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# RECENT UNITED STATES COAL MINE FIRES: LESSONS LEARNED

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## ABSTRACT

Coal mine fires in the United States have historically taught the industry many lessons concerning the forces of nature at work for and against attempts to control and extinguish them. The application of lessons from the past has helped to prevent injury and death to mine rescue and recovery personnel in the present. New lessons learned from recent fires continue to remind the industry that many mine fire events are not within the absolute control of man and machine.

Four US underground coal mine fires and recoveries are discussed in this paper. Each occurred from 1998-2000, and each had peculiar events associated with sealing and recovering them. The data is presented to allow the future fire fighters to benefit from these lessons learned.

## KEYWORDS

Mine Fire, Mine Recovery, Mine Atmosphere Sampling, Air-locking, Mine Re-ventilation, Remote Seals, Pumpable Seals/Plugs

## INTRODUCTION

From November 25, 1998, through January 28, 2000, four major fires occurred in underground coal mines in the United States. As serious as these fires were, none of the fires resulted in a loss of life. Each mine was operated by a different company. Extinguishing each fire required sealing of the entire mine, or portions thereof. The circumstances surrounding each fire were different. However, all four fires began in, or eventually propagated to, longwall gob areas. The fire fighting techniques and recovery operations at each mine differed due to the available resources and the conditions specific to each mine (including surface terrain, depth of cover, and coal seam characteristics). During each fire, unusual circumstances caused the mine operator to modify traditional mine fire fighting techniques.

The first fire occurred in an underground coal mine near Price, Utah, on November 25, 1998. The fire started in by the longwall tailgate. It became out of control very quickly. The mine was evacuated and sealed at the surface. The operator of this mine used some innovative methods to successfully recover the mine. A degasification system was used to assist in

controlling the mine atmosphere within the sealed area during traditional air-locking procedures by mine rescue teams. Due to the surface topography, the operator contracted to have angled boreholes drilled into the mine to test the mine atmosphere. Also, doors were installed in explosion resistant seals to permit future access to the area by mine rescue teams. Finally, after a year of air-locking and re-ventilation, the mine was recovered and production resumed on November 15, 1999.

The second fire occurred in an underground coal mine near Delta, Colorado, on January 26, 1999. Elevated carbon monoxide concentrations were detected coming from a gob area. The mine was evacuated and sealed on the surface. Approximately 30 hours after the seals were completed, an underground explosion damaged the seals and the mine openings had to be resealed. The explosion compromised underground ventilation controls in the mine. The damaged ventilation controls, storage of waste material in the mine entries, and anticipated water accumulations affected the decision on how re-ventilation would be approached. The mine operator pumped water into parts of the mine to form a partial water seal that was expected to inundate the fire area. However, added

water production from within the mine greatly exceeded the expected levels. Approximately 101 days after sealing, re-ventilation of the mine was initiated. However, during initial re-ventilation of mine drift openings, carbon monoxide levels in the remaining sealed portions of the mine began to increase. The lack of sufficient data from the sealed area caused a delay in the continuation of the re-ventilation process until the source of the carbon monoxide could be determined. Further delays were encountered during the recovery process until it was determined that information from a borehole sampling location in one entry of the mine was not representative of the atmosphere in adjacent entries. The re-ventilation was completed and production resumed on May 22, 1999.

The third fire occurred in an underground coal mine near Morgantown, West Virginia, on June 22, 1999. Approximately 90 minutes after discovery, all personnel were evacuated and the mine was sealed on the surface. On June 26, 1999, approximately 77 hours after sealing, an explosion occurred which destroyed one of the surface seals and a fan installation. This shaft was located over 1 kilometer from the site of the original fire. Another shaft, located less than 0.5 kilometer from the original fire area, suffered no damage. Seals were remotely installed to isolate the original fire area from the rest of the mine. However, sampling indicated the remote seals were ineffective. Use of plastic tubing for sampling lines in some of the boreholes resulted in inconclusive results. The above factors had to be considered in the re-ventilation of the mine. Approximately 393 days after sealing, re-ventilation of the mine was initiated. Recovery continues at the time of this publication.

The fourth fire occurred in an underground coal mine near Delta, Colorado, on January 28, 2000. The mine was evacuated and the fire area was sealed underground. Very limited information was available about the location and extent of the fire because the suspected fire was in an inaccessible area of the mine. Although elevated carbon monoxide and hydrogen was detected in the airflow coming from the fire area, no smell or smoke was detected. At one point, a neighboring abandoned coal mine that had been burning was considered as a possible source for the carbon monoxide. An extensive drilling, remote sealing and flooding project was undertaken to first locate and then extinguish the fire. Remote seals were installed at critical locations. Water was then injected into the area to extinguish the fire. However, while boreholes were being drilled and water was being pumped, the fire began to increase in intensity. Foam and inert gas had to be injected into the mine through boreholes to control the fire. A ventilation

change was also made to reduce the leakage airflow into the fire area. By May 8, the fire area had been remotely isolated from the remainder of the mine and much of the area inundated with water. The mine has been recovered and production resumed.

#### FIRST FIRE - NOVEMBER 25, 1998

The first fire occurred on November 25 at an underground mine in Utah. The mine began operation in 1996 into the Castlegate "D" Seam. Mining heights ranged from 2.1 to 3.3 meters. The seam dipped at 8 to 9 degrees to the North. The mine had three continuous mining machine units and one retreating longwall. The mine was developed through five drifts and one 30 meter deep shaft.

The fire started behind the longwall face along the tailgate side of the gob during normal coal production. Approximately 46 miners were underground at the time. The longwall shearer was about 30 meters from the tailgate. Several workers on the face, near the tailgate, were knocked down by a rush of air. An orange colored flame was observed in the gob that appeared to move toward the face area and then back into the gob. An immediate evacuation of the mine was begun. All personnel exited the mine. Three members of mine management re-entered the mine to assess the situation. They encountered a hot personnel door between the intake and return entries a short distance into the mine. They exited the mine and began to seal the mine at the surface openings. The mine was completely sealed approximately nine hours after the fire was discovered. No injuries resulted from the incident.

Gas samples collected from the mine indicated carbon monoxide was 23,000 parts per million (ppm), methane was 25 percent, carbon dioxide was 12 percent, oxygen was 1.4 percent, and hydrogen was 10,110 ppm. Boreholes were drilled into the mine to help to determine the status of the fire. A conceptual over-all mine recovery plan was developed by the mine operator. The three phase plan would begin with a recovery of a limited area just inside the portals. The second phase called for the recovery of the mains area of the mine while installing seals in the adjacent areas. The final phase called for the recovery of the remainder of the mine. An air-locking procedure using standard mine rescue techniques was proposed. During exploration, approximately 300 meters would be explored by the mine rescue teams. Ventilation controls or "substantials" would be established near the limit of exploration. The area outby the substantials would be re-ventilated. The procedure would begin again.

It was important to establish monitoring locations in the mine prior to beginning mine recovery to insure the safety of the mine rescue team. Boreholes were drilled from the surface into the mine for this purpose. Steel sampling pipes, ranging from 1.9 to 2.5 centimeters in diameter were installed through the boreholes to obtain samples from the mine atmosphere. This sampling method provided consistent, accurate samples of the mine atmosphere. While the boreholes were being drilled, approximately 255,000 cubic meters of carbon dioxide was injected into the mine through the gob degasification borehole. This borehole was located close to the fire area. The purpose of the injection was to cool the fire area and to insure that the atmosphere in the fire area was oxygen deficient.

Because of the difficult topography, one of these boreholes had to be drilled at approximately a 45 degree angle approximately 742 meters into the mine. Although the drilling operation was slow, it was successful. The successful completion of this borehole proved that it is not necessary to locate the surface of a borehole directly over the targeted location in the mine.

Samples from the mine atmosphere were collected at the portals and the fan shaft while the boreholes were being drilled. Samples were also collected at the boreholes as they were completed. The results of these samples indicated the atmosphere in the mine to be fairly homogenous, indicating possible air movement within the mine. The results also indicated that the mine atmosphere was stable, nonexplosive, and it was safe for mine recovery to begin.

The mine rescue teams began the first phase of the operation on December 9, 1998. They entered the mine and explored the first 300 meters inby the portals. Visibility was good and no fire damage was encountered. Significant air movement, approximately 7.1 to 9.4 cubic meters per second, within the sealed area was measured. Initially thought to be the results of the fire, it was later determined to be the results of large elevation and temperature differences. This natural ventilating potential within the mine also confirmed the information collected earlier at the boreholes and at the portals and fan shaft. During the air-locking procedure, it was necessary to remove some ventilation controls inby the substantial in order to not disrupt the stability of the atmosphere in the sealed portion of the mine. Additionally, this helped to control the methane levels outby the substantial during re-ventilation.

During the re-ventilation of the first 300 meters of the mine inby the portals, it became apparent that the methane liberation from the sealed area would make it

difficult to adequately ventilate the area outby the air-locks. The pressure differential across the air-locks would often exceed 250 pascals of water pressure. A horizontal degasification system was developed to control the methane liberation. A degasification pump was installed on the surface of the mine near the mine portals. Pipe was installed from the surface pump to just inby the air-locks. Initially, degasification pipe installation was completed by mine rescue teams using breathing apparatuses. However, each joint of pipe was about 6 meters in length, 35.6 centimeters in diameter, and weighed about 320 kilograms. It was difficult for the mine rescue team to transport and install this pipe. The procedure was then modified to have a short section of pipe with a valve installed through the substantial. After the outby area was re-ventilated, other mine personnel with equipment could transport and install the degasification pipe.

As the mine was recovered, it was necessary to install explosion resistant seals in the bleeder entries and in the gate roads so that the main entries could be completely recovered. Although these areas were sealed, they would be recovered at a later time. Therefore, to provide easier access to this area, fabricated steel doors were installed in the approved standard concrete block seal. These steel doors could easily be removed for exploration and re-ventilation. They also could be used to re-seal an area quickly if it became necessary.

The recovery process continued through November of 1999 when the longwall equipment was removed from the area and explosion resistant seals installed around the fire area.

## SECOND FIRE - JANUARY 26, 1999

The second fire occurred January 26, 1999, in an underground mine in Colorado. The mine opened in 1991 into the C-Seam with rock slopes driven into the underlying B-Seam. The seams dip at approximately 5 degrees to the northeast and the separation of the seams averaged fifteen meters. The mine had three drift portals, one rock slope, and one shaft. The mine had one continuous mining machine unit and one retreating longwall.

Workers were in the process of making preparations to begin to remove the longwall face from the first panel to the second in a three panel district. The General Mine Foreman was in the bleeder entry checking the water levels that had been increasing at the back of the bleeder system when he found elevated levels of carbon monoxide. The carbon monoxide gas was coming from the portion of the bleeder system inby the tailgate side of the longwall face. Carbon monoxide levels continued to

increase, forcing the Foreman to leave the area and begin evacuation of the mine.

All personnel were safely evacuated from the mine. Carbon monoxide levels at the exhaust shaft fan began to climb. Smoke was soon exhausting from the exhaust shaft fan. Preparations were made for sealing of the mine openings. Earthen seals were used in two drift openings and at the rock slope. An idle fan in the forth drift opening and the return shaft fan was sealed. Sealing was completed about 24 hours after the incident was detected.

Approximately thirty hours after the mine was sealed, an explosion occurred that damaged two of the earthen seals and an idle fan housing located in the sealed No. 4 Portal. The seals were repaired and the mine continued out gassing. A mine air sample collected four days after the initial event at the Return Shaft Fan contained the following approximate gas concentrations: methane – 30 percent, oxygen – 9 percent, carbon monoxide – 3,331 ppm, carbon dioxide – 4 percent, and hydrogen - 892 ppm.

A conceptual, overall mine recovery plan was developed by the mine operator. The location of the suspected fire area and the dip of the coal seam enabled the mine operator to develop a recovery plan that included flooding the fire area and re-ventilating the mine all at once or “shotgunning the mine”. The plan called for drilling of a water infusion borehole and installation of a pump and waterline from a nearby river. Additional boreholes were drilled to monitor the mine atmosphere during re-ventilation. Although the original plan called for completely flooding the bleeder system, it was later modified to only flood the inby portions of the bleeder system.

The locations of the boreholes were limited because of the abandoned mines that overlaid portions of the mine. The rugged terrain also caused difficulty in accessing the proposed sites. The water injection borehole was completed and pumping began on February 12. The total volume of water pumped into the mine was carefully calculated to only flood the desired amount. Work continued on additional boreholes to monitor the mine atmosphere.

On April 1, 1999, mine rescue teams entered the portal openings to begin re-ventilation of the first few crosscuts of the mine so that the earth could be removed from all of the mine openings. Substantial stoppings were used to isolate the first few crosscuts from the rest of the mine. Air leakage through the substantial stoppings allowed for a steady increase in the oxygen within the

sealed area followed by an increase in carbon monoxide. As carbon monoxide had not previously been reported in sealed areas of the mine, the concern was that oxygen had reached the fire area and it had begun to rekindle.

To further determine the conditions in the mine, an additional borehole was drilled into the mine near the fire area. After two failed attempts, the third borehole intersected a mine opening on April 18. Water was encountered in the borehole that indicated there was a much greater volume of water in the original fire area than expected and that the original fire area was under water. However, the carbon monoxide reading continued to trend upwards. On April 26, mine rescue teams explored another 300 meters into the mine only to find extensive damage to the ventilation controls in the area. There was concern that the fire had spread further than expected or that the subsequent explosion had started a fire at some other location in the mine. Additional boreholes were drilled into the mine to gather more information. These boreholes were completed on May 7. The analysis of the information at these boreholes as well as at the other sampling locations indicated that the carbon monoxide had stabilized. It was suspected that the rise in carbon monoxide was the result of a normal high rate for oxidation to the coal seam.

On May 8, 1999, one of the blowing fans at the portal was energized. The mine atmosphere was monitored at the return shaft and at the boreholes. Conditions at the monitoring locations stabilized. On May 13, mine rescue teams proceeded underground to explore the mine.

On May 19, 1999, exploration had progressed to the area near the bottom of the return shaft. Elevated methane concentrations continued to be sampled from a monitoring borehole inby the return shaft. It was determined that the ventilation, provided by the blowing fan at the portal, was not adequate to ventilate the rest of the mine inby the return shaft. Therefore, the return shaft fan was turned on and the blowing fan at the portal was turned off. Although the methane levels at the borehole diminished slightly, they remained elevated. A mine rescue team sent to explore the area found that the borehole was drilled into an isolated area or pocket in the mine and was not representative of the air quality in the adjacent areas of the mine. Adjustment to the ventilation controls in the area caused additional air to flow into the isolated area and the methane levels decreased. On May 22, 1999, the exploration of the mine was completed.

THIRD FIRE - JUNE 22, 1999

The third fire was found in an underground coal mine on June 22, 1999, near Morgantown, West Virginia. Production at the mine began in 1960 in the Pittsburgh No. 8 Seam. Ventilation and access was provided through five shafts and one slope. The mining height was about 2.1 meters. The seam dips slightly to the Northwest. Although a relatively large area had been mined out, most of the older workings had previously been sealed. Only main aircourses and haulage entries remained open to access and provide ventilation for the developing sections and the longwall bleeder system.

The mine was in a temporary idle period at the time of the fire. Prior to the temporary idle period, coal was normally produced using three continuous mining machine units and one retreating longwall. The headgate of the longwall section at the time of the fire was the sixth gate development in the district. The gob of the longwall district was ventilated using a bleeder system.

The fire occurred in the main return entries near the gob at the front of the second gate development. Cutting operations had been performed during the removal of unnecessary equipment in the intake entries near this area on the previous day. Nothing unusual was observed during examinations of the area conducted later in the workday. Workers entering the area on the midnight shift noticed that material covering the intake side of a return stopping was melted. Further investigation revealed a fire on the return side of the stopping. The fire was found at approximately 1:15 a.m. Roof falls had already occurred in the fire area and the intensity of the fire necessitated evacuation of the miners. All miners were safely evacuated by 2:30 a.m.

The exhausts from the mine fans were monitored and samples were collected for analysis to determine the trend of the fire. By morning, a decision was made to seal the surface openings of the mine. In addition, a plan to remotely install “plugs” in the mine entries in two specific zones was developed. A cement/flyash mixture was to be injected through vertical boreholes drilled from the surface into the ten entries that accessed the area in the mine in which the fire occurred. It was hoped that the plugs would further isolate the fire area. Additional monitoring holes were to be drilled on each side of the plugs to better evaluate the effectiveness of the plugs.

By 9:30 p.m., approximately 20 hours after the fire was found, the surface openings were sealed. Also, locations for the drill holes had been established and work was being performed to prepare the drill sites.

Initial samples taken from an old borehole located in by the original fire area revealed carbon monoxide concentrations as high as 4.0 percent and hydrogen concentrations as high as 8.3 percent. An additional borehole was drilled to inject inert gas into the mine at the initial location of the fire. By June 24th, the inert gas injection borehole was completed and nitrogen began to be pumped into the mine at a flow rate of about 0.9 cubic meters per second. Later, carbon dioxide was also injected with the nitrogen.

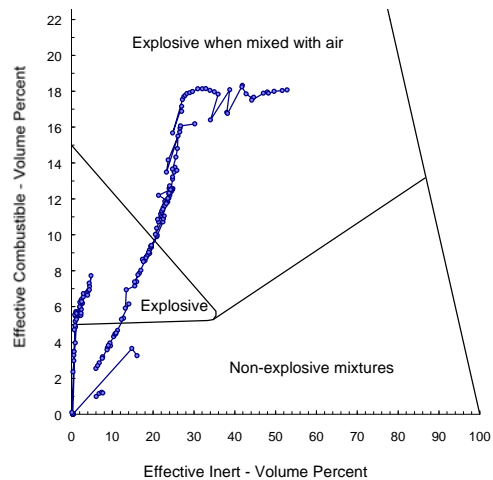


Figure 1. Explosibility Determination of Atmosphere

A 72-hour waiting period has usually been sufficient for the mine atmosphere to become settled following sealing of mine fires. Approach to mine openings is not permitted within the 72 hours or later if the environment is considered unstable. Generally, explosions after the 72 hour waiting period are not common. Explosibility determinations as shown in Figure 1 did not permit approach to the shaft area.

On June 26th, at 3:20 a.m., approximately 77 hours after the mine was sealed, an explosion occurred underground which damaged the temporary seal and fan installation at one of the ventilation shafts. The damaged shaft, shown in Figure 2, was more than 1.6 kilometers from the original fire area. The explosion caused little disturbance at a ventilation shaft much closer to the original fire area and was initially undetected at the other surface openings.

The damaged shaft was resealed later that day. Air samples from the old borehole located in by the original fire area revealed the gas concentrations in that portion of the mine to be oxygen - 12.39 percent, methane - 18.18 percent, carbon dioxide - 3.52 percent, carbon

monoxide - 7,377 ppm, and hydrogen - 11,351 ppm.



Figure 2. Damaged Surface Facilities

An attempt to use boreholes as sampling locations without inserting rigid sampling pipes proved unsuccessful. Problems that were encountered, including contamination by gases liberated from within the sample hole itself and a lack of certainty as to the exact location of the bottom of the sampling line, resulted in erroneous and misleading information about the mine atmosphere. Many sampling locations eventually were equipped with steel sampling pipes which were placed such that the bottom ends were within the mine openings. The bottom section of the sampling pipes was perforated to gain an air sample that better represented the gases in the mine. These rigid sampling pipes have proven to be essential to obtaining reliable information about the mine environment. Sampling of the mine gases also indicated airflow was entering the mine through the temporary seal atop the damaged shaft. Measurements revealed the natural ventilation pressure created a pressure differential from the surface of the damaged shaft to the other mine openings. A tarp was placed over the seal covering the opening of the damaged shaft to impede the amount of air leaking into the shaft. Sand was used as a weight to keep the tarp in place.

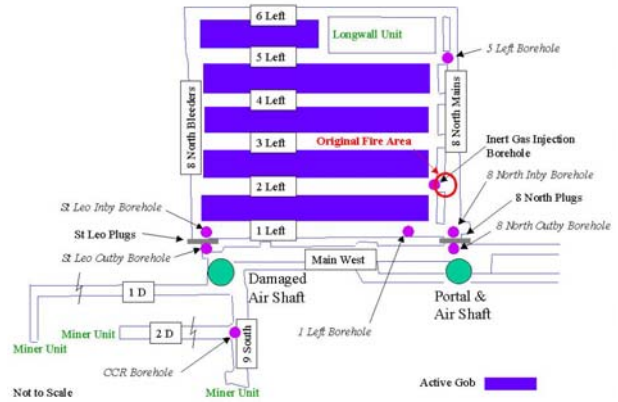


Figure 3. Remote Plugging Plan Detail

Mine management developed a plan to use remote plugs, injected through boreholes, to try to separate the fire area from the rest of the mine as shown in Figure 3. The ventilation plugs were completed on July 13, 1999. The total amount of material injected was approximately 900 metric tons. Continued sampling analysis revealed similar changes in gas trends on both sides of the plugs. These similarities indicated the effectiveness of the plugs was questionable. The ability of the plugs to isolate the fire area from the remainder of the mine was doubted. Successful installation of the plugs might have enabled the remainder of the mine to be re-ventilating more quickly. Recover operations settled in for a longer waiting period.

Nitrogen and carbon dioxide injection ceased on July 14. The volume of inert gas injected was approximately 1,800,000 cubic meters of nitrogen and 390,000 cubic meters of carbon dioxide.

Samples continued to be collected and analyzed. Gas trends were monitored to determine when a sufficient time had elapsed for the fire to be extinguished and heat to dissipate. These conditions were necessary to prevent the fire from re-kindling upon re-ventilation of the fire area. The mine atmosphere eventually stabilized at 25 - 45 percent methane, less than 3 percent oxygen and 10 - 20 ppm carbon monoxide.

By July, 2000, gas trends were promising. On July 19, 2000, re-ventilation at the far end of the mine began. The seals were removed from the three of the five airshafts and the slope and the exhaust fans at two of these ventilation shafts were started. Gases continued to be monitored.

After about one week, conditions stabilized and mine rescue teams began the slow but steady process of mine

recovery. Recovery of the mine was quickened because of the limited extent of the active aircourses. Eventually, an exhaust fan at another ventilation shaft nearer the fire area was started. As recovery progressed near the fire, new sample lines were established from the surface and extended by the mine rescue teams.

Exploration during recovery near the fire area confirmed the results indicated by the gas trends: the plugs were not effective. Also, exploration revealed the explosion had not originated in the fire area. The explosion source was located on one of the development section and was not related to the fire. Thus, the degree and extent of damage on the surface caused by the explosion was understandable. Completion of the mine recovery continues at the time this was written.

#### FOURTH FIRE - JANUARY 28, 2000

The fourth fire occurred on January 28, 2000 at an underground mine in Colorado. The mine began operation in 1982 by developing a multiple number of drift openings into the "F" Seam. Upon mining the available reserves of the "F" seam, two slopes were developed from the "F" seam down to the "B" seam. Mining height in the "B" seam was around 3 meters. The seam dipped to the Northwest. The mine had multiple continuous mining machine units and one retreating longwall which was in the process of being recovered. The headgate of the longwall section at the time of the fire was the second gate development in the district. Mine ventilation was maintained via the use of three exhausting main mine fans. Two of the main mine fans were located on a drift opening while the remaining fan was located on a shaft opening.

Elevated concentrations of carbon monoxide were detected at the exhaust of one of the three fans. This fan ventilated the active longwall gob and two sealed gobs. An immediate evacuation of the mine was begun. Mine management teams were dispatched to try to identify the area in the mine producing the high carbon monoxide concentrations. The teams were able to eliminate as a possible source of the elevated carbon monoxide one of the two sealed gobs and the majority of the active gob. However, a set of mains developed between the north side of the active gob and the south side of a large sealed longwall gob could not be traveled. This prevented mine management teams from further eliminating areas possibly producing elevated carbon monoxide levels in the mine.

Mine management also at this time decided to reduce the amount of air directed through those areas that were not eliminated as the possible fire source. Mine

management teams erected temporary seals across the outby end of the inaccessible mains and any outby entry used to direct air through the active longwall gob. Air was directed through the next developed longwall headgate entries to the inby perimeter of the active longwall gob which then flowed to the main mine fan. The air quantity to this fan was only marginally effected by those air changes.

Mine atmosphere monitoring locations were established at several accessible points on the inby side of the inaccessible mains and the active longwall gob. Sampling results continued to show elevated carbon monoxide levels, therefore, continuous monitor sampling was started on February 5. These results could not be used to pinpoint the area of the fire. In fact, there was some discussion at this time that the elevated carbon monoxide levels might even be coming from a fire in an adjacent mine.

A plan was developed by the operator to use a pattern of vertical boreholes drilled from the surface to identify the fire area or at least to reduce the suspected fire area. Boreholes had to be drilled to a depth that ranged from 380 meters to 410 meters. By February 20, five boreholes were completed. Steel sampling pipes, ranging from 1.9 to 2.5 centimeters in diameter were installed in the boreholes to obtain samples from the mine atmosphere. Air sample results continued to reduce the size of the suspected fire area in the mine.

Three drill rigs were contracted to drill the boreholes. Additional boreholes continued to be drilled and the mine atmosphere from those holes sampled. Continuous monitor sampling was started on March 16 at selected completed boreholes. In addition, to help to identify the fire area a remote, a down hole camera and a temperature probe was used. Figure 4 is a picture of the camera. Using this method, the fire area was identified to an area north of the inaccessible mains and a set of old headgate entries in the sealed gob.

A plan was developed to create a water plug in each of the three old headgate entries. The plugs had to be done remotely, using a concrete mixture injected through a borehole. Water was then pumped into the suspected fire area. Mine floor elevations would permit the water to dam at the plugs and to fill the headgate entries to the inaccessible mains.

By April 2, eight to ten additional boreholes were completed further identifying the fire area and the three water plugs were completed. The water injection rate into the area was increased from 19 liters per second to 38 liters per second. Also, bentonite was injected into



the vicinity of the cement water plugs to help fill or “shore up” any cracks or fissures which allowed water to leak from the dammed area. Once these were completed, water rapidly filled the area.



Figure 4. Remote Monitoring Borehole Camera

On April 4, carbon monoxide concentrations measured at the main fan and several other locations increased significantly. These measured increases indicated that the fire had intensified and potentially had traveled into the inaccessible mains. To combat this, mine management developed a plan to reduce the ventilation (leakage) to the area, to drill a new series of boreholes to surround the new suspected fire area and to pump inert gas, foam, and water into the expanded fire area. Remote water plugs were pumped in the new boreholes. The plugs provided a two-phase approach of assisting in reducing the leakage through the area and also enabling water to be impounded.

By May 8, drilling was completed and water had roofed much of the fire area as shown in Figure 5. Fire gasses had fallen to the lowest levels measured since the event started and continuous monitoring was stopped. A total of 43 boreholes were drilled during the recovery operation along with the installation of 17 remote plugs.

Mine recovery continued in anticipation of production being able to start. Production was started later in the summer. To date, this mine recovery operation is considered the most successful remote sealing and flooding project conducted in the United States.



Figure 5. Final Plug Locations and Extent of Water

## CONCLUSIONS

In each of the four fires, important lessons were learned about what happens after a mine fire occurs. In each situation, boreholes were used to gain limited access to an otherwise inaccessible portion of the mine. The information gained through atmospheric samples collected through these boreholes or from shafts and drifts is invaluable to the mine operator. Cameras lowered into a mine through a borehole can provide significant insight into the conditions in the mine. This information is needed to develop an effective recovery plan for the mine while providing a measure of safety for mine rescue and recovery personnel.

Inert gas, water and time were used successfully in these four operations. In each case, sufficient monitoring locations were needed to determine the changing conditions in the mine. Obtaining sufficient accurate gas data is critical in executing a successful mine fire recovery.

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