powered troughs was more effective than rock dust but still unable to arrest some strong explosions.[42] Other tests, with a nitrogen propelled water barrier were completely successful.[10] Explosion actuated water barriers have arrested at least one actual explosion in Europe.[8]

The effectiveness of water as an explosion suppressant seems to be determined largely by the manner of its dispersal and test conditions. In some tests it has been found to be either slightly[11] or considerably[7,41] less effective than dry chemical formulations. In other tests, it was found to be equivalent or even superior to other common extinguishants, including dry chemicals.[40,45] In any case, water is among the most effective extinguishing agents.

In recent work, 60 lb. of water, discharged from Fenwal bottles by pressurized nitrogen, was sufficient to extinguish fully developed explosions in a passage 6 ft. high by 9 ft. wide.[45] This is less than one cubic foot of extinguishant required, which may be a practical volume for storage in appropriate areas in a mine.

4.4.2 Dry Chemical Extinguishant

Dry chemical extinguishants are any of several solid chemical powders, often with additives which prevent caking or otherwise enhance effectiveness.[32] Typical primary constituents are:

1) Sodium or potassium bicarbonate, sometimes with urea,

2) Potassium, calcium or magnesium chlorides,

3) Ammonium phosphate.

When combating slow burning fires, dry chemical if often used where rapid extinguishant is required.[32] In these applications, it works primarily by liberating inert vapors when exposed to high temperature, and thus interferring with combustion reactions.[29] It also tends to smother and cool a flame. However, when used for ignition suppression and exposed to flame only for milliseconds it appears to function primarily by cooling the flame without significant chemical change. In ignition suppression tests, obvious chemical change occurred only in unsuccessful tests where the unchecked flame was of relatively long duration.[14] Average particle sizes for dry chemicals are in the range of 30 to 40μ[14,46] so that, in addition to any chemical action, dry chemical functions as a heat absorber as well as rock dust.

Dry chemical in powered suppression systems has been found effective against methane ignitions and developed explosions.[11,13,14] To be used effectively, it must be ejected directly into a flame front or the front will propagate around it.[12,14] When properly used it is about 20 times more effective than rock dust.[41]

Regarding the relative effectiveness of various dry chemical formulations:

1) Potassium bicarbonate has been found to be most effective in some tests.[7]

2) Ammonium phosphate has been found to be most effective in other tests.[11]

3) A proprietary formulation known as Monnex was found to be most effective in controlled tests at the USBM.[47]

4) Differences in effectiveness are small and the various formulations have been found to be equally effective, within experimental uncertainty, in some tests.[14]

Dry chemical extinguishant is readily available in most mines, since it is used for general fire protection, and is low in cost.[14,29] It is not toxic, nor does it form toxic decomposition products.[32] It is relatively non-abrasive and safe for use on machinery, compared with stone dust.[29,32] However, when dispersed with valves it does cause a noticeable reduction in valve life, the magnitude of which depends on the formulation used.[48]

4.4.3 Halons

Halons are halogenated hydrocarbons, some of which are useful in extinguishing fires by chemically interferring with combustion reactions.[33] The one most commonly used is Halon 1301 (bromotrifluoromethane). It is recommended by the FDA because it has lower toxicity than other extinguishant Halons.[49] In particular, since it contains no chlorine, it cannot decompose to phosgene. The remainder of this section is concerned primarily with Halon 1301.

Halon is often used in extinguishing systems where very fast reaction is required.[49] It has been used for explosive ignition suppression applications in powered, triggered systems in military and industrial equipment. The first such application was in fuel tanks of British military aircraft. Industrially it has been used to suppress both gas and flammable dust explosive ignitions.[15]

Halon is also effective in conditions of rapid air movement and turbulence. It has been applied to automatic fire extinguishing in aircraft engine compartments.[50] This feature may be attractive for use on a longwall face, where high local flows may exist due to ventilation around obstacles.

Ample data and specifications exist on the amount of Halon required to suppress particular kinds of ignitions in a closed volume. At least two percent by volume of the local atmosphere is sufficient to prevent or extinguish an ignition of methane in stoichiometric concentration with air. This includes a ten percent safety factor but requires that the Halon be uniformly distributed in the local atmosphere.[33] Where uniform distribution and quick reaction may not be compatible, a minimum of five percent is generally used,[51] and concentrations of six percent to ten percent are commonly specified.[49]

There is no specification on how much Halon to apply to an ignition hazard that is not in a closed volume. Based on analysis of each individual case, enough should be applied so that its concentration is over two percent at every point that combustion might take place.

There are two types of toxic effects associated with the use of Halons: [33]

1) The Halons themselves are somewhat toxic.

2) At elevated temperature they form decomposition products which can be more dangerous than the parent compound.

Undecomposed Halon 1301 can be tolerated up to twenty percent concentration in air without irreversible harmful effects and is less dangerous than carbon dioxide in extinguishant concentration. [52] However, concentration over 10 percent can be temporarily disabling. [49] The following exposure levels are recommended for complete safety: [33]

1) Concentration ten percent or more - evacuate immediately.

2) Concentration seven to ten percent - evacuate within one minute.

3) Concentration under seven percent - evacuate within five minutes.

The amount of Halon required for local ignition suppression in a mine is well within safe levels, especially as the gas is subsequently diluted through the mine.

Decomposition products, formed in trace amounts, may be far more dangerous than the Halon. They are formed at temperatures over 900°F and are essential to the Halon's function, since it is actually the decomposition products that chemically inhibit combustion. However, the amount of such products formed is not solely proportional to the amount of Halon used. It is also a function of exposure time to high temperature and, therefore, of the rate at which Halon is applied to a fire. In extinguishing a series of repeatable test fires:[33]

1) Halon applied slowly, to cause extinguishment after ten seconds, produced 250 ppm of hydrogen fluoride gas, a dangerous level.

2) Halon applied more quickly, to cause extinguishment in 1/2 second, produced 12 ppm hydrogen fluoride.

3) Halon applied extremely fast, to extinguish combustion in milliseconds, produced negligible hydrogen fluoride.

Decomposition products are therefore within safe levels when Halon is used for very fast reaction ignition suppression.

Some tests indicate that Halon is quite effective against ignition of both methane and coal dust,[41] while other tests have indicated very low effectiveness as compared with the better dry chemicals.[11] Efficiency of dispersion is at least as important as inherent effectiveness of the extinguishing agent. In practice, Halon is sufficiently effective to be competitive with dry chemical for use in ignition suppression. However, there are operational differences which may make one preferable over another in a particular application:

1) Halon is a gas when dispersed and does not settle.

2) Halon is a liquid in storage; dry chemical is in powder form; and the two are not generally optimal for use with the same type of actuator.

Halons are not recommended in general for ignition suppression use because they appear to be less effective overall than water and dry chemicals for the proposed special applications. Halons are effective, however, for certain specific applications, such as the cable protection system discussed in Chapter 5.

4.4.4 Rock Dust

Although widely used in mines, rock dust is the least effective of common extinguishing agents.[30,41] It was found unsuitable for use against methane explosions, even with powered dispersion, in one test program.[11] Its wide use is attributable to the relatively low cost of using a lot of it and to the absence of harmful effects on men, machines and mining procedures. These characteristics are less important in a powered ignition suppression system, however, since the extinguishant is distributed judiciously and only when needed.

Approximately 20 to 80 lb. of rock dust per square foot of roadway cross section, depending on siting, are required to arrest an explosion with an explosion actuated barrier. The large quantity is required primarily because dispersion of an inert material with this type of barrier is not reliably uniform or synchronized with flame front arrival.[6] Effectiveness is a very strong function of the uniformity of dispersion.[22] Explosion actuated barriers, even with the large amount of rock dust, do not always successfully arrest explosions.[9]

Rock dust is more effective in preventing an ignition than extinguishing one, basically because an ignition occurs less readily than propagation and growth afterward.[6] Nevertheless, rock dust can be used as an extinguishant if efficiently dispersed in sufficient quantity.

4.4.5 Carbon Dioxide

Carbon dioxide, dispersed from liquid storage under pressure, extinguishes flame by smothering and cooling. It smothers flame simply by its presence as inert gas in large quantity. Its cooling function is due in part to the large quantity and also to the fact that it absorbs heat when vaporizing.

Carbon dioxide is more toxic than Halon 1301 in the quantities required locally for ignition suppression.[52] However, ventilation or diffusion through a mine would dilute a high local concentration. It requires no separate propellant to disperse it since its vapor pressure at room temperature is about 800 psi.

4.4.6 Salt

Common salt (sodium chloride), especially prepared as a dispersable powder, has been found to be about 20 times as effective as rock dust in arresting explosions.[30] It is therefore approximately as effective as the dry chemicals or Halons and may be slightly less expensive. It is, however, potentially corrosive to machinery in a wet environment.

4.4.7 Steam

Water can be stored as steam and, when released through a nozzle, condenses to very fine droplets which are most effective in ignition suppression. Condensation may also tend to nucleate on suspended coal dust, which would help to inert those particles. However, extra equipment is required to maintain pressurized steam in storage, which may be more of a hindrance than is justified by the attainment of fine droplets.

4.5 Means of Storing and Discharging Extinguishant

A powered ignition suppression actuator must release and disperse a quantity of extinguishant quickly and uniformly. The requirement for speed makes conventional fire extinguishers unsuitable. Most very fast suppression actuators are self destructive in operation in varying degrees. They therefore generally need to be replaced, at least in part, rather than simply refilled after discharge.

The following primary requirements should be met by an ignition suppression actuator for the longwall application:

1) It should be fast acting and reliable.

2) The volume occupied by the actuator per effective volume of extinguishant dispersed should be minimized.

3) Actuator design should be inherently rugged to withstand underground mine conditions.

4) Overall cost of recharging should be minimized. Cost of occasional full system testing, including firing the actuator, should be as low as possible.

5) Discharge of the actuator should create no safety hazards for nearby personnel.

FMA believes that the most practical storage and discharge configuration for use in a mine will utilize extinguishant pressurized with nitrogen and released with a reusable valve. The valve may be a high performance solenoid type or may be explosively actuated for high speed in larger sizes.

Use of exploding containers is not completely ruled out at this point, especially as exploding containers may provide the most efficient storage of a given volume of extinguishant. However, a practical exploding container for the mine environment will need to be:

a) Extremely rugged, yet easily and controllably frangible,

b) Inexpensive

c) Designed to fracture and disperse extinguishant in a repeatable and predictable way.

d) Designed to prevent fragments from impacting personnel.

The following sections describe several actuator concepts, including some which have been tested or applied.

4.5.1 Solenoid Valves

Solenoid valves have been commonly used for slow response automatic fire protection. They have been made sufficiently leak proof so that there is no measurable loss of extinguishant or pressure for up to 10 years of storage.[51]

Commercial extinguisher systems are available using valves in conjunction with halons, dry chemicals, water with chemical additives, or virtually any other extinguishing agent.[53] Some specialized systems for protection of mine equipment have used dry chemical.[29] However, valve life is shortened in this type of service, to a degree depending on the valve design and chemical type.[48]

Small, single-stage solenoid valves can be opened in well under 100 msec.[53] They restrict and limit the extinguishant discharge rate, however, and can be used only in slow acting systems.[29] Large valves, over 1" diameter, are often pilot actuated and are far too slow for use in an ignition suppression system.[49] Single-stage valves up to approximately 1" diameter, opening in about 30 msec, represent the limit of performance for commercially available valves.[54]

Solenoid valve actuators have been used successfully in the development of a powered barrier system for developed mine explosions.[12]

Large diameter, single-stage solenoid valves can be developed to meet the response time requirement of ignition suppression if a real commercial requirement can be demonstrated. A larger than usual solenoid and special actuating circuit would be required. Such valves have been developed in the past for military applications.[51] However, the development may not be called for, due to the high cost of a "special" valve and its probable large overall size.

4.5.2 Explosively Opened Valves

Rupture disc actuators must be virtually taken apart and reassembled with a new actuator when recharged. Recharging an actuator with a solenoid valve would be less cumbersome, but available solenoid valves are generally too slow acting in larger sizes. Explosively opened valves would represent a compromise between these two approaches. A small explosive charge would be used non-destructively to drive a piston, and open the valve.

Explosively actuated valves are not used in fire protection systems and we are not aware of any presently commercially available. They should be considered for the ignition suppression application because:

1) Only the explosive charge and extinguishant need be replaced for recharging. The actuator need not be replaced or disassembled.

2) Explosively actuated valves can be made with response times almost as low as a rupture disc.

4.5.3 Exploding Packages

Containers filled with an extinguishing agent and a small explosive charge have been used for ignition or explosion suppression. After discharge, the entire container must be replaced. Containers are often scribed or deliberately weakened in some places so that they will blow open in a predictable way and not fragment.

This type of actuator has been effective. Polyethylene containers with water extinguishant are blown open to create a precautionary mist curtain in shot firing operations in Russia.(7) The U.S. Bureau of Mines has had good results with exploding bags filled with solid suppressant dust.(10) Actuators of these types would have relatively low replacement cost.

Exploding actuators commercially available are of metal construction, in the form of scribed cylinders or hemispheres. They are filled with Halon 1301 and an explosive. They have an excellent performance record in military equipment and industry but are expensive. A hemispherical actuator with 5 litres of Halon costs over $800.(15)

Exploding packages are versatile in that they can be designed for any type of extinguishant. They are also the fastest acting actuator type, much faster than actually required for most applications. They are vulnerable to abuse in most configurations since most of their surface must be light and frangible.

4.5.4 Rupture Disc Actuators

Rupture discs, with a small explosive charge behind them, have been widely used for medium-fast fire protection. The discs are used in lieu of valves and are much faster acting than most available valves of comparable size.[49]

Most commonly, rupture disc fire extinguishers employ Halon as extinguishant. It is propelled by its own vapor pressure (about 200 psig at room temperature), or by nitrogen for faster discharge.[13, 15] While the rupture disc opens in milliseconds, response is limited by the flow rate of Halon through the exit orifice. Discharge may take from under one second[49] to several seconds.

Rupture disc actuators have been used in development tests of powered barriers for developed mine explosions. They have been applied successfully with water[10] and with Halon and dry chemicals.[11]

Application of these actuators to close-in ignition suppression in mines has utilized dry chemical extinguishant, pressurized with nitrogen. The actuators have performed well in tests simulating methane ignitions in mines.[13, 14]

Rupture disc actuators can be designed for use with virtually any extinguishing agent. They are sufficiently fast acting for the application. However, they are not inherently modular and an entire actuator must be removed from service for recharging.

4.5.5 Light Gas Gun Derivative

An actuator developed by NASA was tested and found effective against methane ignitions. It used a 20 mm. aircraft cannon shell for propellant, with a polyethylene piston in place of the normal bullet. The piston is driven down a tube to compress hydrogen or helium to 40,000 to 50,000 psi. The light gas breaks through a diaphragm and pressurizes water in a container with small, weakly sealed perforations. Aluminum foil was used to seal the perforations in the test model. Under pressure, the water breaks the weak seals and sprays out through the perforations. The spray is a fine mist due to the combination of small holes and extreme high pressure. The discharge of water can be completed within a few milliseconds.[34]

The light gas gun technology was initially developed to drive relatively light projectiles at a very high muzzle velocity. In the mine ignition suppression application, no projectile is being driven and the water or other extinguishant is a high mass load. The intermediate stage of compressing helium and breaking a diaphragm is therefore not necessary. Extinguishant can be propelled directly by the cartridge and polyethylene piston.

This type of actuator can be made modular in the parts which must be replaced, and the cost of recharging can be made low. Exposed portions of the actuator are inherently rugged. Response is very fast. The approach is better suited for use with liquid or gas extinguishing agents than solid powders.

5. Triggered Suppression System Conceptual Designs

Preliminary conceptual designs of powered, triggered suppression systems for four applications on a longwall are described. These are:

a) Point ignition suppression at a shearer,

b) Explosion barriers at the face ends,

c) Point ignition suppression in conjunction with welding equipment,

d) Power cable protection system.

The designs incorporate and illustrate features that have been considered important to practical ignition suppression equipment.

5.1 Shearer-Mounted Ignition Suppression System

Figure 4 illustrates the conceptual design of an ignition suppression spray system mounted on a dual drum shearer. High capacity sprays and optical light pipe terminations are mounted on the ranging arms. Primary extinguishant storage, sensor and trigger electronics are mounted remotely. The remote sensor views the locations of potential ignitions through fiber optic flexible light pipes. The system incorporates the following features:

a) The extinguishing agent used is water, to allow commonality of some components with the shearers normal spray system. The common components are, primarily, piping from the shearer body into the ranging arm, including a rotary hydraulic union. These components on the shearer will need to be

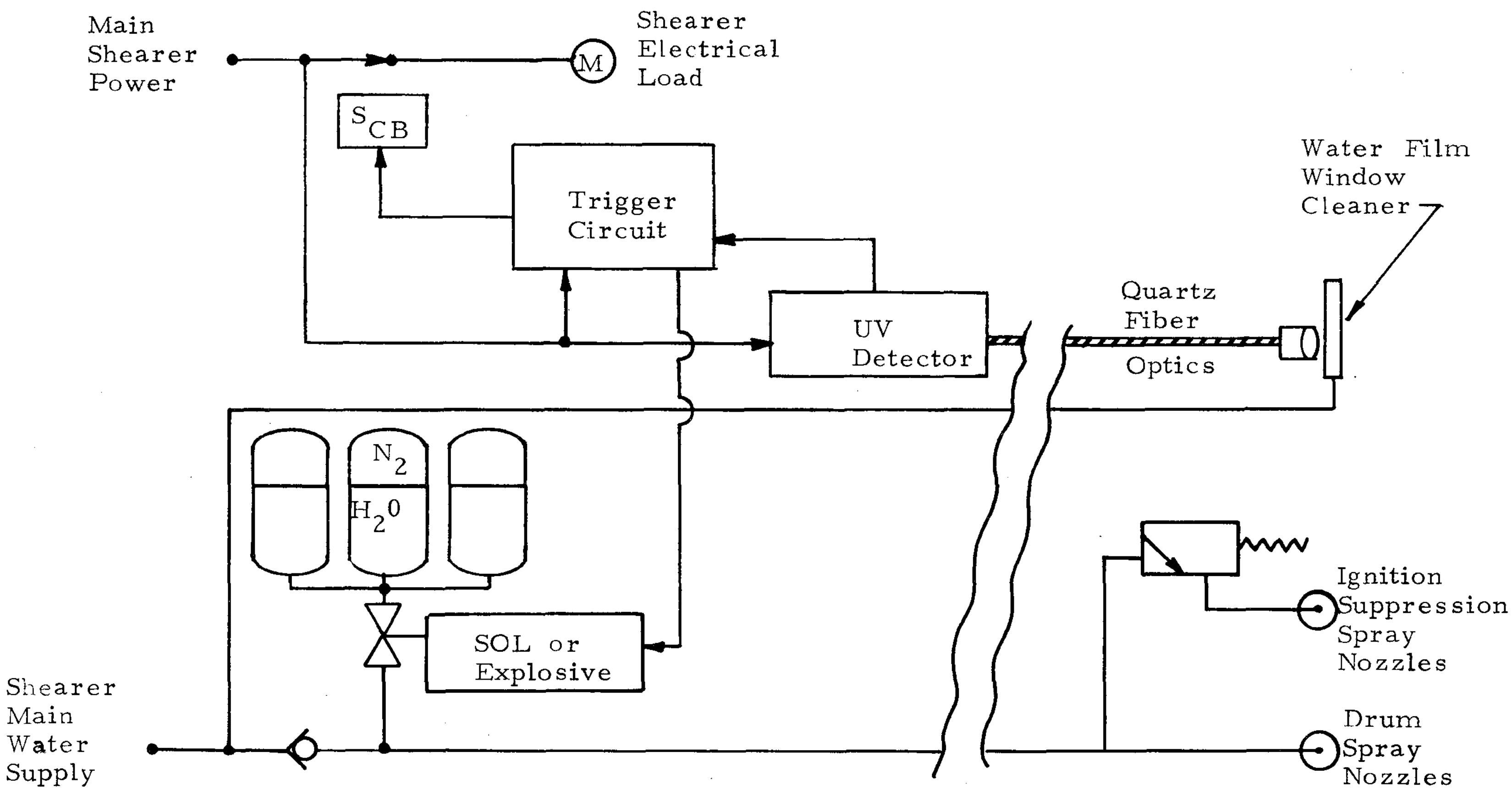


Figure 4 - Schematic of Shearer Mounted Ignition Suppression System

enlarged and strengthened to withstand the pressure surge of ignition suppression system operation.

b) Commonality of extinguishant flow piping to the ranging arm allows rugged internal piping to be used for ignition suppression rather than cumbersome and vulnerable external hoses to accommmodate movement of the ranging arm.

c) Remote location of extinguishant and electronics allows this equipment to be mounted securely and unobtrusively. On double drum shearers it also allows use of a single set of equipment to provide protection at both drums.

d) A check valve is provided to prevent extinguishant water pressure and flow from working back into the normal water supply line.

e) Optical windows are protected from contamination by a water system, such as that developed by Lee Engineering Div. of Consolidation Coal Co. for use on a continuous miner ignition suppression system.[14]

f) A trigger circuit that opens the extinguishant valve also opens a power circuit breaker to terminate shearer operation.

Although a continuous supply of water flows into the shearer, a separate extinguishant water supply is provided because the normal water supply cannot meet the flow rate and pressure demands of the ignition suppression system. Preliminary calculations indicate that up to eight gallons of pressurized water will be stored, to be released at a rate of 5,000 to 10,000 gpm in the event of an ignition. The amount of water actually required will need to be determined experimentally; however, the projected requirement of eight gallons may be quite conservative.

Ignition suppression sprays, mounted and aimed as shown in Figure 5, are intended to completely isolate the region of the shearer drum behind a curtain of water. The sprays are not intended to reach into the dead air space behind the drum to extinguish flame there. Instead, the water curtain will last from 50 to 100 milliseconds, long enough for the flame to consume available fuel and oxygen in the dead air space and self extinguish if it is prevented from growing.

Figure 6 illustrates how major ignition suppression system components will be mounted on shearers incorporating different basic layouts. These mounting configurations are based on an assumption of adaptation to existing shearer designs. With slight modification of shearer designs the system can be mounted completely internally and will provide a minimum of mechanical obstruction.

5.2 Explosion Barriers at Gates

A barrier for developed explosions will require considerably more extinguishing agent than a shearer mounted ignition suppression system. For reference, scaling from a survey of literature, indicates that a quantity of water or dry chemical on the order of 4 to 5 $feet^3$ is required to arrest an explosion in a 100 $foot^2$ cross section passage.[36] Therefore, one of the significant problems associated with the barrier is finding an optimum location which prevents propagation from the face back into entries.

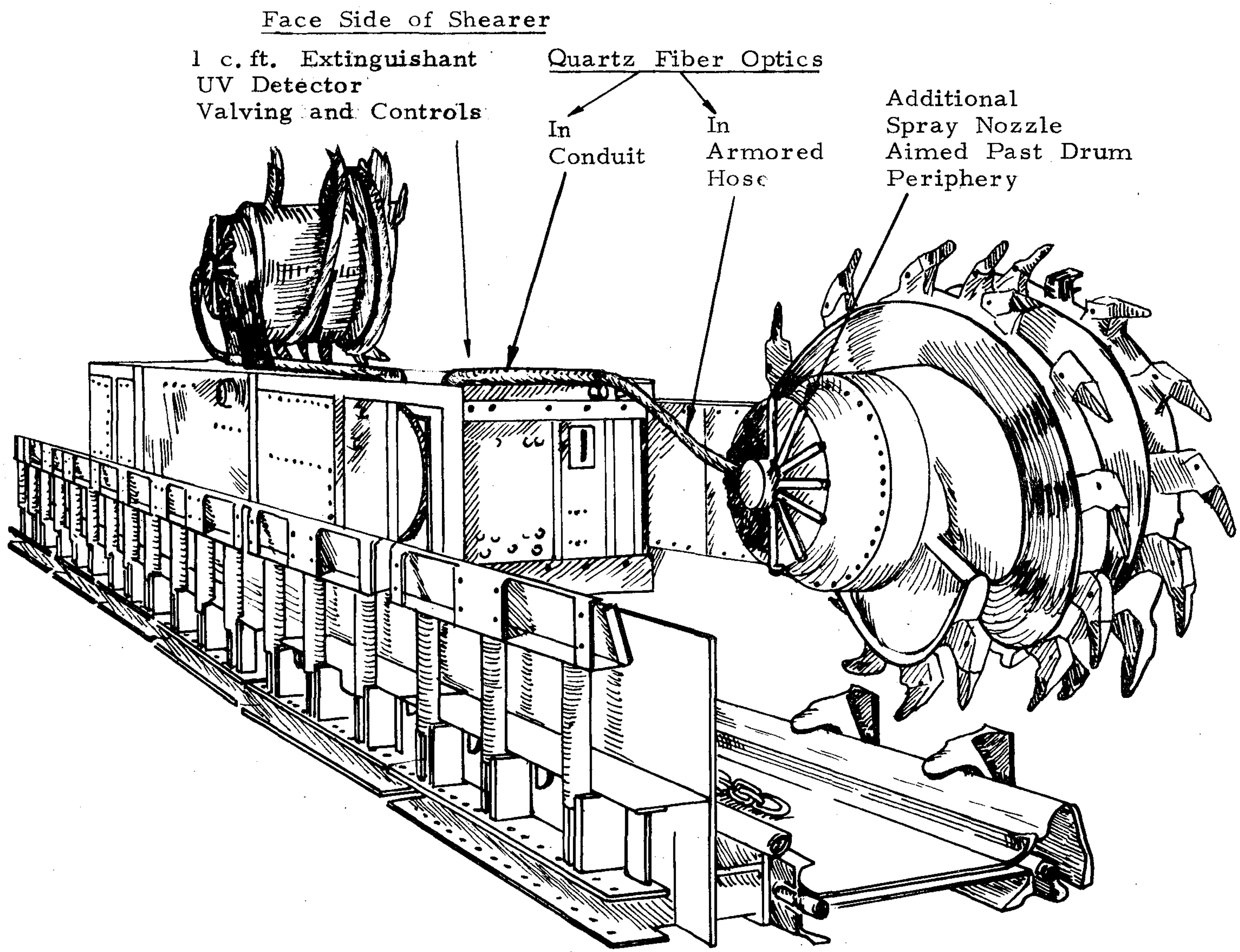


Figure 5 - Typical Installation of Suppression System on Shearer

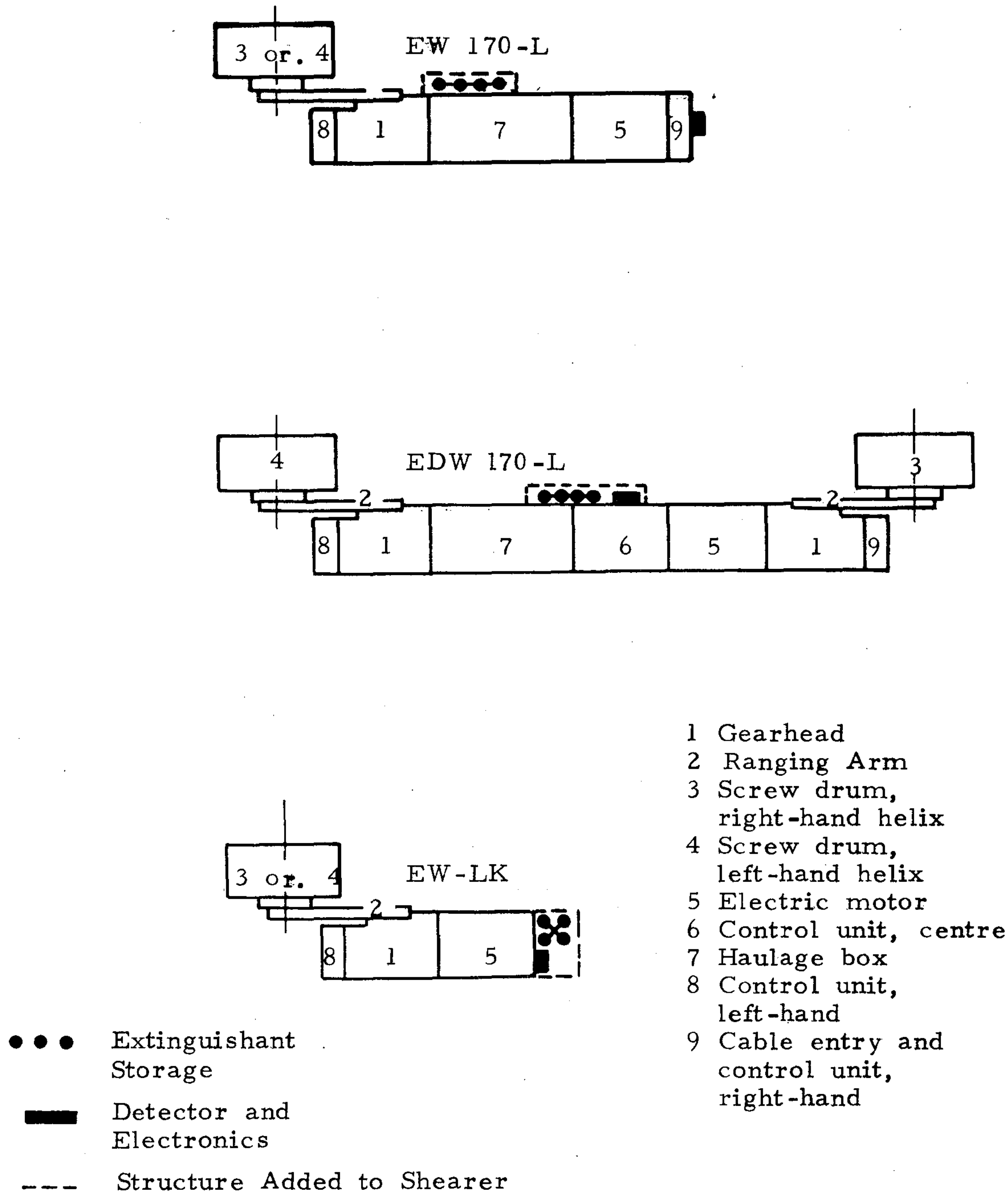


Figure 6 - Typical Locations of Ignition Suppression Components on Shearers

The effectiveness of suitably placed explosion barriers is often destroyed by the presence of alternate paths for explosion propagation alongside the gob and back toward the bleed system.[28] Possible routes for explosion propagation are illustrated in Figure 7. The route alongside the gob may be the result of a small hangup of roof along edges of the gob leading to both exposed roof coal and an air passage, as illustrated schematically in Figure 8. An explosion barrier system must therefore be designed to arrest propagation into the entries and along the gob. This requirement restricts possible locations of barrier components and necessitates uniform discharge of extinguishant in two different directions, adding more bulk to the system.

The only location that may be practical for the extinguishant storage and actuators of face end barriers will be mounted to and overhanging the ends of the chock line. This is illustrated in Figure 9. The actuator shown is of the exploding container type, a plastic container protected in an expanded steel cage. This type of actuator is necessary to propel the extinguishant more or less uniformly in several directions at once.

Functionally the barrier is similar to the ignition suppression system described in Section 4.6.1, but simpler since it does not interface with existing mine machine systems. The same type of optical detector system can be used, with fiber optics and convenient remote location of electronics.

Unlike the shearer mounted system, the barrier will use dry chemical extinguishing agent. Timing of extinguishant discharge, rather than simply fast response, is important for the barrier. Finely divided chemical powders have the advantage over water in this application in that they remain effective air suspension over a longer interval.

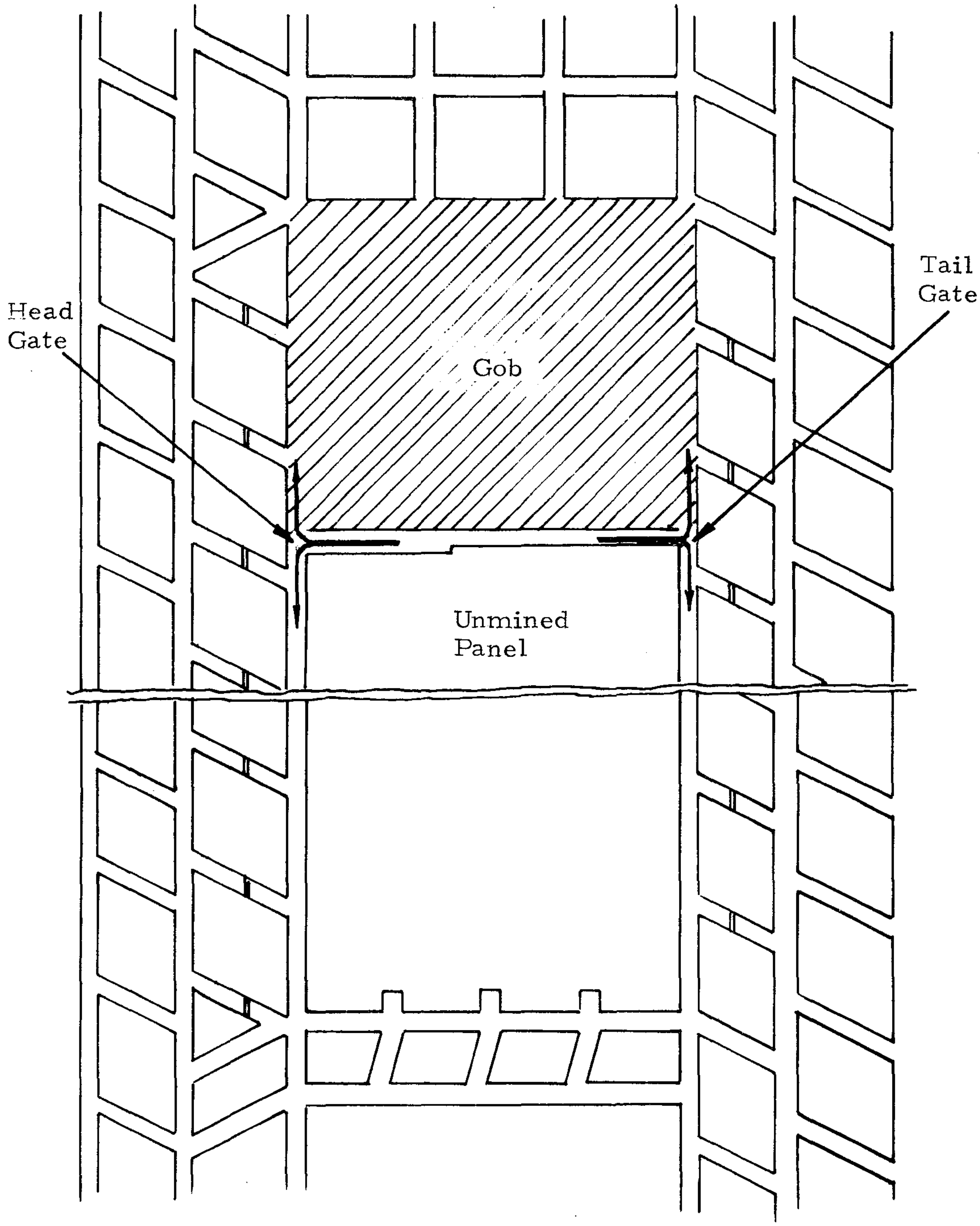


Figure 7 - Possible Routes for Explosion Propagation From Face (signified by ⟶)

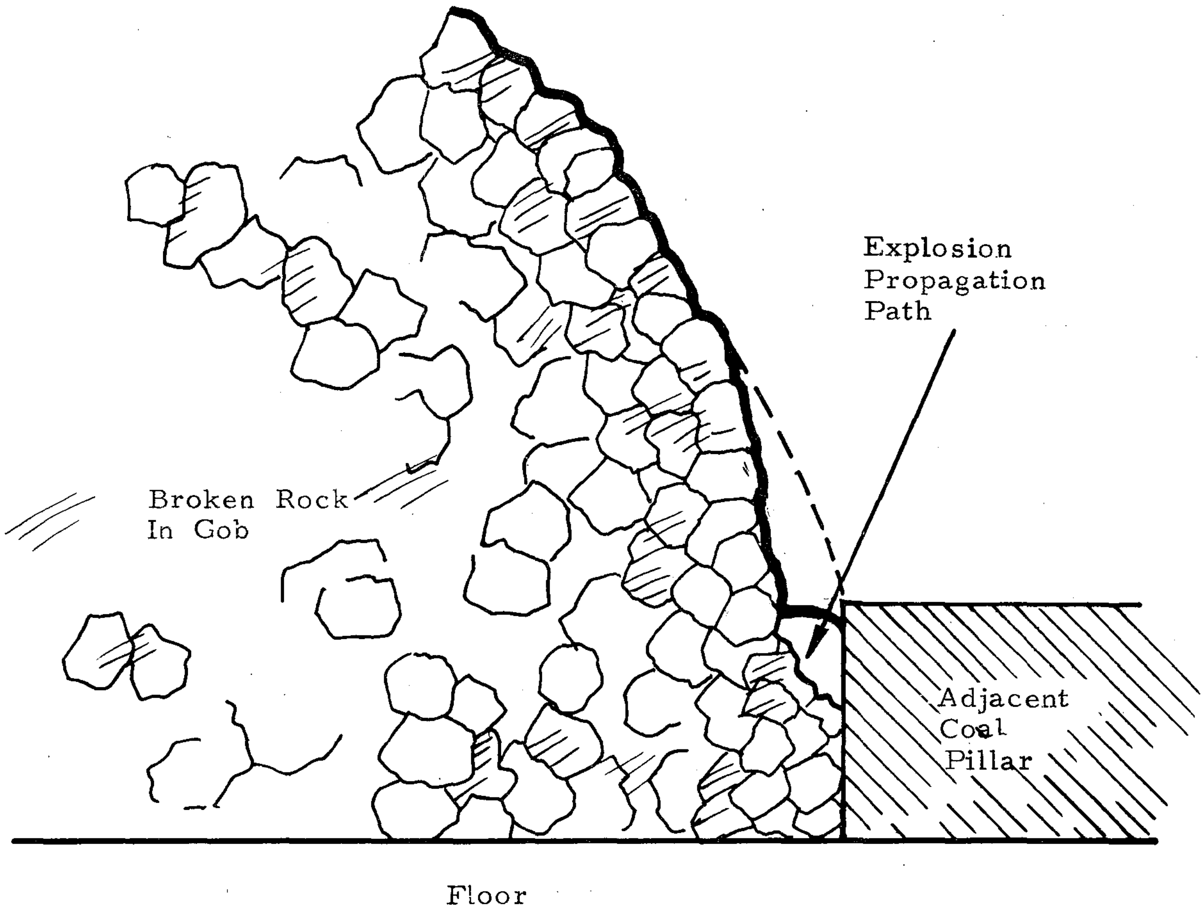


Figure 8 - A Path For Explosion Propagation Toward Bleeders Along Edges of the Gob

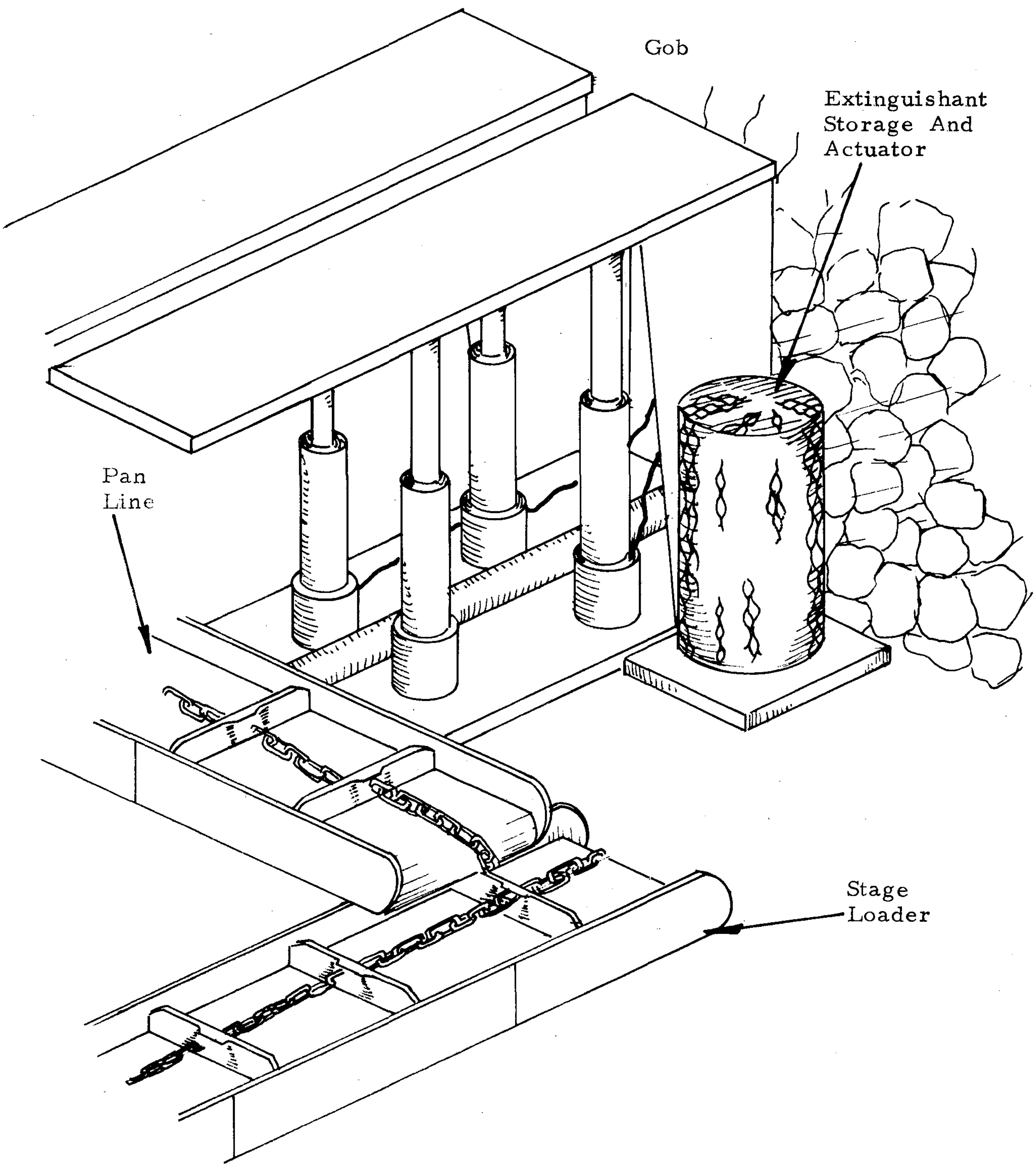


Figure 9 - Explosion Barrier Extinguishant Mounted To End Of Chock Line

5.3 Portable Suppression System with Welding Equipment

A dedicated ignition suppression system to extinguish ignitions initiated by the flame of a welding (or cutting) torch must meet several demanding requirements:

(a) It must be extremely small and portable to be transported together with welding equipment, and may possibly be packaged integral with the equipment.

(b) It must not be triggered by presence of the normal oxyacetylene flame.

(c) Its actuator must be miniaturized to the point of being packaged on the torch (or electrode holder if incorporated in arc welding equipment), so as to be always aimed directly at the point of possible ignition.

(d) Due to item (c) above, the actuator will always be very close to the potential ignition source. Therefore, the system must be extremely fast acting.

A system to satisfy these requirements in a welding torch is illustrated schematically in Figure 10. It has the following features:

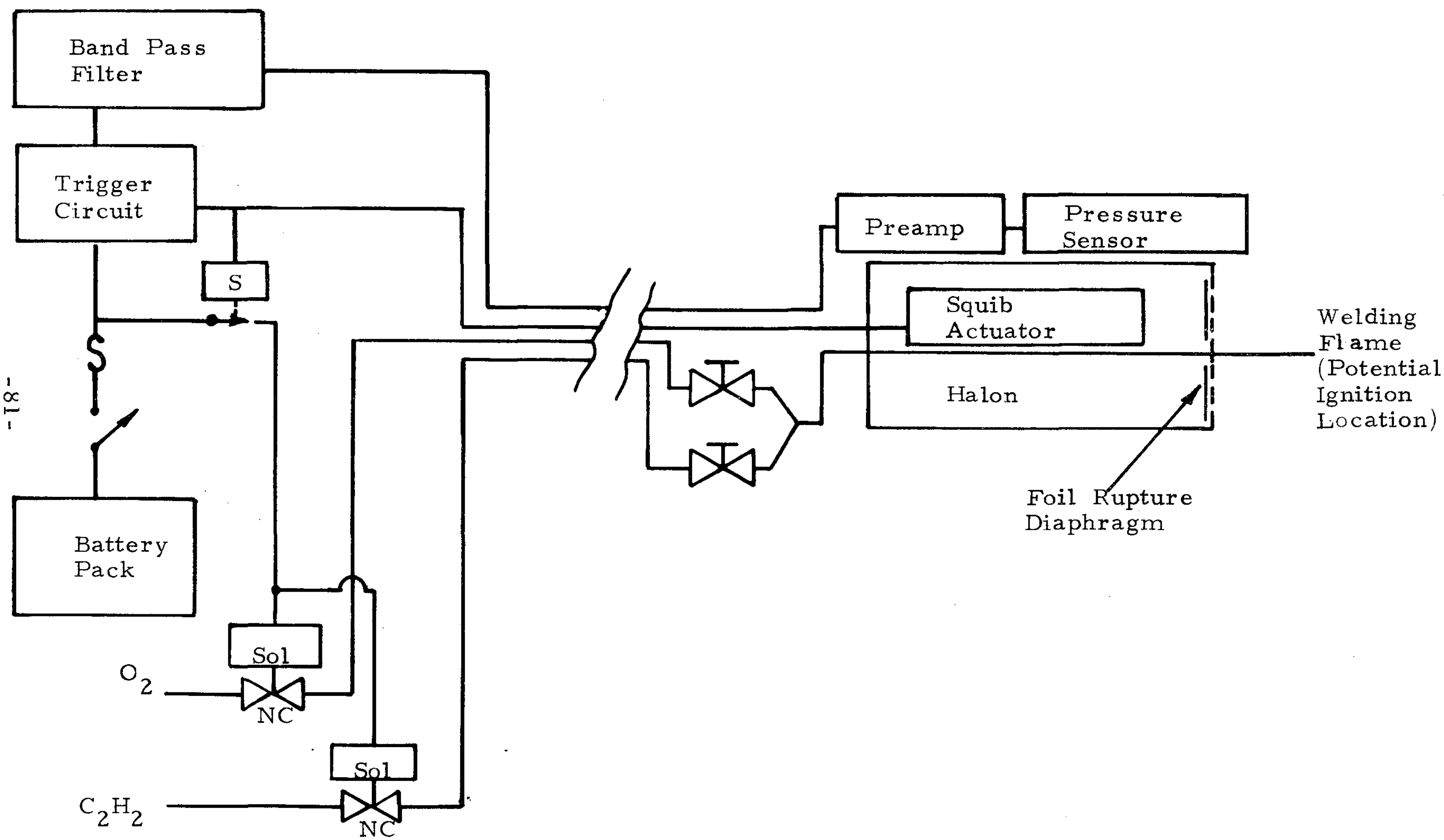


Figure 10 - Schematic of Portable Ignition Suppression System Integrated With Welding Equipment

(a) Approximately 1/2 lb of Halon 1301 is stored in the body of the torch. There is ample unused space for this in a conventional torch, which has a thicker body, for insulation and ease of handling, than is required by the volume of component parts.

(b) The actuator is of the rupture disc type, actually a rupture diaphragm over a multiplicity of orifices surrounding the torch's mixing and flame tube. To actuate, the diaphragm is broken by an explosive squib, packaged with the Halon in the torch body.

(c) The ignition detector is a high frequency pressure sensor and possibly a shaped band-pass filter. Detection of ignition induced pressure will be insensitive to the normal welding flame. Purpose of the filter is to eliminate the effects of both barometric (very slow) pressure variations and strong audio frequency noise. An effective shape for the filter must be verified empirically, but preliminary indications are that a band center frequency in the order of 100 Hz will be both sufficiently fast acting and sufficiently immune to normal noise.

(d) Triggering the suppression system cuts off the supply of oxygen and acetylene to the torch.

Figure 11 shows the preliminary design of a torch and actuator system suitable for use with the system described above. Note that although both Halon extinguishant and pressure detection have not been considered generally optimal, they are incorporated here because their characteristics are especially suited to the particular application.

5.4 Power Cable Protection System

As discussed in Section 2.3.4, the power cable is a significant ignition hazard on a longwall face; it represents a line source running the entire length of the pan line. It would be almost impossible to provide a conventional triggered suppression system for such a line source. Hence, a power cable protection system can be based on the assumption that with any cable fault, insulation breakdown is likely to preceed electrical arcing and thus can be used as both the fault sensing and suppressant triggering system.

One embodiment of this system could be as follows. The shearer power cable could be manufactured with hollow tubes within its jacket running parallel to the length of the conductors along the full length of the cable. These tubes would be pressurized with an inert or suppressant gas and connected to a reservoir at one end to provide for sufficient release of material. Localized breakdown of the cable insulation and rupture of the tube would release the suppressant material which would disperse the methane and blanket the potential hazard area with the inerting or suppressant gas. Arcing would thus occur in a non-explosive atmosphere. The system would have to rely on eventual protection provided by the circuit breakers, however it would provide the immediate protection which may be essential for ultimate safety. Protection time depends on the choice of suppressant material, the size of the reservoir, the distance from the reservoir, the size of the tubing or feed lines, and the size of the rupture.

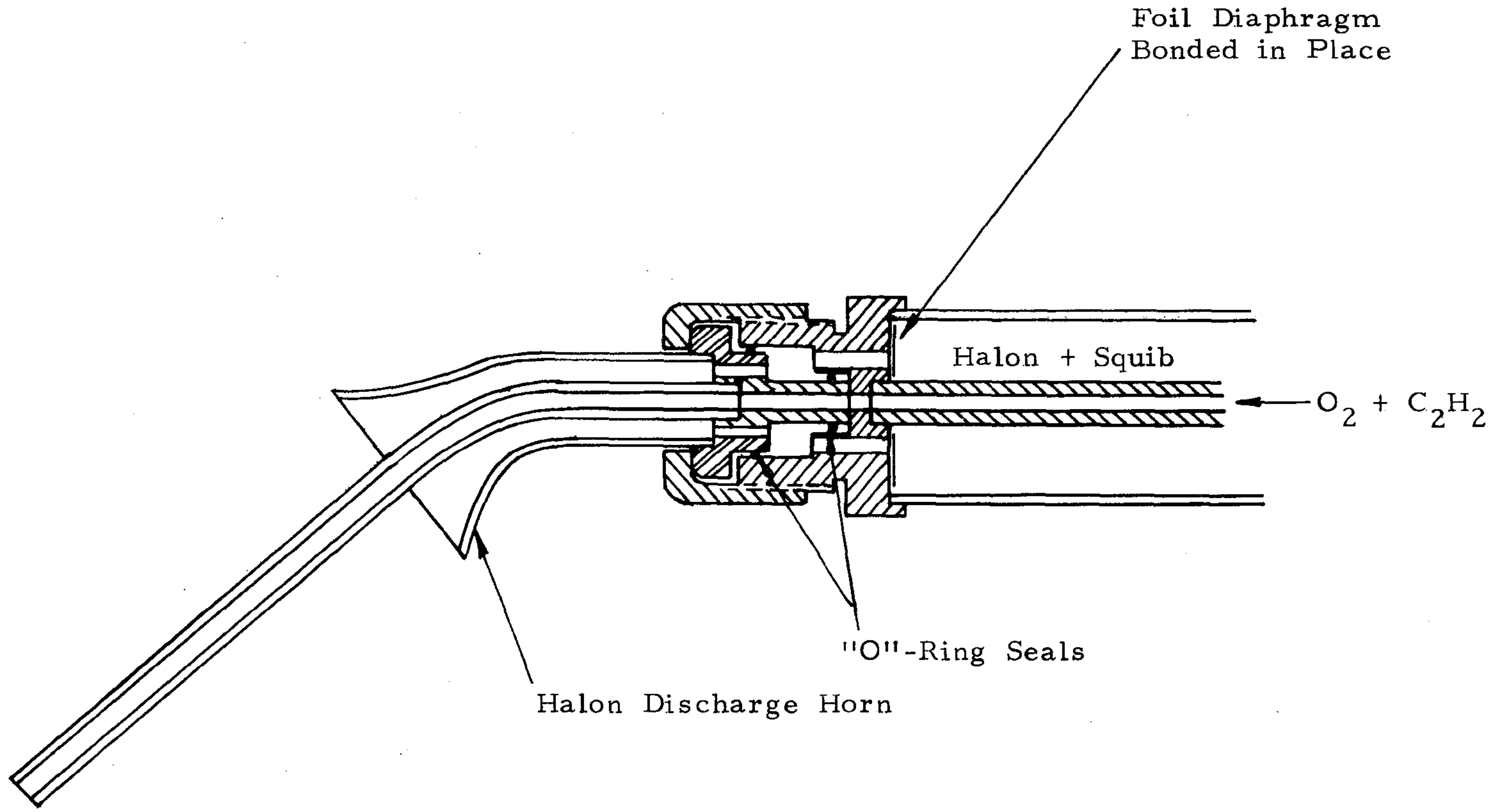


Figure 11 - Welding Torch With Ignition Suppression Feature

Figure 12 shows a schematic of such a cable ignition suppressant system. The flow of suppressant material or a drop in pressure level of the suppressant material would be used to trigger open the circuit breaker thus providing an extra measure of fault protection. The system would be designed with suitable interlocks so that the electrical circuit breaker would not close unless the suppressant system was charged to a certain minimum pressure level. A continuous loss of suppressant material by leakage would be an indication of an impending failure of cable insulation. A sensitive leak detection check could help to isolate faulty insulation before ultimate breakdown. Monitoring gas pressure in utility cables is a common way of checking for cable damage in gas filled utility cables.

The ignition suppressant cable functions by storing within its jacket a suppressant material under pressure. Any damage to the cable sufficient to result in arcing or short circuit will also break the cable jacket and release the suppressant. The suppressant will then flood the immediate area surrounding the break and inert the local atmosphere. Use of inerting atmospheres is accepted as a reliable means of ignition suppression in oil tankers and other hazardous industrial applications.

The protection thus provided is temporary, since ventilation air will be removing suppressant as it is released. The duration of protection can be increased by connecting a reservoir to one end of the cable through an appropriate connector, and filling the reservoir with an additional reserve of suppressant material.

5.4.1 Cable Design

The cable design is based on technology associated with gas and liquid filled cables.

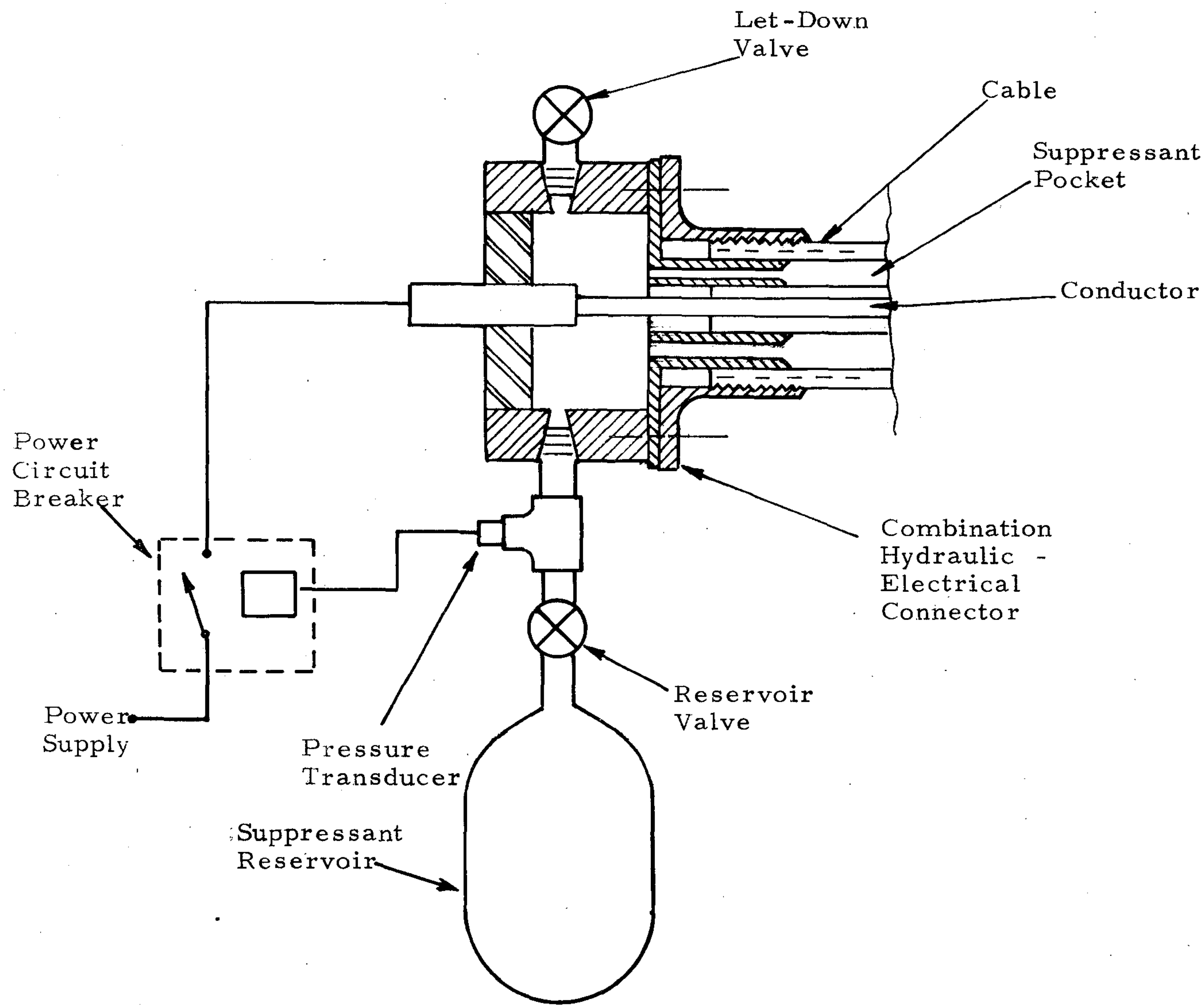


Figure 12 - Schematic Of Ignition Suppressant Cable System

Cables in pressurized jackets have been common in high voltage underground utility applications, generally about 100,000 V. or more. The jackets are generally rigid, lead for low pressure and steel lined for high pressure applications up to 200 psig. The higher pressure cable is more difficult to make and use, but provides better dielectric strength. Generally the cables are pressurized with either nitrogen or oil.

Low pressure cable is manufactured continuously by extruding the lead jacket around insulated conductors and tubing. High pressure cable is normally provided in discrete lengths by pulling conductors through the jacket. Continuous lengths up to 7,000 ft. have been produced by the General Cable Corp., of New York. Use of the principles of gas filled cable on a longwall will require use of a reinforced, flexible hose type casing instead of the rigid jacket. The hose type casing can be manufactured continuously rather than in discrete lengths.

Samuel Moore Company of Mantua, Ohio is one of several companies that manufacture cables with both electrical conductors and discrete pressure tubing. This type cable is used in process industries for steam tracing and process sampling. Technology is therefore well developed, and the tubing need only be compatible with the gas or liquid being contained. However, the present application may require locating the tubes and conductors within the cable differently from process bundles. The differing location will affect the manufacturing procedure and would require an enlarged cable size.

Connectors which route both conductors and fluids into the ends of a fluid filled cable are existing technology. They perform reliably for long periods in static situations. Their use in a dynamic, severe underground environment may require some upgrading.

Typical configurations of the ignition suppressant cable are illustrated in Figure 13. The configurations have the following characteristics:

(a) Discrete tubes are molded into the cable along with its conductors as shown in Figure 13(a). Primary advantage of this configuration is that it can be manufactured with minimum change in existing procedures. It has the following disadvantages:

(i) If tubes are placed in interstices between conductors to minimize cable size, they will provide incomplete protection around the conductors.

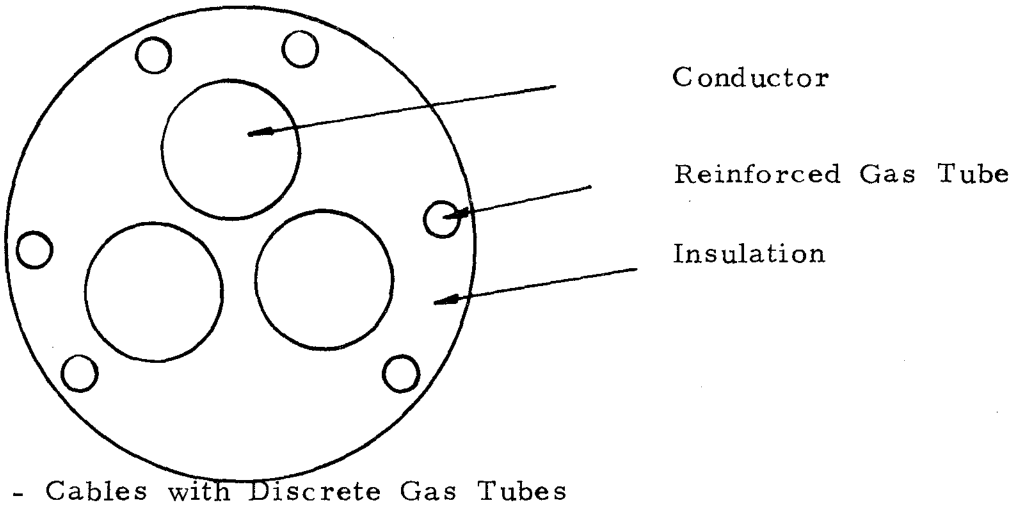
(ii) If tubes are located around the conductors rather than in interstices, the cable will be larger, more expensive, less flexible, and more difficult to manufacture and handle.

(b) Insulated conductors are routed through a single large, pressurized tube, or tube with extruded pockets and webs to hold the conductors. This configuration will require development particularly in manufacturing methods. However, any damage sufficient to expose conductors will also release the ignition suppressant material.

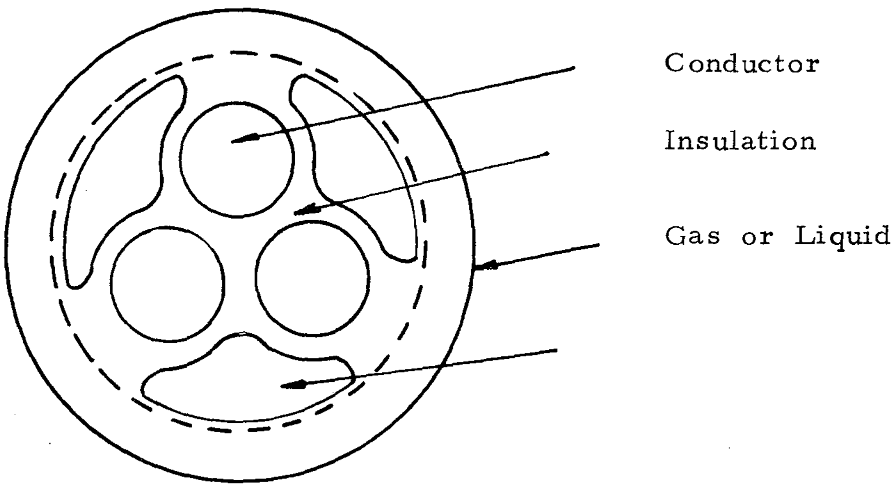
The configuration of (b) is preferred from a performance standpoint. However, it will require a development effort to implement.

5.4.2 Suppressant Material Selection

Of the possible suppressant materials, three are considered to be prime candidates:



(a) - Cables with Discrete Gas Tubes



(b) - Conductors in Single Pressurized Tube

Figure 13 - Gas Filled Shearer Cable Configurations

(a) Nitrogen Under Pressure

If the cable is cut, the damaged area will be blanketed by the inert gas. Nitrogen will also tend to reduce the likelihood of intensity of arcing; it is used for this purpose in some utility cables.

The primary advantages to using nitrogen are that it is inexpensive and widely available.

The disadvantages are: at reasonable pressure, up to a few hundred psi, it must be stored as a gas. This limits the amount that can be stored. If there is any leakage, nitrogen pressure in storage will drop rapidly.

(b) Halon 1301, As Liquid

If the cable is cut, the liquid will boil and Halon gas will fill the damaged area in at least sufficient concentration, typically over 7 percent, to prevent or extinguish combustion. Liquid vapor pressure at mine ambient temperature will be about 200 psi, so storage as liquid is practical.

Advantages of Halon are: (1) A strong likelihood of being able to prevent or extinguish ignitions. (2) Compact storage as a liquid. (3) Due to two phase storage slow leakage can be tolerated, within limits, without reducing storage pressure and effectiveness.

The major disadvantage associated with Halon 1301 is that it forms toxic decomposition products on exposure to a flame. However, the concentration of these products should be low and in most cases they should be continuously removed by ventilation.

(c) Sulfur Hexafluoride (SF_6) as Liquid

If the cable is cut, SF_6 will blanket the fault area and function as both an inert gas and arc suppressant. Liquid vapor pressure at mine ambient temperature is about 300 psi.

Advantages of SF_6 are: (1) Like Halon, it is storable as a liquid. (2) It is more effective than nitrogen at reducing arc intensity and has been used for this purpose in high voltage transmission lines and in power circuit breakers up to 345,000 V. (3) It is non-toxic.

Disadvantages of SF_6 are: (1) It is not as effective an extinguishant agent as is Halon, so that a larger quantity of SF_6 would be required. (2) Cost. It is expensive and may add more than $2.00 per foot to the cost of cable.

Preliminary considerations lead to Halon as the preferred material.

4.5.3 Design of Gas Suppressant System

The sizing of the gas or liquid filled cable system will be determined by the volume to be inerted around the point of cable, damage the duration of gas release and the allowable leakage rate that can be tolerated during normal operation. The rate of gas discharge and its dispersion around the point of cable damage will effect the system's functional reliability in suppressing ignitions. A preliminary design goal of inerting at least 20 cft of local atmosphere within one second after the jacket being punctured was established. Based on this requirement the average cable cross-section area for the suppressant can be determined. This will depend on the type of suppressant material used. For Halon, preliminary estimates indicate that 0.6 in^2 of cable cross-section would be required.

The total capacity of suppressant material in the system will determine the duration of protection the system can provide. The blanket of gas must remain in the damage area at least long enough to allow the circuit breaker to operate and further to allow the surfaces to cool where arcing may have occurred. Ventilation air flow will be removing suppressant gas from the area constantly, so that gas must be released continuously during the required interval. Protection time of one minute is estimated to be a conservative design goal. For the Halon system under consideration, this would require a 10 lb Halon reservoir for a 500 ft long cable with 0.6 in^2 cross-section area for suppressant material.

Any increase in cable size over the standard cable is to be minimized. However, the suppressant filled cable will be undoubtedly larger in order to accommodate the suppressant. Preliminary calculations indicate that the Halon filled cable will be 0.3" larger in diameter than the standard 2 1/4 inch diameter cable.

Leakage of suppressant material must be minimized in order to maintain system effectiveness over a reasonable period of time without the need for recharging. As a preliminary design guide, the system should be designed to maintain sufficient pressure and stored material to operate satisfactorily over a period of six months.

Low pressure or low suppressant material limit switches will be incorporated in the system designed to trip the circuit breaker and maintain fail-safe operation.

These requirements will be met with a cable configured generally as shown in Figure 13(b). The precise shape and location of gas pockets will be determined in detailed design, based on the need to minimize electric stresses in these pockets which will be the most highly stressed portions of the cable.[72]

5.4.4 Other Applications

Although this concept for a cable protection system has been directed primarily toward eliminating one of the ignition hazards on a longwall face, the principle could be applied to the protection of any power cable in an underground coal mine.

5.5 Impact on the Mining Cycle

5.5.1 Shearer Mounted Ignition Suppression System

(a) The system will add several cubic feet to the size of a shearer. However, packaging the system smoothly into system structure will result in little or no disruption of mining procedures, particularly on single ended shearers.

(b) One possible vulnerable component of the system as described in Section 5.1 is the fiber optic detector light pipe. The light pipe will be packaged in armored hose where ability to flex is required, and in heavy conduit where possible. Nevertheless, experience may indicate a need for further protective measures. Elimination of the light pipe by mounting optical sensors up near the shearer drum would aggravate rather than help this problem since the sensors are also vulnerable in addition to being bulky appendages.

(c) Any shearer mounted suppression system will require some modification to the shearer. The degree of modification will depend on both the design of the existing shearer and the type of suppression system being adapted to it.

5.5.2 Explosion Barriers at Gates

(a) The primary problem area associated with these barriers will be their size, since the headgate in particular is already crowded with equipment. This problem can be mitigated somewhat by careful design and choice of location, but remains a severe problem due to the unavoidable large quantity of extinguishing agent required.

(b) Use of an optical ignition sensor will necessitate special procedures and overrides when performing maintenance which may involve use of a welding or cutting torch.

(c) Further work may indicate that barriers at the gates are not sufficient. Barriers may be required, instead or in addition, in the entries, at crosscuts, and in the bleeder system. The result would be a complex system requiring significant maintenance and further restricting already limited space.

5.5.3 Portable Suppression System with Welding Equipment

(a) Welding or cutting equipment is used only during maintenance operations, so that the system will have no effect on the normal mining cycle.

(b) The system will add some bulk and weight to the equipment with which it is packaged, and therefore make the equipment somewhat less portable. This effect will be marginal, however, since the suppression system components will be small compared to normal welding or cutting gear.

(c) Use of the suppression system with gas welding and cutting equipment will necessitate use of either an electric supply, not normally needed, or a battery which must be kept charged.

5.5.4 Cable Protection System

(a) The system is expected to have a minimum impact on the mining cycle and could be retrofitted into existing longwall mining equipment relatively easily, requiring no additional equipment along the face.

(b) The suppressant cable may be larger in diameter than conventional cable and thus less flexible.

(c) Special cable connections and splicing equipment will be required to repair cable damage.

(d) If not properly maintained, the system will disrupt the mining cycle by virtue of cutting power to the shearer.

5.6 Scope of Necessary Development Work

Programs to develop any of the triggered suppression systems discussed herein, to the point where they can be practically utilized in a longwall face, will have the following objectives:

(a) Develop a breadboard prototype of the system, with provision for ease of modification.

(b) Test and refine the system for best performance.

(c) Design and package the refined system in a configuration compatible with the mine environment, including any necessary modifications to existing equipment.

(d) Field test and further refine the system to eliminate flast firing and minimize maintenance requirements.

The order of costs and durations of programs to achieve the above objectives for the three types of suppression systems will be:

(a) For the shearer mounted suppression system, approximately 24 months and $350,000.

(b) For the face-end explosion barrier, approximately 18 months and $300,000.

(c) For the portable suppression system with welding equipment, approximately 18 months and $200,000.

(d) For the cable protection system, approximately 24 months and $430,000.

6. Passive Systems for Ignition Prevention and Suppression at the Cutter Head

6.1 General Description of Ignition Prevention at the Cutter Head

Friction between cutters and rock is the most frequent single cause of ignitions at the face area of a longwall. The extent of the face ignition hazard has been detailed in Section 2.3 of this report. Since the location and characteristics of a cutter induced ignition are predictable, a variety of concepts have been proposed and studied to protect against this particular ignition hazard.

Recent work indicates that the primary source of cutter induced ignitions is a smear of hot or molten metal, left on rock by the pick due to friction. Visible spark showers may be capable of causing ignitions under certain circumstances, but in general the hot-spots left on rock are the far more probable and dangerous ignition source.[55, 56] The following controllable factors have a strong influence on the probability of ignitions from this source:

a. Physical size of the hot smear on rock,

b. Temperature of the hot smear,

c. Flammability of the local atmosphere.

Therefore the suppression concepts described are attempts to reduce the probability of significant ignitions by controlling these factors. These concepts are:

- a) Improved spray systems
- b) Redesigned cutters for reduced pick speed
- c) Auxiliary local ventilation equipment
- d) New less incendive pick materials.

Some of these concepts, such as sprays, cutter drum and pick designs all represent modifications, in varying degree, of existing equipment and systems. Other concepts for auxiliary ventilation equipment represent possible new systems. Whether new or modifications of existing equipment, all concepts extend the practical state-of-the-art in mining equipment in that they are optimized for ignition suppression.

6.2 Improved Spray Systems

Existing water spray systems are known to reduce the frequency or probability of ignitions, even though not specifically optimized for that purpose.[18] Water sprays can be configured to provide protection in two ways:

- a) Directly, acting primarily as a coolant. Water can cool a potential ignition source to below a dangerous temperature, or cool incipient ignitions to extinguish them.

- b) Indirectly, as an aid to ventilation. Water sprays tend to pull air with them, and can be used to improve ventilation in hard to reach places.

In any case, to be effective, sprays must be made reliable and must be used. An interlock to prevent shearer operation unless the sprays are operating first is important,[18] and the interlock should be constructed to prevent its being bypassed.

Following sections describe several different approaches to optimizing spray systems for ignition suppression.

6.2.1 Sprays for Inerting

An atmosphere of methane and air that would otherwise be explosive can be made inert by the addition of water. However, the amount of water required is large, and the method of inerting is most effective if the water is in the form of vapor or extremely fine droplets.

The theoretical requirement for liquid water to inert a methane-air atmosphere is approximately 18 percent by weight. Fine fogs with water droplet size around 1 micron can inert the atmosphere as predicted, but the combination of fine drops and high water content is difficult to achieve in practice. Average droplet size from commonly used spray nozzle systems is generally in the order of 100 microns (approximately .004 inch) diameter, which is far too large for the suppression function. Droplets of this size at 18 percent moisture concentration in the atmosphere are completely ineffective as an inerting agent.[57] This may be because of too large a distance between droplets, or insufficient surface area for heat transfer, or both.

Liquid water is more effective than vapor as a coolant because its latent heat of vaporization allows absorbing a lot of heat at a low temperature. Therefore if water vapor is used to inert, rather than liquid, more is required. Approximately 27 percent water vapor in a methane-air-vapor atmosphere will inert the atmosphere.[58]

Generation of these very high concentrations of water in the atmosphere, either liquid or vapor, presents severe practical problems. The following approaches to inerting with sprays have been studied.

6.2.1.1 Fine Droplets

The production of very fine fogs is difficult in itself, requiring specialized nozzles and often very high water pressures. Where fine mists are produced, the total moisture content is generally less than 3 percent by weight in the atmosphere. This level of moisture content is insufficient to inert. The concentration is limited to a low value for the following reasons:

a) Fine sprays tend to educt a large quantity of air with them thus diluting the moisture concentration with air. This dilution effect is particularly severe when large quantities of fine sprays are used to achieve high moisture concentration limiting the maximum concentration achievable to a low value.

b) Fine mist producing nozzles are often two phase in design, relying on compressed air to break up the droplets. The air is then sprayed with the water and dilutes it.

Test results indicate that a water spray can entrain and drag with it an air flow up to ten times the water flow by weight.(57) This in itself would limit the attainable water concentration to approximately 9 percent. This result is extreme, however, since the measurement was taken with water sprayed along a tube open at both ends in a configuration resembling a jet pump.

Further testing may indicate that less air is entrained when water is sprayed in an open area than in a confined one. Also, further testing should take into account the dynamic effect of normal ventilation in a real mine environment. Airflow velocity along a longwall face is generally in the order of 1 ft/sec. The undesirable diluting effect of air entrainment may be reduced substantially by directing fine sprays against the ventilation flow, with the resulting dense mist then carried back by ventilation.

In a purely laboratory context, very fine mists up to 18 percent concentration have been achieved by mixing steam and liquid water in a two phase atomizing nozzle.(57) Practical utilization of this technique would depend partly on the development of sufficiently rugged and reliable equipment.

Based on the above considerations, there is reason to believe that high density, fine mist sprays are one of several suppression techniques that can be made workable at a longwall face.

6.2.2 Hot Water Sprays

The effectiveness of water sprays in inerting a methane-air atmosphere can be improved by the use of heated water. This somewhat counter-intuitive result may be due to the increasing vapor pressure of water at elevated temperature, which increases the amount of water present as vapor in addition to liquid droplets. Water at 144°F has a high enough vapor pressure to form an atmosphere with approximately 28 percent vapor, which is sufficient for inerting.[58]

The use of electric motor waste heat to obtain high temperature coolant water for spraying has been considered. Typical shearers are provided with motors rated NEMA class B, F or H,[59] with H being the highest temperature rating. The maximum winding temperature to which these motors are rated is 130°C to 175°C (approximately 260°F to 340°F). Most American made mining machines utilize class H motors as a precaution against being run without any coolant.[60] The motors can sustain running temperatures high enough to boil water,[61] and so can easily heat it to a moderate temperature.

The difficulty in using motor waste heat to generate hot water for spraying is that the motors can only generate sufficient heat for this purpose while cutting coal and generating maximum torque. The cutting operation is intermittent, and the motors have high thermal inertia. Thus the motors are likely to be cold at the start of the cutting cycle and not hot enough to provide significantly heated water when it is needed. Even in the steady state, the equivalent of 50 HP of waste heat, is only capable of heating 3 GPM of water to 144°F. Though this amount of coolant water is all the motors need, higher flow rates are used to satisfy spray requirements for dust control.[61]

Machinery electric motors are therefore not a practical source of heat for hot water ignition suppression sprays. Implementation of this concept will require a system including auxiliary heaters.

6.2.3 Steam

Conceptually the use of steam sprays is a further extension of hot water spraying. Water is supplied as vapor, so more is theoretically required than when liquid is used. However, the need for generating extremely fine droplets is eliminated. In practice, steam spraying will result in the formation of fine droplets due to condensation of some of the vapor.

Equipment for generating steam for spraying in mines is commercially available,[62] used primarily for dust suppression. The existing equipment generates and maintains a steam pressure up to approximately 50 psi in a package sufficiently rugged for the mining environment.

A major obstacle to practical implementation of this concept is possibly very high power consumption. Face ventilation in a longwall mine will constantly draw away vapor from the region around the shearer, and this vapor must be replaced. The energy required to vaporize 1 GPM of water would require approximately the energy equivalent of 200 HP.

Commercially available equipment is designed to spray at the rate of only 4 gallons per hour for dust suppression. Under contract to the National Coal Board, Dosco Corp. is now testing the steam spray in a British longwall mine. Interim results are encouraging, and seem to indicate that with proper placement of sprays the steam is not too quickly blown away by ventilation. The tests are not yet complete. It should be noted that even if 4 gallons per hour is found to be sufficient for dust suppression, higher rates up to 20 times this value may be required to inert the local atmosphere.

6.2.4 Sprays as Aids to Ventilation

One of the problems associated with using sprays for inerting, as discussed in Section 5.2.1, is that they entrain air. This entrained air is then dragged along by the sprayed droplets and tends to dilute the water content of the sprayed region. This same effect can be used to bring fresh air for ventilation into hard to reach places. This pumping action is the principle of operation of the hollow shaft ventilator, which is optimized specifically for air moving.

Even without a venturi configuration, properly located and oriented sprays can be used to improve local ventilation. This has been verified experimentally in work performed by Foster-Miller Associates under USBM contract and described in an interim report to the Bureau entitled "Guidelines for Optimum Methane Control at the Coal Mine Working Face Through the Installation of Diffuser Fan Systems and Modified Water Spray Systems on Continuous Mining Machine". Use of sprays in this manner has not been optimized and tested in the context of the longwall layout and equipment, but some improvement in ventilation should be obtainable.

Sprays in this application rightfully fall into the class of auxiliary ventilation equipment. Such equipment is known to be helpful, when properly configured, in improving ventilation local to a shearer.[63] Sprays in this context may have two advantages over mechanical ventilation aids:

a) Sprays can serve the multiple functions of air moving and dust suppression. In addition they may be helpful in suppressing ignition directly, in conditions which can sustain but are not ideal for ignitions.

b) Sprays are a mechanically simple means of implementing auxiliary ventilation. They require no additional equipment or equipment types.

Despite their mechanical simplicity, sprays are not entirely reliable in the mine environment. Since the use of sprays for air moving requires a small orifice diameter the reliability problem may be aggravated.

6.2.5 New Spray Locations

Current practice consists of near random placement of dust suppression sprays on a shearer drum. This is illustrated in Figure 14, which shows a common drum and spray configuration. There is some evidence that redesign of the spray system to apply water behind the picks would virtually eliminate cutter induced ignitions, at least when the sprays are operating.

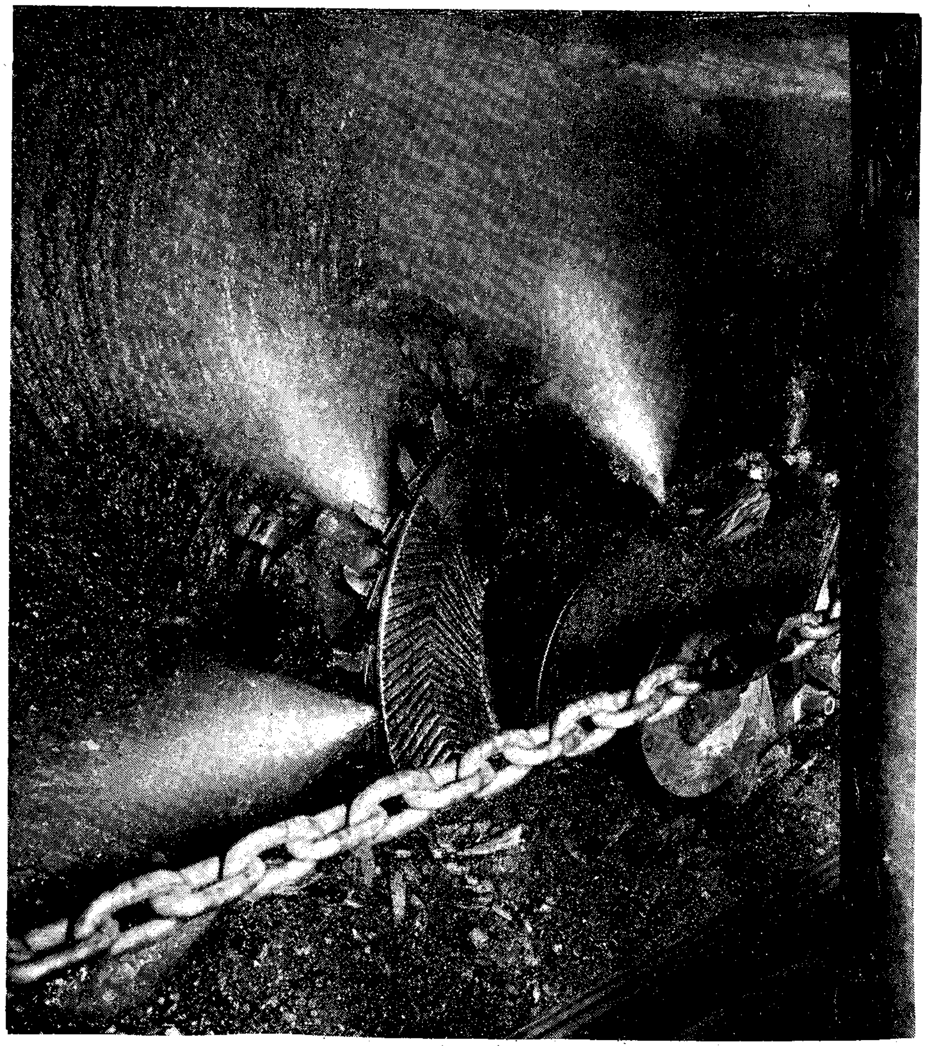


Figure 14 - Typical Spray Locations For Dust Suppression on Shearer Drum

The primary cause of these ignitions is a hot streak left on rock behind the pick.[55, 56] Laboratory tests have determined that if water is sprayed on rock in the area immediately behind a pick in an incendiary methane-air atmosphere, the probability of ignition is reduced to near zero.[55, 64, 65] These results were obtained in conditions such that the probability of ignition was 100 percent if the sprays were removed. Significantly the same amount of water sprayed ahead of the pick, rather than behind it, did nothing to prevent ignitions. Therefore the location at which the water is applied is a more important variable in this case than the amount of water or other considerations often associated with ignition suppression.

Implementation of this concept in actual mining conditions will require modification to shearer drums, and a very large number of spray nozzles, probably one behind each pick.

6.2.6 Spray Reliability

To be effective in ignition suppression, sprays must be operating properly when coal is being cut. Spray systems should include interlocks, to insure that mining machines are not operated with sprays off. This feature was recommended for use even with existing sprays by H. M. Chief Inspector of Mines and Quarries in 1973. Interlock systems are now available options on many mining machines. The interlocks should be made as secure as possible to avoid tampering by miners, since bypassing the interlock may at times seem easier than fixing a clogged spray.

Clogging of sprays is a major operational problem, even with the relatively coarse orifices now used. If coal is cut while sprays are not working, the orifices can become clogged with coal. More frequently, the sprays are clogged internally by buildup of foreign particles from the water supply. Of the two problem areas, the first is adequately provided for with a good interlock system as described above.

There have been several developments in filtration equipment to help alleviate the latter problem. Under contract to USBM, Eastern Coal Association has developed a three component system which effectively removes particles over 100u. The system consists of a Y-strainer for very coarse particles, a hydrocyclone and a final filter.

An outstanding commercial development in filtration equipment by the Deron Research & Development Company consists of a very reliable and convenient filter system with quick backflush capability.[(66)] This independent development has received wide initial acceptance on continuous mining machinery, both in retrofit applications and as an OEM subsystem. It is compact, available, and could easily be applied to longwall machinery.

No matter what filter system is used, spray nozzles can still be clogged by particles originating in water lines downstream of the filter, particularly due to corrosion. Elimination of these particles is essentially a matter of careful detail design. As much as possible, materials exposed to water downstream of filters should be non-corrosive. This includes pipes and fittings, motor coolant jackets and any valves. Critical parts of the Deron system are made of bronze or stainless steel. Similarly critical parts of the water line should be made of, or lined with, compatible materials.

6.3 Hollow Shaft Ventilator

Hollow shaft ventilator (HSV) systems represent a developed approach to auxiliary ventilation behind the cutter drum. The principle of operation is illustrated in Figure 15.[63] A water spray is used to pull air through the cutter drum shaft, introducing both the spray water and fresh air between the face and end of the drum. The spray is used here primarily because it is a simple and presumably rugged means of pumping air.

In 1974, four out of 17 face ignitions in British mines occurred with machines equipped with HSV equipment.[25] In all four cases, the equipment was not functioning properly due to problems with the driving spray. In 1973 there were six ignitions with HSV equipped machines and again, in four of the six cases, the equipment was inoperative due to blocked water jets.[18] However, two of the ignitions occurred where HSV was in normal operation.

Work is still in progress toward further optimization of the HSV, and results have been encouraging.[26] However, at this stage it cannot be said to completely eliminate ignitions, partly due to jet clogging problems, but also due to inherent limitations when operating normally.

Continuing laboratory work has provided a more quantitative understanding of how the HSV works. In one series of tests, zones of stagnant or slow moving air were measured near the shearer, where normally rapid ventilation flow is disrupted. A zone of relatively slow moving air generally exists just outside the cowl on machines so equipped. The HSV substantially reduces the extent of that

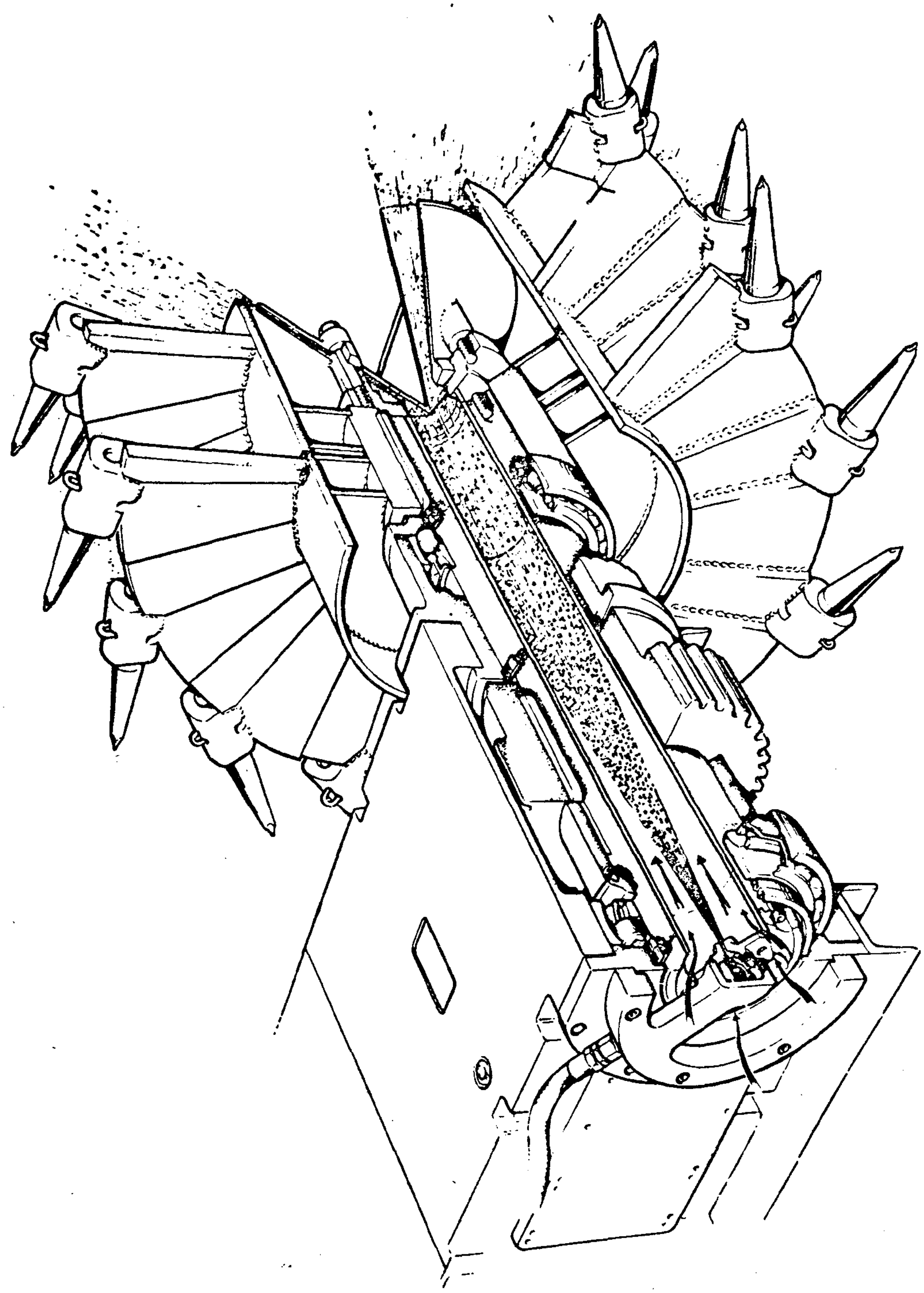


Figure 15 - Hollow-Shaft Ventilator on a Drum Shearer

slow moving zone. However, in the almost completely stagnant region directly under the drum the HSV had no effect, or an adverse effect in some cases.[63]

In tests with methane it was found that the HSV can reduce by 50 percent the methane concentration under the drum when cutting coal. It should be noted that in conditions of very high methane release directly under the drum, this can create a combustible atmosphere where one would otherwise not exist. In methane scouring tests while not cutting, the HSV yielded conflicting results. It improved the rate of methane reduction under the drum, but disrupted normal face ventilation around the drum.[63]

Firm conclusions regarding the HSV are difficult to draw. It appears to be helpful in reducing the probability of ignitions under normal circumstances. However, present configurations do not reduce methane under the drum sufficiently to completely prevent ignitions.

6.4 Auxiliary Ventilation Equipment

Unassisted face ventilation cannot reliably flush the region immediately surrounding the drum and cowl of a shearer. Auxiliary ventilation equipment would divert some of the main ventilation flow and enable it to go around corners, to provide fresh air at hard to reach locations under the drum. Sprays and HSV equipment for this purpose are discussed in Sections 5.2 and 5.3 respectively. Those concepts utilize the momentum of water droplets to draw fresh air. This section discusses auxiliary ventilation through direct or mechanical air movement.

Tests with a shearer mockup and several types of auxiliary ventilation indicate that forced air jets reduce local methane concentrations as much as, or more than, an HSV in all drum positions. These results were obtained with an airflow rate of 350 CFM, the same airflow provided by the HSV tested. The jets provided uniformly better ventilation under the drum while cutting. In methane scouring tests while not cutting, the jets again provided better results (shorter scouring time) than the equivalent HSV system. Measurements were also made away from the immediate vicinity of the drum, in the zone of slow moving air just outside the cowl. Air jets reduced the extent of this low velocity zone by up to 80 percent.[63] The results seem to indicate that fresh air can be more accurately and effectively provided by direct means than by induction with water.

There are a number of ways of providing auxiliary ventilation capability. Diffuser fans, commonly used on continuous miners, are effective and could be as easily used on longwall shearers.[26] A possible new development to provide air directly to cutting picks has also been recommended.[18,25] Auxiliary ventilation, however provided, is clearly necessary if ventilation is to be used as a means of preventing face ignitions. The deficiencies of normal face ventilation in the vicinity of the shearer have been clearly demonstrated.

6.5 Reduced Cutter Speed

Recent work indicates that ignitions are initiated behind a cutter pick, by hot material left on rock or projected behind the pick. The intensity of this potential ignition source is found to be in part, a function of pick speed, with high speed increasing the probability of ignition when methane is present. Conversely, ignition probability can be reduced by cutting at a lower pick speed.[64]

In present practice, shearers operate with pick speeds of about 600 ft/min or more. Pick speed as high as 900 ft/min is encountered. Against this high level of cutting speed, it has been found that:

a) When cutting into rock a pick speed as low as 500 ft/min will readily ignite a methane air mixture.[65]

b) The probability of ignition is reduced at cutting speeds below 450 ft/min.[56]

c) The probability of ignition with a pick speed of 300 ft/min is minimized, and development of machines and methods utilizing this speed is recommended.[56, 64, 27]

Slower pick speeds will also result in reduced energy consumption per ton of coal mined.[67] Given the above, low cutter speed is an attractive approach to ignition suppression, requiring no equipment specifically dedicated to that function. However, it must be recognized that a significant redesign of drums and picks will be required to maintain a high production rate with reduced pick speeds.

6.6 New Pick Materials

Some of the same work that led to recommendations on cutter speed and spray locations also compared ignition probability with different pick materials.[27, 55, 56] Some improvement can be made in choice of pick materials. For example:

a. Hardenable stainless steel is recommended over commonly used low alloy steels for cutter picks.

b. Tungsten carbide bit inserts can be replaced by certain Titanium diboride forumulations. In particular, Titanium diboride bonded with copper-nickel alloy appears promising.

The new materials discussed above show less tendency to cause ignitions than conventional materials when cutting sandstone. The choice of bit insert material may be especially significant, and is a minimal and inexpensive modification to existing equipment.

6.7 Comparison of Concepts to Suppress Ignitions at Cutter Head

Concepts discussed in this section have been dedicated to prevention, rather than extinguishment, as a means of reducing the ignition hazard. We believe this approach is preferable from the standpoint of both effectiveness and practicality. In overall evaluation, it is considered that a concept which is expensive to implement, or impacts on procedures or productivity, must be extremely effective to be justified. Conversely, an inexpensive concept is attractive if it at least reduces the ignition hazard but need not be completely effective, since a combination of several such concepts could reduce the hazard significantly.

The following paragraphs describe pertinent features in evaluation of the concepts.

6.7.1 Sprays for Local Inerting

A large quantity of water is required to inert, and it must be in the form of either vapor or extremely fine droplets. Based on past experience of researchers, the necessary equipment is unlikely to be completely reliable. If water vapor is used, both bulky equipment and considerable power consumption will be required.

In addition to practical problems described above, significant development will be required to achieve the very high moisture concentration needed to inert. Effectiveness of the system will be limited primarily by its reliability.

6.7.2 Sprays as Ventilation Aids

Development required by this concept is related to:

a) Determining optimal location of the nozzles
b) Generating relatively fine sprays reliably.

The equipment will not be expensive, and installation will not require major rework of existing equipment. Reliability will be subject to the same problems associated with any fine spray system in a mine. Effectiveness will be limited by:

a) Spray system reliability
b) The inherent limitations of ventilation in severe situations.

6.7.3 Coolant Sprays Behind Picks

No significant development is required. However the concept calls for use of a very large number of nozzles, one behind each pick. The extensiveness and vulnerable location of the nozzle system may create reliability problems. The system will be very effective in eliminating ignitions, to the extent that it can be kept operating properly.

6.7.4 Improved Spray Reliability

Even existing spray systems help to reduce the probability of ignitions, when they are operative. Therefore improvements to spray systems which will keep them operative will be beneficial to a limited degree in preventing ignitions. Equipment to improve spray system reliability is commercially available at reasonable cost.

6.7.5 Hollow Shaft Venturi

The HSV is already developed, although further development and optimization is in progress. A limited selection of HSV equipment is commercially available from British sources. Availability can be easily expanded if there is a significant demand. However, although little or no development cost is required, purchase and installation costs are significant due to necessary modifications of existing equipment. Experience in Britain indicates that HSV's are not entirely effective in ignition suppression even when operating properly, and also have reliability problems similar to those of other spray systems.

6.7.6 Auxiliary Ventilation Systems

Development required by this concept will be related primarily to optimizing location of the auxiliary ventilation equipment. The equipment itself will require little or no development. Some auxiliary ventilation equipment such as diffuser fans is already in use on continuous miners and may be directly transferrable. Purchase and installation costs will be moderate, and no significant modifications to mining machinery are required (unless air is provided directly to picks, as has been recommended by one source).[25] Operating costs will be low. The equipment will probably require maintenance, but the requirement will not be as great as for spray systems.

The properly designed auxiliary ventilation system will be more effective in ignition suppression than the HSV. However cutter induced ignitions will still not be eliminated.

6.7.7 Reduced Cutter Speed

No development will be required except for redesign of drum and drive equipment by manufacturers. Modifications to existing machines may be expensive. However there will be no marginal operating cost or maintenance requirement over existing equipment. This modification will be extremely effective in reducing the probability of ignitions.

6.7.8 New Pick Materials

No development is required except for possible modifications to manufacturing methods. Cost of implementing the concept will be low, and no operating costs or maintenance requirement will be incurred. Appropriate pick materials will reduce the frequency of ignitions, but probably not dramatically.

6.8 Impact on the Mining Cycle

None of the concepts that have been discussed in this section will have any significant effect on mining procedures or productivity, as long as they are functioning properly. In this regard, design for reliability will be important. Otherwise, a need for significant maintenance on additional equipment would have some detrimental effect on overall productivity.

Modifications to the cutter itself are an exception to the above. There should be no change at all in procedures resulting from implementation of these concepts.

6.9 Scope of Necessary Development Work

Only three of the concepts discussed in this section will require significant development work beyond the normal product development activity of manufacturers. The three are:

a) Sprays for inerting
b) Sprays for ventilation
c) Auxiliary ventilation equipment

Development in each case should include analysis, construction, test and refinement of a breadboard model. This should be followed by construction of a prototype system, and test and further refinement in a longwall mine. Costs and durations of programs to achieve these objectives will be on the order of:

a) Sprays for inerting, approximately $250,000 and 18 months.

b) Sprays for ventilation, approximately $200,000 and 18 months.

c) Auxiliary ventilation equipment, approximately $200,000 and 18 months.

7. Control of Ignition Hazard in the Gob

7.1 General Description of Ignition Control in the Gob

There have been at least three gob fires in U. S. Longwall mines in recent years. One of these occurred in a mined out and abandoned area. Two were at the Virginia Pocahontas #3 mine and led to the mine being sealed, for several months each time. Fortunately, none of the ignitions propagated to work areas or caused ignition of wood or coal in bleeder entries. The exact cause of the ignitions is unknown. Friction induced ignition of methane due to roof falls, or spontaneous combustion of coal, are both possible causes.

Frictional impact of sandstone on sandstone is known to be a potential source of methane ignitions.[27, 64] In one series of tests with metal picks striking sandstone, ignitions were caused only after bits of rock had adhered to, or become imbedded in, the metal.[64] There is ample laboratory evidence that frictional impact of rock on rock as occurs during roof falls can cause ignition of methane in the gob.

Spontaneous combustion of some coals may also cause gob ignitions, since coal is present in the gob both as chunks of fallen roof and as float dust.[70]

The gob is a difficult region in which to take preventive measures against ignition. Most of it is inaccessible at any given time. Also, most of the formation of new gob volume, by roof fall, takes place away from the gob's perimeter and is never accessible. In the U. S., ventilation and the bleeder system is used to limit methane concentration and direct it away from the face. In Europe, the gob is sealed to keep air out as much as possible. Both approaches are logical, but both have practical limitations.

Flow of ventilation through the gob is not uniform. Therefore ventilation results in regions of very low methane concentration, regions very rich in methane, and gradients between the two. Within these gradients there are large volumes of methane-air mixtures in the ignitable range.

In locations where methane is completely swept away by gob ventilation, coal remains where it fell or has settled. Ventilation does nothing to mitigate the ignition hazard due to coal in the gob.

Another current method of reducing the methane ignition hazard is drainage through boreholes from the surface. This is particularly appropriate where strata overlying the seam are gassy, since gas from these strata will accumulate in the gob as the roof breaks. Again, drainage is not effective against ignition of coal in the gob. It can materially reduce, but not eliminate, an otherwise severe methane problem.

Injection of dry material into the gob, both refuse and fly ash, is practiced in Japan to serve a dual purpose: ignition suppression and ground control. The material is injected nearby the face in bulk and is not diffused with ventilation flow.

The gob area is the least controllable environment in a longwall mine. It is therefore the least likely to be soluble by diligent observance of conventional techniques, and presents a real need for practical improvements.

7.2 Gob Isolation Curtains

Explosive ignitions do occur in the gob area. These explosions do not generally propagate out of the gob, they result in gob fires, but the possibility of propagation exists if float dust at the chock line is ignited. The following concepts are aimed at restricting the explosive flame front in the gob to behind the chock line. Both consist of non-flammable inert materials to absorb heat in the manner of rock dust. Unlike rock dust, however, they are hung as porous curtains behind the chocks rather than settling onto surfaces. Both would be held and protected between panels of perforated or expanded steel or chock shields.

7.2.1 Wire Mesh Curtains

Knitted wire mesh is commonly used as a flame arrestor in chemical processing and gas equipment where passage of flame or sparks out of a contained area could be hazardous. The high surface area absorbs heat at a high rate, cooling and quenching the flame front.[68] In most applications, the mesh flame barriers are used in pipe sections or other possible flame paths that cannot be closed because they normally carry gas flow with minimum flow restriction. While quenching an explosive flame front, the curtain does not attempt to contain explosion generated pressure.

7.2.2 Porous Insulating Blankets

Insulating blankets were initially developed for use with steam turbines to about 1,200°F. They have been further developed for more demanding applications to 2,300°F.[68] They differ from the wire mesh barriers in two respects:

(1) The inert filler is a refractory mineral wool rather than metal.

(2) They are normally not porous. This is a function of the cover material rather than the filler.

The blankets can be made porous by proper choice of cover material, and be used as a gob isolation curtain. Commercial blankets, used to isolate areas within buildings, are now available under the trade name "Fire Plug Pillow".[69]

7.2.3 Gob Water Spray

Water continuously sprayed into the gob from the chock line would protect the face area in two ways:

(1) It would provide a curtain along the chock line making ignition propagation from the gob less likely.

(2) It would keep the gob material wet, at least in a region near the face. This would reduce the chance of flame propagation through, or ignition in, that region.

The gob spray may be an opportune way to use excess water. A large quantity of water may be required for equipment cooling or a dust scrubber, or both. Some of it can then be diverted to the gob, rather than spraying it all at the face which makes the floor excessively wet without accomplishing anything.

7.2.4 Chock Washing

Heavy and potentially hazardous accumulations of float dust may form on chocks.[1] Low volume water sprays on the chocks would reduce the ignition hazard by:

(1) Inhibiting ignition propagation at the chocks by virtue of the presence of water in the air.[18]

(2) Wetting or washing off float dust on the chocks.

(3) Wetting fines on the floor around the chocks, with runoff.

The sprays may be intermittent to avoid an excessively wet floor that would hinder chock advance.

7.3 System to Disperse Chemical Extinguishant in the Gob

This concept involves the continuous dispersion of a chemical extinguishing agent into the gob with ventilation air. The agent is sized to settle on rock and coal in the gob over some distance from the point or points of dispersal. Distribution of the chemical will be inherently ideal in one respect, since it goes where ventilation flow creates an ignition hazard. Also, the chemical will settle out and accumulate most readily where the velocity of ventilation flow is low, which is where fresh air is present but only marginally effective. Thus the chemical will become concentrated in regions of greatest hazard. Properly dispersed, the chemical should reduce the hazards of both frictional ignition of methane and subsequent ignition of coal dust; it should also reduce the spontaneous combustion hazard by tending to quench if not arrest the transition from glowing to open flame on coal.

Equipment necessary to implement the concept in mines is commercially available, though minor modifications may be in order to minimize corrosion. Many chemical extinguishing agents are potentially suitable for this application. The following are typical and promising candidates:

(a) Sodium or calcium chloride. The primary advantage of these salts is that they are inexpensive. Work is ongoing under a USBM contract with Virginia Polytechnic Institute and State University to develop NaCl formulations dispersible in humid atmospheres and to reduce its corrosiveness.

b. Sodium or potassium bicarbonate. These chemicals are also relatively inexpensive. Dispersibility as dry powder in very humid conditions can be enhanced by various treatments. However, the impact of these treatments on extinguishant effectiveness is not well known.

The concept can be implemented in either of two ways: trickle dusting, or spraying depending on the type of hazard encountered in a particular mine.

7.3.1 Dry Chemical Dispersion by Trickle Dusters

Essentially standard trickle dusters are used to distribute dry chemical powder where ventilation air enters the gob. To be practical the concept requires a dry chemical that is not economically prohibitive and remains dispersible at relative humidity as high as 97 percent. Since trickle dusters are designed for use with rock dust, minor modifications may be required to minimize corrosion when used with chemical extinguishants.

Trickle dusting is appropriate where methane accumulations and ignition in the gob is the predominant hazard. For example, two gob fires at Pocahontas #3 have involved methane ignition in extremely gassy gob areas. The chemical will ideally settle out of the ventilation stream within the gob, but will remain easily dispersable. The combination of easily dispersable chemical dust on rock surfaces throughout the gob, plus some airborne dry chemical, will reduce the probability of a sustained or propagating methane ignition. The effectiveness of particular dry chemicals when treated to remain dry in a humid atmosphere will require test and verification.

7.3.2 Salt Solution Sprays

Salt water spraying, directed at the gob from nozzles at the rear of chocks, is common in Germany. The solution is supplied to the nozzles via a hose running along the chock line. This spraying is intended to serve two purposes: control of dust for prevention of silicosis, as well as ignition protection. As practiced, the sprays are relatively coarse. They are applied to nearby portions of the gob and do not result in a significant diffusion of the spray.

For greater diffusion the spray droplet size must be finer than commonly produced by face sprays. Droplet sizes in the 10 to 20 micron range should be sufficiently small for the spray material to be carried a significant distance into the gob before settling.

Unlike the case of fine droplet generation for inerting (discussed in Section 4.1 of this report) where a certain concentration of water droplets is required and air atomization tends to dilute the spray concentration, droplet concentration is of no great concern in this case. Therefore nozzles utilizing compressed air to obtain fine droplets present no conceptual difficulties. However, the use of such nozzles would lead to practical problems of providing a compressed air supply at the face and an extra hose or line where required.

Spray of liquid solution is particularly appropriate where the primary gob ignition hazard is due to spontaneous combustion of coal. Settling of the droplets on a warm surface will tend to cool that surface. In addition, evaporation of the settled droplets will leave a crust of the chemical agent which will inhibit combustion of the solid both by chemical action and by isolating it from air.

7.4 Impact on the Mining Cycle

The major impact of this concept will be a need to more accurately and predictably control the flow of ventilation air around the face, gob, and main entries. This is necessary to avoid the drift of chemical dust or solution back from the gob to the face. The chemicals are not toxic, or corrosive in some cases, but could create a nuisance if allowed to drift to working areas.

Figure 16 illustrates the gross flow of ventilation air at the face and gob areas of a longwall. Air is routed toward the face in both sets of entries, but with much larger flow up the head entry. As a result of this flow imbalance, air tends to flow across the face from the head gate toward the tailgate. This flow across the face is an assymetry in the overall flow toward the face through entries, then past the face, and through the gob and bleeder system as shown. When ventilation air flows in the manner illustrated, as intended, there is little or no backflow from the gob to the face.

A non-ideal flow situation may arise due to unavoidable non-uniformities in the gob or collapse of some adjacent passages on its periphery, or partial blockages in the bleeder system. This is illustrated in Figure 17. This undesirable flow pattern can cause backflow of airborne material intended for deposition in the gob. To overcome this obstacle:

a. Local, independent control is preferred at each point where material is injected into the air stream. Dusters or sprays whose output drifts back to the face will be turned off while those functioning properly continue to operate.

b. The bleeder system and stoppings should be well maintained, and regular modification and control of the ventilation flow should be exercised.

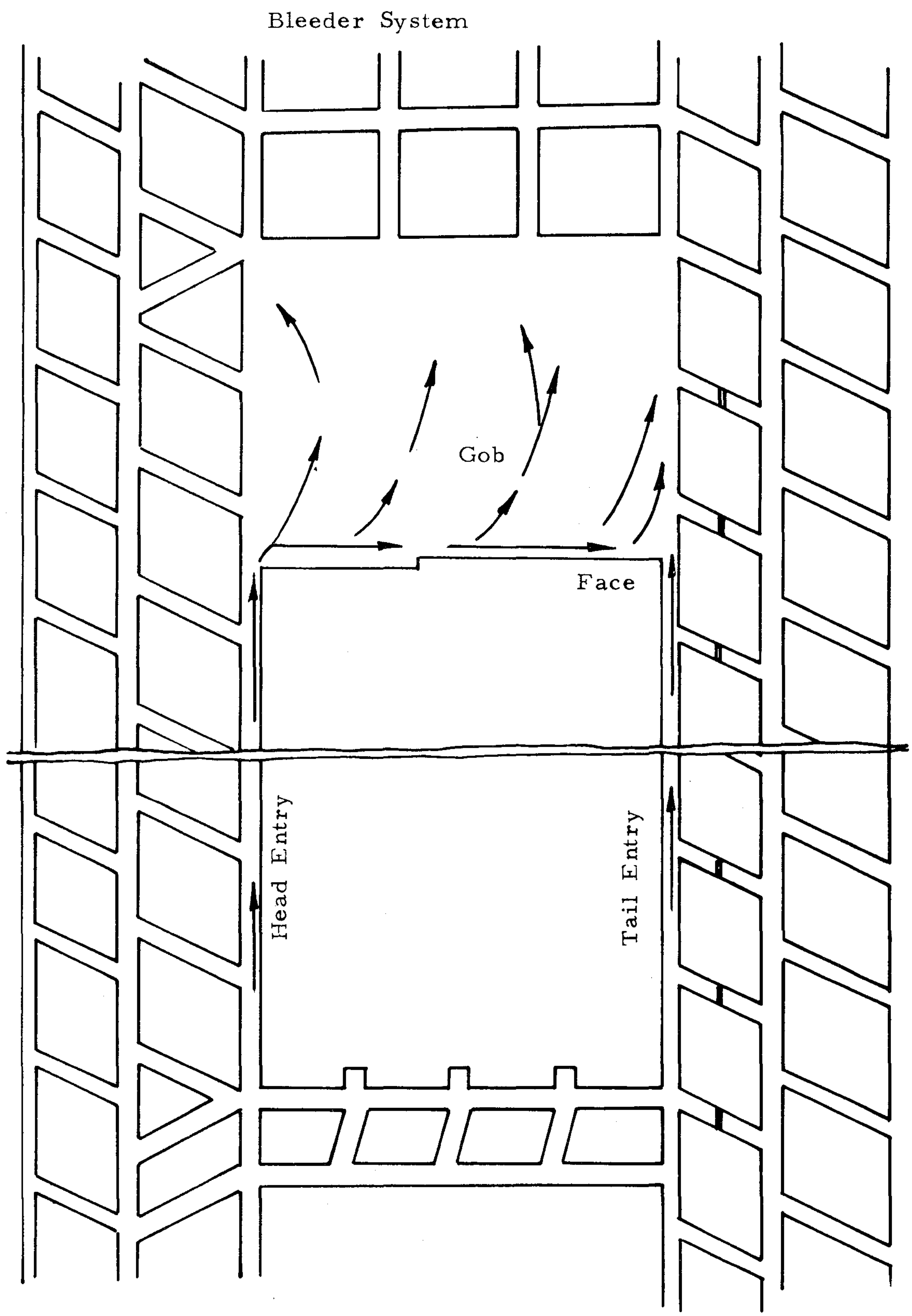


Figure 16 - Ventilation Along Face and Through Gob

Bleeder System

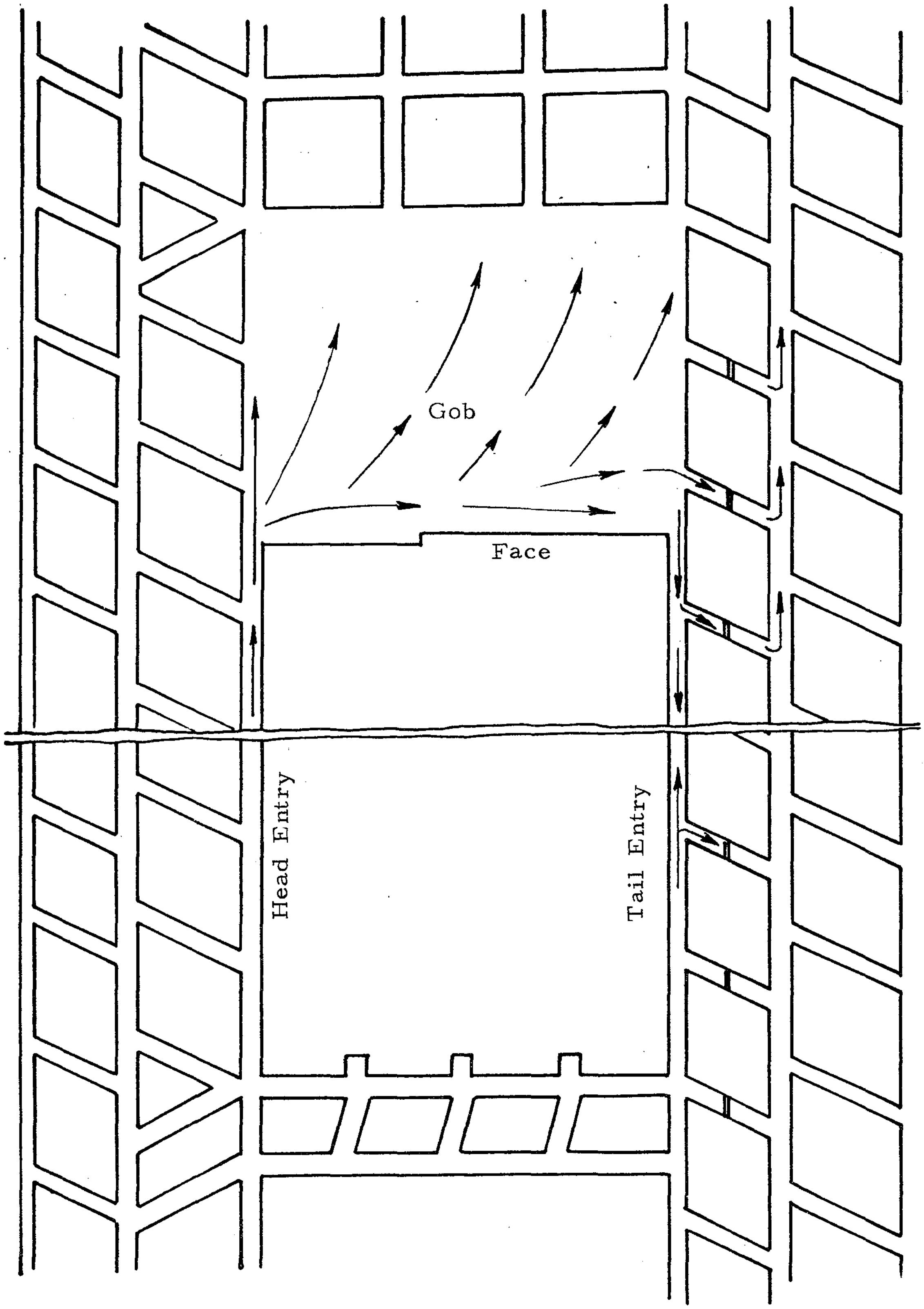


Figure 17 - Poor Ventilation Flow Pattern

In our limited survey of longwall mine operators summarized in Appendix A we found at least one mine operator, who had a problem with gob ignitions, very favorably inclined to trying the trickle dusting concept.

It is very difficult to evaluate the potential for success with such chemical dispersant systems since the gob is essentially uncontrollable and ventilation patterns are unpredictable. However, the basic concept of trickle dusting is quite simple to implement, it does not require any new technology and could only result in an improvement in the control of gob ignitions with a minimum impact to the mining cycle.

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APPENDIX A

ABSTRACTS OF CONVERSATIONS WITH COAL INDUSTRY PERSONNEL

Individuals professionally involved in U.S. longwall mining were contacted for their views on ignition suppression. The individuals are involved with longwalls as:

(1) Mine workers, superintendents and corporate officers.

(2) Mining equipment, manufacturing or sales personnel.

(3) UMW personnel.

(4) Mine industry consultants.

The conversations were related to:

(1) The extent and nature of ignition hazards on longwalls and shortwalls.

(2) Means of dealing with the hazards.

Following paragraphs are summaries of the individuals' expressed views and experience. Names are withheld by agreement of the U.S. Bureau of Mines and at the request of responding individuals.

(1) The major problem on bridgewalls is conveyor systems. There is no good, flexible conveyor. In addition to frequent electrical and hydraulic malfunctions, the conveyors spill far too much coal. Spillage is off the side of the belt, as well as from fines not off-loading properly and coming loose on the return.

(2) Fires are often electrical in origin. In particular, the most frequent cause of electrical fires is shorting, overheating or arcing of damaged cables supplying power to face machinery. Nominally

stationary cables along snaking conveyor lines may also pull out of sockets and junction boxes, resulting in arcing. If ventilation is good, this may cause fires, but not explosions. Most electrical fires are at ends of the face.

Slow burning coal fires are also caused by defective mechanical equipment which generates excessive frictional heat. This is more frequent in haulageways than at faces.

Methane accumulates under conveyors and other machinery. It may be ignited by friction, but is primarily a hazard if its presence is not anticipated.

Ventilation is difficult directly under a cutter head. There are relatively many small ignitions at this location on gassy longwalls. Sprays with wetting agents help keep these ignitions from growing.

(3) I have never had a fire or explosive ignition on any longwall-type face under my supervision. Mine workers are instructed to check for methane under the conveyor before using a torch. Trapped methane pockets can be hazardous if not anticipated. There are some potentially severe hazards on longwalls, but they are much easier to deal with through preventive procuedures than in room and pillar mining.

Bridgewalls are even safer than longwalls. Roof control is easier and diffuser fans on continuous miners improve ventilation at the cutter.

Cowls are helpful in reducing the dust hazard. Dust collectors will also be very helpful when developed and available for use in mines.

Different mines may have markedly different ignition histories, more so than one would expect on the basis of local conditions. This is true even where nominally identical safety procedures are in force. Ultimately, respect for safety procedures on the part of mine workers is required, and this may lead to significant differences between mines.

(4) Ignition hazards can exist on longwalls but precautionary measures can be taken more easily and effectively than in room and pillar mining. Ignitions, when they do happen, are generally freak occurrences related to some lapse of safe practice. Ignitions can therefore happen virtually anywhere on the face.

An example of poor procedures: I have recently seen an experienced mine worker go underground with a lit cigarette. I was told that he smokes regularly underground, but not when Company officials or inspectors are present. Other less blatant instances of poor practice are very common. Electrical machinery is not properly maintained. Methane control is often practiced to the bare minimum that meets Federal regulations. This may not be sufficient at a particular mine, depending on local methane conditions. Float dust accumulations are not cleaned up regularly in some mines.

Shooting the roof behind the chock line, for roof control, resulted in an explosion in England that killed 100 people. The practice is no longer permitted in England. In the U.S., however, this means of roof control is still permitted though not generally practiced.

Some "typical" examples of ignitions in U.S. longwall mines:

(a) A fire that started on mine machinery in the head entry spread toward the face and killed several people.

(b) There was a recent electrical fire in a machine at the headgate. Insulation burned; there was no coal or gas ignition.

(c) One small explosion occurred when falling roof behind the chock line raised a dust cloud while maintenance workers were using a cutting torch. The explosion propagated only about 100 ft. and there were no fatalities.

My own opinion is that gob fires need not happen if precautions are taken appropriate to the local hazard.

Small ignitions at the cutter head are unavoidable if a shearer is used in gassy coal. They do not propagate if ventilation and dust suppression are adequate. If the coal is soft enough, use of a plow instead of shearer effectively eliminates this ignition source.

(5) The major ignition problem on longwalls is the gob, because it is inaccessible and conditions inside it are difficult to control. There have been several gob fires in U.S. longwall mines.

Regulations, requiring methane concentration under 2 percent in all bleeder passages, aggravate the gob hazard. In diluting to this level, large portions of the gob contain methane in ignitable concentration. It might be preferable to develop a controlled ventilating system that extracts methane from the gob at over the ignitable concentration, and dilutes it at a controlled locality.

Vertical methane drainage through boreholes to the surface is a necessity in mines with gassy gobs. Well regulated division of ventilation flows to face and gob areas would allow better methane control within the gob as well as around it. Some means of inerting the gob, or at least reducing its flammability, would be helpful if it could be made practical.

Ventilation requirements in a gassy longwall far exceed the flow rates called for in regulations. 30,000 cfm is a minimum on the face alone, and much more may be required to meet methane concentration requirements in all passages.

Mines with essentially identical methane conditions, ventilation, layout, procedures, etc., may have very different records on ignition occurrence. Negligence by individuals or even deliberate sabatage, has to be considered a major factor in ignitions.

(6) We have had one minor ignition in our longwalls, a "pop" under a conveyor. Methane accumulated there due to seepage from the floor and was ignited, during a maintenance shift, by a welding torch. There was no propagation. The potential hazard was corrected by cutting ventilation and drainage holes at the top of the volume.

We have also had a couple of pops under the cutter head, but these were extremely small and localized.

We regard the gob area as our major hazard location. We haven't had a serious gob ignition, because of precautions that have been taken. Methane is drained, with drillholes from the surface, at almost 100 percent concentration. This is in addition to normal gob ventilation. The only significant region where an ignitable concentration exists is therefore around the fringes of the gob.

(7) The gob is the major hazard in our mines, due to uncontrollable conditions that may exist within it. Preventive methods such as proper ventilation system design, ongoing programs of vigilance and adjustment are generally recognized as the best defense against potential ignition. We have, fortunately, not had a gob ignition in any of our longwall operations.

Gob ventilation and peripheral bleed-off as practiced cannot make the gob area immune to ignition. Channeling of ventilating air within the gob may produce large areas of methane concentration gradient through the ignitable range, in addition to the perimeter area. A gassy gob area, properly ventilated, may contain millions of cubic feet of ignitable methane-air mixture.

Degasification via surface boreholes permits better control of methane buildup in previously inaccessible gob areas. The tremendous volumes involved in mining render impractical some techniques normally effective in plant environments. For example, inerting the atmosphere with a low concentration of Halon would be attractive but for the immense amount of material which would be required.

(8) We have relatively limited experience with longwalls in our mines since we haven't had them in operation very long. We have had several ignitions in room and pillar sections, which have been reported, but none on the longwalls during the same period. The mines are very gassy.

(9) We have never had an ignition on a working longwall. We had one fire in an abandoned area which we attribute to spontaneous combustion. The area was sealed off and mining continued.

Our mines are very gassy and we have gone to great lengths to protect against ignitions. Our ventilation is 30,000 cfm along the face (between the face and chock line), measured at a location on the face between the headgate and tailgate. The total ventilation requirement is even greater. Existing regulations are useless to us, particularly the ventilation requirements. If we operated our mine strictly in accordance with regulations we would be plagued by ignitions. Our preventive measures go far beyond those required.

(NOTE: This respondent was pressed for time when we spoke and could not describe his operation in detail. He suggested contacting him again late in the summer when he expects to be less busy. This will be followed up.)

(10) The potential for serious ignition is greater on a longwall than in room and pillar mining. The hazard is aggravated by float dust accumulation on machinery along the entire face. Chocks, in particular, should be washed regularly. The exposed portion of the gob can be wet down at the same time.

High power electric cables are also exposed and vulnerable over the length of the face.

Protection against gob ignitions, in addition to ventilation, if often necessary. Gobs may be drained under negative pressure, and extracted gas should contain at least 30 percent methane. Also, rock dust distributed behind the chock line would reduce the gob ignition hazard.

Float dust in the tail entry is especially hazardous because it is mixed with ventilation exhaust from the gob, with possible high methane content. Trickle dusters at the tailgate would reduce that hazard.

(11) The only serious hazard on a longwall is in the gob. I don't know of any face ignitions in U.S. longwalls. With good, sensible procedures, there is essentially no hazard of face ignitions. Proper maintenance of electrical equipment is important because faulty electrical gear is the major cause of fires anywhere in a mine.

(12) Coal dust is the major ignition threat, particularly around the shearer or wherever there is a potential source of ignition energy. We see occasional small gas pops, but with good ventilation and dust control they aren't a serious hazard. Coal dust can ignite explosively even without gas under the right conditions, expecially the higher volatile coals. Any serious explosion or fire has to involve coal dust.

The danger of serious gas ignition is alleviated by ventilation. 3,000 cfm across the face is a bare minimum, generally not sufficient. At least 10,000 - 12,000 cfm is usually required. The requirement depends on local conditions in a particular mine. If there is enough ventilation for the mine there is no gas buildup anywhere on the face.

Control of coal dust requires that everything be thoroughly wetted down. A scrubber system around the shearer would be highly desirable if developed and practical. Water sprays to eliminate dust can never be wholly effective.

Even with the best precautions, gob ignitions can't really be prevented because the gob isn't accessible.

Ignitions at the face should be prevented, because there are no practical means to immediately suppress them.