PB95-128807

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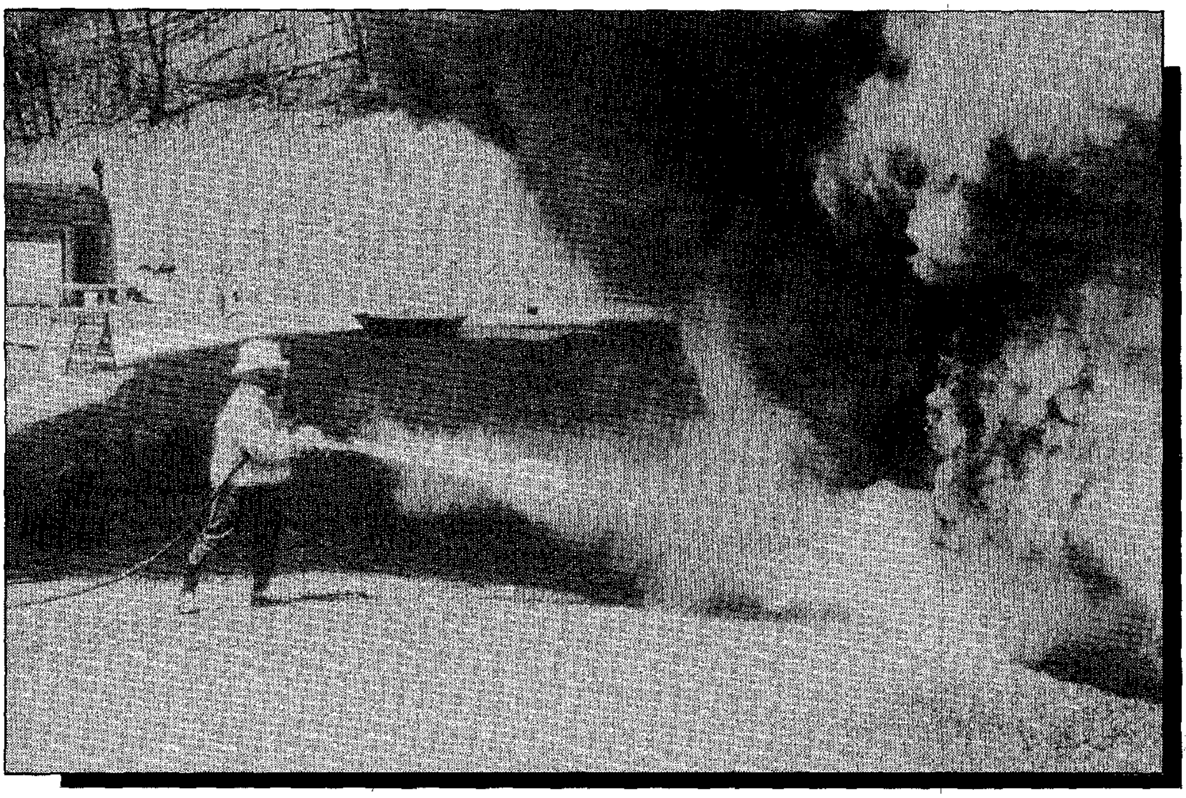
INFORMATION CIRCULAR/1994

Fire-Fighting Resources and Fire Preparedness for Underground Coal Mines

By Ronald S. Conti



UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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Cover: Extinguishment of liquid fuel fire with dry chemical.

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

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13. ABSTRACT (Maximum 200 words)

This U.S. Bureau of Mines report describes various fire fighting resources available to the mining industry and examines the fire preparedness of four western coal mines. The fire fighting resources covered include fire extinguishers, water hoses and nozzles, and fire fighting foam. Information regarding fire fighting equipment indicates that an inadequate maintenance program may cause component failure of fire extinguishers; damage to water hoses is usually a result of improper care; and foam may be a convenient means of conveying water to the fire. One area of particular interest was fire hose water nozzles. Several brands of fire hose nozzles randomly selected, both expensive and inexpensive, were tested at various water pressures. Little difference was found in the maximum throw distance in the fog stream mode. However, dramatic differences were seen among these nozzles when tested for throw distance in the straight stream mode. Performance data relative to water nozzles and specific practices to improve the state of preparedness in many of these areas are discussed.

Studies also indicated that a high expansion foam plug, will travel down an entry, with a 1% rise in elevation, 207 m (680 ft) before a plywood stopping separating the generator and plug failed. The advance rate of the foam plug decreased when the entry is dry, requiring more foam concentrate and as the foam spread further down the entry.

An examination of the mine emergency preparedness of four western coal mines showed state-of-the-art monitoring systems were common at the mine sites. All four mines used carbon monoxide (CO) sensors, and one mine incorporated smoke sensors. Fire safety at all the mine sites was stressed, including early detection and rapid response of the miners to evacuate the mine. However, the mines placed little emphasis on performance of water nozzles, or personal protective clothing for the underground firefighters.

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CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot per minute	m	meter
cm	centimeter	mi	mile
fpm	foot per minute	min	minute
ft	foot	ML	megaliter
ft^3	cubic foot	m/min	meter per minute
gal	gallon	MPa	megaPascal
gpm	gallon per minute	m/s	meter per second
h	hr	m^3/s	cubic meter per second
in	inch	ppm	part per million
kg	kilogram	psig	pound per square inch, gauge
kL	kiloliter	s	second
km	kilometer	st	short ton
L	liter	t	metric ton
lb	pound	°C	degree Celsius
L/s	liter per second	°F	degree Fahrenheit
M	million	%	percent

PB95-128807

FIRE-FIGHTING RESOURCES AND FIRE PREPAREDNESS FOR UNDERGROUND COAL MINES

By Ronald S. Conti[1]

ABSTRACT

This U.S. Bureau of Mines (USBM) report describes various fire-fighting resources available to the mining industry and examines the fire preparedness of four western coal mines. Information regarding fire-fighting equipment indicates that an inadequate maintenance program may cause component failure of fire extinguishers, damage to waterhoses is usually a result of improper care, and foam may be a convenient means of conveying water to the fire. Performance data relative to water nozzles (throw distance) and specific practices to improve the state of preparedness in many of these areas are discussed.

Studies also indicated that a high-expansion foam plug, will travel down an entry, with a 1% rise in elevation, 207 m (680 ft) before a plywood stopping separating the generator and plug failed. The advance rate of the foam plug decreased when the entry is dry, requiring more foam concentrate and as the foam spread further down the entry.

An examination of the mines showed state-of-the-art monitoring systems were common at the minesites. Fire safety was also stressed, including early detection and rapid response of the miners to evacuate the mine. However, the mines placed little emphasis on performance of water nozzles, or personal protective clothing for the underground firefighters.

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INTRODUCTION AND BACKGROUND

An underground coal mine fire is a serious threat to miners and to the mine itself. Coal mines contain a nearly unlimited fuel supply; therefore, the fire has the potential to grow and spread very rapidly. The detection of a fire in its initial stages is necessary to ensure the safety of miners and to extinguish the flames. Over the past several decades, the mining industry has experienced significant technology advancement and has demonstrated increased awareness of the hazards of underground mine fires. During the period of 1970 through 1990, the Mine Safety and Health Administration (MSHA) (*1*)[2] investigated 307 reportable underground coal mine fires. This is an average of 15 reportable mine fires a year. Federal regulations (*2*) define a reportable mine fire as an unplanned mine fire not extinguished within 30 min of discovery or causing an injury or a fatality. Table 1 and table 2 (*3*) depict a 19-year reporting period of coal mine fires in track and conveyor belt entries and their causes. Sixty-five of these underground fires were in the belt entry and 60 in the track entry. These fires represent 43% of the total number of fires reported in this period and resulted in 42 fatalities and 23 injuries. The predominate cause of fires in belt and track entries are friction and short circuits, respectively.

[2]Italicized numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

Table 1.—Belt and track entry fires compared with all fires within a 19-year reporting period, 1970-88

Range, years	Total fires	Belt entry fires		Track entry fires	
		Number	% of total	Number	% of total
1970	36	5	13.9	5	13.9
1971 to 1973	53	6	11.3	17	32.1
1974 to 1976	39	5	12.8	8	20.5
1977 to 1979	30	5	16.7	10	33.3
1980 to 1982	45	12	26.7	8	17.8
1983 to 1985	39	18	46.2	5	12.8
1986 to 1988	51	14	27.5	7	13.7
Total	293	65	22.2	60	20.5

Source: MSHA (*3*).

Table 2.—Cause of fires occurring in track and belt entries, 1970-88

Cause	Belt entry fires		Track entry fires		Total number, belt and track
	Number	% of total	Number	% of total	
Derailment	NA	NA	2	3.3	2
Electrical (other than trolley)	8	12.3	20	33.3	28
Friction	22	33.9	NA	NA	22
Fuel	1	1.5	NA	NA	1
Heat	3	4.6	NA	NA	3
Roof fall (trolley wire shorts)	NA	NA	9	15.0	9
Transporting equipment	NA	NA	12	20.0	12
Trolley pole	NA	NA	5	8.3	5
Trolley wire	NA	NA	4	6.7	4
Welding and cutting	13	20.0	4	6.7	17
Unknown	18	27.7	4	6.7	22
Totals	65	100.0	60	100.0	125

NA Not applicable.

Source: MSHA (*3*).

Two recent fires are of particular interest. A fire at the Pattiki Mine, Illinois, in November 1991, (*4*) resulted in a portion of the mine being sealed. Fire-fighting efforts failed due to delays in initiating fire-fighting activities and the rapid growth of the fire. Around 12:30 p.m., miners detected an unusual haze near a belt transfer point, and as they were investigating the source of smoke, the CO fire detection system alarmed. At that time, the CO level in the main intake entry was 100 ppm. About 45 min later, an order to evacuate the mine was given. The CO level at the surface mine exhaust fan was 8 ppm. Once the source of heavy smoke was located and a water delivery system assembled, water was finally introduced to the fire area at 5:00 p.m. A half hour later, the CO reading at the surface exhaust fan was 100 ppm. During this period, low expansion foam applied by hand pumps was sprayed onto the ribs after quenching them with water. This had minimal success in preventing the ribs from reheating, but it allowed the firefighters more time inby, closer to the fire. Around 3:00 a.m., the first signs of flames were observed. Large high expansion foam generators were positioned in the entry, but proper connections and sufficient water pressure were not available. During the fire attack, plastic water nozzles melted due to the intense heat when they were placed through holes in the stoppings. Subsequently, the fresh air base had to be moved back about two crosscuts because of the heavy smoke. About 18 h into the mine fire, a decision to seal the fire area was made. Peak CO levels at the surface exhaust fan reached 1,978 ppm during the fire. A roof fall during the sealing operation crushed a permanent stopping, further hampering fire-fighting efforts. After the fire area was sealed and boreholes drilled (only one of the three boreholes drilled from the surface successfully intersected an open area), it required 114 t (126 st) of liquid carbon dioxide (CO_2) to quench the fire. The liquid (CO_2) was pumped through the hollow drill stemming and allowed to discharge in a gaseous form into the fire area through a special discharge nozzle in the drill bit. Twenty days later, an additional 16 t (18 st) of liquid CO_2 were pumped into the borehole to maintain low CO and oxygen (O_2) levels in the sealed area. One hundred seventy hours after detecting the fire, the mine returned to normal operations outside the sealed area. The cause and origin of the fire were not determined, however, spontaneous combustion was suspected. The cost of fire-fighting supplies and other materials was estimated at $273,000. Additional costs are inferred for labor and loss of productivity.

A fire at the Mathies Mine, Pennsylvania, in October 1990 (*5*), resulted in the entire mine being sealed. Several injuries were sustained, and over 400 jobs were lost. At the time of the fire, the operator used continuous mining equipment to extract the Pittsburgh coalbed. The mine liberated an average of 28.3 ML (1,000,000 ft^3) of methane a day. Point type heat sensors were used for fire detection along the conveyor belt entries. Coal was transported from the working faces via shuttle cars, and discharged onto conveyor belts. A series of conveyor belts transported the coal to underground loading tipples where the coal was loaded into mine cars. Track locomotives transported loaded coal cars to the surface. It was around 5:00 a.m. when the trolley power fluctuated. A short time later two miners observed smoke rapidly building along the roof near the number 1 crossover at the bottom of Thomas Portal. Reported visibility was less than 2.4 m (8 ft). During the evacuation, smoke was so thick that vehicles collided. The electrical power went off a short time later. A group of nine escaping miners became so disoriented by the smoke and stress that it took them 3 h to travel 3 km (10,000 ft) before exiting the mine. Upon locating the fire, the contents of two portable (multipurpose dry chemical) fire extinguishers failed to extinguish it. Seven 3.8 L (1,000 gal) water cars were available for fire fighting; at 6:30 a.m. water from one of the cars was sprayed onto the fire. Additional water cars and roof support materials could not be taken to the fire area because a number of empty cars had derailed. Over 90% of the underground fire-fighting equipment was stored inby the fire area, and because of the heavy smoke and heat, could not be put to use. Additional water was pumped into the mine from a pond on the surface. This effort required waterlines to be assembled and rerouted. It was estimated by the investigating team that the flame propagation rate of the Mathies Coal Mine fire was 0.52 m/min (1.7 fpm). An explosion occurred at 2:20 p.m. (somewhere in the underground shop area) while the miners were fighting the fire. At 9:45 p.m. the next day, a decision was made to seal the mine.

MSHA investigators concluded that a roof fall caused an energized trolley wire to come in contact with steel rails and created a high resistance electrical arc, which ignited the fallen roof coal. The cost of this mine fire was estimated at $23,000,000. This includes both losses of mining equipment and supplies, and the expense of sealing the mine. Fire-fighting efforts may have been successful in both of these cases if firefighters would have been able to effectively attack the fires in their incipient stages.

The success of safely controlling and extinguishing an incipient mine fire depends on several factors, such as an awareness of the fire hazards, early detection, availability of effective fire-fighting equipment, quick response time and trained firefighters. If a coal mine fire cannot be contained by direct fire-fighting methods within a few hours after discovery, the chances of successfully extinguishing the fire without sealing a portion of the mine or the entire mine are greatly diminished. Many mine operators and personnel are not aware of how fast mine fires can spread, have little knowledge of the magnitude of a detectable fire, nor have any experience in the proper selection and use of modern fire-fighting equipment. Information on the latest mine fire detection, alarm and extinguishing technologies and fire-fighting strategies may be difficult to obtain. Such equipment and techniques could significantly improve the success rate of safe fire-fighting operations and reduce the risk and occurrence of severe mine fires.

Recent USBM fire research and actual data from mine fires have shown that fires can spread very rapidly. For example, large-scale fire gallery experiments have demonstrated that conveyor belt fires can propagate at rates of over 0.10 m/s (20 fpm) (*6*). Yet, many in the mining industry still believe that fire-resistant belting will not burn. Modern fire detection and fire-fighting equipment, though available, is not often found in underground mines. Longer detection times result when fire sensors are improperly placed in the entries, or sensors with slow response times are employed (*7-10*). In many instances, mine fires grow out of control due to poor planning, inoperative detection systems, inadequate water supplies, inappropriate fire-fighting equipment, broken waterlines, failed suppression systems, and improper personal protective equipment. Facilities and programs for mine personnel to learn about the hazards of mine fires, evaluate modern fire detection and fire-fighting equipment and technologies, and observe the proper methods to combat mine fires are lacking. Recent mine fire application seminars and briefings, sponsored by MSHA at the National Mine Health and Safety Academy (*11*) and the USBM at Lake Lynn Laboratory, are positive steps. Increasing the mining industry's awareness of the dangers of underground mine fires and conducting periodic fire audits, could reduce the probability of having a major fire and improve the current state of fire preparedness.

Some mines have already developed extensive checklists to improve their state-of-preparedness. For example, MSHA reported that more than 20% of belt entry fires were caused by welding-cutting operations. Some mines require a hot work permit (appendix A) before any welding or cutting operations are performed. This permit requires the miner to perform certain safety checks before and after the planned maintenance activity. Each permit is monitored by a communications coordinator. Other ways to decrease the probability of a fire due to dust accumulations, defective equipment, etc., in conveyor belt drive areas, are to have beltline checklist inspections (appendix B) or to have the total drive area (roof, ribs, and floor) covered with noncombustible material and hosed down once a shift. The checklist requires the examiners to look for potentially known problem areas and available safety equipment. Infrared heat sensors could be used to monitor the welding-cutting work area for hot materials or residue that may cause a fire. Such devices may also be useful for detecting hot rollers along beltlines or defective trolley hangers.

This report is not intended to represent an all inclusive discussion on each area, but does point out important factors often overlooked. Detailed information on various fire-fighting resources (dry chemical powders, foam, etc.) can be obtained from the product manufacturers, Federal regulations, and the National Fire Protection Association (NFPA).

FIRE-FIGHTING RESOURCES

Federal regulations, as spelled out in 30 CFR Part 75 Subpart L-Fire Protection (*2*), require each coal mine to have suitable fire-fighting equipment adapted for the size and conditions of the mine and this equipment must meet certain minimum requirements.

FIRE EXTINGUISHERS

Normally, a mine has a wide range of extinguishing agents available for fire fighting: water, dry powders either in the form of rock dust or the chemical powder used in fire extinguishers, and foam. A requirement for coal mines in the Federal regulations (30 CFR Part 75.1100-1(e)) is that a portable fire extinguisher either be, (1) multipurpose dry chemical, minimum of 1.9 kg (5 lb), or (2) a foam producing type containing at least 9.5 L (2.5 gal) of foam producing liquids. If the fire is detected in the early stages of development, water or dry chemicals properly administered should extinguish the fire.

Dry chemical fire extinguishing agents stop the chemical chain reaction sequence associated with the fire. Some of the common agents in this class are sodium bicarbonate, potassium bicarbonate, and monoammonium phosphate (multipurpose dry chemical). Only multipurpose type fire extinguishers are permitted in underground coal mines. The dry chemical used in this fire extinguisher is very effective on class A fires in addition to the normal class B:C capability. Hand portable dry powder or chemical fire extinguishers are available with extinguishing contents ranging from 0.45 to 14 kg (1 to 30 lb). Wheeled extinguishers are available in sizes ranging from 34 to 159 kg (75 to 350 lb). Stationary units are available in sizes up to 1,361 kg (3,000 lb).

Time is a critical factor when using a fire extinguisher in any fire situation. Two or three seconds saved can mean the difference between a fire extinguishment or disaster. Very often, due to an inadequate maintenance program or to the inexperience of the operator, a fire extinguisher fails to operate or to extinguish the fire. Recently, a miner who attempted to extinguish a fire that developed in a power center was overcome by smoke because the fire extinguisher did not operate. The following section addresses component failure in fire extinguishers and not the human error that may be due to lack of hands-on training.

Fire extinguishers are placed in strategic locations throughout the mine and may not be handled until an emergency situation exists. During this quiescent period, the dry chemical powder can settle and compact. This phenomenon is known as packing. Caking occurs when moisture chemically reacts with the dry chemical powder. Caking and packing are normal occurrences in dry chemical extinguishers and will affect performance. When the extinguisher is actuated, high pressure gas (nitrogen or carbon dioxide) flows from the stored cartridge and fills only the gas tube pickup that is inserted into the housing of the extinguisher. The packed or caked powder cannot become airborne. One way to prevent this is to turn the fire extinguisher over and shake its contents every few months to keep the powder disaggregated. Mines are notorious for high humidity that may cause fire extinguishers to rust and seals to deteriorate. This could leave the powder exposed to moisture and leaks. It is important to have the fire extinguisher hydrostatically pressure tested for leaks at required intervals. Another problem occurred with fire extinguishers that were in underground service for a lengthy time period. When a miner activated the extinguisher, the hose blew off the nozzle assembly. The manufacturer was notified and all the fire extinguishers were retrofitted with a new hose. An adequate maintenance program, as outlined in "NFPA 10 Portable Fire Extinguishers" (*12*), should be initiated to address problems like caking, and packing.

An important element to consider in any fire safety program is adequate hands-on training for all miners. An inexpensive 0.9 by 1.5 m (3 by 5 ft) mortar box filled with several centimeters (inches) of water, and a mixture of 11.4-L (3 gal) diesel fuel and 3.8-L (1 gal) gasoline, is suitable for training in the use of fire extinguishers and various other fire-fighting equipment. Hands-on training builds confidence and skill levels and shows miners what to expect in the event of a fire. Figure 1 illustrates the extinguishment of a small liquid fuel fire with a portable fire extinguisher.

Considerable thought should also be given to the type, size, quantity, and possible recharge of hand portable (figure 2) and wheeled fire extinguishers. If the plan calls for an on-site recharge of fire extinguishers, a sufficient supply of dry chemical agent and charged gas cartridges must be available.

WATERHOSES

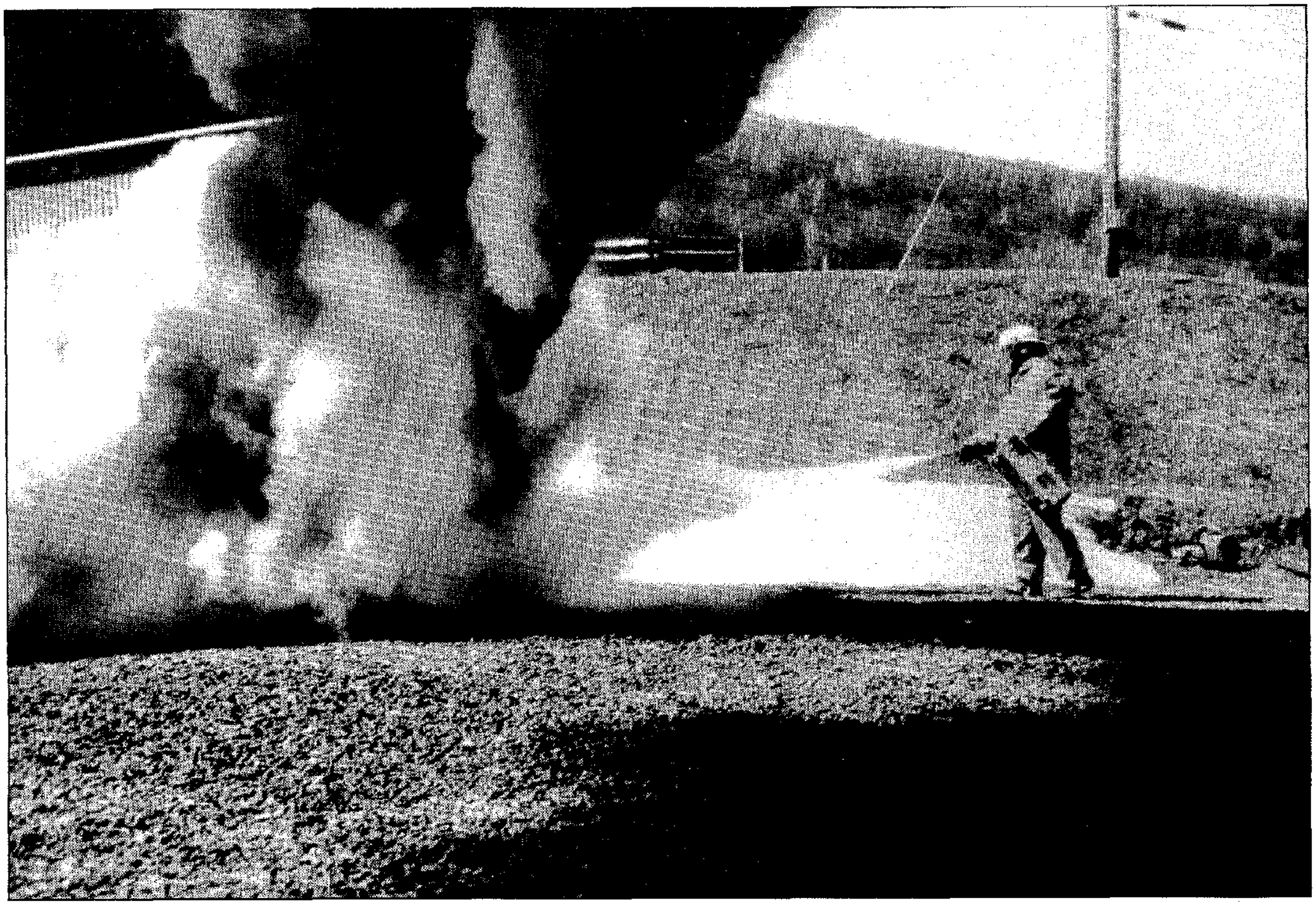
In the event of an underground coal mine fire, it is critical to extinguish the fire in its early stages. Any delay in initiating fire fighting activities can result in an uncontrolled fire. During one underground fire that occurred in a remote area of a mine, the nearest water hydrant was over 610 m (2,000 ft) away. After the fire was detected and located, 610 m (2,000 ft) of 5.1 cm (2 in) plastic water line, in short lengths, was connected to the 10.2 cm (4 in) water main. The connection of numerous pieces of waterline resulted in a considerable delay in fighting the fire. The initial water pressure of the 10.2 cm (4 in) main was 1.38 MPa (200 psig); however, the pressure decreased dramatically at the end of the long 5.1 cm (2 in) plastic line. The decreased water pressure made fire-fighting efforts ineffective. This situation may have been avoided if the mine was properly prepared (water cars for remote areas) or if a waterhose was used. For example, instead of using short lengths of small diameter plastic line, a 10.2-cm (4-in) flexible waterhose could have been laid from the water hydrant to the firesite in less than half the time it took to connect the plastic pipe. Consequently, the water pressure drop would not have been so drastic.

It is crucial that an adequate length of water hose or line be on hand in a mine. Mine operators should be prepared in case a fire starts in a remote section of the mine. One mine suggested having ready a minimum of 610 m (2,000 ft) of 10.2-cm (4-in) diameter plastic waterline in 3-m (10-ft) lengths, including a supply of fittings necessary to connect these lines. All fittings should be standardized so all fire-fighting equipment is compatible. For example, converting the minesite over to one standard thread, like National Standard Thread (NST), could be a choice. A waterhose serves as a flexible, portable, and adjustable conduit of water, but without a reliable water source and means of bringing the water supply to the fire, an effective fire attack is not possible.

Water is usually economical, and most of the time, abundant and easily pumped. However, water may not always be available in sufficient quantity to fight a large fire. Considerable planning should be given to adequate water pressures, types and sizes of waterhoses, nozzles, and fittings and an appropriate hands-on training program.

There are various types of fire waterhoses in use today. The typical one found in underground mines is lined with polyester. Waterhoses vary in size from a nominal inside diameter of 1.9 to 15.2 cm (0.75 to 6 in). Industrial fire brigades utilize either 3.8 or 6.3 cm (1.5 or 2.5 in) diameter hoses. Hoses of 5.1 cm (2 in) diameter or less are considered attack lines, while the larger hoses are used as supply lines. Considerable care must be taken to prevent

Figure 1



Extinguishment of liquid fuel fire with dry chemical.

hose damage which can result from several causes. A common occurrence is mechanical injury. A waterhose deployed in the entry from the water hydrant to the fire-site can be damaged by vehicle traffic crossing over the hose to transport supplies to the site, roof falls, and the constant drag of the hose on the floor over sharp materials and around corners. Sudden changes in water pressures or extreme water pressures can also inflict mechanical damage. Excessive temperatures or hot residue from the fire can destroy the outer jacket of the hose. However, when a hose fails it is most commonly caused by improper care. Improper cleaning, drying, repacking, and storage practices can induce mold and mildew damage. Exposure of the hose to chemicals and handling a frozen hose may cause damage. Requirements for underground mines specify that firehoses be lined with a material having flame and mildew resistant qualities. The bursting pressure of the hose should be at least four times the water pressure at the valve-to-hose inlet with the valve closed. The maximum water pressure in the hose nozzle with water flowing should not exceed 0.689 MPa (100 psig), according to CFR 30 Part 75.1100-1(f)(1).

One way of protecting a waterhose from damage is to coil it into a donut roll. This method of storage stows the hose compactly with both couplings accessible and protects the thread of the male coupling. Both hose couplings may be covered to prevent materials accumulating inside the hose. Two miners can deploy the hose very easily without kinks. The male coupling should be unwound towards the fire or water nozzle and the female coupling towards the water hydrant. Donut rolls can be dropped off along the entry in route to the fire for rapid deployment and convenient connection with other waterhoses. Several hoses can be stored in a moveable plastic barrel or bin, as shown in figure 3.

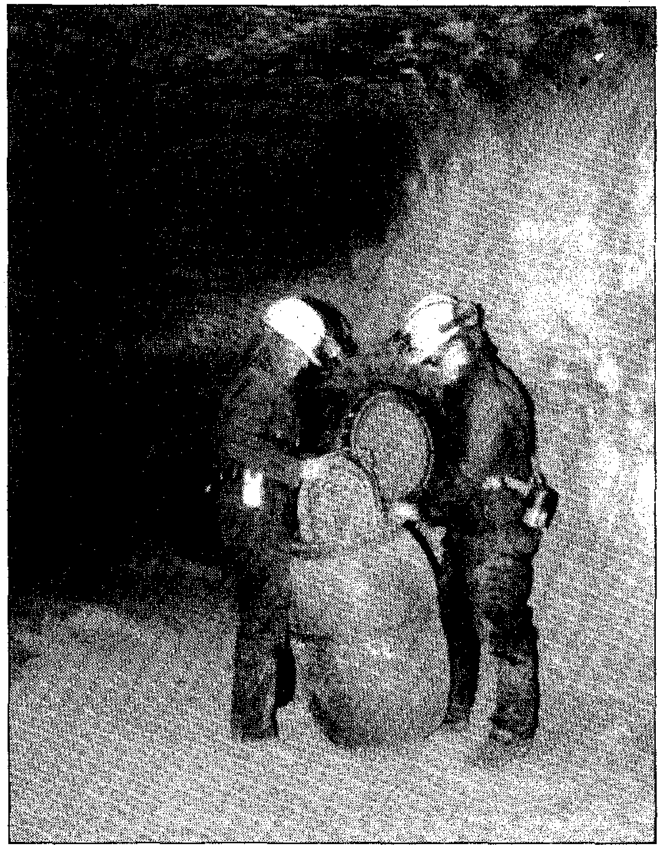
NOZZLES—SOLID STREAM AND FOG

Typical firehose nozzles can discharge water in a solid stream or fog stream. Some brands of nozzles also have a flush mode to clear any debris that may accumulate in the nozzle from the water supply. Most nozzles can change easily between these three discharge modes. The purpose of the solid stream nozzle (figure 4) is to release

Figure 2

Recharging of portable fire extinguishers.

Figure 3



Underground firehose storage.

Figure 4

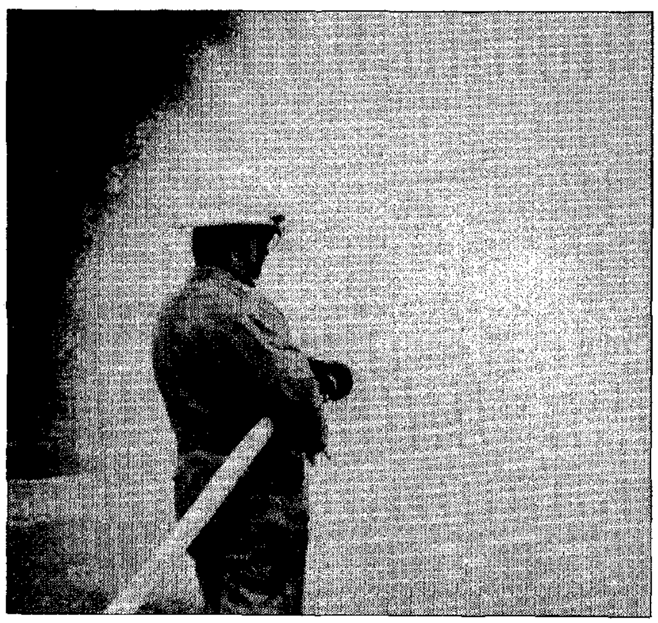
Firehose water nozzle in solid stream.

water so that it will travel an adequate distance to keep firefighters away from the flames. This type of nozzle can also be used to penetrate loose or porous materials commonly found in class A fires. Wood, paper, cloth, and coal are examples of materials found in Class A fires. These common combustibles usually result in the development of deep seated embers that can reignite if not properly quenched. Advantages of solid stream nozzles include: a greater reach with the stream and high knockdown potential of the flames because the stream is able to penetrate and cool intense fires; a greater penetration of loose and fibrous material, for example, burning coal or wood cribbing; and a lower nozzle pressure for an effective stream. Some disadvantages include: less heat absorption per unit of water, greater electrical conductivity through the stream, limited effectiveness on flammable liquid fires since the stream can cause fire spread, and a greater nozzle reaction or back thrust per unit of water. As a stream flows from a nozzle, it creates a force in the opposite direction known as nozzle reaction. The amount of reaction depends directly on the weight or quantity of water flowing out and the pressure forcing it through the nozzle. A pistol grip used with many nozzles allows firefighters to fight fires for longer periods of time with less fatigue and stress, and permits more control of the water exiting the nozzle due to kickback.

The fog or spray nozzle breaks up the water stream into particles of water, as shown in figure 5, creating a greater surface area (smaller droplet size) and increasing the water's heat-absorbing capability. Some advantages of fog nozzles are greater heat absorption per unit of water, more control of roll back smoke, less electrical conductivity through the fog stream, considerable effectiveness on flammable liquid fires, and less nozzle reaction or back thrust per unit of water. The disadvantages include: shorter reach than with the solid stream, less penetration of loose or fibrous materials, and a higher nozzle pressure for an effective fog stream. Figure 6 illustrates two firefighters extinguishing a liquid fuel fire using water nozzles in the fog stream mode. Foam and powder are more effective in extinguishing such a fire and are the recommended agents.

Several fire hose nozzles, figure 7, varying in price from under $25 to well over $400, were evaluated at various water pressures in the quarry area of Lake Lynn Laboratory *(13-14)*. The water system consisted of a 37,000 L (10,000 gal) storage tank, a pump house with a diesel-powered water pump capable of delivering 1,300 L (350 gal) of water per minute at 1.379 MPa (200 psig) (figure 8), and a hydrant with a three-port manifold (figure 9).

Figure 5



Firehose water nozzle in fog stream.

The water nozzles were grouped into two categories, inexpensive and expensive. These nozzles were randomly selected and the data are not all inclusive of other brands. Inexpensive nozzles were priced under $25. All tests were conducted with 3.8 cm (1.5 in) inside diameter hose.

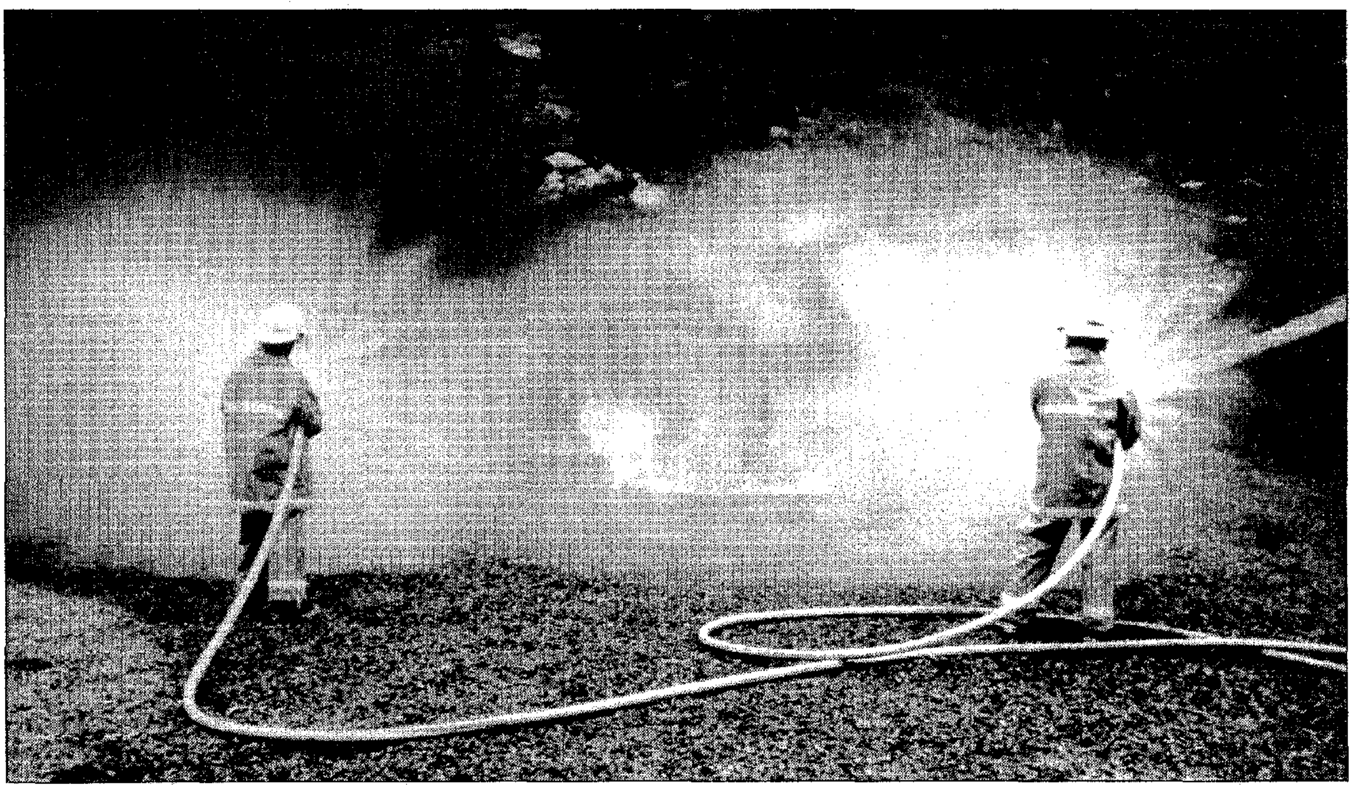
The water throw distance of these nozzles, with respect to dynamic water pressure, is shown in figure 10. The open circles are the averaged data from both the inexpensive and expensive nozzles in the fog stream mode. The average data are shown because there was very little difference between the two groups of nozzles. Increasing the water pressure produces a slight increase in distance in the fog stream. When comparing the spray pattern of all nozzles in the fog stream, little difference could be seen. The triangles represent the average data of the inexpensive nozzles in the straight-stream mode. A minimal increase in throw distance is shown as water pressures are increased. For example, at a water pressure of 0.345 MPa (50 psig) the throw distance is 18.3 m (60 ft) compared to 36 m (120 ft) at 1.379 MPa (200 psig). More dramatic effects are quite obvious with the expensive nozzles (solid circles) in the straight stream. Increasing the water pressure from 0.345 to 1.379 MPa (50 to 200 psig) results in a throw distance of more than 67 m (220 ft). One curve (x's) depicts the fail mode of a nozzle when the manufacturer's pressure rating is exceeded. At pressures above 1.034 MPa (150 psig) the throw distances decrease with increased water pressures. The throw distance in underground mines is generally limited by the roof height. Therefore, throw distance in a 1.8 m (6 ft) high coalbed would be shorter.

Waterflow from the nozzles with respect to water pressure is shown in figure 11 for both expensive and inexpensive nozzles. A Sho-Flow[3] device (portable flow meter) attached in series between the end of the waterhose and the nozzle was used to measure the water flowing through the nozzle in m^3/s (gpm). The range of this device is 0.315 to 1.577 m^3/s (50 to 250 gpm). The dashed line represents the average values of the inexpensive nozzles in the straight-stream mode. The water pressure had to be raised to 1.034 MPa (150 psig) to obtain a 0.378 m^3/s (60 gpm) flow through the nozzle. The solid line indicates the fog stream of the inexpensive nozzles and shows its increased water delivery. For the expensive nozzles, increasing water pressure results in a significantly greater increase in waterflow. For example, for the nozzle represented by the open circles, at a water pressure of 0.345 MPa (50 psig), the waterflow is 0.883 m^3/s (140 gpm) in the fog mode. The water nozzles that were evaluated indicate increased water levels in the fog stream and the superiority of the expensive nozzles in both discharge modes.

[3]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

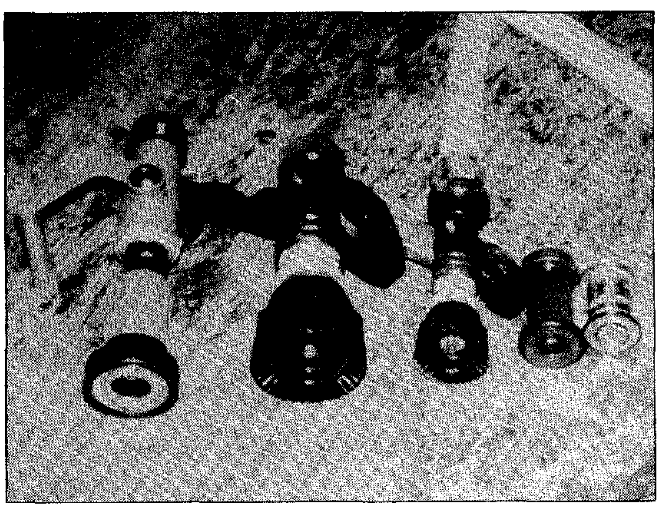
Tests were performed to determine the water pressure at which plastic hose nozzles, often used in underground mines for fire fighting, would fail. Nozzles with NST and pipe thread fittings were used. The data indicated that the plastic water nozzles started leaking at a static water pressure above 4.48 MPa (650 psig), regardless of the type of fitting. Cross-threading an NST nozzle onto a pipe thread causes the nozzle to blow off the pipe fitting at a water pressure of 0.62 MPa (90 psig). Several mines, experiencing similar problems at even lower water pressures, have replaced plastic nozzles with brass nozzles.

Figure 6



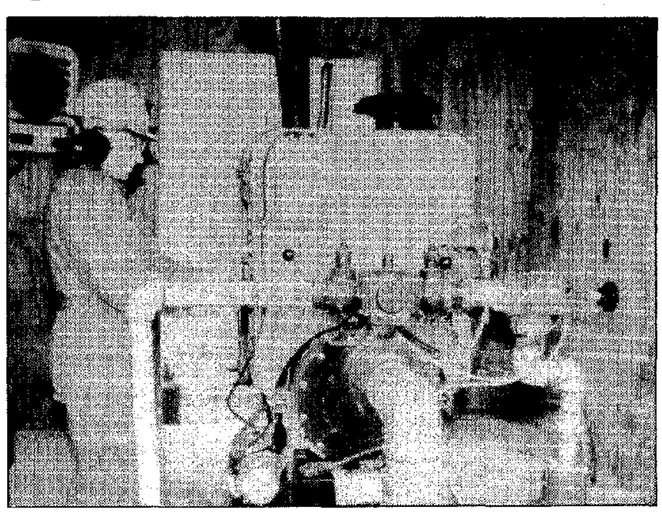
Extinguishment of liquid fuel fire with water in fog stream mode.

Figure 7



Various firehose nozzles.

Figure 8



Variable speed water pump.

Figure 9

Multiport fire hydrant.

FIRE-FIGHTING FOAM, EDUCTORS, AND GENERATORS

When an underground fire cannot be directly attacked due to heat, smoke, or hazardous roof conditions, high-expansion foam may be the only means to remotely quench the fire. Foam is a blanketing and cooling agent that is produced by a combination of water, air, and foam concentrate. The foam concentrate, combined with proper amounts of air and water and expelled through an application device, will form a finished foam appropriate for fire-fighting applications (figure 12).

Foam is a convenient means of conveying water to the fire, diluting the oxygen concentration by producing steam, and blocking both air currents to the fire and radiant energy from the fuel. Before a foam system is implemented, the mine operator should consider the training and resources needed to use foam, foam concentrate, and delivery devices and the amount of foam concentrate and equipment required. Once the equipment and supplies are purchased, a plan must be developed for using foam in the mine. Foam equipment should be compatible with the mine water system in regard to pressure and fittings. Whether using foam or any other means of extinguishment, the mine operator should have an organized strategy for fast response, and have a group of well-trained miners ready for an emergency situation. The mine should also have periodic drills to test the effectiveness of the fire-fighting plan.

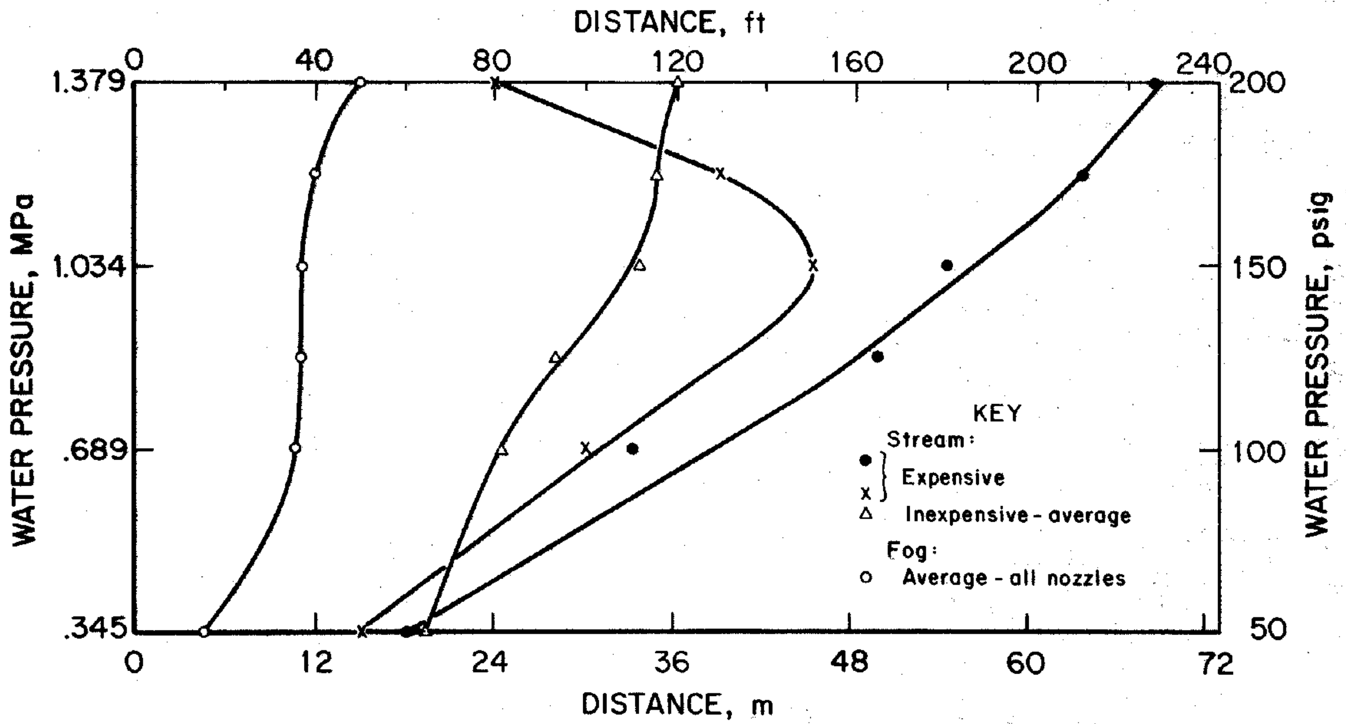
Foam concentrates are designed to cover the widest possible range of fire-fighting applications. Selection of foam concentrate and equipment should be based on foam characteristics that are appropriate for each particular mine. Some of the foam concentrates available include: aqueous film-forming foam (AFFF) for flammable liquid fires, polar compound aqueous film-forming foam for both hydrocarbon and water-soluble liquid fires, and high-expansion foam for three-dimensional fires where total flooding is the objective, such as in mines. Water retention is the most important property of any foam. The more water the foam can retain, the better its fluidity, spread, resistance to bubble collapse, and ability to withstand the effects of heat and products of combustion. High water retention also means less foam is required.

As foam moves down an entry, a continuous shrinkage process occurs. A foam bubble cannot exist touching a dry surface; it will collapse wetting the surface so that the next foam bubble can replace it. As a foam plug advances, there is a constant bubble collapse. This shrinkage is not large and takes place on the leading edge of the foam plug. It is also useful, since the foam cools and wets all dry surfaces, therefore, controlling or extinguishing the fire.

Most handheld foam generators are operated by one firefighter. By adjusting a knob, these generators can produce foam in either low (expansion ratio up to 20), medium (expansion ratio 20 to 200), and high expansion (expansion ratio 200 to 1,000). A foam maker can also be purchased with a single expansion foam function. The foam expansion ratio is the volume of foam formed to the volume of foam concentrate used to generate the foam. For example, an expansion ratio of 8:1 means 8 units of finished foam from 1 unit of foam concentrate. Low expansion foam is used to knock down a fire from a safe distance or to blanket a hazardous material if there is a threat of fire or explosion. After completing the initial attack with low expansion foam, the firefighter can move in closer to apply medium and/or high-expansion foam for a vapor-tight blanket.

Once the proper type of foam concentrate is selected, it must be mixed in the right proportion with water. Foam concentrates are available for mixing with water in various concentrations, such as 2%, 6%, etc. Proper mixing of foam concentrate and water is the single most important element to good foam making. For example, a 3% concentrate must be mixed at the rate of 3 measures of foam concentrate to 97 measures of water.

Figure 10



Relationship of throw distance for various waterhose nozzles with respect to pump pressure.

Foam proportions are designed to introduce the proper percentage of foam concentrate into the water stream. Eductors, the most common form of proportioning equipment, work on the Venturi principle. Water is introduced, under pressure, at the inlet of the eductor. The eductor reduces the orifice available for the water to pass through and so it increases the water velocity. This creates a pressure drop that, in turn, puts suction on the pickup tube. As the foam concentrate is pulled up the tube, it passes through a metering valve that introduces the correct percentage into the water stream. By-pass or in-line eductors are matched systems that require specific water pressures for operation. Therefore, the manufacturer's recommendations for hose size, hose length, and water pressure should be considered before purchasing an in-line eductor system.

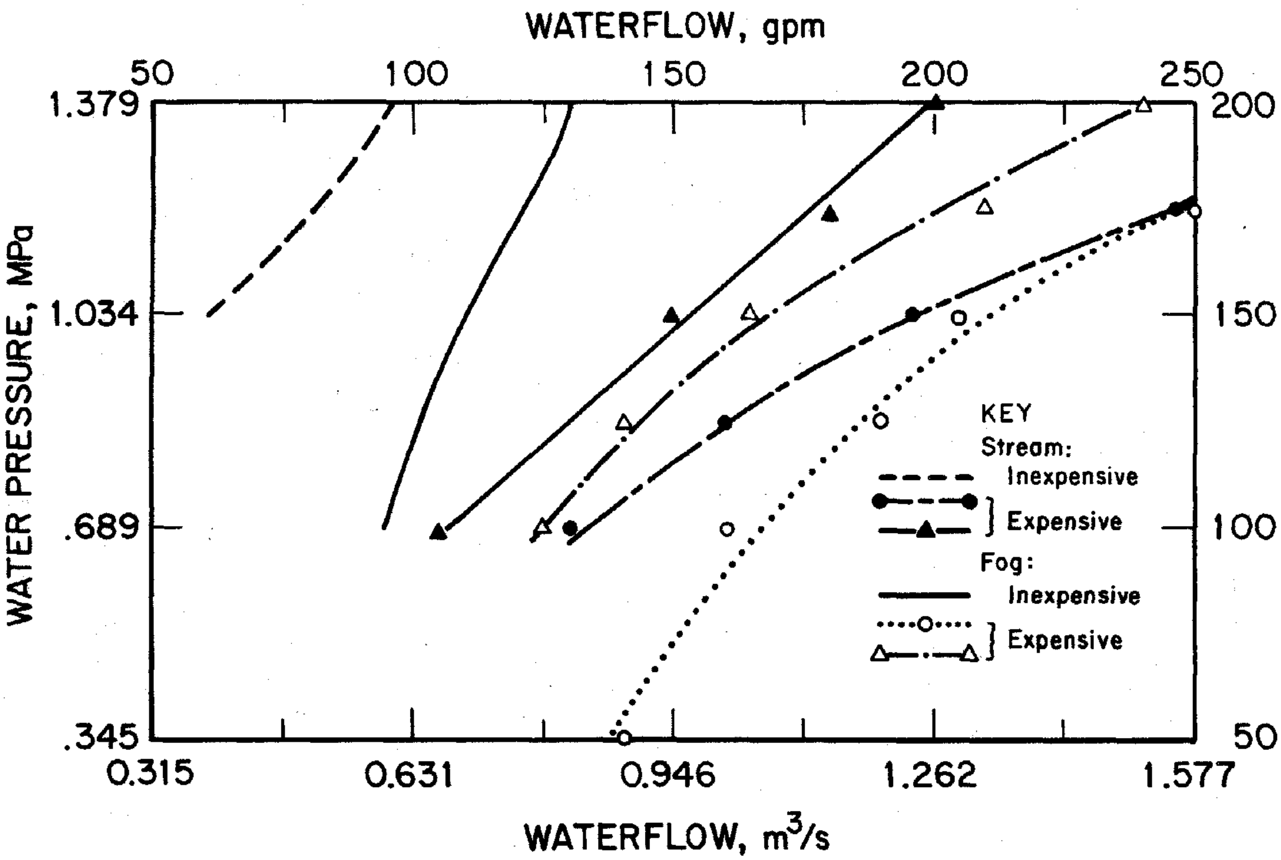
When using foam or storing foam concentrate, the manufacturer's recommendations should be followed. Storage temperatures at the minesite should be in the recommended range. Foam concentrate should not be stored outside if there is a risk of freezing. A typical temperature range for foam concentrate storage is 1.7° to 49° C (35° to 120° F). The cloud point, or when the material becomes gelatinous, is usually below the lowest temperature specified. When foam concentrate becomes cloudy, it cannot produce foam. This same temperature range should be maintained when transporting the foam concentrate. Care must be taken to ensure that plastic containers are not cracked or dented, and 19-L (5 gal) plastic pails of foam concentrate should not be stacked more than three containers high. A foam manufacturer indicated that containers could fail when moved, if they are stacked higher than recommended.

An adequate supply of foam concentrate should be readily available at the minesite in either 19-L (5 gal) pails or 113-L (30 gal) and 208-L (55 gal) drums. If drums are used, consider transportation difficulties and compatibility of the eductor, or transferring the foam concentrate into smaller containers. Arrangements should be made beforehand to obtain additional foam concentrate from nearby mines or a local distributor. Additionally, a prepayment plan can be initiated with the distributor so that no delays are encountered during an emergency.

In a fire that occurred in a Colorado coal mine (*15*), miners started fighting the fire with 15 208-L (55 gal) drum supply of foam concentrate. Additional foam was obtained during the ordeal from several other mines and a local vendor. Unfortunately, sufficient quantities of foam to quench the fire were unavailable and as soon as the foam was depleted, control of the fire was lost.

Foam was made for most of three days at the Montour 4 Mine fire (*16*). Over 15.1 kL (4,000 gal) of foam concentrate and 1 ML (270,000 gal) of water was depleted during that period. "The foam took over successfully at a critical time and reduced one of the largest mine fires on record to a safe sealing operation (*16*)."

Figure 11



Relationship of waterflow for various waterhose nozzles with respect to pump pressure.

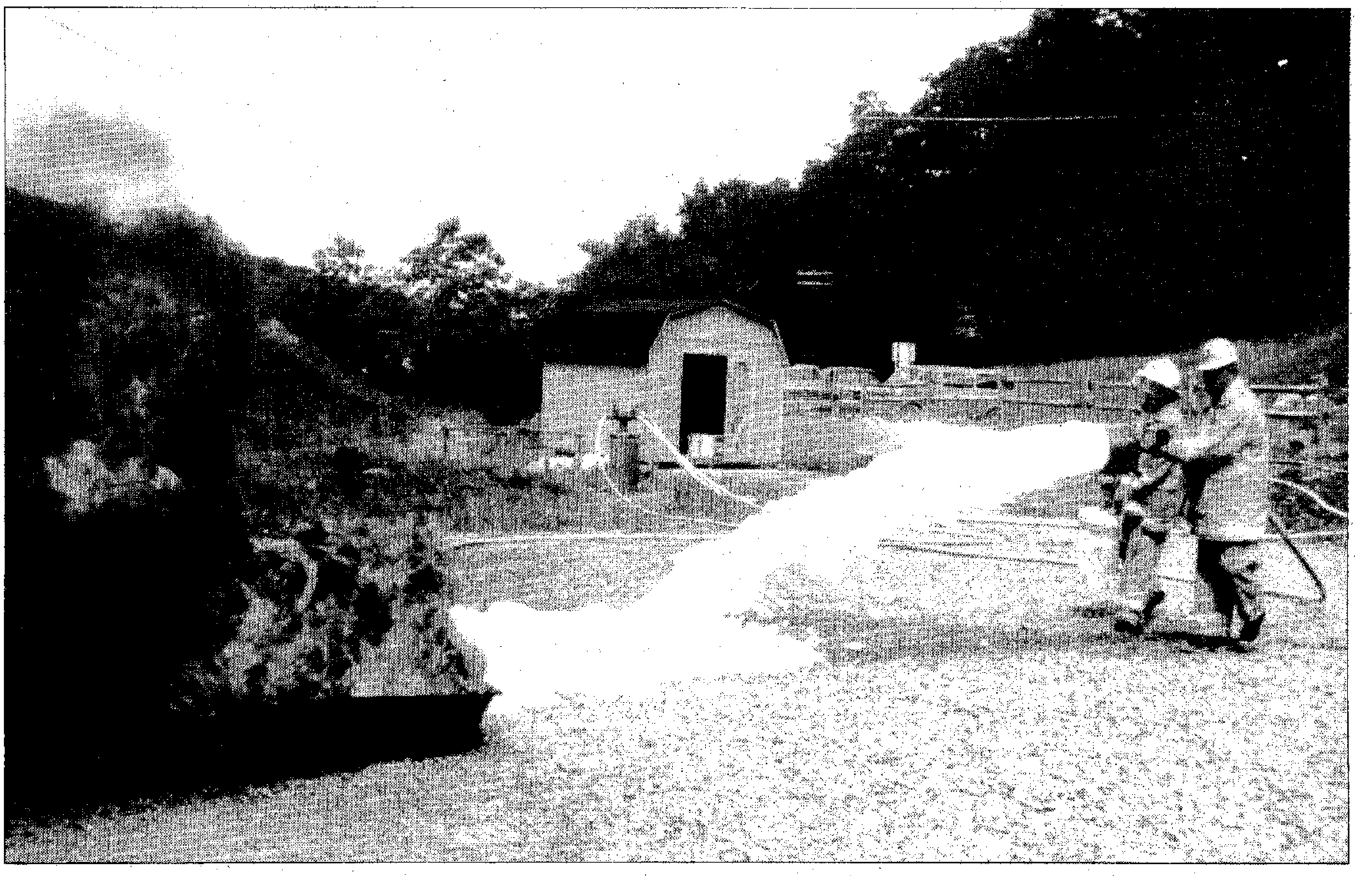
Recent tests conducted in the Lake Lynn Laboratory Experimental Mine illustrate how much foam concentrate may be required for an emergency operation. For a 2,800-L/s (6,000 cfm) diesel-powered, high-expansion foam generator (figure 13), the expansion ratio is 850:1, using a 2% foam concentrate solution, and operating parameters set at 0.315 m^3/s (50 gpm) of water and 0.551 MPa (80 psig) at the eductor. In 1 h, 11,600 L (3,000 gal) of water and 227-L (60 gal) of foam concentrate are used with this foam generator. It requires 2.2 min to fill 30.5 m (100 ft) of a 5.8-m (19 ft) wide by 2.1-m (7 ft) high entry.

Tests in the Lake Lynn Mine also showed that a high-expansion foam plug will readily travel down and completely fill an entry with the above dimensions and with a 1% rise in elevation (figure 14). With a plywood stopping to separate the foam generator from the foam plug, the foam spread 207 m (680 ft) before the stopping failed (the failure criterion was foam leakage from the foam feed tube or around the stopping, that rolled back over the foam generator). The stopping failure is highly dependent on how well the stopping is constructed. The advance rate of the foam for the first 30 m (100 ft) was 11.7 m/min (38.5 fpm), then decreased to 1.74 m/min (5.7 fpm) when the foam reached 207 m (680 ft). The amount of foam concentrate used in the test was 182 L (48 gal). Additional tests indicated that the advance rate of the foam plug over the first 30 m (100 ft) of entry during dry conditions was 12% slower than when the entry was wet (entry was prewet with a waterhose prior to the test). It also required 38% more foam concentrate to fill 30 m (100 ft) of the entry with high-expansion foam for the dry as compared to wet conditions. The foam initially shrunk 0.305 m (1 ft) from the roof over the first 24 h, and continued to shrink an additional 0.457 m (1.5 ft) over the next 96-h period. Figure 15 shows the height of the foam plug in the entry with time.

High-expansion foam cannot control a fire unless the foam plug reaches the fire (*16-17*). Attempts have been made to push foam plugs into the burning entry ahead of the fire. The tremendous heat and gases moving on the downwind side of the fire will break the foam and most of it will be heated into steam and blown down the entry away from the fire. On the other hand, if foam is pushed into the fire on the upward side of the fire, only foam will reach and cool the fire. High-expansion foam generators will not produce quality foam if the intake air is contaminated with smoke[4].

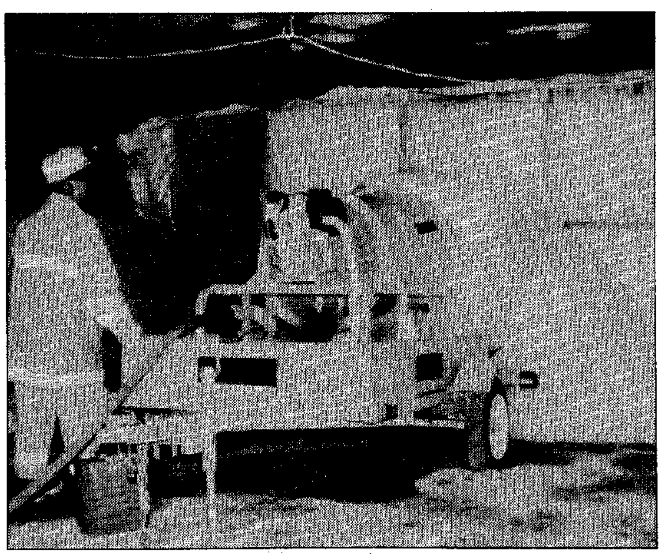
[4]Private communication with Will Jamison, Jamison Eng., Aug. 1993.

Figure 12



Extinguishment of liquid fuel fire with foam.

Figure 13

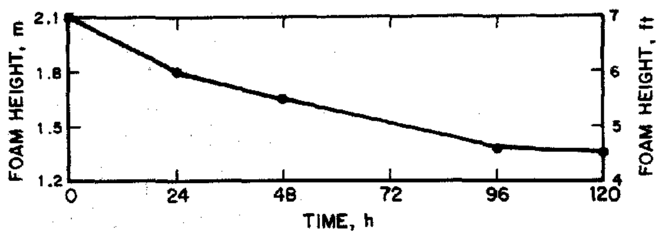


Diesel powered high-expansion foam generator in drift of Lake Lynn Mine.

Figure 14

Foam plug propagating through mine entry.

Figure 15



Shrinkage rate of foam plug.

UNDERGROUND FIRE CARS, TRAILERS, OR FIREHOUSES

Federal regulations (CFR 75.1101-23(a)(1)(ii)) require the rapid assembly and transportation of necessary miners, fire suppression equipment, and response apparatus to the scene of the fire. Many mines exceed Federal regulations in outfitting underground fire cars, trailers, or firehouses. These mobile vehicles are designated for fire-fighting equipment and placed strategically throughout the mine for rapid transport to the firesite. Several mines recommended the following list of items as being essential for fighting a fire:

- A properly stored and accessible firehose, either a 3.8- to 6.3-cm (1.5 to 2.5 in) diameter or a lightweight high volume (large diameter) nonpolarized (universal fitting) hose.
- A hose clamp to reduce delays in turning the main water supply on-off if problems are encountered.
- A spanner wrench to secure and detach waterhoses and fittings (the wrenches are small and easily lost, so several wrenches should be provided).
- Hose nozzles that are suitable for firefighters and are appropriate to use with the mine water pressure and equipment.
- Booster pumps to raise water pressure and regulators to lower pressure.
- Fire-fighting foam equipment and an adequate supply of foam concentrate.
- Portable and wheeled fire extinguishers, and a supply of dry chemical agents with replacement gas cartridges.
- A pager phone with extra wire.
- An up-to-date plastic laminated mine map with grease pencils.

The latter items are ideal for effective communications between the team leader of the firefighters and the surface command post. The map can be used to plot fire-fighting strategies and keep track of progress. A pager phone should be stationed at the fresh air base closest to the firesite. It is extremely important that the person communicating with the surface command post be knowledgeable of the fire situation, and accurately communicate the fire status. During one underground mine fire, the surface command post did not realize the magnitude of the fire for several hours because of miscommunication.

In addition to various tools and supplies, roof jacks may be necessary for temporary roof support or pump jacks to lift heavy objects. First aid kits to treat minor burns and injuries should be nearby. Turnout gear (personal protective clothing) should be available for firefighters. It is also important to identify and maintain the locations of hydrants and fire-fighting equipment.

UNDERGROUND FIRE BRIGADES

At times, a fire is discovered by a miner who has limited training in extinguishing relatively small fires. The fire continues to grow before trained personnel arrive on the scene. Underground fire brigades or firefighters are important in combatting mine fires. It is important that brigade members be highly trained, physically fit, equipped with advanced personal protection, and be aware of the potential dangers.

Some underground fire brigades consist of eight members per shift and are usually dispersed throughout the underground sections. When the brigade members assemble at the fire location, personal protection equipment should be readily accessible. At this time, the mine may already have been evacuated leaving only highly trained individuals in the fire area. Proper turnout gear allows firefighters to fight fires in entries where high temperatures and smoky conditions are common. Various materials have been developed for firefighters' turnout gear. For example, Kevlar is an outer layer of material that protect firefighters from the intense heat produced by fire and flashovers and allows them to get closer to the flames. Gortex is a moisture barrier that is often part of the inner layer of a firefighters' uniform. Turnout gear varies from long and short jackets, including pants, to one-piece suits. In low coalbeds, longer jackets can be a hindrance to mobility because they are more cumbersome and their length can cause the firefighter to trip. Short jackets may expose the upper body to heat when the brigade member is bent over during the fire attack in low coal. Coveralls or one-piece turnout suits (somewhat bulky) are more suitable for these conditions. It is also important to outfit the members with gloves and metatarsal firefighter boots for extra protection and walking over hot residue.

Several devices are available that can alert firefighters to high temperatures, a condition that they might not otherwise be aware of due to the protection provided by the turnout gear. Another function of these units is to alert other firefighters if someone becomes motionless due to an injury. These units will produce an audible sound within 25-35 s after detecting no motion. The temperature sensor is preset to alarm at temperatures between 93.3° and 287.8° C (200° and 550° F). The response time decreases with increased temperature.

Conventional fire helmets are bulky and ergonomically unsuitable for underground fire fighting. They protect the firefighter from steam condensing on the helmet, but can cause serious neck injuries when used in low coalbeds. A helmet designed for an underground firefighter should be lightweight, incorporate a built-in quartz lamp assembly with a plug-in and removable belt battery pack, built-in motion and thermal sensors, and a moveable face shield that would not obstruct the lamp assembly. A more elaborate state-of-the-art helmet could include a faceshield that permits the firefighter to see through smoke. The faceshield could also display the ambient temperature and concentrations of particular gases, for example: CO, CH_4, and O_2.

Infrared heat sensors or thermometers can aid firefighters in locating hot spots or fires. These units can detect a hot spot that eyes may miss, and in dense smoke can indicate the specific fire area.

A variety of options are available when selecting self-contained breathing apparatuses (SCBA's) for underground firefighters. Many mine operators prefer SCBA's with a minimum rating of 60 min. A pressure demand regulator is designed to maintain positive pressure in the facepiece during both inhalation and exhalation. A facepiece with a replaceable lens, adjustable headband, speaking diaphragm, and optional spectacle mounting kit may also be considered. A breathing tube connects the facepiece to a regulator for ease of cylinder replacement. A low pressure warning alarm is important. For example, a 60-min cylinder will produce an audible sound when the rated service life is at 15 min. Cylinder construction may be of steel or composite (aluminum liner fully wrapped with high strength glass filaments). The material and contour of the cylinder harness, padding, and pull straps should be well constructed and easily adjustable to accommodate various sizes of cylinders. Rapid and easy cylinder recharging should be considered when choosing units.

Several mines have initiated in-house training programs that allow miners an opportunity to escape or travel through smoke with a breathing device. Self-contained self-rescuers (SCSR's) that are about nearing the end of their shelf life are ideal for this purpose, otherwise SCBA's should be used. The training program is conducted in a mine entry, section, or bathhouse. Brattice is used to partition off areas. A nontoxic smoke generator is used to create smoke levels that are representative of the various stages of a fire. Figure 16 shows miners donning SCSR's at relatively low levels of smoke, before entering other sections of dense smoke and obstacles. This exercise provides the miners with ample hands-on experience in traveling through smoke, donning SCSR's or SCBA's, and enhances their problem-solving skills.

Discussion with miners who have fought underground mine fires led to the following question. What might be appropriate food for firefighters who could be at the firesite for several days or more? Many miners feel that hot entrees and carbonated beverages are inappropriate items. Hot foods are usually cold before they reach the firefighter and carbonated beverages cause bloating. A sports drink was preferred and may help replenish carbohydrates and electrolytes which speed fluids into the body's system to provide energy to working muscles. Water, too, is an excellent source of fluid replenishment. This is necessary because perspiring during intense fire-fighting activities robs the body of vital fluids and minerals. Granola bars and candy bars provide instant energy, and cold meats and fruit were recommended.

Figure 16

Donning self-contained self-rescuers in smoke.

AN EXAMINATION OF MINE FIRE PREPAREDNESS AT FOUR MINES

Four western coal mines were surveyed to determine their mine fire preparedness, including fire-fighting resources, suppression techniques, and fire detection methods. The study included an escorted tour of both the surface facilities and the underground mine with either the safety director or supervisory mining engineer, who also answered a series of prepared questions. The following briefly describes the mines.

Mine A is a slope mine that varies in pitch from 10° to 17°. It extracts the Wyoming No. 80 coalbed, a high-volatile C bituminous coal. The mine has an extremely weak roof and a history of spontaneous heating problems, including two reported fires. Because of these conditions, Mine A uses a two-entry longwall system. Rubber conveyor belting is used extensively throughout the 6.5 km (4 mile) haulage system and coal production is over 1.09 Mt (1.2 millon st) per year. The main mode of transportation is by diesel tractor.

Mine B is a longwall operation mining the Colorado F coalbed. It is a slope mine utilizing diesel powered jeeps as the major mode of transportation. The mine had a reportable fire caused by spontaneous combustion. Since that incident, the mine has used a bleederless ventilation system with squeeze stoppings. It has installed an extensive in-mine gas monitoring system to detect fires. The belt haulage system is madeup of over 4 km (2.5 mile) of rubber conveyor belting. The mine has a yearly coal production of 2.09 Mt (2.3 millon st).

Mine C is a longwall operation that mines the Colorado D coalbed. It is a slope mine that employs diesel jeeps for transportation. It has had no reportable fires due to spontaneous combustion. The mine has a subsidence problem and liberates significant amounts of methane as the upper strata caves into the longwall gob. It has some problems with ethane and high concentrations of CO. The belt haulage system, including all working sections and mains, consists of 5.6 km (3.5 mile) of rubber belting. The mine produces over 1.36 Mt (1.5 millon st) of coal a year.

Mine D mines also works the same Colorado D coalbed. A sister mine in the same coalbed was closed due to a fire of unknown origin. Continuous mining equipment is used in a room and pillar type of operation yielding an annual coal production of 680,000 t (750,000 st). Rubber conveyor belting is used extensively throughout the 3.2 km (2 mile) haulage system. It also has an extensive mine monitoring and fire detection system, including an automatic sprinkler system along the beltline and in the portal area.

State-of-the-art monitoring systems for surface and underground operations were common at the minesites. A description of the underground atmospheric monitoring systems is given in table 3. All four mines use CO sensors for fire detection, but only mine D incorporates smoke sensors. Point type heat sensors are also used in mines B and C. All the mines calibrated their systems monthly by personnel in either the electrical or safety department. The alarm levels for each sensor varied at each site and depended on past experience and the current working environment. All fire alarm signals were transmitted to the surface. The alarms at mines A and B were also transmitted to the working sections. The alarm at mine B is interfaced with a computer voice that alerts personnel in the control room and those in the mine within hearing distance of an emergency situation.

The data in table 3 indicate that only one heating went undetected over a 12-month period. This incident occurred at mine A and was due to an overheated take-up roller. The hot roller was found by the section supervisor.

Table 3.—Description of underground atmospheric monitoring systems

	Mine A		Mine B		Mine C		Mine D	
Sensor type (number):								
CO	Yes	(25)	Yes	(15)	Yes	(37)	Yes	(27)
CH_4	Yes	(5)	No		Yes	(4)	Yes	(2)
O_2	No		No		No		Yes	(2)
Smoke	No		No		No		Yes	(2)
Point-type temp	No		Yes	(NA)	Yes	(NA)	No	
Alarm:								
Audible	Yes		Yes		No		Yes	
Visual	Yes		Yes		Yes		Yes	
System age, years	1		3		5		4	
Fires or heatings:								
Detected	>10		2		>10		2	
Not detected	1		None		None		None	
Nuisance alarms	>10		>10		>10		>10	

NA Not available.

Note.—>10, over 10 incidents during a 12-month period.

The major reason for the nuisance alarms is diesel exhaust. Equipment failure, wiring damage, and electrical transient spikes also were responsible for many false alarms. Cave-ins and subsidence in the gob temporarily increased CO levels and also resulted in nuisance alarms. Excessive liberation of methane can occur if the longwall advances too rapidly for the ventilation system to keep pace. When this happens, the methane detector will go into an alarm stage. Calibration procedures and the start-up of equipment after idle periods are other activities that can stimulate false alarms. At the time of the survey, all the mines utilized handheld CO monitors and their procedures require the use of handheld units for verification of an alarm before evacuation. The mines also felt that it would be advantageous if each miner were equipped with their own miniature fire alarm, providing that the device was reliable, not bulky, and resistant to malfunctions.

Three of the mines had an elaborate, printed copy of a fire-fighting and evacuation plan. The plans included mine emergency notification, where in the event of a mine emergency, key personnel (company officials, government, etc.) were to be notified. All mine personnel (operators, mechanics, supervisors, etc.) had a specific list of instructions to follow. The plan also included the procedures the miners were to follow if fire occurred on the equipment they were operating or in the section where they were working.

One company's extensive program included instructions on fire-fighting equipment, location of escapeways, exits and routes of travel, fire drills, and self-rescuer training. Miners received classroom instruction on all fire-fighting equipment used at the minesite, the location of this equipment, the various methods of fire fighting, and the hazards involved in fighting fires. Wherever practical, hands-on training or demonstrations were offered to the miners.

The mine management felt that the miners could realistically be evacuated within 45 min or less if the evacuation decision was made. It was the consensus of the four operators that fire fighting could be started within 30 min after fire detection. Three of the mines had a trained group of firefighters on each working shift.

Of the four mines surveyed, two had a phone system that could handle an emergency load (multiple incoming-outgoing phone calls); the other two felt that the phone company could upgrade their systems within 2 h of notification. Each operator felt that they had an adequate underground communication system that could reach all their miners. However, total mine coverage could be ensured through installation of a ultra low frequency electromagnetic fire-warning system (*18*).

Each minesite had a central location on the surface that was fully equipped with records, forms, maps, etc. Two mines had an area for mine rescue teams that was furnished with various supplies, including rotation rosters and sleeping quarters.

An important element of mine fire preparedness is the availability of fire-fighting supplies at the minesite. Table 4 lists some of the more important components required for fire fighting and their numbers at the surveyed mines.

Table 4.—Underground fire-fighting resources

	Mine A	Mine B	Mine C	Mine D
Fire extinguishers	175	500	70	55
Fire hose:				
Length .... km	3.1	4.5	2.4	2.7
Length .... miles	1.9	2.8	1.5	1.7
Diameter .... cm	3.8	5.7	3.8	3.8
Diameter .... in	1.5	2.25	1.5	1.5
Fire nozzles	20	150	25	40
Fire hydrants:				
Number	70	60	34	45
Spacing .... m	91.4	91.4	91.4	91.4
Spacing .... ft	300	300	300	300
Water supply:				
Amount .... ML	17	UL	>3.8	3.4
Amount .... 10^6 gal	4.5	UL	>1	0.9
Regulated	No	Yes	Yes	No
Foam generator:				
Number	3	1	1	3
Concentrate .... KL	1.1	37.8	18.9	11.3
Concentrate .... 10^3 gal	0.3	10	5	3
SCBA's	17	16	19	NA

NA Not available.
UL Virtually unlimited.

Fire extinguishers are stored in underground mines at various locations such as battery charging stations and mobile equipment vehicles. A wide range in the number of fire extinguishers was found in these four mines. Mine B had 500 fire extinguishers available for an emergency, while 175 were ready at mine A. The number of fire extinguishers at mines C and D were 70 and 55 units, respectively.

Fire hose nozzles, one of the significant components of fire-fighting equipment, can vary in price from $10 to well over $800. These four mines placed little emphasis on nozzles, considering them a low priority item. One of the mines had inexpensive plastic nozzles which blew apart when exposed to the high static water pressure during a test. They were replaced with inexpensive brass nozzles. No emphasis was placed on spray patterns and some of the nozzles were straight stream only. Mine B averaged two fire nozzles per fire hydrant, whereas mines C and D had less than one nozzle per hydrant. Mine A averaged one nozzle for every three hydrants.

With the exception of mine B, which had a 5.7-cm (2.25 in) diameter firehose, the other mines were using 3.8 cm (1.5 in) diameter firehoses. Mine B also had more waterhose available than their total length of conveyor belt. Water supplies for underground fire fighting were either large aboveground storage tanks, ponds, or rivers. Mine B was fortunate to have an unlimited water supply. However, if mine D operated three waterhoses at a waterflow per hose of 0.946 m^3/s (150 gpm), its water supply would be depleted within 34 h. The water supply at this mine may not be sufficient to fight large fires.

Mines B and C had one foam generator on hand; mines A and D had three foam generators. Mine A had 1,100 L (300 gal) of foam concentrate on site. In comparison to the amount of foam concentrate used at the Colorado coal mine fire previously discussed, the amount of concentrate stored at this mine is 64% less. Mine B had 37.8 kL (10,000 gal) of foam concentrate.

Personal protective clothing for the underground firefighter was not a high priority item for the majority of the mines. Clothing varied from flame resistant coveralls to more sophisticated turnout gear. SCBA's were available at mines A, B, and C.

Federal regulations require that fire suppression systems and devices (deluge-type water sprays, foam generators, water sprinklers, or dry-chemical systems) be installed at specific locations throughout the mine, for example on belt-drives, and on certain underground equipment. Table 5 lists the various suppression systems currently used at these mining sites on belt-conveyor drives, and the types of fire suppression devices on attended electrically powered equipment using nonfire-resistant hydraulic fluid. One mine coated roof, ribs, and floor of the belt-drive areas with incombustible material and initiated a maintenance program to hose down these dust prone areas at least once a day. Sump pumps were used in remote or poor drainage areas. Mine A used fire-resistant hydraulic fluid and did not fall into this category. High-expansion foam systems were not being utilized to protect electrically powered equipment at any of the minesites.

Table 5.—Fire suppression system and devices

	Mine A	Mine B	Mine C	Mine D
Systems:[1]				
Dry chemical ...			X	
Foam				X
Water deluge ...	X	X		
Water sprinkler ..			X	
Devices:[2]				
Dry chemical ...	NA	X	X	X
Water spray	NA		X	X

NA Not applicable. Mine A fire resistance hydraulic fluid.
[1]For belt conveyor drives.
[2]For attended electrically powered equipment using non fire-resistant hydraulic fluid.

All the water suppression systems used at the mines were installed by mining personnel; the average age of these systems ranged from 2 to 8 years. One mine had an automatic sprinkler system along the entire beltline and portal area. None of the systems had ever been activated by a fire; however, there was an accidental discharge at one mine during maintenance. The only maintenance problem observed is corrosion in the pipes due to hard water.

In general, all the mines had weekly safety meetings with mandatory miner attendance. Fire safety was stressed at all the minesites. The mining personnel felt that the most important elements of fire safety are early detection of the fire and rapid response of the miners to evacuate the mine. They would like to see smoke-free escapeways, better fire doors and improved communications. More training and preventative measures were also an issue and it was the consensus that the equipment should be more reliable. Even though fire safety is stressed at the mines, it was felt that the mine operators lack the expertise to properly train the miners and would welcome a facility devoted to training on underground mine fires (since completion of the survey, such a facility was opened at the MSHA National Mine Health and Safety Academy). They felt that miners, in particular, need to be more aware of what causes fires, how to fight fires, and how to survive a mine fire.

The miners had some suggestions for improving the fire-fighting procedure. One suggestion involved availability of equipment during the fire emergency. Mine operators with experience in fighting underground fires suggest that an attempt be made to move mine equipment outby the fire during the evacuation. Thus the equipment can be used to move supplies and aid fire-fighting efforts. In some cases, fire-fighting activities were hampered due to a lack of equipment because all mobile machinery was left inby the fire. Another suggestion dealt with events when other mine rescue teams or fire brigades are summoned for additional help. In those instances, escorts from the host mine should assist and lead the cooperating teams underground.

Additional comments by the mine personnel focused on problem areas and recommendations for improvement. Some problem areas included equipment reliability and lack of expertise and facilities to properly train miners to recognize, fight, and survive mine fires. Another problem area is the importance of effective communications and valid decision making by key officials (mine, government, etc.) during a mine disaster. By retaining key officials on the premises during a mine emergency, these decisions may be made more expeditiously.

Improved training can be an effective means of bringing about a reduction in the number of fire incidents. An example of such a program is given in appendix C. Quality training enhances the awareness of mine fire hazards and increases confidence in combatting underground mine fires.

SUMMARY

Preparedness is an important element of any underground mine's strategic plan in dealing with an unexpected fire. It is important that the fire be detected in the incipient stage, and that well trained and fully equipped miners respond during that crucial period. Time is a critical factor and any delay may mean serious injuries, the loss of a mine, and elimination of jobs.

Several expensive and inexpensive firehose nozzles, tested at various water pressures, indicated little difference in a throw distance while in the fog stream mode. However, dramatic variations in a throw distance were seen in the straight-stream mode of some brands of nozzles and when the manufacturer's pressure rating was exceeded. The data also showed that more water is available for fire fighting when the nozzles are in the fog stream mode. Tests have also shown that plastic hose nozzles, often used in underground mines for fire fighting, started leaking at static water pressures above 4.48 MPa (650 psig), regardless of the type of fitting. However, cross-threading an NST nozzle onto a pipe thread causes the nozzle to blow off the pipe fitting at a water pressure of 0.62 MPa (90 psig).

The foam generator experiments indicated that for the type of foam generator and plywood stopping used, the foam plug traveled down an entry, with a 1% rise in elevation, 207 m (680 ft) before the foam rolled back over the generator. The amount of foam concentrate used in the test was 182 L (48 gal). The advance rate of the foam plug decreased when the entry was dry and as the foam spreads further away. More foam concentrate was required to fill the dry entry because the foam bubbles are collapsing, thereby wetting the surface for the next foam bubble.

As a supplement to meeting Federal regulations in regards to responding to a mine fire, many mines have equipped mobile vehicles or fire houses with additional fire-fighting supplies. These vehicles are strategically placed in a mine for the rapid transport to the firesite, of the necessary tools required by firefighters.

A minesite must be equipped and well-maintained with updated fire-fighting equipment. The mine operator must evaluate the need for a supply of dry chemical agents with replacement gas cartridges for portable and wheeled fire extinguishers. Storage locations, quantity, types and compatibility of firehoses, water nozzles, and foam generators with the water system of the mine must also be assessed by the mine operator.

Underground fire brigades are a specialized group of firefighters trained to combat mine fires. It is important that these brigade members be physically fit, be equipped with state-of-the-art personal protective equipment, be aware of the potential dangers, and be properly trained.

The mine fire preparedness of the four western coal mines indicated advanced monitoring systems for surface and underground operations were used and these systems were calibrated monthly. A wide range of fire-fighting supplies and equipment were also utilized. Although all these mines were prepared to fight fires, some were better prepared than others. Fire safety was stressed at all the mines. The mining personnel felt that the most important elements of fire safety are early detection of the fire and rapid response of the miners to evacuate the mine.

The review of underground coal mine fires and the mine survey both indicated a necessity for programs and facilities designed to enhance the mining industry's awareness of the hazards of underground mine fires, to improve upon the miner's chance for escape and survival, and to illustrate the latest methods to detect, suppress, and fight such mine fires. A fully implemented mine emergency and preparedness plan is critical in dealing with and reducing the probability of a mine fire.

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APPENDIX A.—CUTTING-WELDING PERMITS

Call Communications Coordinator for permit number.

PERMIT NUMBER__________

DATE_______SHIFT: A B C

UNIT/LOCATION__________

PERMIT GRANTED TO________

TIME STARTED___a.m.___p.m.

TIME ENDED___a.m.___p.m.

1. Call communication coordinator

2. Methane check-every 20 min

3. Rock dust before starting

4. 10 lb fire extinguisher or 240 lb rock dust

5. Blankets to cover area-surface only

6. Protective equipment:

   a. Long sleeves or welding leathers
   b. Welding gloves
   c. Safety glasses
   d. Welding hood-check for holes, cracks in lens
   e. Cutting goggles-check for broken lenses
   f. Leg bands or cuffs tied

ADDITIONAL SAFETY CHECKS

1. Examine work area for:

   a. Stumbling hazards
   b. Unsafe roof conditions
   c. Adequate ventilation-coursed to return
   d. Cleanliness-grease, oil, coal dust removed

2. Ground clamp secured

3. Inspect equipment before using-torch, welder, etc.

4. Warn others before striking an arc

5. When welding overhead-protect ears with non-flammable material

6. DO NOT GOB HOT MATERIAL

CLOSE-OUT INSPECTION-1 H

1. Inspection date: ______________________________

2. Inspected by: ______________________________

3. Conditions found: ______________________________
____
____
____

4. Call Communications Coordinator to inform of follow up inspection

5. Turn in tag to shift manager or preparation plant supervisor (surface)

APPENDIX B.—BELTLINE CHECKLIST INSPECTION

Date:__________ Shift__________

Belt #__________

Okay	Defective	Date Repaired	
			Stoppings
			Doors
			Guards
			Cross Overs-Unders
			Dust
			Roof-Rib Conditions
			Belt Idlers
			Drive-Takeups
			Splices-Wipes Accumulations
			Trash-Coal Accumulations
			Wire-Electrical
			Fire Sensors
			Fire Line
			Risers-Valves
			Fire Hose-Nozzles
			Water Sprays
			Fire Suppression
			Extinguisher
			Ventilation
			Phones
			Welds-Tie Downs
			Walk Ways
			Belt Bank or Takeup Pressure
			Belt Training

Comments:

Examiners:__________

Corrected By:__________

Routing List:
- Belt Crew
- Down Shift Supervisor
- File

APPENDIX C.—AN EXAMPLE OF A MINE FIRE TRAINING PROGRAM

Mine fire training can be divided into the following three areas:

- Basic training for all miners.
- Intermediate training for mine fire brigades.
- Advanced training for fire brigades.

The basic fire training for all miners may consist of the following and could be conducted aboveground:

- Basic fire chemistry (classes of fires, fire triangle, smoke, heat).
- Assessment of containability of fightable fires.
- Types of portable fire extinguishers, hose lines, and water nozzles.
- Extinguishing a liquid fuel and solid fuel fire with portable fire extinguishers.
- Extinguishing a solid fuel fire with water lines.
- Paper and pencil simulations on fighting a small mine fire.
- Mine evacuation procedures.
- Understanding the operation of fire sensors (thermal, smoke, CO).

Intermediate training for mine fire brigades would include basic fire training, plus the following:

- Use of handheld and large foam generators.
- Turnout gear and equipment used for fire fighting.
- Fighting fires in smoke, wearing SCBA's.
- Paper and pencil simulations on fighting fires outby the section.
- Fire fighting strategies: underground fire houses, fire cars or trailers.

Advanced fire-fighting training would include all the acquired skills obtained in the basic and intermediate levels, plus the following:

- Combatting simulated mine fires in ventilated entries with portable and wheeled fire extinguishers, water lines and foam generators. The fires would include equipment fires, conveyor belt fires, etc.
- Erecting seals to isolate fire areas.
- Examining the effect of ventilation on fires and regulating air during a fire.

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