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INFORMATION CIRCULAR/2005

Fire Response Preparedness for Underground Mines

Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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By Ronald S. Conti, Linda L. Chasko, William J. Wiehagen,
and Charles P. Lazzara, Ph.D.

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
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December 2005

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DHHS (NIOSH) Publication No. 2006–105

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic feet per minute	kHz	kilohertz
fpm	feet per minute	lb	pound
ft	feet	min	minute
ft^2	square feet	mm	millimeter
g	grams	mW	milliwatt
hr	hour	nm	nanometer
Hz	hertz	sec	second
in	inch		

DEDICATION

This report was initially prepared by Ronald S. Conti and is dedicated to his memory. Ron passed away unexpectedly on October 28, 2003. His efforts to enhance the training, safety, and effectiveness of mine emergency responders have been recognized worldwide.

FIRE RESPONSE PREPAREDNESS FOR UNDERGROUND MINES

By Ronald S. Conti,[1] Linda L. Chasko,[2] William J. Wiehagen,[3]
and Charles P. Lazzara, Ph.D.[4]

ABSTRACT

Fire has long been a concern for underground mine workers. A mine fire can occur at any time and can result in a partial or total evacuation of mine personnel and the loss of lives. Fires can grow rapidly. Time is the critical element. Prompt detection, timely and accurate warnings to those potentially affected, and a proficient response by underground miners can have a tremendous impact on the social and economic consequence of a small underground fire. Fire preparedness and response have components of technology and people. These components can work synergistically to reduce the time it takes to bring the system back in balance. This report deals with the preparedness of miners to respond to underground mine fires. It is intended to aid the mining industry in understanding the various roles of emergency responders and the training techniques used to increase their skill levels. The report also presents a technology overview to assist in effective response to mine fires.

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[2]Physical science technician.
[3]Industrial engineer.
[4]Supervisory physical scientist.
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INTRODUCTION

There has been significant progress over the years in reducing the number of lives lost due to mine fires. Today, there is a better scientific understanding of fire risk within the mining community and ways to minimize risk when fire does occur. This is mostly attributed to improved fire-resistant materials, better detection systems, fire suppression systems, and a more skilled workforce. Research conducted over a long period has led to better standards of acceptable performance. At the same time, due to the nature and characteristics of mining, fire is a constant. Small fires have occurred and always will occur in underground mines.

There is no accurate record of small mine fires. However, some fires are required to be reported. Statistics maintained by the Mine Safety and Health Administration (MSHA) indicate that 137 underground coal, metal, and nonmetal mine fires were reported in the United States during 1991–2000.[5] The fires resulted in 2 fatalities and 34 injuries (these statistics include the Willow Creek Mine explosion and fire, which accounted for 2 fatalities and 8 injuries). 30 CFR[6] 50.20 requires mine operators to report to MSHA any unplanned mine fire that is not extinguished within 30 min of discovery or any fire, regardless of its duration, that causes an injury or fatality. There are different levels of reporting across companies; the only constant is those fires that are required to be reported to MSHA. For example, some mines track small fires by the number of fire extinguishers used; others track them through production downtime reports. Some mines require internal incident reports for all unplanned fires. For planned fires, many mines require "hot work permits" when flame cutting and welding underground.

Table 1 shows the various categories of the 137 underground mine fires that were reported to MSHA during 1991–2000: 76 underground coal mine fires and 61 underground metal/nonmetal mine fires. As the table shows, friction is the most common cause of underground coal mine fires, while mobile equipment malfunction is the leading cause of fires in underground metal/nonmetal mines.

Fire is a common concern for underground workers. A fire occurred during production on November 25, 1998, at Cyprus Plateau Mining Corp.'s Willow Creek underground coal mine near Price, UT. All underground miners evacuated with no serious injuries. The mine was sealed and inert gas injected into the fire area. The mine returned to normal operations about a year later. Nine months later on July 31, 2000, two miners died and eight were injured because of a series of four explosions and a fire [McKinney et al. 2001]. Another fire occurred on February 8, 2001, at the Homestake Gold Mine, Lead, SD. Thirty-seven miners evacuated. Rescue teams mustered

Table 1.—Categories of underground mine fires, 1991–2000

Category	Percent: Coal	Percent: Metal/nonmetal
Cutting and welding	14	16
Electrical	14	10
Friction	24	5
Mobile equipment[1]	15	46
Spontaneous combustion	12	2
Other	21	21
Total	100	100

[1]For a more in-depth summary of mobile equipment fires, see De Rosa [2004a].

Source: MSHA accident reports, 1991–2000.

and discovered the fire in an old timber stope (inactive area) between the 3,500- and 3,652-ft levels. Water was used to flood the affected area. More recent reportable underground coal mine fires occurred at Mine 84 in Pennsylvania (January 6, 2003), VP 8 Mine in Virginia (April 9, 2003), Pinnacle Mine in West Virginia (September 1, 2003), Dotiki Mine in Kentucky (February 11, 2004), and Excel No. 3 Mine in Kentucky (December 25, 2004).

These examples suggest that the remote nature of underground mining requires on-site workers to be well trained and prepared, especially in the early stages of emergency response.[7] *The early stage is critical.* Decisions and actions greatly influence the outcome. When fire does occur, escape is often complicated [Cole et al. 1998; Vaught et al. 1997] and may not always be a viable option. Thus, the concept of fire preparedness for the individual mine site is an ongoing process.

Fire preparedness is a subset of emergency preparedness and has logical components of both prevention and response. Methods to measure aspects of fire prevention and response are complex and difficult to quantify. In an emergency, it is commonplace for those involved to get the system back to normal—in minimal time. Figure1 illustrates this concept. From the model, being prepared minimizes the negative consequences (social and economic costs) of getting the system back in balance. It takes less time when workers are skilled in their response and have access to adequate technology. Being prepared can reduce, but not eliminate, the probability of negative consequences.

With little preparation for emergency response, higher risks for severe and long-term consequences are probable. Negative consequences are not always limited to the specific organization and employees affected. In a serious emergency when lives are at risk, consequences (e.g., new regulations) can affect the entire industry. Likewise, when prepared, the unexpected event offers a good opportunity

[5]Mine fire statistics were obtained from information maintained at MSHA's Office of Injury and Employment Information, Denver, CO.

[6]*Code of Federal Regulations.* See CFR in references.

[7]The large majority of U.S. worksites rely on community services (e.g., volunteer or paid professional emergency responders) if fire occurs. In contrast, underground miners need higher levels of fire prevention and response skills similar to those of Navy personnel out at sea.

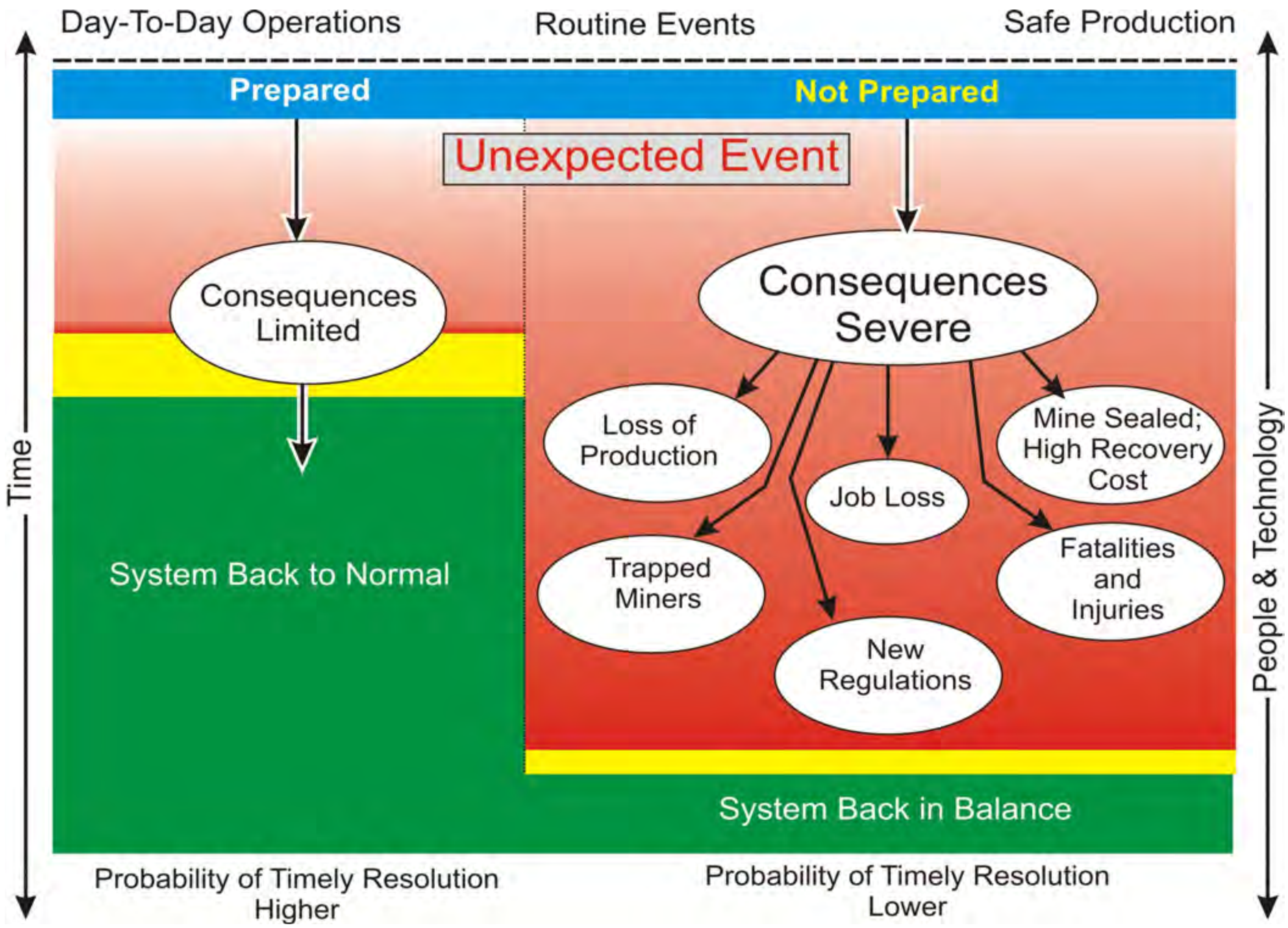

Figure 1.—Emergency preparedness model.

for organizational learning not only within the site, but also across sites—if the information is accurately and objectively shared. For example, when a small fire is extinguished, it can help individuals and the organization learn about their emergency response capability. In effect, it is a test of the emergency response system. Small fires are likely at any worksite,[8] and in one context, what is learned from those small fires can help prevent larger, more serious fires. It depends on the analysis and how one perceives and acts on the opportunities. There are some tools available to help assess and enhance levels of fire preparedness, such as an underground coal mine fire preparedness and response checklist [Conti et al. 2000].

Figure 2 shows a fire preparedness model and is one example of emergency response. Fire preparedness is defined within the context of prevention and response. Normal, everyday aspects of safe production tacitly assume some aspect of fire prevention. Fire prevention is integrated with production tasks. Examples include housekeeping, examining electrical cables, fire bossing, and washing down equipment. The work system is in balance. For any organization, the large majority of time is spent in normal, day-to-day work activities. Time is always important in a balanced, productive work system. In an emergency, the importance of time dramatically increases and the perception of time changes. When a fire is detected, time becomes critical. The work system is out of balance, and production is interrupted. Decisions are often made very quickly to evacuate or fight the fire.

Once a fire is detected and confirmed, there are three logical and progressive stages of fire response: first, second, and sustained response (Figure 2). At each stage, time is the main measure of effective response. The less time it takes to detect a small fire, the less time it takes to warn coworkers and evacuate, the less time it takes to muster, fight, and extinguish the fire (by first or second responders)[9]—the greater the odds are of quickly getting the

[8]Although it is very likely that any small, accessible fire will be extinguished at mine sites, that "success" does not mean that the response system is adequate. With a practical and objective incident analysis, the system might be improved with small investments designed to better prevent or respond to future similar events.

[9]Responders in this context are considered the entire workforce and are categorized as follows. First responders are the first to encounter a fire and either (1) evacuate or (2) investigate, then initiate firefighting. Second re-sponders, or fire brigades, have advanced firefighting skills and specialized personal protective equipment. They assume firefighting activities when the fire becomes too dangerous to be fought by first responders. Sustained re-sponders, or mine rescue teams, are trained to rescue trapped and injured personnel, fight fires, or recover a mine [Conti et al. 1998, 1999]. Evacuating miners are categorized in this model as first responders.

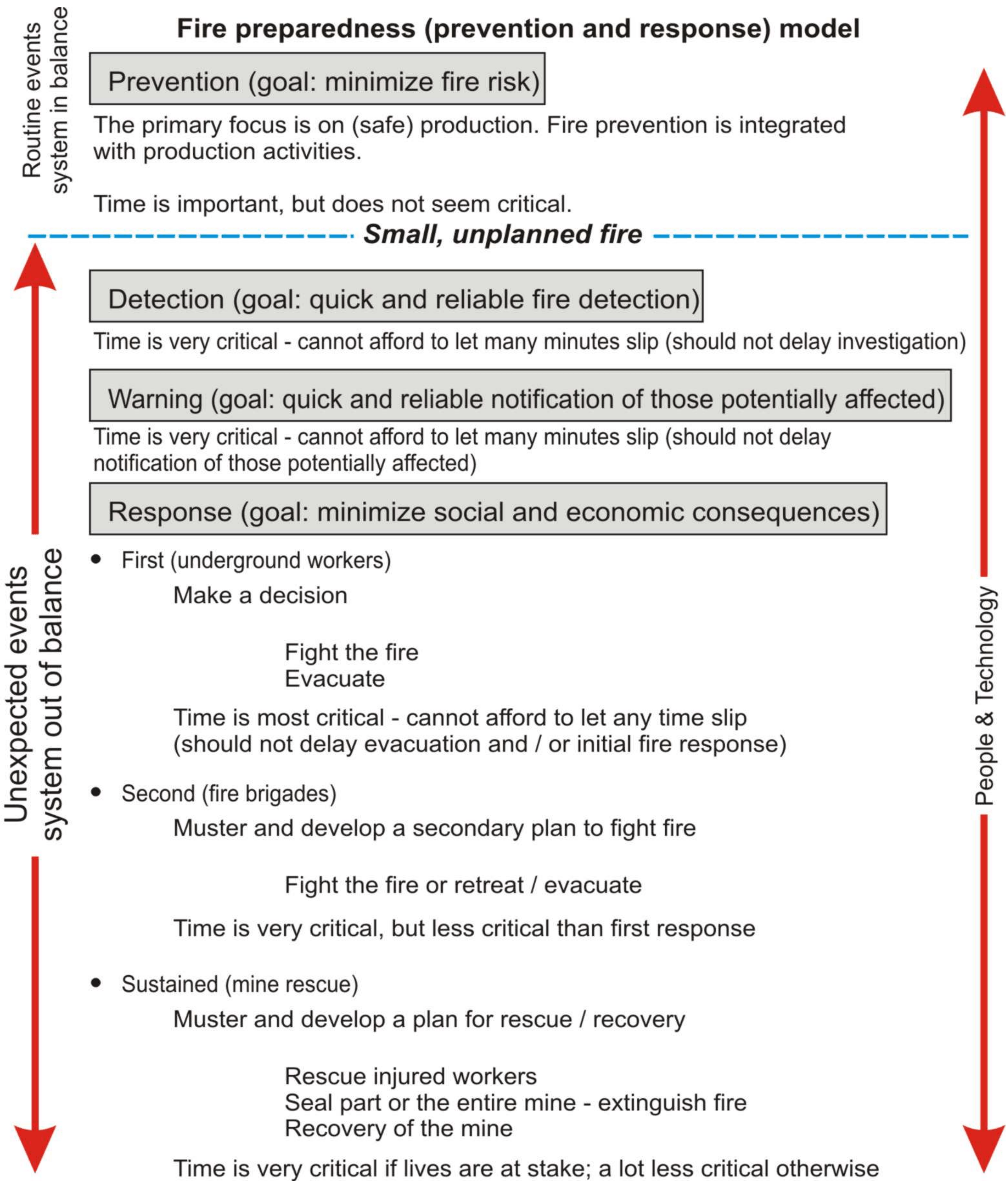

Figure 2.—Fire preparedness model.

system back in balance. It requires effective firefighting technology and skilled responders.

Response time is directly related to the time it takes to detect, issue warnings, and muster an effective response. If those first on the scene are not skilled in fire response and do not have adequate firefighting equipment, it delays effective response. If a second response is needed, it further delays the time to bring the system back in balance. With a mine rescue and recovery response, the time it takes to bring the system back in balance is extensive—it can vary from a few weeks, to months and years, or not at all. Figures 1 and 2 indicate that in a fire emergency, time is the critical measure. It remains critical until the system is back in balance, implying that no one is at risk and the fire is either extinguished or safely contained behind seals.

The success of safely extinguishing an incipient mine fire depends on several factors, such as an awareness of the fire hazard, early and accurate detection, availability of effective firefighting equipment, quick response time, and skilled re-sponders. If a mine fire cannot be contained by direct fire-fight-ing methods within a short time after discovery, the chances of successfully extinguishing the fire, without sealing, and getting the work system back in balance are greatly diminished.

Previous fire research and actual underground fires have shown that mine fires can spread rapidly. For example, large-scale fire gallery experiments [Lazzara and Perzak 1990] have shown that conveyor belt fires can propagate at rates of more than 20 fpm. This can surprise underground workers, as many may believe that fire-resistant belting will not burn. Mine fires often grow out of control because of poor planning, inoperative or slow-responding detection systems [Conti and Litton 1992, 1993; Morrow and Litton 1992; Edwards and Morrow 1994], inadequate water supplies, inappropriate firefighting equipment, broken waterlines, failed suppression systems, improper personal protective equipment, and time wasted in response due to poor communication and inappropriate decisions and actions.

Mitchell [1990] states: "The best facilities and equipment can never compensate for poor preparation." Skilled responders can often compensate for the lack of state-of-the-art response technology. At the same time, tested technology in the hands of skilled workers can save significant amounts of time in a fire emergency.

In response to fire, a decision is often quickly made to fight the fire or evacuate. Figure 3 illustrates these critical decisions and plausible actions. A large part of mine fire preparedness is management and worker capability, experience, motivation, and training.

One of the goals of NIOSH is to enhance the safety of mine workers by preventing disasters caused by fires and explosions. This report deals with the preparedness of responders to underground mine fires. It is intended to aid the mining industry in understanding the various roles of emergency responders and the training techniques used to increase their skill levels. Fire preparedness and response have components of technology and people. These components can work synergistically to reduce the time it takes to bring the system back in balance.

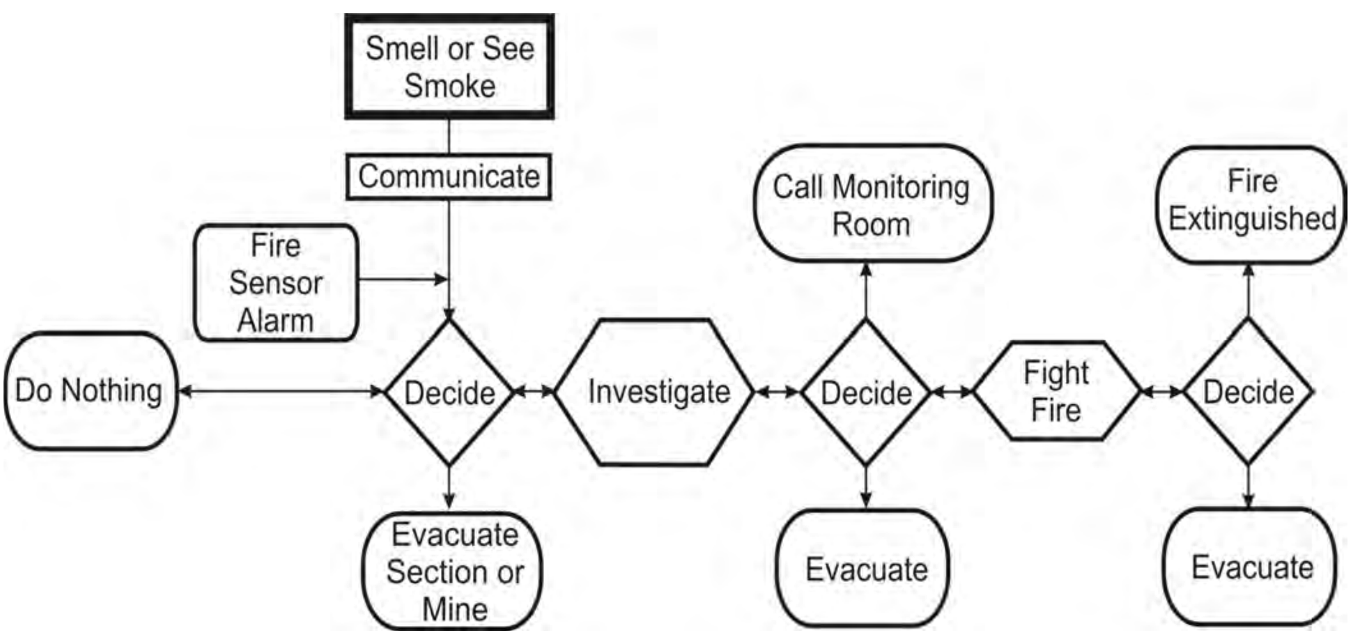

Figure 3.—First response on discovery of underground mine fire.

FIRE RESPONSE PREPAREDNESS

EMERGENCY PLAN

The first few minutes after discovery of a fire are crucial. The key is to minimize the time it takes to respond. Because most mine fire emergencies are unique, an emergency plan for every situation is not possible. However, there are certain elements common to all emergency plans, and preparing a written plan can help reduce the turmoil associated with the emergency. One of the most important elements of an emergency plan is a communication protocol that includes notification of key officials—and especially responders—immediately after discovery of an emergency. A competent person on-site is key. Competence implies skills—both training and experience. Communication, protocol, and leadership skills can be taught, and assessing those skills occurs either through simulated practice or real events. Mine emergency plans that are well thought out contain many other provisions, including the surface organization, facilities, and outside sources of assistance for support purposes. At times, having access to outside experts is key, as advice from these experts can be weighed to help save time and limit the consequences. Good sources of planning for mine emergency response can be found in Title 30 CFR and at several Web sites.[10] In addition, the National Mine Rescue Association (NMRA) offers information on the mine emergency command structure [NMRA 1994a].

The mine emergency plan should be periodically reviewed and understood. Everyone should be kept informed of any changes as modifications to the plan are made. Fire drills are an important part of the plan and are required at 90-day intervals or more frequently. The main purpose of the drill is to test certain aspects of the emergency plan. Organizations need to be reasonably sure that there is a balance between the technology to prevent, detect, and respond to fire and the skills within the workforce to use the technology. Fire drills, in a sense, are opportunities to help workers develop or maintain skills to put the response (emergency) plan into action. As shown by Figure 3, upon discovery of a mine fire, decisions are often complicated as the situation unfolds.

FIRE DETECTION

During the incipient stages of a fire, smoke and gaseous products, including carbon monoxide (CO), are produced and released into the mine atmosphere. If these products are not detected in the early stages of combustion, they can result in severe hazards to personnel in remote and confined areas. Many underground mine fires are discovered in their early stages by mine personnel who see or smell smoke, then make a quick decision to either investigate and fight the fire or escape. Pomroy and Carigiet [1995] and De Rosa [2004a,b] reviewed MSHA investigative reports for underground coal mine fires that occurred during 1978–1992 and 1990–1999, respectively. They found that over 75% of these fires were first detected by miners who saw smoke, smelled smoke, or saw the fire start. These findings are supported by more extensive field research detailing miners' experiences in responding to small fires [Vaught et al. 1996; Wiehagen et al. 1997b]. The study detailed the experiences of workers at 7 underground coal mines to gain a better understanding of fire preparedness from 214 underground workers. Of note, only one of these mines had an MSHA reportable mine fire, yet many of the miners interviewed (about 70%) indicated that, over the course of their mining career, they had some direct experience in helping to extinguish a fire. The large majority of those incipient fire incidents were first detected by miners who saw or smelled smoke.

The presence of smoke underground is not unusual, as "hot work" (flame cutting and welding operations) is common and necessary to maintain mining and haulage machinery. Seeing or smelling smoke is not necessarily evidence of an emergency. In interviewing the 214 underground miners, most reported seeing or smelling smoke about once per week to once per month. In many cases, miners are well aware of the source of the smoke. However, being caught off guard by the sight or smell of smoke presents a different picture. Across the seven mines, about 40% of the workers reported being caught off guard within the past month, another 30% in the past 3 months, and about 20% of the interviewees reported being caught off guard within the past 6 months. The source of the smoke is important. If the source is on the working section, finding and correcting the problem can be timely, effective, and relatively straightforward. However, about one-third of the 214 miners indicated that they recalled being caught off guard by smoke coming from somewhere off their section. If miners consider the presence of smoke to be commonplace at some mines, this could lead to complacency and delayed response. They may assume that some-one else is investigating, or it is part of planned flame-cutting and welding maintenance activities.

The success of safely controlling and extinguishing an incipient mine fire depends on several factors. The key is quick detection and response. The successful detection of a developing fire in a mine entry using CO or smoke sensors requires that three events take place, each with some associated time frame [Conti and Litton 1992; Litton et al. 1991]. The first event that must occur is that the developing fire must be large enough to generate bulk average CO or smoke levels greater than, or equal to, the alarm threshold levels of the sensors. Bulk average levels are those levels that result upon complete mixing of the fire-produced CO or smoke with the ventilation airflow. The time it takes for sufficient CO or smoke to be produced depends on the type of fire. For a liquid fuel fire, this time is short because the total surface

[10]For example, see 30 CFR 75.1502, 57.4363, 57.4760(a)(3), 57.11053 and the MSHA Web site www.msha.gov/ets02-31358/etsevacuationtemplate.htm (reproduced in Appendix A of this report).

area of the liquid fuel is involved very rapidly from the moment of ignition. For a more slowly developing coal fire, this time increases. If smoldering occurs at a sufficient temperature, detection of the smoldering stage of a coal fire is possible. If smoldering does not occur long enough and flames erupt before detection, then the coal fire must attain a sufficient intensity to generate the required CO or smoke alarm thresholds.

The second event that must occur is the transport of the CO or smoke from the fire to the sensor location. The time it takes to do this is the sensor spacing divided by the air velocity. At low air velocities, this time can be long and have a significant effect upon the time to alarm. Increasing the airflow decreases the travel time, but also dilutes the CO and smoke levels.

Thirdly, the sensor must rapidly respond to the CO or smoke levels. Although most sensors respond rapidly, the use of a sensor with a longer response time can increase the time to alarm. The delay (from the incipient fire stage to the time it takes for the ventilation system to move the products of combustion downwind to locations where workers are present) could cause the fire to grow in intensity to the point where escape is the only option. When this happens, escape can be very complicated [Vaught et al. 2000]. Timely detection and communication is key. If the fire is off the section, the communication of essential information about the emergency requires personnel to investigate the source. If an alarm sounds on the surface (e.g., sensors indicate a rise in CO levels or the presence of smoke) to indicate a potential problem, it is either a false alarm or a fire. If workers see or smell smoke coming into their working section, there is less uncertainty. In any case, determining the source of the problem is key and time is critical.

For underground mines that use diesel engine-powered equipment, an array of fire sensors may be necessary for the early and reliable detection of incipient mine fires. Particulate and CO emissions from diesel engines can produce false fire alarms that miners can learn to ignore. NIOSH research showed that multiple-type sensors (including CO, smoke, and metal oxide semiconductor sensors) and a neural network analysis program successfully predicted smoldering coal and conveyor belt fires in the presence of diesel emissions several minutes before the onset of flaming combustion. The system did not alarm when subjected only to diesel emissions [Edwards et al. 2002; Friel and Edwards 2002; Edwards et al. 2004].

WARNING SYSTEMS

Underground mines rely on various systems, such as stench gas, audible or visual alarms, pager phones, telephones, and messengers to warn miners of a fire or other emergency that can affect the entire mine. These systems are often slow, unreliable, and limited in their mine coverage. It is imperative during an underground emergency that all persons, no matter their location, be able to get quick notification of the emergency. An Australian mining research initiative resulted in the commercial availability of a "paging" system for underground mines [Zamel 1990]. The Personal Emergency Device (PED) communication system is a "through-the-earth" transmission system that enables one-way communication of specific messages with individuals underground, no matter what their location and without depending on underground cables or wiring. The low-frequency electromagnetic field can penetrate kilometers of soil and rock to reach the most remote shaft or tunnel, which makes it ideal for underground signaling and paging. This system consists of a personal computer, low-frequency transmitter, portable receiving units, and surface and/or underground loop antennas that can be strategically placed to create an electromagnetic signal that can completely envelop most mines without using repeater systems. Messages can be directed to an individual, to a group, or to all underground/surface personnel. Escape routes and the fire location could be communicated, fire brigades and mine rescue teams alerted, and key personnel contacted. When the message is received, the caplamp flashes and the miner can then read the message from a liquid crystal display on top of the lamp battery. The first demonstration of the system in the United States was conducted at NIOSH's Lake Lynn Laboratory in November 1990. Figure 4 shows a typical configuration of the wireless system for a multi-level mine. The transmitter loop antenna is on the surface, and a receiver/transmitter loop antenna is underground. The system can also turn devices such as strobe lights on or off. Additional information on wireless signaling systems and medium-frequency radio communication systems for mine rescue was reported by Conti and Yewen [1997] and Dobroski and Stolarczyk [1982].

A successful evacuation of miners during the Willow Creek mine fire that occurred on November 25, 1998, was attributed to the PED system. The paging system was activated when miners saw flames and telephoned the dispatcher to evacuate the mine. The PED system allowed a mine evacuation plan to be safely carried out before the mine passageways filled with smoke. All 45 underground miners escaped in approximately 45 min. There are approximately 17 PED systems installed in U.S. coal mines and 2 in metal/nonmetal mines.

Transtek, Inc., has developed a wireless, two-way cellular communications system for underground mines [Product and Process News 2001]. The ComCell technology allows mine-wide wireless communication and can be used to reduce communication costs and improve underground productivity in addition to its use for emergencies. The system consists of a master and several remote-control modules connected by a minimal wired network, each module having an antenna associated with it. Miners using wireless two-way radios can communicate from anywhere in the mine with other persons in the mine without being in the direct line of sight of the antennas. In addition to providing voice communication, the system also provides mine-wide data communication between computer terminals, or between remote sensors and a terminal, by using wireless data transceivers. Options include multichannels and integration with existing telephone systems. Also being tested is a unique through-the-earth wireless system that allows two-

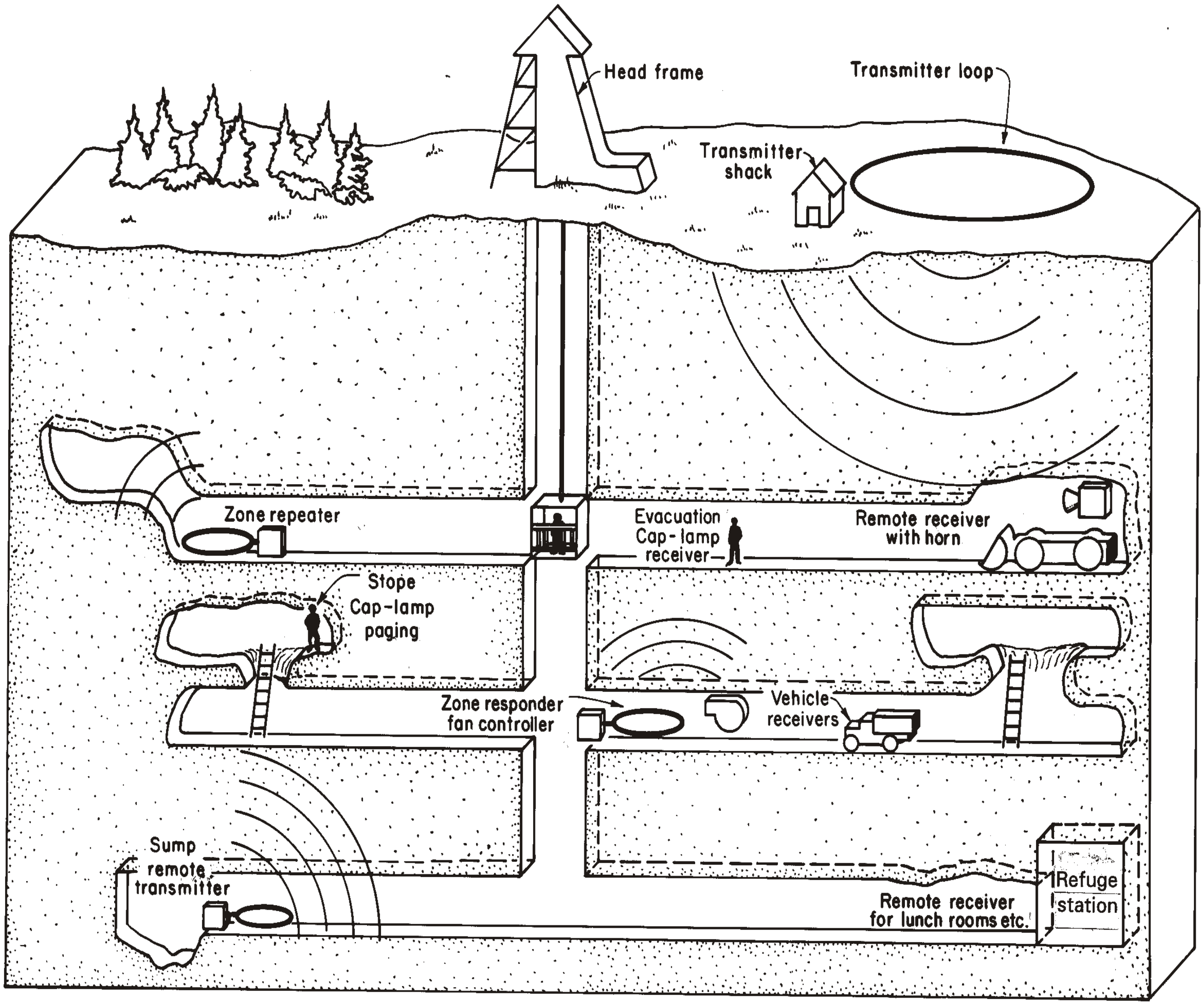

Figure 4.—Conceptual representation of a wireless mine communication and warning system.

way mobile voice and data communications between the underground passageways and aboveground sites. Currently, the systems are installed in an underground mushroom mine and an underground limestone storage facility, both in Pennsylvania.

During mine rescue training simulations at Lake Lynn Laboratory, the ComCell technology was evaluated by team members. Four ComCells were temporarily positioned at stra-tegic underground locations, and the signal was received at over 98% of the underground workings and the surface conference room. One radio was used by the team and another by the briefing officer at the underground fresh air base. The briefing officer in one area of the mine was also able to communicate to the briefing officer in another part of the mine with the two-way radios. This preliminary testing indicated excellent voice clarity of the radio signal. A major advantage of this new system was that all team members were able to hear what the briefing officer was communicating. Transtek has now commercialized a self-contained system, Ron Conti ResQCom, which provides voice communications and a 1,000-ft-long lifeline for mine rescue teams.

FIRE RESPONSE

Upon discovery and confirmation of a fire, decisions are limited—evacuate or investigate/fight the fire.

Evacuation

Fire affects a significant proportion of underground miners at some time during their mining career. A study of the under-ground preparedness of miners at seven coal mines [Vaught et al. 1996] revealed that of the 180 miners who were asked if they had ever been notified to evacuate a mine because of fire, 38% responded in the affirmative. On average, 21% of the same miners at some time in their mining career said that they had donned a self-contained self-rescuer (SCSR) or filter self-rescuer in an emergency.

Considering the potential for fire underground, it is important that miners know their escape routes and mine evacuation plans. Fire drills are important exercises; however, from the same study, fire drills in at least some operations mainly consisted of talking about, or being told, what to do if a fire were to occur at the mine as opposed to a more practical hands-on approach, such as examining fire detection and suppression equipment or a simulated response to a fire involving a battery-charging station, conveyor belt drive, or power center.

Escapeway Aids

Early warning and rapid response of miners to evacuate the underground passageways before they fill with smoke are key elements to survival during an underground mine fire. Underground miners are required by 30 CFR 75.383 to walk escapeways and participate in fire drills every 90 days. However, these drills are conducted in a smoke-free environ-ment that does not fully prepare the miners for the conditions that they may encounter in real escape situations. Miners must know the escape routes from their section and understand the ventilation system and how smoke will travel through the passageways.

Underground mines typically mark their escapeways with reflectors or arrows. Usually two colors are used. For example, red might be used to indicate the primary escapeway and green to represent the secondary escapeway. After a period of time, the dust entrained in the airways can collect on the reflectors and decrease their effectiveness, so they may never be seen if the passageways are filled with smoke. A few underground mines use a continuous lifeline for escape purposes. This lifeline or rope would most likely be secured to the rib of the mine starting at the working section and leading to the exiting portal. Some mines are securing the lifeline near the roof in the center of the entry at an average height of 6.5 ft from the floor and lower in low-seam operations. Depending on the configuration of the mine, the lifeline could be many miles in length.

One manufacturer developed a directional lifeline. It consists of standard spools containing either 300 or 1,000 ft of 0.25-in polypropylene rope with directional (cone-shaped) orange indicators with green reflective tape installed at regular intervals. The cone's tapered end should always point inby (toward the interior of the mine) so that escaping miners would never have to take their hand off of the line. Because of the complexity of mine entries that contain crosscuts, doors, overcasts, air regulators, etc., we suggest that two-directional indicators be mounted together on the lifeline approximately 6 to 10 ft from a door, regulator, etc. This would alert personnel escaping in low visibility and smoke-filled entries that an obstacle of some sort is ahead.

A study to evaluate the feasibility of using prototype pinwheels to identify primary and secondary escapeways was recently conducted at an operating coal mine for a 10-week period. The four-bladed, 5.2-in-diam pinwheels were constructed from durable and highly reflective Scotchlite or holographic prism materials. The four colors evaluated in the mine were green (Scotchlite), silver, yellow, and red (holographic prism). The side of the pinwheel facing the airflow was painted black. Of the 27 pinwheels deployed in the mine, 1 was completely destroyed, 3 were broken and not spinning, and 1 broke loose from its mount and was laying on the floor. These five pinwheels were in entries with airflows exceeding 260,000 cfm and were made from holographic prism material. The green Scotchlite pinwheel performed well in the higher airflows and was the miners' preferred color. Overall, the pinwheels located in the higher airflows tended to have more dust buildup than at the lower airflows. The spinning pinwheels averaged about 1.7 g of dust accumulation at the high airflows and about 0.07 g of dust buildup at the lower airflow of 10,000 cfm. The dust buildup on the 3.25-in-diam escapeway reflectors used at the mine ranged from 14 to 27 g over the same time period.

Another escapeway aid is the commercial laser pointer. During smoke training exercises, the laser pointer was effectively used to negotiate travel through a smoke-filled passageway. The lasers are compact, lightweight, affordable, and have high-quality beams. They use laser diode technology, and several of these handheld battery-powered pointers have ranges of up to about 2,400 ft. Beam diameters are less than 1 mm, and the output power ranges from 1 to 3 mW. The green laser pointer, with a wavelength of 532 nm, appears brightest to the eye and can operate continuously for 2–3 hr.

During several underground exercises, approximately 25 participants traveled about 1,000 ft in a nontoxic smoke-filled entry using a lifeline to lead them to fresh air. Visibility ranged from 1–3 ft, and there were no tripping hazards in the entry. Two to three participants entered the smoky entry at 40- to 60-sec intervals until all participants were headed toward the fresh air base. Another participant followed this group with only the laser pointer to direct him to the other end and with his caplamp turned off. The beam of the laser pointer was continuously moved up and down and left to right. When the beam hit the rib, roof, floor, or other participants, a spot was seen. Although the laser beam range decreases as the smoke becomes thicker, the beam always gives the user some depth perception in the smoky environment. The participant with the laser reached the fresh air base at the same time as the first participant who entered the smoke using the lifeline. The concept of laser pointers for escape aids was success-fully demonstrated in experiments at the Lake Lynn Laboratory Mine and at operating coal and metal and nonmetal mines.

Another escape aid examined was a high-intensity strobe light (xenon-white flash tube) strategically located in the entries to map out an escape route for evacuating miners during an emergency. These weather-resistant strobe lights, with interchangeable colored reflective lenses, are compact and lightweight. The triangular (3.5 inches each side by 1.6 inches high), battery-powered strobe lights can be remotely activated by a wireless through-the-earth signaling system. Using titanium batteries, the strobe light can flash for over 7 hr. Ideally, underground sensors could be used to monitor the gases and smoke in the passageways during a fire. By interfacing the output of these sensors with a computer, the best escape route could be determined and the appropriate strobe lights remotely turned on. In a larger mine, the uncertainties inherent in a complex ventilation system would considerably complicate this process.

During in-mine rescue team simulations conducted at Lake Lynn Laboratory, strobe lights were positioned in the center of the entry about 6 ft from the floor and in the entry crosscuts predetermined to be the best escape routes. The strobe lights were activated by a wireless, through-the-earth signaling system. Rescue team members were told that a roof fall had occurred and severed the main communication/lifeline. Team members detached themselves from the main communication/lifeline and successfully followed the strobe lights out of the smoke-filled entries to the fresh air base. Team members believed that the strobe lights are easier to follow with their caplamps off. A total of 580 miners evaluated five strobe light colors (red, green, blue, amber, and clear) during the simulations. The most visible color in the nontoxic white smoke was green; the least visible was amber.

Similar simulations were conducted for underground mine personnel in coal mines. Miners spaced at 30-sec intervals entered smoke-filled (nontoxic white smoke) passageways and followed strobe lights to the fresh air base. Not only did this exercise allow miners to travel through smoke in their own mine (many for the very first time), but it also gave them an opportunity to evaluate the strobe lights as an escape aid. Miners believed that placement of strobe lights at decision points was quite helpful.

In another underground smoke training exercise, several strobe lights were interfaced with high-intensity, slow-pulsing buzzers (frequency 300 Hz and 2.8 kHz). The beeping sound enhanced the strobe lights for traveling in smoke-filled escapeways. Only 1 of the 140 miners who participated in that training simulation could not hear the two distinct frequencies. Overall, miners believed that the colored reflectors currently mounted in their entries would not have helped them because of the poor visibility from the smoke. The concept of strobe lights to identify escapeways and marking mine obstacles was successful in all experiments.

Evacuation Kits

When smoke is encountered underground, visibility is reduced, anxiety levels increase, and decision-making skills can become clouded. It is extremely important that the crew members stay together and have the necessary tools to aid them in a successful evacuation. Some mines have evacuation or escape kits on each working section. The kit contains rope, chemical lightsticks [Wilson 1999], drinking water, chalk, SCSRs, a first-aid kit, brattice curtain, mine map, handheld multiple gas detector, and radio or pager phone. The rope is used for crew members to attach themselves and to keep everyone together, especially when traveling in smoky passageways. Various colored chemical lightsticks are available to mark passageways, so if the crew members become disoriented they would know that they had previously passed a certain area. Lightsticks can also be used as a light source to negotiate travel through smoke, or a high-intensity lightstick can be used when administering first aid. Miners are encouraged to keep a chemical lightstick on their person. It serves a twofold purpose: (1) if their caplamp malfunctions, they would have an instant source of light, and (2) if they encounter smoke, a lightstick could be used to assist travel through the passageways. Water is necessary to maintain hydration. Chalk can be used to mark the ribs, stoppings, etc. (names, direction, date, and time). Crew members would carry extra SCSRs. A handheld gas detector can alert the crew of hazardous gases. A pager phone or radio may be used to communicate valuable information to the surface or rescue team, such as crew location or underground conditions. Some kits also contain materials to barricade, which should only be used as a last resort when all escape routes are blocked. An updated map is essential for travel out of the section and the mine to safety.

Fighting the Fire

When decisions are made to fight the fire, there are three logical and progressive stages of fire response: first, second, and sustained response.

First Response

First responders are the first persons to initiate firefighting. If a miner who has limited training in extinguishing fires discovers a small fire and evacuates, the fire may continue to grow before trained personnel arrive on the scene. It is important that miners be properly trained in the use of fire extinguishers, water hoses, and firefighting procedures. They should also know how to immediately and effectively communicate information about the emergency to other miners and outside personnel so that others have a complete understanding of the situation. The best way to convey this communication protocol is through training, fire drills, and safety meetings. It is paramount that the first person communicating the content of an emergency warning message convey essential information. This includes all aspects of the communication triangle (who, where, and what) [Mallett et al. 1999].

When miners smell or see smoke underground, they normally investigate the source. If a fire is found, the miners often attempt to extinguish it using rock dust, portable fire extinguishers, or water. After discussing this with miners who have firefighting experience and good training, the protocol most often described is: (1) if the miner is alone, he/she would attempt to extinguish the fire and then call the surface to report the incident; (2) if two or more miners are together, one would find a phone to report the fire and the other(s) would attempt to extinguish the fire. Many of the miners who have no hands-on training or firefighting experience are not sure what size fire they would be able to extinguish and, most likely, would find a phone to report the fire and evacuate, relying on qualified firefighters to respond. Significant delays in firefighting efforts would result in the scenario where miners would rely on qualified firefighters to extinguish the fire. Time is a critical factor in any fire situation, and a few seconds saved can mean the difference between a fire's extinction [11] or a disaster.

Second Response

Fire brigades are the second responders. Fire brigades, although not common in underground mines, are composed of specially trained and equipped miners who work at the mine site and can rapidly respond to a fire. Usually, a fire brigade consists of eight members, with two teams per mine and several members on each shift. Fire brigades have specialized personal protective equipment, like turnout gear, self-contained breathing apparatus (SCBAs), etc. Their firefighting equipment usually includes effective water hose nozzles with pistol grips, which allow team members to fight fires for extended periods of time with less fatigue and to more accurately control water patterns and flows. Fire brigades should also be experienced in using high-expansion foam generators if available at the mine. "Experienced" means that they actually test the foam generator in their mine during training drills and propagate foam in the passageways. This also entails erecting a suitable stopping or partition to be interfaced with the foam generator and/or other stoppings to contain the foam plug. They should ensure the compatibility of the foam and mine water supply and that the proper fittings and adequate amounts of foam concentrate for a 24-hr period are available. Brigade members usually handle fire extinguisher and water hose inspections and ensure that water sources (fire hydrants, fire taps, etc.) are operational, free of obstructions, and adequately identified. The members are usually ideal choices for conducting on-site fire training of the general workforce and for conducting fire prevention audits. The NMRA has defined general guidelines for fire brigades, including the training of fire brigade members [NMRA 1994b].

Sustained Response

Mine operators rely on mine rescue teams for a sustained response to save lives during an underground emergency such as a fire, explosion, roof fall, or water inundation. This special breed of miners often place their lives in peril to save others. Because of the nature of these events, team members should be well trained, physically fit, and fully understand the hazards that may await them during rescue and recovery operations. These hazards often include fighting underground fires.

Historically, underground mine rescue teams have mainly received training in simulated mine environments, usually on the surface, with placards to identify objects and hazards, or in the course of actual emergencies. Although surface training exercises enhance their skill levels, it is extremely important that team members be provided with adequate exploration equipment and that training simulations be conducted in a realistic manner [Conti et al. 1998].

Nourishment for Responders

Discussions with miners who have fought underground mine fires or responded to other mine emergencies raised the following question: What might be appropriate nourishment for responders who could be at the mine for several days or more? Many miners believe that hot entrées and carbonated beverages are inappropriate. Hot foods are usually cold before they reach the responders, and carbonated beverages cause bloating. Soda pop may contain caffeine, which tends to dehydrate. A sports drink was preferred because it helps 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. Replenishing fluids is necessary because perspiring during intense activities such as firefighting robs the body of vital fluids and minerals. Fresh fruits such as bananas and oranges for potassium, energy bars, bagels, and grain products (granola bars) are also an excellent source of nourishment. It was also suggested that MREs (meals ready to eat) be available for emergency responders. The main point is a need for high carbohydrates and a high caloric intake during intense activities.

WORKFORCE SKILLS

Fire prevention and response skills are learned through train-ing or experience. Training is an effective means of developing skills within the workforce to reduce the number of serious fire incidents and injuries. Two key skill domains are (1) preventing fires and (2) responding to small fires. The importance of these domains was borne out in interviews with underground workers at seven underground coal mines. Of 214 underground miners interviewed, over 70% indicated that at one point in their mining career they had helped to extinguish a small fire [Vaught et al. 1996; Wiehagen et al. 1997a].

In responding to a small fire, the workers have to decide to (1) evacuate, or (2) investigate the source, warn others, and evacuate, or (3) investigate the source, warn others, and attempt to fight the fire. More than likely,

[11] See appendix B for performance evaluation instruments to provide skill training to workers in he use of handheld extinguishers and water hoses.

option (2) or (3) will be the initial choice. Whereas large fires are rare, small fires are fairly common. Some fires will grow rapidly, resulting in extremely high firefighting and mine recovery costs. Time is the critical measure in any fire event—from small cable fires, electrical power center fires, equipment fires, fires along the conveyor belt lines and at belt drives, fires caused by flame cutting and welding operations, or fires within underground maintenance facilities.

Skills in preventing fires can be addressed, in part, through on-the-job training (OJT). There is a practical fire prevention component for every underground job. For example, equipment operator training often includes fire prevention elements as part of the walkaround inspection, periodic machine maintenance, washing, and good housekeeping practices. Most underground skills are taught through OJT. Good OJT includes a plan for skill development. Worker response to unusual events is a logical part of a job training analysis. Skills in preventing and responding to small fires can also be obtained from prior research in the development of training and performance evaluation aids for conducting a fire audit [Conti et al. 2000]. These checklists can serve as a plan for experienced workers in providing structured training to less experienced miners. The key to good skills training is (1) structure and (2) having personnel interested in teaching/transferring skills to those with less experience [Wiehagen et al. 2002; Robertson et al. 2004]. Well-designed checklists, such as a job training analysis, can offer that structure.

Skills in responding to small fires can be divided into the following three areas: (1) basic training for all miners, (2) intermediate training for mine fire brigades/mine rescue teams, and (3) advanced training for fire brigades/mine rescue teams [Conti 1994]. A basic fire training program for all miners should be conducted above ground and may consist of the following:

- Basic fire chemistry (classes of fires, fire triangle, smoke, heat);
- Assessment of the size of the fire; types of portable fire extinguishers, hose lines, water nozzles, and compatibility of fittings;
- Hands-on practice in extinguishing liquid- and solid-fuel fires with portable fire extinguishers and water;
- Classroom-based simulations on critical decisions in communicating the fire emergency and responding to fire;
- Mine evacuation procedures and scenarios; and
- Understanding the operations of fire sensors (thermal, smoke, CO) and suppression systems (mobile and fixed).

An important element to consider in any fire safety program is adequate hands-on training for all miners. A few dollars spent now for training may prevent a disaster due to an out-of-control fire. Miners cannot gain effective experience by talking about using a fire extinguisher, watching a video, or observing someone else extinguishing a fire. In general, mines have ample in-house firefighting expertise (mine rescue teams, fire brigades, and volunteer firefighters). These personnel can be used to develop an adequate and effective training program. For small mines with limited resources, one option for training may reside with the local fire department.

Figure 5 shows a miner extinguishing a liquid fuel fire with a portable dry chemical powder fire extinguisher. An inexpensive mortar box (several sizes are available) filled with several inches of water and a mixture of diesel fuel and a splash of gasoline is suitable for training in the use of portable fire extinguishers, fire hoses, handheld foam generators, and other types of firefighting equipment. At the same time, miners would have the opportunity to recharge the extinguishers after extinguishing as many fires as they could using one fire extinguisher. Hands-on training builds confidence and skill levels and shows miners what to expect in the event of a real fire.

Figure 6 shows a more complicated fire where two persons with large-wheeled (150 lb of powder) fire extinguishers are required to fight the fire. Fighting such fires on the surface is beneficial, but fighting the same fires underground will pose additional problems and hazards because of the underground environment.

Intermediate training for mine fire brigades and mine rescue teams would include basic fire training, plus use of handheld and large foam generators, fighting fires in smoke, wearing SCBAs, paper-and-pencil simulations on fighting fires out by the section, and review of firefighting strategies (underground fire houses, fire cars, or trailers).

Advanced firefighting training would include all of the above skills acquired in basic and intermediate levels, plus hands-on experience in combating simulated mine

Figure 5.—Extinguishing a liquid fuel fire with dry chemical powder.

ventilated entries with portable and wheeled fire extinguishers, water lines, and foam generators (the simulated fires would include equipment fires, conveyor belt fires, etc); erecting seals to isolate fire areas; and examining the impact of ventilation on fires and airflow changes during a fire. Figure 7 shows a mine rescue team entering a surface fire gallery at Lake Lynn Laboratory with charged water hoses during an advanced training exercise to combat a conveyor belt fire. Figure 8 shows a team member using a water hose to fight the conveyor belt fire inside the fire gallery. Quality hands-on training enhances miners' awareness of mine fire hazards and promotes self-confidence in combating underground and surface mine fires.

30 CFR 75.383 requires all miners to walk escapeways and conduct fire drills every 90 days in a smoke-free environment. Miners would benefit by participating in a preplanned fire evacuation drill with nontoxic smoke at least once, if not more often, during their career before they may encounter a real fire emergency. This would give the miners a better understanding of how they might react during an emergency.

Figure 6.—Extinguishing a 400-ft^2 liquid fuel fire.

Figure 7.—Rescue team entering fire gallery.

NIOSH conducts mine-site smoke training exercises [Conti 2001]. The objectives of these exercises are to evaluate present escape methods, existing technology, and new technology that could be used for escape purposes, while giving the miners an opportunity to travel through smoke-filled entries at their mine. A smoke generator is used to create a nontoxic, smoky atmosphere; visibility can be varied from several yards to zero. An added benefit of these exercises is that a smoke generator is an excellent device to evaluate the smoke leakage of mine stoppings or to observe air currents in the mine passageways. At the end of each of these training segments, miners complete a questionnaire on topics such as anxiety levels, usefulness of the exercise and technology, and most visible colors of light seen in smoke.

Over the past several years, NIOSH, in cooperation with state agencies and operating mines, has conducted mine rescue training simulations at its Lake Lynn Laboratory and at operating mines [Conti 2000]. These exercises have resulted in improved technology and training for mine rescue teams, fire brigades, first responders, and miners in general. For example, existing technologies have been identified to help responders during exploration, rescue, and recovery operations. These include various colored chemical light shapes, strobe lights, light vests, and laser pointers to identify team members. Most of these devices may also be used to mark underground areas and certain mine materials. During these exercises, strobe lights were used for mapping out or identifying escapeways, and lasers were used to negotiate travel through smoke. Using thermal imaging systems allows rescue personnel to see in darkness and locate heated areas [Conti

Figure 8.—Rescue team member fighting a conveyor belt fire.

and Chasko 2002]. These training and evaluation efforts have also spurred the development of improved mine emergency response drills and the development of new technology, such as novel team lifelines and inflatable devices for fire suppression and personnel escape [Conti and Weiss 1998]. These simulations and technological advance-ments have improved the state of readiness for rescue personnel and increased the chances of survival for personnel escaping from underground emergencies. Other U.S. mine rescue training facilities include the Edgar Mine Rescue Training Center, Idaho Springs, CO; Central Mine Rescue Unit, Wallace, ID; and MSHA's National Mine Health and Safety Academy, Beaver, WV.

NIOSH has also developed an Internet-based computer simulation that can train command center leaders [Glowacki et al. 1996]. The Mine Emergency Response Interactive Training Simulation (MERITS) is a tool for preparing command center personnel in their potential response to a mine emergency. It teaches the importance of planning and preparation, allowing learning via practice in critical communication, judgment, and decision-making. The simulation setting is an underground bituminous coal mine.

SUMMARY

Response and preparedness are essential elements of any underground mine's strategic plan in dealing with an unexpected event, like a fire. Time is a critical factor, and delay may mean serious injury and loss of the mine. Therefore, it is important that the fire be detected in the incipient stage and that well-trained and equipped miners respond during that crucial period. An important element to consider in any fire safety program is adequate hands-on training for the entire workforce (first, second, and sustained responders). Quality training enhances the awareness of mine fire hazards and promotes self-confidence in combating both underground and surface fires.

Fire affects a significant proportion of underground miners at some time during their mining career. Therefore, all miners need to walk their escapeways and participate in preplanned fire drills with nontoxic smoke early in their career. These exercises give miners an opportunity to learn from the experiences of others and provide them with a better understanding of how to respond in realistic fire drills before they experience an actual emergency. It is imperative during an underground fire or similar emergency that all personnel, no matter what their location, be able to get notified of the event. Through-the-earth wireless transmission systems like the PED have successfully demonstrated that early warning and evacuation can save lives. If mine passageways are filled with smoke, lifelines and other devices (lasers, strobes, pinwheels, etc.) can aid miners when negotiating travel out of the section or mine. Evacuation kits can keep miners together and provide other key tools to aid escape.

During an underground fire, responders need to understand the complex environment (fuel supply, smoke, combustible gases, etc.), escape methods and procedures, and team limits and capabilities. They must comprehend when a fire can no longer be fought because of intense heat, poor roof conditions, or accumulation of flammable gases. Time invested now in preventing mine emergencies and improving emergency and fire response skills will save a great deal of time later in getting the work system back in balance. Small fires are a constant; fire risk will never be zero.

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APPENDIX A.—REVISED MINE EMERGENCY EVACUATION AND FIREFIGHTING PLAN (Source: MSHA [2002])

Mine operators should consider the following issues and topics when developing new mine emergency evacuation and firefighting programs of instruction under 30 CFR 75.1502. As applicable to the particular mine, all of the following procedures should be expanded to cover fires, explosions, and gas or water inundations. Mine operators developing these programs and MSHA personnel approving individual mine emergency and evacuation and firefighting programs of instruction should consider this list as suggestions and guidance for topics to be covered in the plan.

The list may be expanded as necessary to cover the different circumstances at a particular mine.

1. Identify and list the name(s) and/or title(s) of the responsible person(s) (RP) who will take charge on all shifts during mine emergencies involving fires, explosions, or inundations. If there is more than one RP on a shift, who is designated as the primary decision-maker?

2. Describe how the underground miners will be notified of any changes in the RP.

3. What type and where are communications systems located underground that are available to rapidly notify personnel of an emergency? What procedures will be followed if these communications systems fail during an emergency?

4. Describe how underground miners, and their work locations and anticipated movements that change their work locations during the shift, will be identified and tracked for their work shifts.

5. What are the locations of underground and surface assembly points for emergency evacuations? What procedures will be followed to assemble and account for mine personnel during an evacuation?

6. Are there any other personnel responsible to facilitate the evacuation from underground? Identify and list their names and/or titles. Describe how other underground personnel will know who these people are.

7. What equipment and travel routes will be used to evacuate underground personnel?

8. Describe how up-to-date ventilation and escape route maps and/or schematics will be provided for use by the RP.

9. If applicable, define the atmospheric monitoring system parameters (alert and alarm levels) and actions that will be taken in response to these incidents, as well as the alarms initiated due to communication errors or malfunctions.

10. Identify all persons who are trained and qualified to respond to these emergencies (identify their particular training and qualifications, e.g., gas detection, firefighting, mine rescue, etc.). Describe how this information will be made available to the RP.

11. Identify and list the location and type of equipment available for emergency response. Describe how this information will be provided to the RP.

12. Describe how the trained and qualified personnel, emergency equipment, and/or rescue apparatus will be rapidly assembled and transported to the scene of the mine emergency.

13. What are the different types of emergencies that the mine could encounter? If there is the potential for a water inundation, does the RP know where the high ground is so that he/she can direct miners during an evacuation? Do miners understand the dips and orientation of the mine and where water would accumulate?

14. How will underground water supplies be directed in the event of a fire or explosion?

15. What procedures will be taken to deenergize electrical power?

16. What type of gas detection equipment is being used?

APPENDIX B.—PERFORMANCE EVALUATION INSTRUMENTS

Portable Dry Chemical Fire Extinguishers: Hands-on Performance Feedback

(+) Observed (–) Not observed (   ) Not sure (leave blank)

Miner	**Inspection** a. Quick look at the unit for any obvious problems?	**Activation** a. Shake unit? b. Set unit down? c. Release hose? d. Puncture lever?	**Test Extinguisher** a. Quick test (burst) before approaching the fire?	**Approaching the Fire** a. Upwind? b. Posture (keep arm holding hose close to the body)? c. Maintain safe distance in addressing the fire?	**Extinguishing the Fire** a. Sweep unit at the base of the fire? b. Wide enough sweep to cover fire area plus several inches on either side? c. Prevent splashing or scattering of fuel? d. Prevent reflash (keeping unit pointed at the base of the fire)?	**Backing Away** a. Back away facing the fire zone? b. Remain calm and confident in backing away?
1.	a._____	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____
2.	a._____	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____
3.	a._____	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____
4.	a._____	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____
5.	a._____	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____

Water Hose With Nozzle: Hands-on Performance Feedback

(+) Observed (–) Not observed ( ) Not sure (leave blank)

Miner	Inspection	Test Water Nozzle	Approaching the Fire	Extinguishing the Fire	Backing Away
	a. Quick look at the water hose and nozzle for any obvious problems? b. Nozzle preset to fog spray? c. Hose man ready? d. Backup team ready?	a. Quick test (burst of water) before approaching the fire?	a. Upwind? b. Posture (keep arm holding hose close to the body)? c. Maintain safe distance in addressing the fire?	a. Sweep water spray at the base of the fire in a circular motion? b. Wide enough sweep to cover fire area plus several inches on either side? c. Prevent splashing or scattering of fuel? d. Prevent reflash (keeping fog spray pointed at the base of the fire)?	a. When the fire is out, back away facing the fire zone? b. Remain calm and confident in backing away? c. Hose man assisting?
1.	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____ c._____
2.	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____ c._____
3.	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____ c._____
4.	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____ c._____
5.	a._____ b._____ c._____ d._____	a._____	a._____ b._____ c._____	a._____ b._____ c._____ d._____	a._____ b._____ c._____

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DHHS (NIOSH) Publication No. 2006–105