

## REMOTE SEALING SYSTEM FOR EXTINGUISHING COAL MINE FIRES

by

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ABSTRACT

This paper describes a feasible remote sealing system that has evolved from the Bureau's sponsored research on the extinguishment of coal mine fires. The complete system includes (1) a sonar probe and close circuit television camera for initial probing of the mine entry to be sealed, (2) a fly ash or fly ash-cement system for constructing the seals, (3) a froth foam topping system for completing each seal, (4) a combustion-type inert gas generator for conveying the fly ash and inerting the sealed area, and (5) acoustical equipment for determining the completion and integrity of a seal. Design requirements are briefly summarized for the currently developed remote sealing system. In addition, field problems are reviewed from the performance of a prototype system that was used in a mine fire situation.

## INTRODUCTION

Uncontrolled coal mine fires are of great concern to the mining industry because they cannot be directly extinguished, and because they may require such drastic action as sealing the entire mine. The conventional practice of constructing air-tight stoppings from within the mine is difficult and can involve a high fire or explosion risk; therefore, this approach cannot always be relied upon. In search of a more desirable approach, the Bureau of Mines explored the concept of remote sealing from the surface and found fly ash to be a suitable sealant for this purpose.<sup>2</sup> This technique minimizes the risk to the firefighter, it limits the sealing to the established fire area, and it expedites the mine recovery operation, thus reducing potential costs and production losses. This paper describes a complete remote sealing system

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<sup>2</sup>Murphy, E. M., M. O. Magnuson, P. Suder, Jr., and J. Nagy. Use of Flyash for Remote Filling of Underground Cavities and Passageways. BuMines RI 7214, 1968, 27 pp.

that has been developed under Bureau-sponsored contracts<sup>3 4</sup> and the results obtained with a prototype system in a mine fire situation. The system is designed for mine depths of up to 1,500 feet (457 m).

### THREE PHASES OF REMOTE MINE SEALING

The remote sealing of underground coal mine fires requires considerable planning to resolve any logistic and site preparation problems and to insure that all the operational phases are properly coordinated. Figure 1 shows three

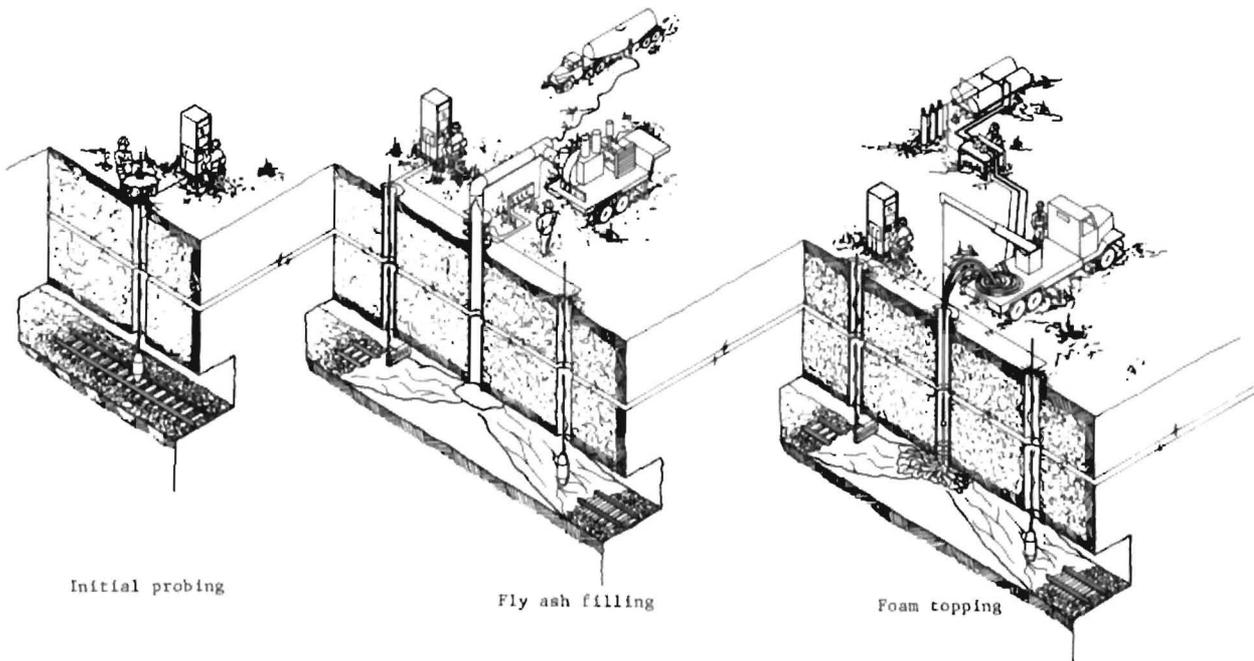


FIGURE 1. - A remote mine sealing system.

<sup>3</sup>Berry, D. R., K. Maser, D. A. Monaghan, and A. R. Guzdar. Technical Report for Extinguishing Coal Mine Fires by Remote Sealing (Research Contract H0122046 by Foster-Miller Associates, Inc.). BuMines Open Fire Rept. 77(2)-75, 1973, 504 pp.; PB 245 899/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

<sup>4</sup>Monaghan, D. A., A. R. Guzdar, and D. R. Berry. Final Technical Report. Joanne Mine, Remote Sealing Operation (Research Contract H0144004 by Foster-Miller Associates, Inc.). BuMines Open File Rept. 55-77, 1975, 224 pp., PB 265 545/AS; available for consultation at Bureau of Mines facilities in Denver, Colo., Twin Cities, Minn., Bruceton and Pittsburgh, Pa., and Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

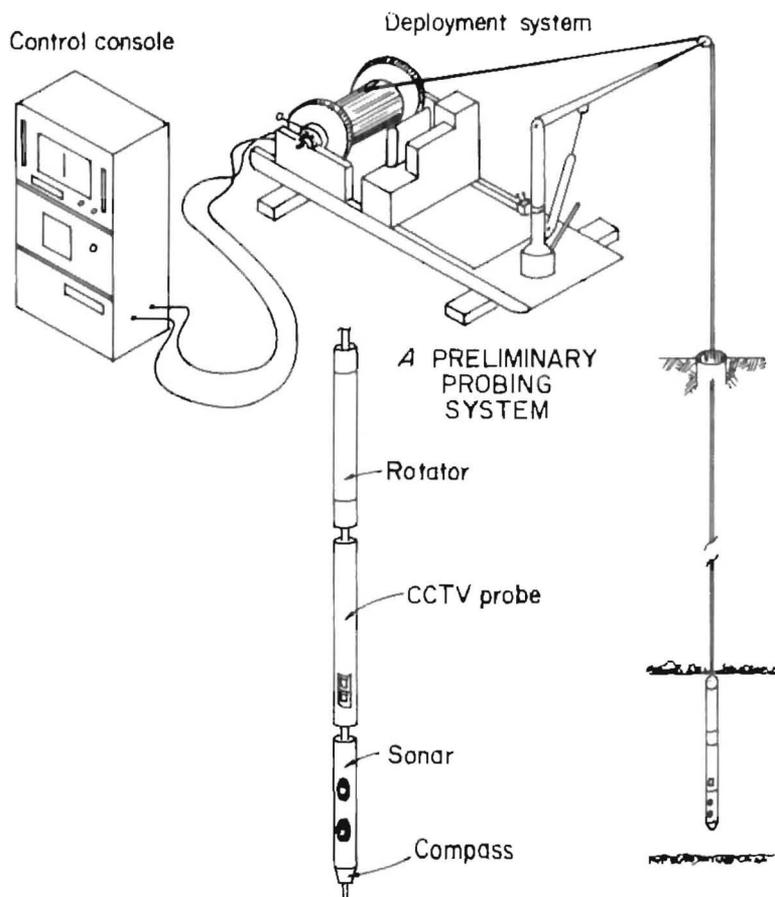
main phases of the sealing operation: initial probing, fly ash filling, and foam topping. Initially, a borehole is drilled through which a probe is lowered to determine the geometry or nature of the passageway to be sealed; the borehole ( $\geq 15$  cm or 6 inches wide) must be cased and grouted to prevent water seepage and subsequently serves as a sealant borehole. In the second phase, the passageway is filled with the fly ash bulk sealant that is pneumatically transported from a supply truck on the surface; two adjacent boreholes are drilled prior to this stage for deployment of acoustical equipment that is used to monitor the formation of the gross fly ash seal. In the final phase, a froth foam topping is added to fill the crater formed by the fly ash and to complete the seal; the foam is formed in place at the bottom of the borehole. This system also includes an inert gas generator which is used to minimize the explosion hazard during the fly ash filling phase and to inert the sealed area of the passageway. In addition, a modified fly ash mixture was found necessary if a watertight seal is required. All of the systems are mounted on skids or trailers.

Generally, the greatest amount of time is involved in drilling the boreholes. Thus, accurate mine maps are essential to avoid "blind" or unsuitable borehole sites. The sealant boreholes should be located midway between two crosscuts of a passageway and where the overburden is least and where overcasts are not present.

### System Descriptions

#### Initial Probing System

The initial or preliminary probing system that was designed for this application consists of a downhole probe assembly, a deployment system, and a control console, as shown in figure 2. The downhole probe assembly includes a low light level, closed-circuit television (CCTV) camera for visual observation of the downhole conditions, and a sonar ranging device for accurately determining dimensions of the passageway or distances to large objects. It is also equipped with a rotator to facilitate scanning, and a



B DETAILS OF DOWNHOLE PROBE  
FIGURE 2. - An initial probing system.

remote reading compass for establishing probe orientation. The probing information is useful for determining suitability of borehole locations, sealing material requirements, potential obstructions to sealing, and reliability of mine maps and engineering surveys at the surface.

The probe is deployed into the passageway using an electromechanical cable and a hydraulic winch that is driven by either a gasoline engine or an electrical motor; the winch has a 1,500-foot deployment capability at speeds of at least 100 ft/min (30 m/min). After the probe is oriented in a known direction, the sonar unit transmits ultrasonic pulses and picks up reflections from objects in front of it. The probe is rotated 360° at various elevations to obtain a complete mapping of the passageway by the sonar measurements and the television camera. This downhole information is transmitted to the control console which includes a CCTV monitor, a sonar readout panel that displays probe to target distance, a rotator control, and a digital readout of the remote reading compass.

The sonar probing unit is capable of locating objects in a mine at distances up to 30 feet (9 m), whereas the CCTV camera can view objects up to 200 feet (61 m) away. In a mine fire situation, the smoke density will limit the effectiveness of the latter unit. This probing system has been certified as explosionproof and can be used in gassy mines.

#### Acoustic Seal Checking System

Another instrumentation system that is vital to the success of the remote sealing operation is one that monitors the filling of the mine passageway and determines the integrity of the seal. The system developed in this work uses acoustic devices, namely a high-intensity speaker and a sensitive microphone. As shown in figure 3, the speaker and microphone probes are lowered into boreholes that are on opposite sides of the sealant borehole. These probes are usually at least 50 feet (15 m) from the seal being constructed and they are deployed by winch systems similar to those used for the initial probing system.

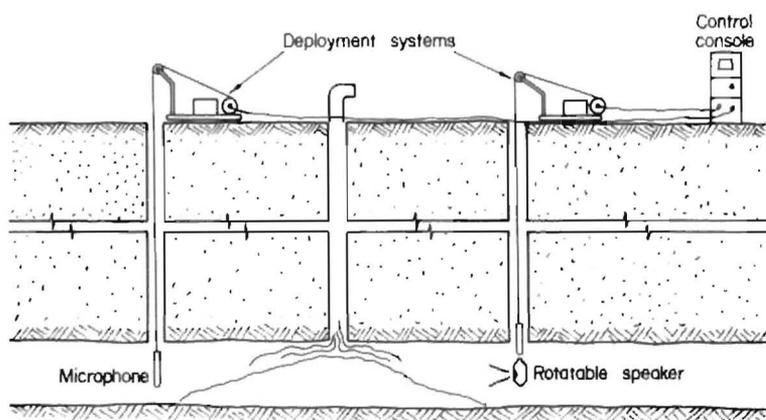


FIGURE 3. - An acoustic seal checker system in operation.

The theory of operation is based on the proved premise that a decrease in the level of signal received by the microphone is proportional to a decrease in the open area of the passageway being sealed. In this system, the speaker probe transmits an amplified noise pulse from a random noise generator which is then picked up by a ceramic-type microphone probe and transmitted to a sound level meter in the control console. A signal processing

module subtracts any background noises. The signal is then displayed in the control console and correlated with existing information to define the completeness of the seal. Sensitivity of the seal checking system is greatest as the seal nears completion (>99 pct). Both microphone and speaker units are intrinsically safe.

### Fly Ash System

Fly ash is used as the bulk sealant material because it is incombustible and relatively inexpensive, it is readily fluidized for pneumatic transport, and it is effective in conjunction with a froth foam topping. This material also normally displays little shrinkage upon wetting, although erosion or leakage paths can develop when a fly ash seal is subjected to certain water pressures. A fly ash-bentonite-portland cement combination has been found to be more effective than fly ash alone in providing a watertight seal. Use of this combination requires only a simple modification of the fly ash deployment system described herein.

The main components of the current fly ash system are fly ash supply trucks, a diesel-driven blower, liquid nitrogen supply tankers to provide an inerting medium, and a plumbing network with instrumentation to monitor flow rates and pressures. Fluidized fly ash is fed from 20-ton supply trucks to an eductor where it is mixed with nitrogen-diluted air ( $\leq 8$  pct  $O_2$ ). The mixture is then pneumatically transported through an 8-inch (20 cm) fiberglass pipe to the borehole by a high-capacity blower (5,000  $ft^3/min$ , 10  $lb/in^2$  maximum). A maximum flow rate of 2,500  $ft^3/min$  (71  $m^3/min$ ) is recommended for pumping the fly ash into most mine passageways; this is generally adequate

to suppress borehole plugging and to insure satisfactory crater formation for seals requiring the foam topping.

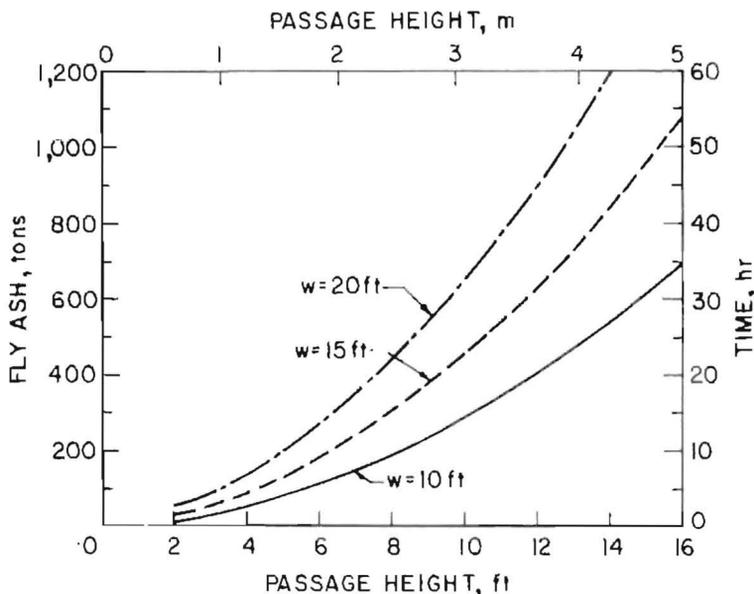


FIGURE 4. - Fly ash requirements and deployment times for 100 pct seals at various mine passage heights and widths.

Fly ash requirements will depend primarily upon the passageway width and height and whether the seal is to be completed with or without a foam topping. Figure 4 shows requirements that were calculated assuming fly ash alone is used to produce a 100-pct seal; a time scale for the fly ash deployment is also included, based upon one truckload (20 tons) per hour. For a passage height of 6 feet (1.8 m) 10 to 20 feet (3 to 6 m) wide, the weight of required fly ash should be

between 100 and 275 tons. Field tests have shown these estimates to be reliable for normal straight passageways. If a 95-pct fly ash seal is initially constructed and then completed by use of the foam topping, the fly ash requirements can be greatly reduced--reportedly by as much as about 50 pct at the recommended flow conditions. The required fly ash for a 100-pct fly ash seal can be substantially reduced by decreasing the gas mixture (air-N<sub>2</sub>) flow rate to minimize the crater formation and lateral spreading of the sealant; these velocity effects increase as the fly ash nears the mine roof.

### Froth Foam System

The foam topping system provides an expanding material that is both airtight and watertight, and it is effective in completing a fly ash seal. It is recommended for fly ash emplacements that are 95 pct or more complete. The complete system includes the froth foam generating components, a temperature conditioning and metering system, a downhole mixing assembly, and a deployment system with a skid-mounted hydraulic boom crane. Figure 5 shows a diagram of this system.

Polymeric isocyanate and polyol components are used to produce the foam topping. These components are conditioned at 25° C and fed separately through

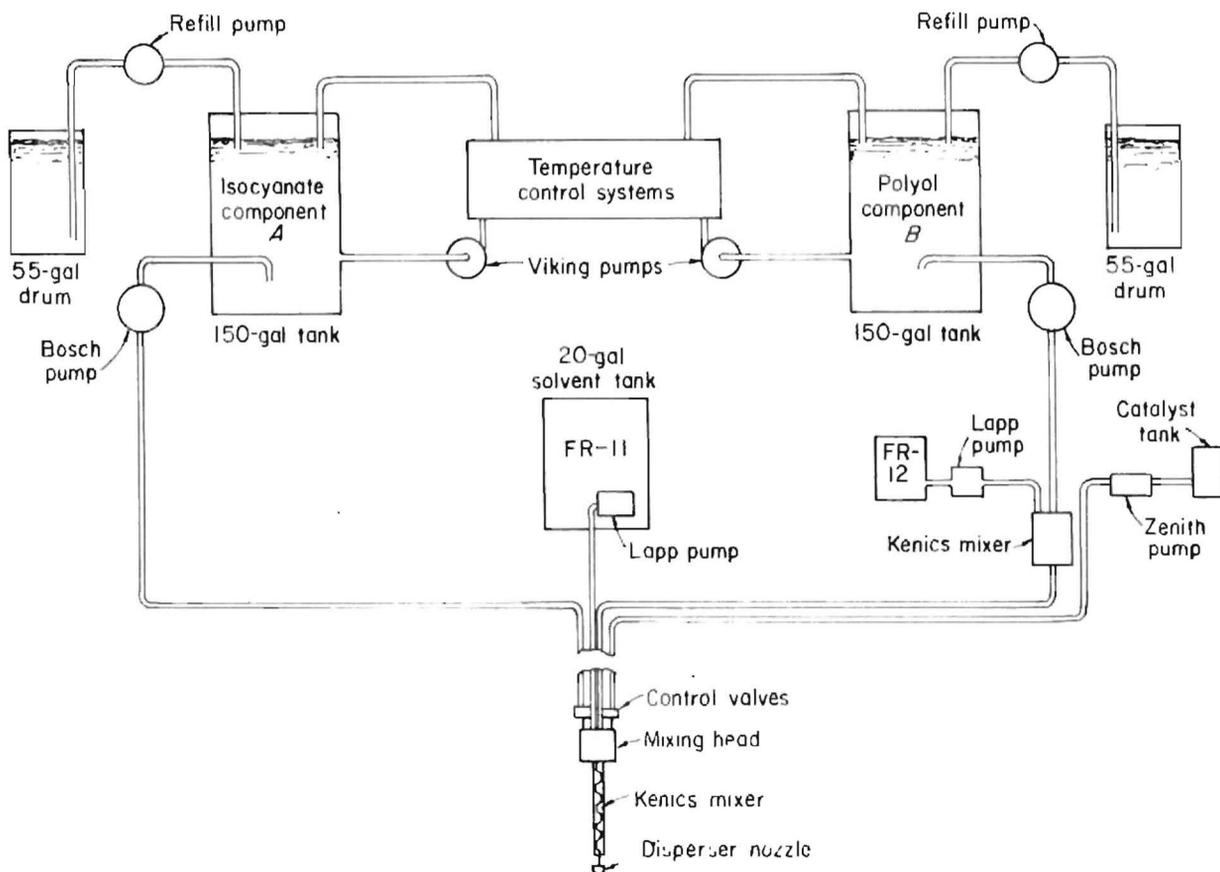


FIGURE 5: - Froth foam conditioning, metering, and mixing systems.

nylon hosing to the downhole mixing assembly where they react together with a catalyst to form a froth foam; Freon 12<sup>5</sup> is used here as the blowing agent. The chemical constituents are metered at a high pressure of 1,000 lb/in<sup>2</sup> (70 kg/cm<sup>2</sup>) to produce the foam at a rate of 40 lb/min (18 kg/min). This foam is a closed cell type (>85 pct) and should be sufficiently fire-resistant to withstand the hot gas temperatures adjacent to the fire zone; a flame spread index of less than 25, as determined by the ASTM E-162 radiant panel test, is a minimum requirement. The amount of foam required will largely depend upon the width of the mine passageway and the completeness of the fly ash sea. About 2,000 lb (908 kg) appears necessary for most 95 pct fly ash seals. In the event of problems, most of the downhole assembly can be retrieved because it is equipped with a pneumatically actuated quick-disconnect coupling.

### Inert Gas Generator

The use of an inert gas for the fly ash fluidization and conveyance is mandatory if the remote sealing operation is to be carried out without risk of gas explosions both in the borehole and in the vicinity of the underground seal. Furthermore, inerting the completed seal helps to control and retard the fire. Experience in the field, where liquid N<sub>2</sub> was used for an inert gas supply, indicated that significant logistic and economic benefits could accrue by use of a system based upon combustion gases. A combustion-type inert gas generator can provide an unlimited supply of inert gas and eliminates the uncertainty and difficulty encountered with liquid N<sub>2</sub> tank deliveries. Also, the estimated cost of producing the inert combustion gas should be less than \$1 per 1,000 ft<sup>3</sup>, compared with about \$8 per 1,000 ft<sup>3</sup> (\$0.28 per m<sup>3</sup>) for liquid N<sub>2</sub>.

As part of the Bureau's ongoing contract research on remote sealing, a new combustion-type inert gas generator is being constructed because the commercially available systems in the United States or Europe did not meet the required specifications. The system specifications include a variable output of 600 to 2,200 ft<sup>3</sup>/min (17 to 62 m<sup>3</sup>/min) at a pressure up to 15 lb/in<sup>2</sup> to facilitate the fly ash deployment, a moisture content not greater than 65° C dewpoint to prevent fly ash agglomeration caused by water condensation, and a maximum gas delivery (exit) temperature of 95° C to avoid excessive temperature in and around the sealant borehole.

The combustible inert gas generator is shown in figure 6; it is mounted on two trailers. On one trailer (hot), a forced draft oil burner consumes a No. 2 fuel oil at ~70 gal/hr and produces hot inert combustion products (<1 pct O<sub>2</sub>) which are cooled to 260° to 370° C in the thermal liquid heater; this heater contains a petroleum based coolant that is circulated through an air-cooled, finned heat exchanger. The gas is then cooled to 65° C in the "heat pipe" heat exchanger and piped to the other trailer (cold) where it enters a drier (enthalpy exchanger) to remove excess moisture. The final stage of the system is compression of the gas up to 15 lb/in<sup>2</sup> by a gasoline-engine driver blower that feeds into the line for transporting the fly ash

<sup>5</sup>Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

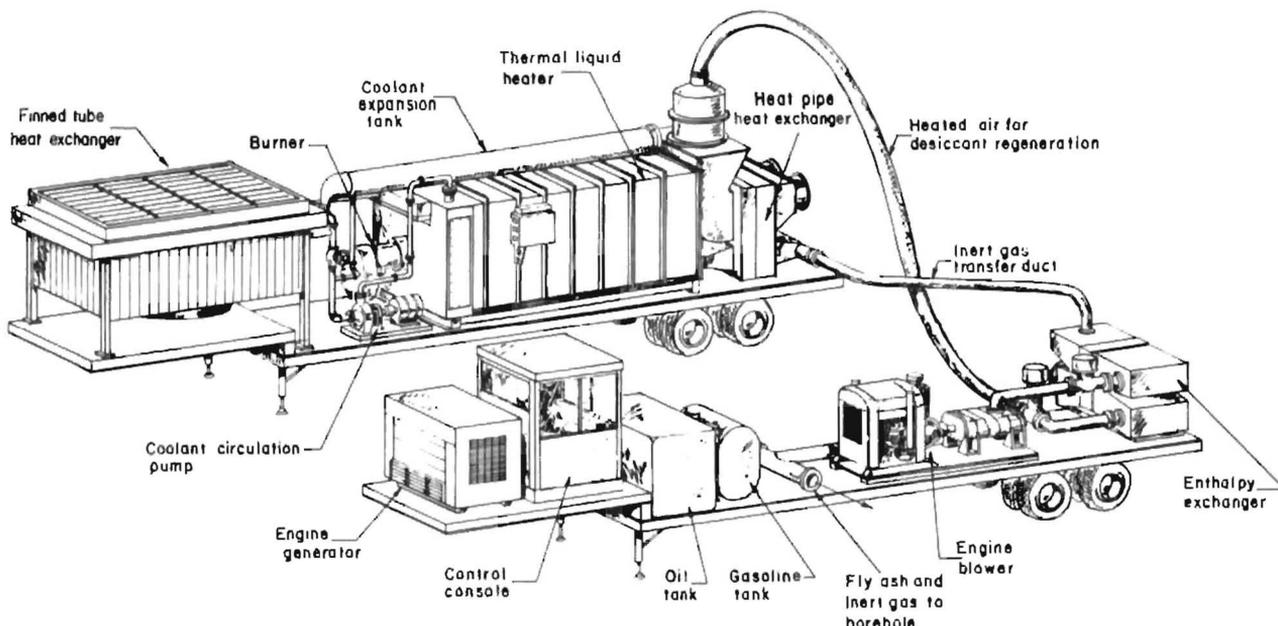


FIGURE 6. - An inert gas generation system.

into the sealant borehole. This system is operable by one person and it is being designed with the capability of maintaining an  $O_2$  concentration between 0 and 8 pct in the sealant borehole and the sealed area.

#### Experience in Remote Sealing of a Mine Fire

Over the past 15 years, several attempts have been made to apply the remote sealing concept to underground coal mine fires in active mines, most of which were of limited or no success because of inadequate sealant materials, serious equipment limitations, or insurmountable mine water problems. The most successful effort occurred a few years ago when a prototype of the present remote sealing system was used to isolate and extinguish an underground fire at the Joanne mine of the Eastern Associated Coal Corp. in Rachel, W. Va. This fire resulted from a derailment and subsequent short circuit that caused a fan stoppage and made it necessary to evacuate the mine. The decision to attempt remote sealing was made 51 days later.

The remote sealing was made from two surface sites that were over 2,500 feet (162 m) apart and located on opposite sides of a hill above the mine. The major considerations in selecting these sites were (1) proximity to existing roads, (2) sufficient separation distance between boreholes and fire zone, (3) adequate distance from existing gas wells to minimize leakage-paths, and (4) avoidance of burying major pieces of mining equipment. Six seals were constructed and each required drilling two adjacent boreholes to accommodate acoustic seal checkers. The boreholes were 600 feet deep (183 m) or less.

<sup>1</sup>Work cited in footnote 4.

Figure 7 shows a map of the underground mine section with the location of the six seals that were constructed to isolate the fire; permanent stoppings in this section were also used to effect the sealing. Three of the seals (RD-1, RD-3, and RD-5) were 95 pct fly ash seals that were topped with urethane foam, and the other three (RD-2, RD-4, and RD-6) were 100 pct fly ash seals. Most of these required approximately 150 tons (95 pct seal) or 250 tons (100 pct seal) of fly ash; except for seals RD-3 and RD-4 which were at or near four-way intersections and required about 500 tons of fly ash. Those that were completed with a foam topping required at least 2,200 lb (998 kg) of foam. The sealing operation was carried out using liquid  $N_2$  tankers to provide the inert gas for deploying the fly ash and inerting the completed seals. At least 650,000  $ft^3$  (18,405  $m^3$ ) of  $N_2$  was necessary in constructing a seal.

A gas monitoring system was useful in indicating the effectiveness of the completed seals, the adequacy of the inert gas supply system, and the potential gas explosion hazard before and during the remote sealing operation. Figure 8 shows the varying composition of the mine atmosphere that was monitored at one of the boreholes. The  $CO$  and  $O_2$  levels decreased to approximately 0.01 and 1 pct within about 60 days after the fire began; thereafter, they were essentially constant until the remote sealing was started. In comparison, the  $CH_4$  and  $CO_2$  concentrations increased and reached maximum levels of approximately 30 and 4 pct within about 80 days. During the initial stage (preliminary probing) of remote sealing, the  $CO$  fell slowly to levels as low as 0.001 pct or less. Some fluctuations occurred in the gas compositions

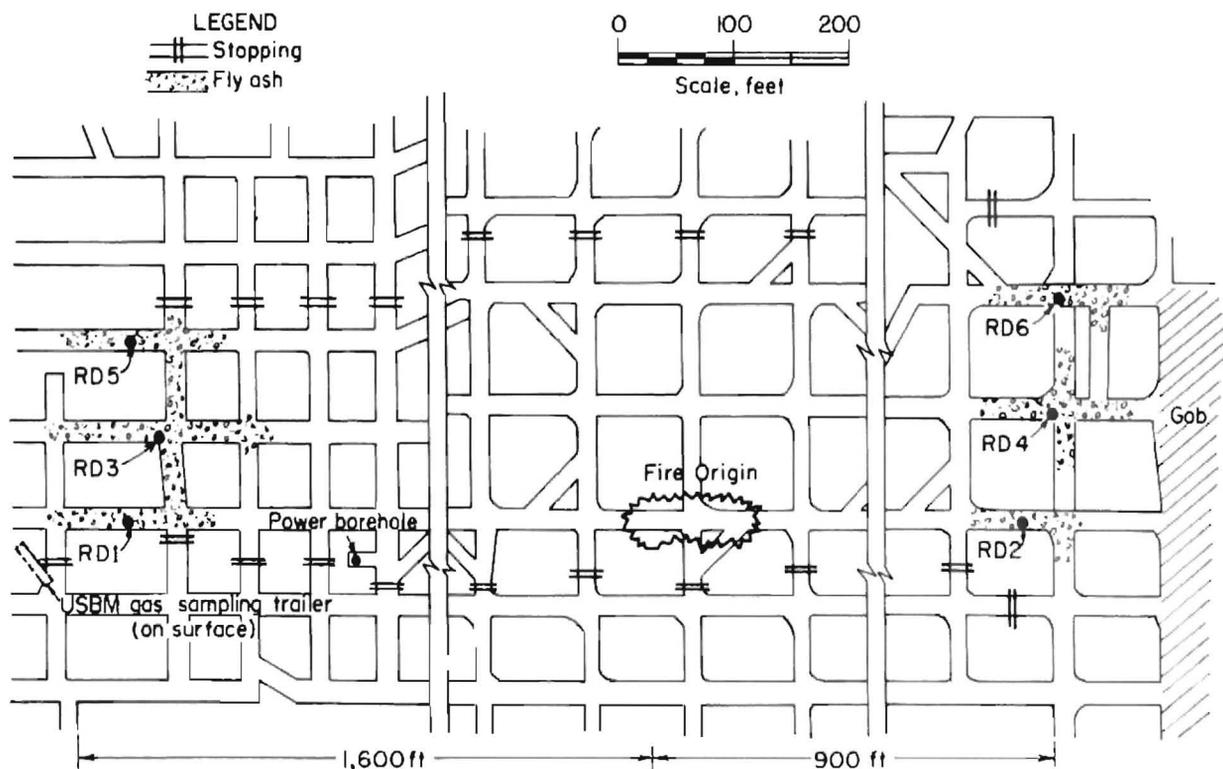


FIGURE 7. - Map of underground section of Joanne mine showing fire zone and fly ash seals.

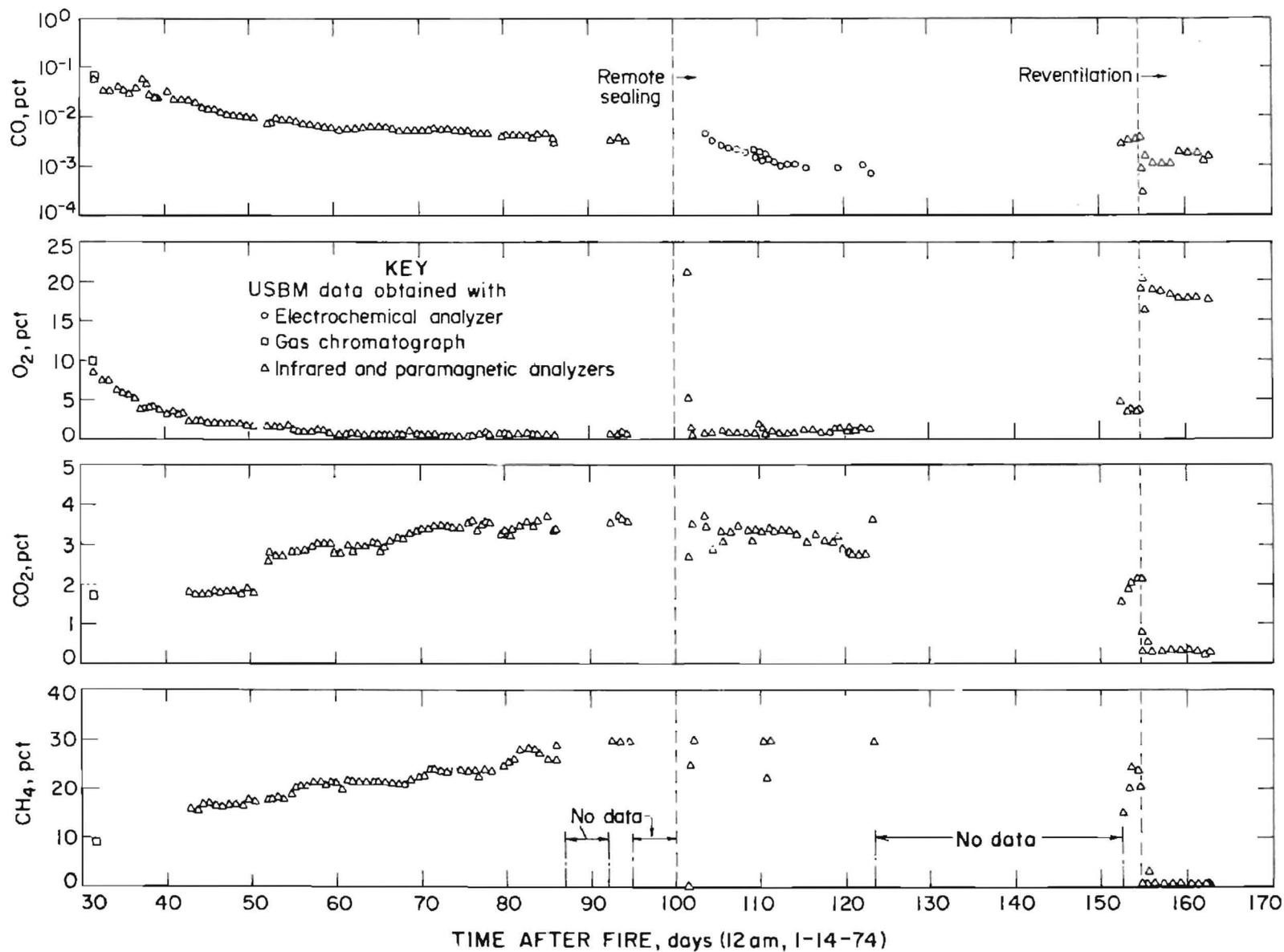


FIGURE 8. - Carbon monoxide, oxygen, carbon dioxide, and methane gas analyses versus time for Joanne mine fire (RD-4 borehole samples).

largely because of leakage or injection of air. Throughout the entire remote sealing operation, the CO- $\Delta$ O<sub>2</sub> index (ppm/vol-pct) varied between 0.1 and 1, indicating the amount or level of combustion was relatively small; the CO- $\Delta$ O<sub>2</sub> index was over 1,000 at the start of this fire. The CO- $\Delta$ CO<sub>2</sub> index (ppm/vol-pct) is also a useful indicator of combustion and was generally an order of magnitude greater than the CO- $\Delta$ O<sub>2</sub> index during sealing.

Because of supply and delivery problems with the liquid N<sub>2</sub> system, it was not possible to maintain an inert atmosphere ( $\geq$ 90 pct N<sub>2</sub>) in the sealed area for extended periods throughout the recovery phase. Nevertheless, the seal emplacements proved to be sufficiently successful so that the mine was reventilated within a few days after completion of the seals. The fact that the mine was reventilated prior to its recovery was a significant accomplishment resulting in considerable savings to the mine operator. This field experience has been very useful in current efforts to develop a more reliable and acceptable remote sealing system for use by the mining industry in fighting mine fires.

#### Present Status

All three subsystems (instrumentation, froth foam, and inert gas generator) were successfully tested. A field test with the froth foam system deployed to depths approaching 800 feet (244 m) is planned. This test will permit accurate calibration of the subsystem and increase the skills of the operating personnel for more reliable service during an actual fire.

Another field demonstration is planned at the Jenny mine, Prestonsburg, Ky. This test will encompass all three subsystems and it will involve approximately 12 operators. It is hoped that this field test will answer questions regarding the effectiveness of fly ash development during instances where the mine's ventilation system is operating and water is flowing on the mine floor. A complete seal will be made through approximately 180 feet (55 m) of cover and then subjected to a head of water to determine the seal's resistance towards flooding mines.

The instrumentation subsystem is available for use by the Mining Enforcement and Safety Administration's (MESA) Mine Emergency Operations group. Recent cases where the subsystem was used include the Scotia mine, Bethlehem mine No. 32, and the Porter Tunnel mine.

The remote sealing technology is also being used in controlling the fires and subsidence associated with abandoned mine workings.<sup>7</sup> An example of this technology transfer is the recent request by the Bureau's Denver (Colo.) Mining Research Center to borrow the positive displacement blower unit used during the Joanne mine fire to deploy fly ash. Denver Mining Research Center plans to use this blower to emplace fly ash in abandoned mine workings that are susceptible to subsidence near Rock Springs, Wyo.

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<sup>7</sup>Report cited in footnote 2.

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