Use of an Inertisation Unit during a Coal Mine Fire Recovery Operation

John E. Urosek, PE
Chief, Ventilation Division, Mine Safety and Health Administration
Richard T. Stoltz
Supervisory Mining Engineer, Mine Safety and Health Administration
Dennis A. Beiter
Supervisory Mining Engineer, Mine Safety and Health Administration
George N. Aul
Mining Engineer, Mine Safety and Health Administration
Thomas A. Morley, PE
Mining Engineer, Mine Safety and Health Administration

ABSTRACT: On February 13, 2003, a fire occurred in a large underground coal mine located in West Virginia. Firefighting activities were unsuccessful. The mine was sealed at the surface openings on February 14, with the intent of inerting the mine atmosphere naturally. However, the mine operator proposed a novel approach for controlling the mine atmosphere. The Mine Safety and Health Administration worked closely with the mine operator on a plan to recover the mine. Queensland Mine Rescue Service Limited was consulted and contracted to provide technology, equipment and personnel to operate an Inertisation Unit. The primary component of the unit was a jet engine. The engine was capable of producing large quantities of inert gases and forcing the gases into the mine. The unit was installed on the surface at the slope and the injection of inert gases was started on April 4, 2003. After the mine atmosphere was successfully stabilized to a non-explosive condition, re-ventilation of the remainder of the mine was initiated. Mine rescue teams entered the mine and began exploration toward the fire area. The progress of the exploration work was hampered by roof falls, water, and excessive heat in the vicinity of the fire. The fire area could not be adequately accessed and a decision was made to permanently seal this area from the rest of the mine. Operation of the Inertisation Unit was discontinued after the fire area was partially isolated and a safe and stable atmosphere could be maintained. Eventually, construction of explosion resistant seals was completed around the fire area and rehabilitation of the remainder of the mine began. This paper will discuss the recovery operation with a focus on the use of the Inertisation Unit.

1 INTRODUCTION

A fire occurred within several crosscuts of the slope bottom of a large underground coal mine located in West Virginia. Direct firefighting activities were abandoned when elevated methane and carbon monoxide concentrations were detected near the fire. Subsequently, the mine was sealed at the surface openings. Water was pumped into the mine through the slope to cool the fire. Sample tubes were installed through the seals at each of the mine openings to monitor the atmosphere in the sealed mine. Figure 1 depicts the general layout of the mine and the locations of the shafts and slope openings. Early in the operation, a Command Center, which included members of mine management, the federal and state mine safety and health organizations, and labor representatives, was established. Formal procedures were followed to approve, direct and oversee the work activities during the operation.

Sealing of the mine was expected to result in consumption of the oxygen by the fire in the affected area, resulting in an inert atmosphere that could eventually extinguish the fire. Liberation of methane in a sealed mine can also assist the inerting process, however, methane can also create hazardous conditions. A mine fire is only considered extinguished after the fire area has cooled sufficiently to prevent re-ignition upon re-ventilation of the affected area. Generally, this process requires maintaining an inert atmosphere to prevent continued combustion for a lengthy period of time, often several months or more, thus allowing the fire area to cool sufficiently.

During this operation, monitoring of the mine atmosphere indicated the oxygen concentration in and near the fire area remained elevated. Further,

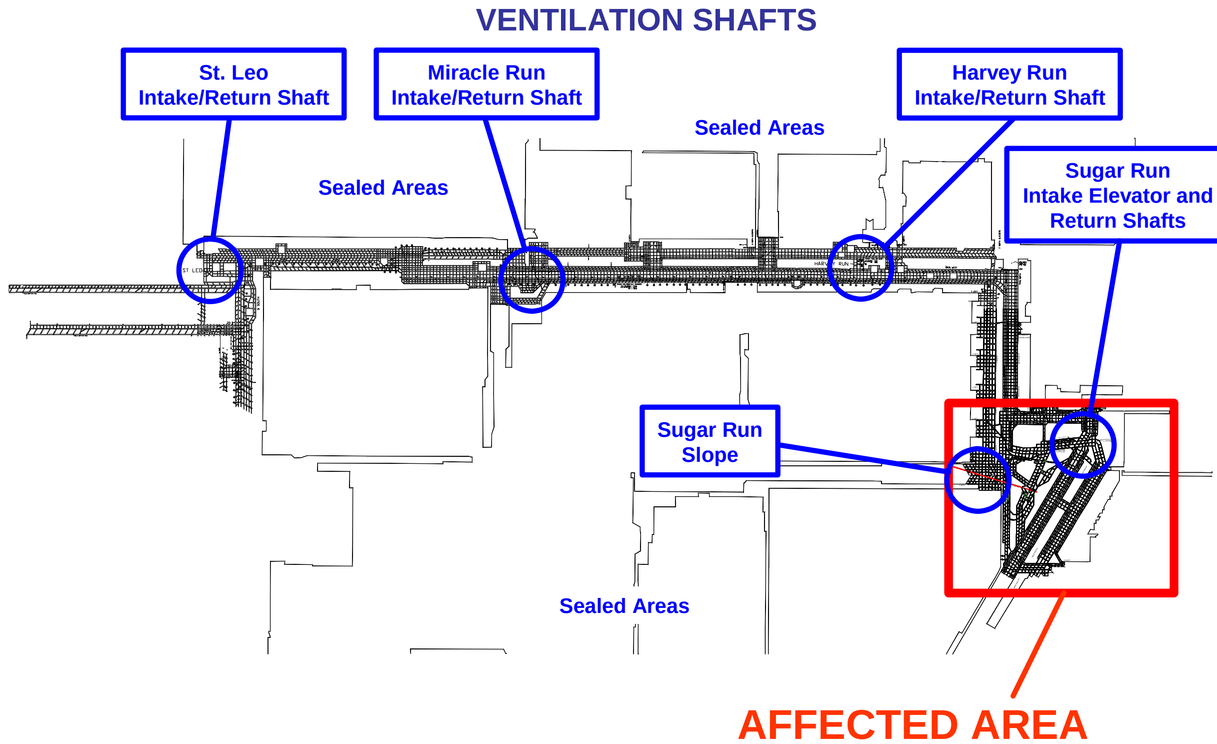


Figure 1. General Mine Layout

much of the atmosphere in the remainder of the mine was entering into explosive methane-air mixtures and concerns arose about the potential for ignition sources other than the fire to cause an underground explosion. Natural ventilation pressures continued to draw air into the mine through the shaft and slope seals adjacent to the fire area and move it throughout the mine. Attempts to sufficiently reduce the leakage through the seals had only limited success. Alternative approaches to reduce the oxygen concentrations in the fire area and decrease the amount of time the mine needed to be sealed were considered.

Mine management made a decision to use an Inertisation Unit (Unit) to force large volumes of mostly inert gases throughout the entire mine. The Unit was owned and operated by Queensland Mine Rescue Service Limited, located in Queensland, Australia. The Unit consisted of a jet engine with modified exhaust that was capable of continuously producing large volumes of inert gases and water vapor. The gas mixture of the exhaust consisted primarily of nitrogen and carbon dioxide. Oxygen concentrations of 2 percent or less were anticipated. This technology was initially developed in Poland in the early 1970's for fighting mine fires. The procedure was later adopted and used in Australia. Prior to this incident, the Unit had not been used for mine recovery in the United States.

The conditions and circumstances surrounding previous applications of the Unit were significantly different than the proposed undertaking. Some officials were initially optimistic the Unit could be used to extinguish the fire. However, usage of the Unit resulted in stabilization and control of the atmosphere in the fire area that enabled the fire to be addressed by other means.

2 INITIAL OPERATIONS AND SAMPLING

Air that entered the mine near the fire area permitted continued combustion and created difficulties with monitoring the mine atmosphere at the surface openings closest to the fire. Additional information was desired to determine the extent and more accurately evaluate the state of the fire. Vertical boreholes were drilled into the mine at locations surrounding the last known extent of the fire. The boreholes were used for injecting water, inserting a borehole camera and temperature probe into the mine to determine the extent of the fire, and sampling the underground atmosphere in close proximity to the fire area. Figure 2 shows a detailed layout of the slope bottom area, the location of the initial fire area, and the locations of the six vertical boreholes.

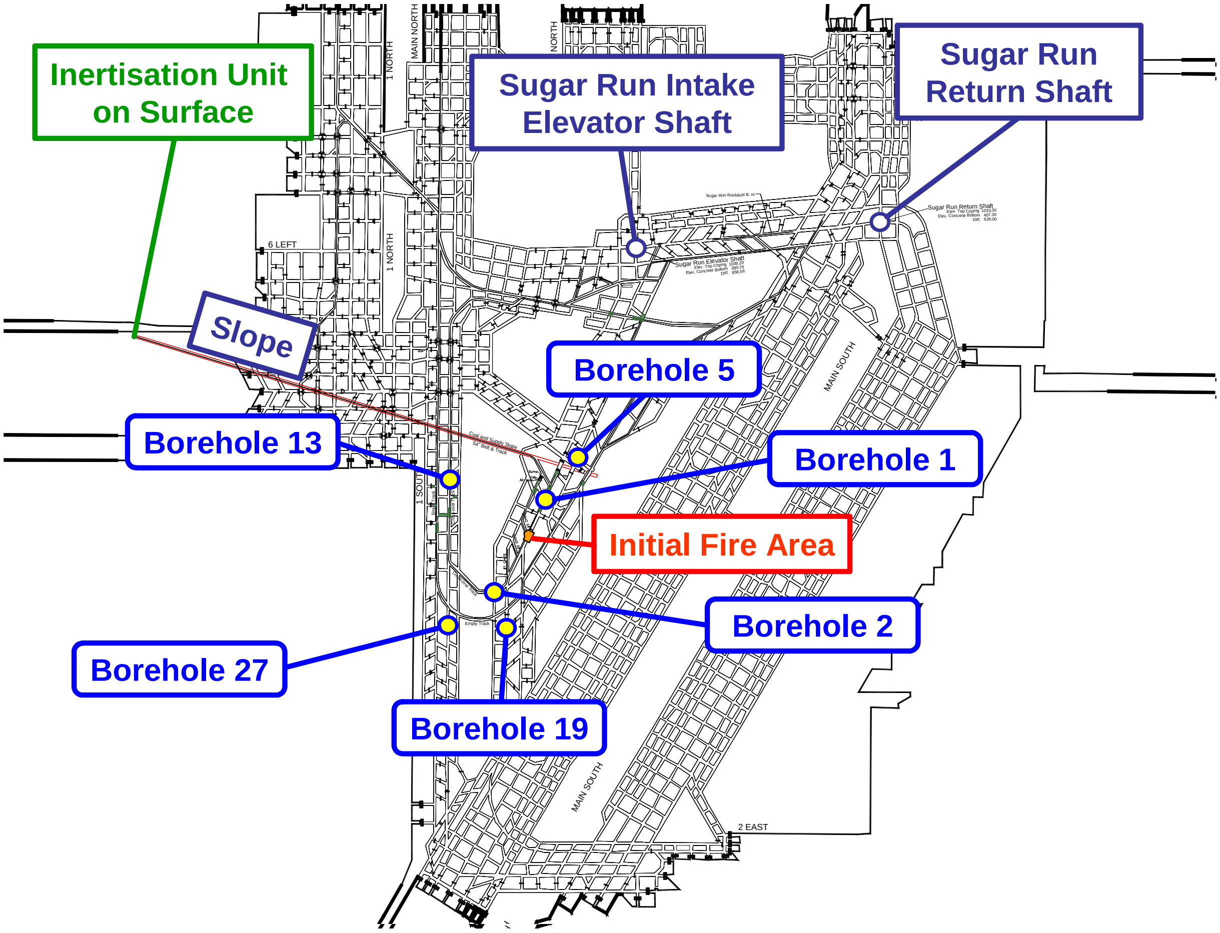


Figure 2. Affected Area and Borehole Locations

Road and site construction for drilling the boreholes was started on February 14. Survey traverses were conducted to locate the borehole sites on the surface. The boreholes were drilled 29.2 cm (11.5 inches) in diameter with a 20.3 cm (8 inch) diameter casing installed to a depth near the mine roof. The depths of the boreholes varied from about 250 m (820 feet) to 274 m (900 feet). Grouting of the casings minimized the migration of strata gases into the sampling location. All of the boreholes were completed by March 13.

A mine atmosphere sampling and monitoring program was established to evaluate the atmosphere in the mine and the state of the fire. Samples were collected at regular intervals and analyzed by gas chromatography. Continuous monitoring of critical locations was conducted using infrared and electro-chemical instruments. Engineers evaluated the air sample analyses and provided interpretations of the results to Command Center personnel. The information was critical for controlling and directing work activities on the surface near the mine openings and underground. Information gained from the results of the mine air samples was also used to evaluate ventilation patterns in the mine.

A sampling line was inserted into each cased borehole. All sampling lines were extended into mine entries. Each sampling line consisted of a 2.5 cm (1 inch) diameter metal pipe that was lowered into the borehole to the mine floor. The bottom of the pipe was plugged. Holes were drilled through the lower 1.2 m to 1.5 m (4 feet to 5 feet) of the pipe to obtain a representative sample of the atmosphere in the mine opening at the bottom of each borehole. Vacuum sampling pumps were used to draw samples to a central location for collection. The sampling lines were designed to ensure that air samples collected were representative of the mine atmosphere and not contaminated with gases liberated from overlying strata in the ungrouted bottom portion of the boreholes. As the recovery operation progressed, the need to more accurately determine the mine atmosphere near the fire area required modifications to the sampling system. Roof falls and differing mine opening heights at certain sampling locations necessitated the sample lines be customized to address the specific conditions. Some sample lines had to be withdrawn

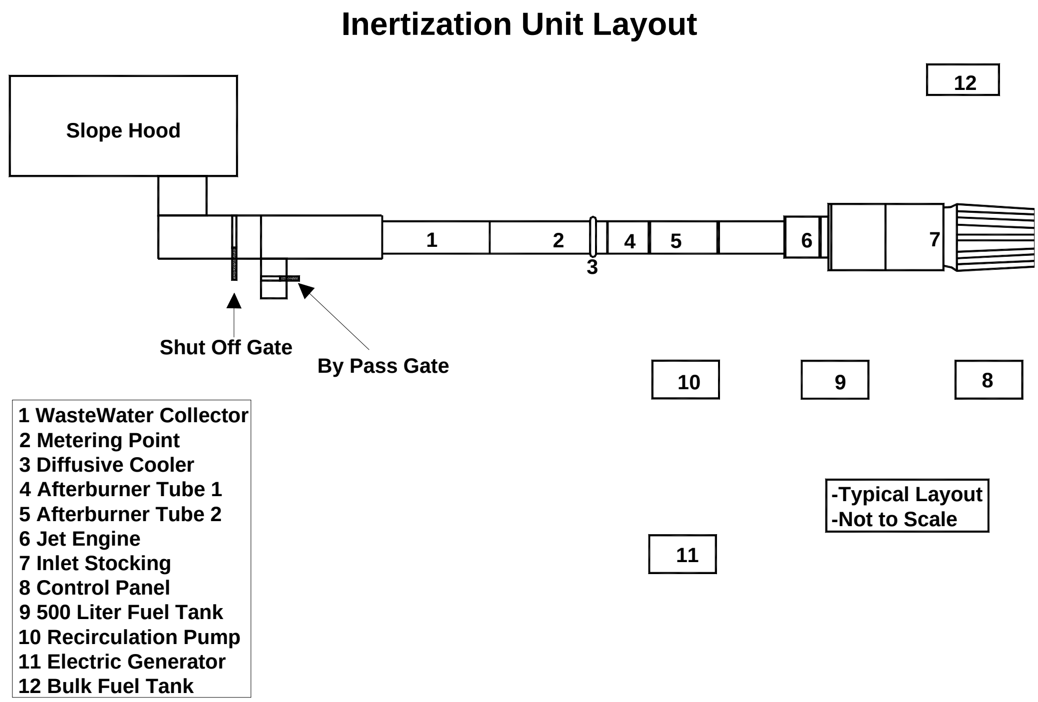


Figure 3. Inertisation Unit Components

and re-inserted in a trial and error method to ensure representative samples were obtained. Accumulated strata gases had to be vented at some boreholes while preventing air from entering the mine.

3 DESCRIPTION AND INSTALLATION OF INERTISATION UNIT

The components of the Unit included a modified jet engine, after-burner, cooling duct, diffusive cooler and waste water collection duct. Figure 3 is a drawing that shows the various components of the unit and the ducting fabricated to allow injection of the Unit exhaust into the mine at the slope opening. A fuel-air mixture was burned in the jet engine, with additional combustion occurring in the after-burner. Most of the oxygen was consumed in the combustion process, resulting in an exhaust composed primarily of nitrogen, carbon dioxide and water vapor.

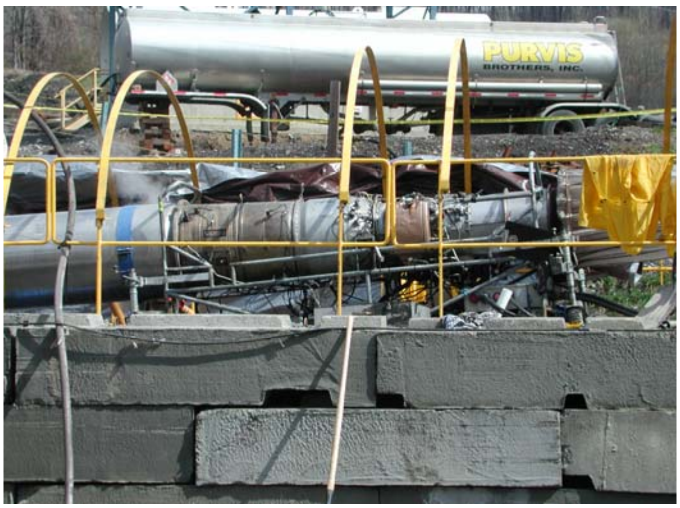
The location of the fire, near the slope bottom, allowed for use of the slope as a conduit through which the exhaust could effectively be directed into the fire area. Preparation for installation of the Unit was conducted according to a detailed plan. The slope coping was constructed of concrete. A plywood seal had been constructed across the slope mouth when the mine was sealed. A pre-existing opening in the concrete at the top of the slope originally designed to facilitate conveyor belt change-out had been covered by a steel panel. A section of duct work was designed to replace the panel and connect the Unit to the slope. The ductwork contained a by-pass gate to enable the Unit output to be vented to the atmosphere during engine startup. To determine the existence of a safe work environment at the slope opening and minimize the potential for changes to the mine atmosphere in the fire area during installation of the ductwork, the following parameters were evaluated and monitored: pressure differentials between the mine and surface at the slope opening, barometric pressure, and the mine atmosphere.

On March 15, when all preparations were completed and readings were favorable, the command center gave approval to replace the steel panel with the fabricated ductwork. A temporary brattice was placed over the breached opening during the exchange which lasted approximately 30 minutes. Exposure of workers during the installation process was minimized through strict control. No work was performed directly in front of the slope opening.

A suitable pad, declined toward the slope at a 3 to 5 degree angle from horizontal, was also required to permit operation of the Unit. The pad was constructed with a retaining wall of pre-cast concrete blocks filled with gravel to obtain the necessary grade. A level pad was also established for the bulk fuel tanks. Components of the Unit began arriving at the mine site on April 1. Installation was completed on April 4 and the unit was connected to the mine ductwork.

4 INERTIZATION UNIT OPERATION

The Unit was operated by Queensland Mine Rescue Service. The engine weighed approximately 5 tons. A 14-man crew maintained continuous operation of the Unit. A control panel continuously monitored temperature, pressure, and engine speed. Adjustments in engine operation were made to control the composition of the Unit exhaust. The engine was operated at speeds that did not develop significant thrust. Table 1 summarizes the operational parameters of the Unit. The rated information was provided by Queensland Mine Rescue Service.



The engine was operated at a speed of approximately 8,000 rpm. The after-burner was cooled by a re-circulating water cooling system. The exhaust was cooled to approximately 85 ^{o}C (185 ^{o}F) before entering the mine. The Unit could produce approximately 14.2 m^3/s (30,000 cfm) of exhaust gases and water vapor. The gas composition of the exhaust varied, depending on the operation parameters. Exhaust gases were monitored from a sample line located in the slope and analyzed by gas chromatography. Oxygen content in the exhaust was also monitored with a sensor in the Unit.

Typically, gas composition of the exhaust gas was 5 percent oxygen, 82 percent nitrogen, 1700 ppm carbon monoxide, and 11.5 percent carbon dioxide. The anticipated lower oxygen concentrations were not attainable because back

Figure 4. Inertisation Unit and Control Panel

Table 1. Operational Parameters of the Inertisation Unit

Parameter	Rated		Actual
Engine Speed	7,200 rpm	11,000 rpm	8,000 rpm
Flow	13.95 m^3 / sec	33.25 m^3 / sec	14.3 m^3 / sec
Fuel Consumption	17 liters/min	32.5 liters/min	370-480 gph
Cooling Water	300 liters/min	300 liters/min	
Exhaust Temperature	85^{o} C	85^{o} C	85^{o} C
Exhaust Gas Constituents			(typical ranges)
Oxygen	0 to 0.5 %	0.5 to 2.0 %	2.5 to 7 %
Carbon Dioxide	13 to 16 %	13 to 16 %	8 to 13.5 %
Nitrogen	80 to 85 %	80 to 85 %	79 to 83 %
Carbon Monoxide	3 ppm	3 ppm	100 to 7,000 ppm

pressure on the engine affected the operation. The back pressure resulted from the buoyancy of the hot exhaust gases in the slope and the restrictions in the mine caused by roof falls, accumulation of materials, and ventilation controls near the slope bottom. The back pressure reached values in excess of 1.7 kPa (7 inches water gauge).

5 INERTIZATION OF THE FIRE AREA

Initial startup of the Unit was hindered by brief setbacks. The Unit was started at 7:45 p.m. on April 4, 2003, with the Unit's exhaust vented to the atmosphere. After 15 minutes of operation, the Unit was shut down because of overheating. Work continued on the Unit until 11:45 p.m., when the Unit was restarted. The by-pass gate was closed and the inert gases were directed into the slope. However, pressure from the initial introduction of the exhaust caused damage to the plywood slope seal, resulting in substantial loss of exhaust. After 15 minutes, the Unit was again shut off to repair the slope seal. Leaks in the ductwork attached to the slope were sealed with polyurethane foam and sand bags.

Figure 5. Exhaust Leakage at Slope

The Unit was restarted at approximately 4:00 a.m. on April 5, and the exhaust again directed into the mine. By approximately 5:00 am, gases from the exhaust were detected at Borehole 1. Within eight hours, the effect on the other sampling boreholes was also evident. The exhaust gases arrived at Borehole 2 at approximately 5:25 am.

To facilitate movement of the exhaust gases throughout the entire mine, the seal on the St. Leo Return Shaft, located at the opposite end of the mine, was breached. After two days of continued Unit operation, samples indicated the mine atmosphere at the St. Leo Return Shaft had been adequately controlled. However, the atmosphere at several other shafts continued to be influenced by barometric changes and natural ventilation pressures and did not show evidence that the exhaust gases had reached those locations.

A decision was eventually made to reseal St. Leo Return Shaft to direct the exhaust to the other openings. The shaft was again sealed at approximately 4:15 p.m. on April 8. Within hours, the desired effect was evident at all openings. Oxygen concentrations at all openings had stabilized below 12 percent by the morning of April 9. Although the oxygen concentration of the exhaust remained too high to halt the combustion process in the fire area, the atmosphere in the fire area stabilized.

On April 10, the seal on the elevator shaft at Sugar Run portal was opened to begin installing a submersible pump to remove water from the bottom of the shaft. The shaft outgassed high levels of carbon monoxide, requiring the work to be performed with self-contained breathing apparatus. On April 12, the elevator shaft was dewatered and work began the following day to return the elevator to a serviceable condition.

Plans and preparations were also made to remotely start the mine fans at the St. Leo, Miracle Run and Harvey Run Return Shafts. On April 13, personnel began removing foam from the intake shaft seals. The fans were started sequentially to better control the gases at the remaining shafts. At 4:04 p.m., the St. Leo Return fan was started. The Miracle Run Return fan was started several minutes later. By 10:45 pm, the Harvey Run Return fan was started and areas of the mine outside the fire area were re-ventilated. The Harvey Run Return fan was shut down on the morning of April 14 because its operation caused air to enter the fire area and adversely affect the stability of the atmosphere in that critical area.

6 MINE EXPLORATION AND RECOVERY

The mine atmosphere within the fire area remained stable with the exhaust from the Unit. Preparations were made to re-enter the mine and begin exploration of the fire area. On April 14, mine rescue teams entered the mine via the Sugar Run elevator shaft.

Mine rescue teams encountered poor roof conditions, roof falls, water, and temperatures in excess of 43 °C (110 °F) as they advanced toward the fire area. Exploration was slowed as ventilation changes were needed to continue advancement and confine the exhaust gases in the fire area. The temperature and water vapor from the exhaust created difficult working conditions near the slope bottom. The heat and humidity near the slope bottom prevented mine rescue teams from traveling in those areas. Access to the fire area from the side nearest the slope was blocked by roof falls and extreme heat. Efforts were made to explore the opposite side of the fire area. After several days of arduous work, exploration advanced to a location beyond Borehole 13. The rescue team encountered evidence that the fire had propagated in that direction from its known location on the day the fire occurred. Attempts were made to cool hot spots directly with water sprays. The roof falls and heat resulted in temporarily abandoning further advancement into the fire area from that direction.

Assessment of the conditions underground concluded the fire was not extinguished by the exhaust of the Unit and rehabilitation of the entire fire area was not feasible. The focus of the operation shifted toward sealing the fire area from the remainder of the mine and developing a new track turnout near the bottom of the slope. Ventilation changes that had been made by the mine rescue teams had reduced the size of, and partially isolated, the affected area. A reduced quantity of inert gas was now needed to maintain a stable atmosphere in the fire area.

A decision was made to replace the high quantity Unit exhaust with a lower quantity nitrogen injection through selected boreholes to maintain a stable atmosphere. The use of nitrogen injection would eliminate the heat and humidity associated with the Unit exhaust. These changes in conditions were expected to improve the working environment for the mine rescue teams and improve the possibility of advancing exploration into the fire area beyond the slope bottom.

During the afternoon of April 18, the Unit was shut down and nitrogen injection began at Boreholes 1 and 2. The buoyancy of the hot gas mixture and retained heat in the slope sustained an outgassing condition at the slope seal. The by-pass gate in the slope ductwork was partially opened to permit controlled venting of the hot gases in the slope. Eventually, the flow was increased to permit cooling of the slope and allow the fan induced ventilation pressures to reverse the flow.

The work environment improved and mine rescue teams advanced slowly beyond the slope bottom but still could not access the fire. Another attempt was also made to explore into the fire area from the opposite side. Mine rescue teams were able to advance exploration closer to the fire area. Evidence of continuing combustion, including flames, was encountered at roof falls. Eventually, the decision was made to abandon exploration work and to seal the fire area, including the track turnout near the bottom of the slope, from the remaining portion of the mine. Permanent bulkheads and explosion resistant ventilation seals were constructed to completely isolate the affected fire area from the remainder of the mine. The sealing process was completed on May 24, 2003. Water was pumped into the sealed area and impounded behind the bulkheads, flooding much of the affected area. Rehabilitation of the rest of the mine continued simultaneous with the construction of a new track turnout near the slope bottom. Coal production resumed in early October, 2003.

7 CONCLUSIONS

The Unit provided an effective means to stabilize the atmosphere in the fire area. Sampling results also indicated the Unit provided a sufficient quantity of inert gases to assist in eliminating explosive methane-air mixtures in remote portions of the large underground coal mine. Determination of the extent of the fire area was made possible and, ultimately, the fire area was permanently isolated from the remainder of the mine. Without use of the Inertisation Unit, recovery of the mine would not have been possible in such a short period of time. However, oxygen concentrations of the exhaust remained too high to halt combustion in the fire area and extinguish the fire. During the exploration and the sealing of the fire area, elevated temperatures and humidity from the exhaust of the Inertisation Unit presented some adverse conditions that hampered operations. The elevated temperatures and humidity may also have contributed to some of the numerous roof falls found in the area.