CHAPTER 6.—FIRE WARNINGS AND INFORMATION UNCERTAINTY

The first steps in the process of mine evacuation are the recognition of a problem and an attempt to communicate the problem to miners who may be affected. This chapter will focus on the way that a problem, fire, came to the attention of mine personnel and the messages that were sent to miners in the affected areas. The concept of information uncertainty, which was introduced in chapter 4, will be discussed as it influences problem perception and diagnosis. Sociotechnical and interpersonal communications will be explored and suggestions for improving these systems will be offered.

It might seem that the first indication of a dangerous fire would motivate individuals to take self-protective action, to evacuate the affected area or structure, and to provide clear warning to others who are in danger. Research has actually shown that in most situations this does not occur. Instead, time is taken to gather more information, confirm information that is provided, and consider possible alternative explanations that could account for the given circumstances [Canter 1990; Scanlon 1979; Bickman et al. 1977]. This process of confirmation can lead to the loss of critical time. Canter [1990] summarizes the problem in his book, which reports studies of a number of fire events: "As discussed throughout this book, ambiguity and confusion, incoherent instructions and time-wasting actions, lack of appropriate instructions and misunderstanding of the nature of the event that is unfolding, are all hallmarks of fires and emergencies that kill people." In this chapter, the detection of each mine fire and the communication of warning to endangered miners will be reviewed with an emphasis on how those processes were affected by the availability and use of information.

Information can become available through a variety of mechanisms during an emergency situation. First, cues may be taken directly from the environment. Smoke is an obvious example. Secondly, mechanical devices, such as smoke detectors, may provide warning messages. A third source of information is interpersonal communications. These can occur face-to-face or through some mechanical device such as a telephone. With all three methods there is a possibility of miscommunication, misunderstanding, and misinterpretation. All of these means of communication were used with varying degrees of success in the three mine fires analyzed here.

A fire, like any nonroutine situation, engenders uncertainty about a diagnosis and understanding of the problem [Mead 1938]. This uncertainty leads to delays in realization of the seriousness of the situation and therefore in the proper response to it. Delay in action is an important concern in any fire setting, but is even more at issue in underground coal mine fires. Mine fires are qualitatively different from structural blazes: workers' escapeways may be miles long; the seam height at many operations is so low that it is impossible to walk upright; access to underground workings is always limited to a few (sometimes only two) openings; the coal provides an inexhaustible supply of fuel; explosive concentrations of gases may build up quickly; and logistics are difficult [Mitchell 1990]. In these difficult circumstances, anyone who delays too long before beginning an escape attempt or who gets lost in the maze of dark smoke-filled entryways will likely die. Given such a scenario, it is easy to understand the increased importance of early detection and clear communication of warning.

When transmitted warnings or direct stimuli from the environment convince people that danger exists and they perceive that options are available, they are likely to take action. According to Nigg [1987], the tendency to believe a warning and take action is influenced by the credibility of the source of the warning and the content of the message. The content will, however, be interpreted in terms of what people expect to happen [Auf der Heide 1989]. Since fires or other potential disasters are nonroutine events, the predisposition is to disbelieve messages that could be interpreted as signs of such danger. Coupled with the tendency toward disbelief is the inclination to interpret an occurrence from a normal or usual perspective as long as possible [Meltzer et al. 1975]. In disaster situations, unfortunately, potential victims are likely to put the best face on the situation whenever possible and decide that response is unnecessary [Perry 1987]. Therefore, the more credible a source and the more unambiguous the message, the more disposed individuals will be to switch their frame of reference and believe that a nonroutine event is occurring [Mileti and Fitzpatrick 1991]. Even when the message appears to be clear, however, interpretation is a subjective phenomenon that will vary by individual and context because of personal and social history [Duchon 1986]. Therefore, warning messages must be as timely and unambiguous as possible. Regardless of the warning provided, though, it must be anticipated that some people will respond more quickly and more appropriately than others.

Use of Information in Mine Fire Detection

Like structure fires, underground mine fires can be detected by environmental cues, verbal warnings, or alarms from detection systems. Research conducted in the area of response to fire warnings shows that warnings given by any of these means are not always effective. Canter [1990], for instance, explained that in many fire settings environmental cues are not recognized as warnings:

> "In every disaster that has been examined in this book, it has been found that, in the early stages of fire growth, people have ignored or misunderstood the early cues indicating that a dangerous fire was developing."

Canter [1990] then provided three reasons that traditional audible alarms are also often ineffective:

1. A failure of people to differentiate fire alarms from other types of alarm.
2. A failure of people to regard fire alarms as authentic warnings of a genuine fire.
3. A failure of fire alarms to present information that will assist fire victims in their attempts to deal with fire.

It is evident that these findings may be readily generalizable to the fire detection and warning systems in a mine setting.

The following sections will describe how the fires were discovered at the three mines. The means of detection differed at the three sites. In one location, the fire was discovered when a resulting situation created a problem with continuing routine work and the miners went in search of the cause of that problem. In other words, the fire was not detected by a system designed for that purpose, but instead was happened upon by personnel during the course of their work. Systems for detecting dangerous conditions did come into play at the other two sites. At one site, a mine examiner discovered the problem during a routine check for hazards. The third site had installed a mine-wide monitoring system that provided their initial warning. The stories of fire detection can therefore be seen to range from the casual finding of smoke during routine tasks to the use of sophisticated warning equipment. Details of each event will be discussed in the following sections in order of increasing use of formal warning systems. Each account is given from the perspective of the individuals who first determined that a serious situation did exist.

Fire Detection at Cokedale Mine

The workday began to vary from routine at Cokedale Mine when workers driving motors noticed fluctuations in power supplies to their vehicles:

> When I went to put the power on, there was none, and I asked my buddy if he had lost power, and he says, yeah, but it came back on. And then I hit my controller and the power was back on again, and then I heard [the haulage foreman] say, "Well, my power's on down here, but it's real weak...My lights are real dim...I've got this thing on full power, and it's hardly moving."

The two motormen and the foreman driving the affected vehicles then began to search for the source of electrical power fluctuations that were impeding routine work. First the dispatcher was called and asked to check the above-ground substation. The dispatcher found that the automatic system had locked out the power and called back to report this information. Meanwhile, one of the motormen saw "about an inch of smoke along the roof." His initial diagnosis was that a switch had burned out. The dispatcher explained why this diagnosis was made: "I heard [the foreman] telling [the motormen] to check No. 1, which we had a switch burned up once before down there. It was about the same way." The motormen put the smoke into a framework that had been created by a past event (which gave similar environmental cues) and went to the area of the earlier problem to search for confirmation.

> About half the entry was filled with smoke. I ducked down and tried to look around the corner and I wanted to see if that trolley switch was burning, which was probably maybe 6 to 8 feet in...I couldn't really see so I took a step into it, and it was just—black. I mean, everything right now was black. It was nothing, and I couldn't even, I turned around and I couldn't see anything.

At that point, the motorman determined that this situation was not a repeat of the prior one, as he had been expecting. He called the dispatcher and reported what he had found.

> We got a problem down here...Something's burning and I don't know what. I said, I don't think it's a trolley switch, there's too much.

The dispatcher realized the seriousness of the situation from this verbal communication and called to tell miners working inby the fire to evacuate the mine.

Fire Detection at Brownfield Mine

Detection of the fire at Brownfield Mine consisted of a process that involved the experience of one individual. On the day of the fire, a mine examiner was performing a preshift examination. A mine examiner's job is to routinely check the mine for hazardous situations before and during shifts. He was walking a beltline when he went through a door and then smelled smoke. Like the motorman at Cokedale, this miner assumed the smoke was the result of a situation that occurred in the past: "I just kind of thought it was, you know, maybe a bad roller. The belt was rubbing on the straps, or something like that." He continued his examination, specifically checking the rollers to see if one of them was the source of the smoke. As he walked on, the smell of smoke grew stronger, but there was still no sign of the source of the problem. He began to hurry toward an overcast because that was the location of a past problem. When he got to a section belthead, "the smoke just seemed—it was there. I mean, all of a sudden it was there." Even though the amount of smoke provided undeniable warning that this was an abnormal situation, the mine examiner still wanted to confirm exactly what was happening. Therefore, he started running through the entries searching for the source of the smoke and for a safe passageway. He heard a rumbling, which sounded to him like a welding torch. Again trying to understand his surroundings within a routine framework, he thought that maybe someone was welding and a problem had resulted. "I yelled for [the welder]. I yelled about two or three times for him and there was no answer or anything." At this point, the mine examiner began having problems maneuvering through the smoke.

> When I got in there, the smoke was real thick in there, too, and I couldn't see, ...I was coughing around and it really burned my chest at this time, so I probably stayed there a couple minutes to get my bearings again.

The mine examiner still had not reported the situation to anyone. He chose instead to continue to search for the welder who he thought might be in jeopardy in the smoke-filled area of the mine. He also was attempting to determine the exact source of the problem so that he could take action in response to the threat.

> I crawled up along the rib, 'cause I still thought [the welder] was in there and had a fire or something had happened. I thought there was a man in there. I went up along the rib and I got my head around the corner and I looked in and I yelled for [the welder] a couple more times and I could see the flames...coming off the top of the motor. I went back and I knew that there was a cutout...in the high spot, but in the smoke I couldn't see it, so I wasn't about to try and find that cutout, so...I run back down to 6 Left and pulled the cutout blade.

When the mine examiner saw the flames coming off the motor, he knew that this fire was a major problem. He determined that he could not find the welder, so after he had taken the only response action that he felt was available to him, cutting the power to the trolley wire, he called to report the fire to miners at inby locations and to the shift foreman.

Fire Detection at Adelaide Mine

Warning of the fire at Adelaide Mine was given by a carbon monoxide (CO) monitoring system. Adelaide's dispatcher was alerted by a CO warning of 10.5 ppm, which cleared from his computer screen almost immediately. A few seconds later, the same sensor registered a warning of 11.5 ppm, but cleared in less than 30 seconds.

> I turned to the page where the alarm was and it dropped straight back off the normal and I took it as a false alarm.

An element in how this particular warning got diagnosed was the fact that past false alarms had strongly conditioned Adelaide's dispatcher to question the legitimacy of each alarm. Due to his mistrust of readings provided by the monitoring system, the dispatcher did not follow a normal protocol for responding to this first CO warning of the shift. Instead, he continued his ordinary routine until he received an alarm that was more likely to be a true reading of an abnormally high CO level. At that time the dispatcher looked for more information about the situation:

> [The monitor reading] went 18, 20, 22. It just started going straight up. I got on the phone and called the dumper's shanty...I told them I had a high alarm at 23 stopping, to get up there now and check it out. I guess it was like 5, 6 minutes later, he called me back and said I better get some fire extinguishers up there fast, that there was a lot of smoke.

Upon confirmation of a serious blaze from the miners at the dumper shanty, the dispatcher determined that miners in three areas of the mine were in danger and must be evacuated.

Discussion of Fire Detection at the Three Mines

To those unfamiliar with the mining environment, it may be difficult to understand how seeing unexpected smoke could be interpreted as normal. During a study in which 214 miners from 8 mines were asked about mine fire related experiences, however, 65% reported that they see or smell smoke in the mines where they work at least once per month [Vaught et al., 1996]. Furthermore, 15% said that they had been surprised or caught off guard by the smell or sight of smoke within the past month. There are a number of potential sources for smoke underground that do not usually lead to large fires.

In all three cases, the miners who discovered the fires initially attempted to interpret the messages they were receiving within a framework of normal mine operation. In the first two mine fires discussed above, the miners who initially discovered smoke attempted to attribute it to such sources. Like the miners in the Vaught et al. [1996] study, they had past experience with smoke in the mine that had not led to major fires. The suggested causes—a burned-out switch, a hot belt roller, or a welding torch—would not necessarily create major problems. In these first two cases, however, the environmental cues provided, the amount of smoke, and/or a view of the flames, could not be explained within the miners' normal frameworks. When they reached that conclusion, the initial warning was received successfully.

In the third mine, initial detection came from a mechanical device instead of directly from the environment. As discussed in the introduction to this section, for fire alarm systems to be effective they must be viewed as "authentic warnings of a genuine fire" [Canter 1990]. Unfortunately, the dispatcher at Adelaide had background filters that predisposed him to not take heed of the CO monitor's warning. The system had in the past given multiple false alarms and had thereby made false CO warnings a normal frame of reference:

> It's just unbelievable. There was times that all I did was go back and forth and back and forth, you know, just turn the other alarm off and hit the next page. That's all I did. There was times where I would be talking and they'd be going off for like 30 or 40 seconds before I could get over there and shut it off and check it.

The system had been put into service while still being finished. Unfortunately, some of the monitors were attached to roof bolt plates, causing a short circuit. The resulting false alarms seem to have lulled the dispatchers into complacency. These false alarms were particularly problematic because of the way the system was implemented at the mine. Adelaide's dispatchers had been placed in charge of the monitoring terminal, but no analysis was performed to determine if this job was complementary with their primary tasks—to "direct traffic and move coal." The dispatcher occupied a key role: being able to recognize and communicate potential danger from readings of increased CO levels, but did not view that as an important part of the job.

Another implementation problem was the lack of adequate training. The system manufacturer's representatives conducted two formal training classes that were attended by supervisors and maintenance personnel but not by the dispatchers: "I had no classes. It was just as they got things in, they told me little bits and pieces." Mine management had allocated resources to the implementation of a sophisticated system which, if working properly, should provide early warning of fire. However, the same attention was not given to the human-machine interaction that was a vital link in the system. When the dispatcher decided that this time the warning might be real, he still asked for confirmation from miners who had to go and look for the alarm's source before he determined that miners inby the fire were in jeopardy.

Communication of danger was delayed in all three mines because individuals tried to place the abnormal cues into normal unthreatening frameworks. Miners caught inby the fires could have begun their escapes earlier if those who discovered the problems had risked making errors on the conservative side and reported the potential danger as soon as the first cues were received. In the first two cases, the environmental cues could have been somewhat ambiguous. One way to improve that situation would be to use mechanical devices that could remotely provide more explicit information and clearer warnings. While this could have helped in the interpretation of conditions in the first two examples, the third case shows that implementation of technology without careful consideration of how its messages will be interpreted will not be successful.

Warning Information Communicated to Miners Inby

Regardless of the means used to detect a fire, after it has been discovered any workers in the affected areas must be warned about the potential danger. They must be given messages that will allow and encourage them to act appropriately and escape efficiently. In these cases, eight separate groups of miners were forced to escape from inby the three fires. In some cases, the information they received assisted them with an effective egress from the section. In other cases, little information was conveyed to the miners at risk. Communication of the initial warnings will be discussed in the following sections.

Warning Miners Inby at Cokedale

When the dispatcher at Cokedale heard confirmation of the fire from the miners who discovered it, he attempted to communicate a warning to workers who might be in danger. Miners were working or traveling in two areas that could be blocked by smoke from a safe exit. In both sections, however, the dispatcher's message was not the first cue they had that something was not normal. The miners who started looking for the reason for the power fluctuations discussed previously were communicating on an open channel. Individuals on the sections, therefore, could overhear the conversations regarding the problem and the speculations about a trolley switch burning. Miners in the inby sections got another cue as they began to smell and/or see smoke. They began to think that something unusual might be happening and looked for confirmation of that fear. The dispatcher provided confirmation through phone calls in which he relayed the information that a fire was burning underground and that they should evacuate the mine. Each section started evacuation after that message was received. They began the trip, which would take them through thick smoke, knowing that a fire was burning. The other information at their disposal was more vague, however. From the overheard conversations, they had some notion of where the miners were who had discovered the fire. They therefore could make a reasonable guess about the fire's location, but had no information about its severity.

Warning Miners Inby at Brownfield

The fire boss who discovered the fire at Brownfield called miners working on the three sections at risk. The message given to two of the sections, 4 South and 5 South, was that there was a belt fire and that they should evacuate the mine. The fire boss, with the vision of hindsight, discussed what was lacking in the warnings received by those miners.

> So I called them and told them there was smoke coming out, they better get out of there. But the one mistake I did make is, well, the man that I talked to in both cases never—he never give me the opportunity to tell them where the fire was at. It made it kind of a bad situation for those guys coming out, cause they really didn't know where the fire was, which was one thing I learned from the whole situation.

The stories of the miners who took the fire boss' calls confirm that, as the fire boss reported, they did not wait for additional information after hearing that the mine was burning. In both cases the miners were forced to make decisions about their evacuation without knowing the fire's location. The third section, 6 West, had more information available as they decided which way to go. The foreman who took the call from the fire boss explained why: "I was the only one of all the guys [who escaped] that knowed where the fire was. And the reason for that is I took and asked [the fire boss] where the fire was." This miner had asked for and received exact information about the fire's location and used it to make decisions about evacuation.

Warning Miners Inby at Adelaide

As discussed in the section about detection above, the dispatcher at Adelaide received warning of high carbon monoxide levels and sent the dumper to explore the situation. When the dumper reported back that a fire was burning, the two workers split the task of contacting miners inby. There were three sections affected and all three were told, either by the dispatcher or the dumper, that there was a fire on the belt and that the mine should be evacuated. No information about location or severity of the fire was provided and no further details were requested by the miners who answered the calls. All of the miners inby the Adelaide fire evacuated without knowing where the fire was and, therefore, how far they had to travel.

Discussion of Communication of Warning at the Three Mines

Most of the miners who evacuated from the three mines did not have information that would allow them to make decisions about efficient escapes.

The communication breakdown came from two directions: the individuals providing the warning did not offer details about the situations even though some details were known, and the individuals who received the warnings did not ask for clarification of the situation. As discussed in chapter 4, this lack of information allowed miners to continue attempting to place cues into normal frameworks after they should have evaluated the situation as abnormal and threatening. When the environment left no doubt that this was not a routine exit from the mine, it was too late to gather more information because there was no form of communication to the surface in those locations. Most decisions about appropriate travel directions had to be made without the miners knowing where the fire was, and therefore where the smoke was likely to be. Equally important, the miners did not know whether they must face the extreme conditions for a hundred yards or 5 miles. In the case of Cokedale, miners could guess where the problem was from monitoring the radio calls. They could not be absolutely certain of its source, however, and they had no indication of its severity. As shown in figure 5.1, uncertainty created by a lack of information increased stress on the escaping miners and influenced their decision-making (and therefore their actions).

Improving Fire Warning Systems in Underground Coal Mines

Data from the three fires studied show information that could have been used to help with evacuation decision-making had it been provided to the miners who were most in jeopardy. In all three cases, delays in activating the warning communication system happened because the individuals who first determined that an abnormal situation existed sought additional confirmation before communicating the cues they had received. Further delays occurred when the miners inby also sought confirmation before evacuating, and often, even then, did not believe that an emergency was in progress. The lack of reliable detection methods and standard protocols for emergency communication caused those miners who were put in danger by the fires to delay their self-rescue attempts, and often to act without needed information. The following sections will suggest methods that could be used to address some of the causes of faulty communication that occurred during these mine fire evacuations. First, technological advances in fire detection will be discussed. Then, human interaction with technology and human reaction to warning and risk communication will be explored. The last section of this chapter will summarize issues that should be considered in the design of a fire warning system.

Fire Warning With Smoke Detectors

The fire at Adelaide was detected initially by a mechanical device. Having any mechanical device installed to provide early warning of a fire may allow miners inby more time to escape. The CO detector system used at Adelaide, however, may not be the best choice. Instead, a smoke detection system might provide even more time for evacuation decision-making and actions before the mine atmosphere becomes irrespirable. Data from fire testing indicate that a fire will generate smoke reaching levels that will force evacuation, and make travel difficult, significantly earlier than it will generate a toxic environment due to its product gases [Litton et al. 1991]. This is significant because it implies that for even moderate levels of smoke, the air is still breathable and life-supporting. It is only when the levels of smoke begin to totally obscure visibility that the toxicity of the combustion products begins to play a role in the question of escape and survivability.

As shown in chapter 7, smoke from a fire is a significant obstacle to escape. The rapid detection of smoke at very low levels can increase the time miners will have to escape before smoke obscures visibility completely. Such rapid detection is possible because smoke is produced much earlier than other fire signatures during the stages of fire growth and development, and smoke sensors are extremely sensitive devices. Smoke sensors can respond to smoke levels that are barely visible to the human eye. Furthermore, smoke sensors will alarm while CO levels are often still near the ambient threshold of CO alarm sensors. Since smoke may be the greatest impediment to survivability during a mine fire escape, its early detection can optimize the chances of surviving.

Smoke Detection

In the United States, both Underwriters Laboratories, Inc., and Factory Mutual Research Corp. use standard tests for approving smoke sensors to be used as early-warning fire sensors. Abroad, similar standard tests are employed for approving smoke sensors (such as EN-54, used by the European community). These standards are based on the optical density of the smoke. In very general terms, a smoke detector passes the sensitivity tests if it alarms before the smoke optical density reaches a value of 0.058 m^{-1}. Many approved smoke sensors typically alarm at optical densities of one-third to one-fourth of this value.

It has been proposed [Litton et al. 1991] that smoke sensors approved for use in underground coal mines be classified more rigorously by defining two classes. Class 1 smoke sensors are those which always alarm at smoke optical densities less than 0.022 m^{-1}. Class 2 smoke sensors are those which always alarm at optical densities less than 0.044 m^{-1}. Any smoke sensor that alarms at optical densities greater than 0.044 m^{-1} would not be approved for use in underground coal mines. For a class 1 smoke sensor, the range of visibility would exceed 40 m.

In determining which type of alarm system should be installed in underground mines, it is appropriate to compare the approximate levels of CO that would be present at the alarm thresholds of class 1 and 2 smoke sensors. This comparison is shown in table 6.1 (flaming). For a class 2 smoke sensor, the average CO levels at smoke alarm are 5.7 ppm for flaming fires. For a class 1 smoke sensor, the CO levels at smoke alarm are 2.9 ppm. These numbers are clear indications of the superiority of smoke sensors over CO sensors in providing early warning of fire.

Table 6.1.—Approximate CO levels present at alarm threshold for flaming fires

Combustible	ppm CO at smoke alarms	
	Class 1	Class 2
Wood	5.5	11.0
Coal	1.7	3.4
SBR conveyor belt	1.9	3.8
PVC conveyor belt	4.1	8.2
Neoprene conveyor belt	3.2	6.4

The earlier the warning given to miners who will be required to travel through smoke, the better their chances of making a successful escape. Assuming the maximum time available for escape is that point at which visibility in an escapeway becomes critical, it is possible to determine how much of this time is available to miners warned by different types of sensors. In detection of a fire in the belt entry, a reasonable time before smoke obscures visibility is about 38 minutes. It is possible to determine when, during that time span, various types of sensors would alarm and therefore how much evacuation time would be made available. For smoke sensors, 30 minutes (79% of the total time) are estimated to be available; for 5-ppm CO sensors, 23 minutes (61%); for 10-ppm CO sensors, 19 minutes (50%); and for thermal sensors, 3 minutes (8%). Such an analysis clearly shows that smoke sensors can provide earlier warning than CO monitors.

Smoke Sensor Classifications

Smoke sensor classification systems are based on various criteria. Smoke sensors are often classified according to their principle of operation. Smoke sensors are either ionization-type, photoelectric-type, or some combination of the two. An ionization-type smoke sensor is one that uses a small source of radioactive material (usually americium 241) to produce molecular ions in the air space between two electrodes. When a small voltage is applied to these electrodes, the ions produce a current. Smoke particles that enter the air space between the electrodes serve to deplete the ions correspondingly by reducing the flow of current. When the current loss is 10% to 20% of the total current, an alarm is given.

Photoelectric-type smoke sensors, which are based on measurement of light, may be divided into two subcategories. The first subcategory contains sensors that measure the light that is scattered from smoke particles. This type of detector is located to the side of a beam of light at some fixed angle (usually around 45E from the forward direction). In the absence of smoke particles, this detector receives no signal. When smoke enters the projected beam of light, some of the light is reflected (scattered) into the detector producing a measurable signal. When the detector signal reaches some preset level, an alarm is given. The second subcategory contains sensors that measure the transmission of light through a cloud of smoke. A light beam is projected into a detector, producing a steady-state signal level. When smoke enters this light beam, it reduces the detector signal level and produces an alarm.

Smoke sensors may also be classified according to their use. Deployment can be fixed-station, sampling, or open area. The most common sensor deployment method is called fixed-station sensors. These sensors are mounted on or near the roof and are fixed into place. Another type of smoke sensor is a sampling-type smoke detector. The sampling-type smoke detector usually employs a small axial-vane fan to convey a sample of air from some desired point back to the sensor via plastic tubes. Very often, this type of smoke sensor draws samples from several different monitoring locations (usually about 10 per detector). This allows 1 sensor to essentially replace 10 fixed-station smoke sensors, but also means that the 1 sampling-type detector must be more sensitive, since smoke from any one location can be diluted by a factor of 10. As with fixed-station use, either ionization-type or photoelectric-type can be employed in sampling.

The final type of smoke sensor to be discussed here is the open area (or projected-beam) detector. It requires the use of a photoelectric-type system. For this system, a light source is located remotely from a light detector. The light detector measures the transmission of the light beam through a cloud of smoke particles. This type of smoke sensor can function at separations between light source and light detector up to 90 m. It is intended for use in structures that are relatively open on the inside, such as warehouses.

Use of Smoke Sensors in Underground Mines

Most smoke sensors that have been approved by a recognized testing laboratory should perform reliably in an underground coal mine. The major obstacle to their effective use is dust. Both coal dust and rock dust are present, often at elevated levels, in underground coal mines. Two problems can be created by this condition. First, false alarms can be given when dust enters the smoke sensors. Because dust is similar to smoke except that the dust particles are larger, dust can cause smoke sensors to alarm. Second, dust may contaminate a smoke sensor causing the sensor to become more sensitive over time. This is particularly true for ionization-type smoke sensors and those photoelectric-type smoke sensors that use light attenuation as the means for detecting the smoke. Increased sensitivity due to dust buildup eventually results in an increasing frequency of random false alarms. For photoelectric-type smoke sensors that use light-scattering to detect the smoke, dust accumulation can eventually render them totally insensitive.

There is one fixed-station smoke sensor that is impervious to dust—the Becon Mark IV ionization-type smoke sensor, manufactured by Anglo-American Electronics, Inc., of the Republic of South Africa. It achieves this result by using a radioactive source (Kr-85) that emits β-particles rather than the α-particles produced from americium 241. This radioactive source has an activity level greater than the exemption level specified by the Nuclear Regulatory Commission, and special licensing requirements are needed by a United States distributor before it could be used extensively in underground mines in the United States.

Other than the Becon smoke sensor, sampling type smoke sensors offer the greatest potential for reducing or eliminating the problems of dust in underground coal mine use. They use a forced flow to bring the sample of the mine atmosphere to the detector for measurement. Dust particles are much larger than smoke particles. Techniques exist for selectively filtering out these larger dust particles from the flow and allowing only the much smaller smoke particles to be transmitted to the detector for measurement. With current readily available technology, the sampling type of detector seems to provide the best solution to problems created by coal and rock dust.

Communication of Fire Warnings

Timely detection of fire is only one step in the fire warning process. As shown by the activities that took place after the CO monitor alarmed at Adelaide, proper response to mechanical detection devices is required for the warning system to be activated. If the individual responsible for monitoring the alarm system trusts that the sensors are reliable and valid, and if that person has been trained in the proper actions to take when an alarm sounds, the warning system is likely to be activated immediately upon receiving the first alarm. If, however, the system has given multiple false alarms or the sensors are set inappropriately and alarm to low levels of smoke, such as from welding, or to dust, then the person monitoring the detector is likely to look for confirmation of a serious problem before providing warning. Even when the alarm is believed or the situation confirmed, if the individual has not been trained in the proper way to relay warning, vital information is likely to be forgotten.

A person who is responsible for communicating warning information will be doing so under stress. That individual is in the position of telling others that their lives may be in jeopardy. In that situation, the person providing warning must have a detailed protocol for relaying information that has been explained, discussed, and practiced *before* the emergency occurs. At a minimum, the protocol should include elements such as (1) identification of the individual providing the warning, (2) the location of the situation, (3) definition of the type of problem occurring, (4) severity of the problem if known, and (5) instructions for those at risk. Information about changes to the environment or response to protocol that have occurred because of the emergency should also be communicated. As discussed previously, none of the individuals who communicated a message to evacuate the miners in this study relayed all of the pertinent information available. In the worst cases, the miners inby were not told the location of the fire and therefore lacked information vital to planning an appropriate escape route.

For a warning system to be successful, the communicated message must also be received appropriately. This requires that everyone underground be trained in the proper way to gather information during a warning communication. In many instances, workers who received warnings of the fires did not ask any questions of the person telling them to evacuate the mine. In the worst case, one person simply ran from the phone as soon as the beginning of the message was relayed. Miners must be prepared to control their stress levels as they hear about the potential threat and obtain as much information as possible so that later decision-making can be done in an informed manner. At a minimum, they should be trained to ask (1) the nature of the problem, (2) the location of the problem, (3) the severity of situation, (4) which actions should be taken, and (5) any details of the situation that would be relevant specifically to the people in that area. If the person providing the warning and the person receiving it are both trained in emergency communication protocols, the potential for an effective warning system can be greatly enhanced.

Recommendations for an Effective Warning System

When an individual is warned of danger, that person will act if (1) he or she believes the danger is real and (2) feels that there are options. A warning system should be designed to provide the most information possible to comply with those two needs. The detection of a problem, whether by mechanical or other means, must be trusted so that warning can begin immediately upon discovery of the problem, as opposed to waiting for confirmation. After discovery, warning must be provided to everyone who is in danger. Secondarily, warning must be provided to those who will be called on to respond to the emergency, and in such a way that it allows informed decisions to be made about what actions should be taken. Training is needed for both giving and receiving warning messages properly. Developing an effective warning communication system should include—

1. Installing proper detection devices as appropriate to the situation.
2. Training personnel who will be monitoring the detection system and its functioning.
3. Developing a warning message protocol to be used to provide warning.
4. Training personnel who will be monitoring the detection system in proper protocol for providing warning when the system alarms.
5. Developing a receiving warning message protocol to be used when receiving warning.
6. Training all personnel in the proper methods for use of the receiving protocol to gather information when receiving a warning.
7. Incorporating this system within a general mine emergency response plan.

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