AN OVERVIEW OF TECHNOLOGY AND TRAINING SIMULATIONS FOR MINE RESCUE TEAMS

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ABSTRACT

Mine operators often rely on mine rescue teams to save lives during an underground emergency such as an underground fire, explosion, roof fall or water innundation. It is extremely important that team members are provided with adequate exploration equipment and that training simulations are conducted in a realistic manner. A series of mine rescue training exercises was developed, conducted, and evaluated by the National Institute for Occupational Safety and Health (NIOSH) in cooperation with the Pennsylvania Department of Environmental Protection, Bureau of Deep Mine Safety and several mining companies. The exercises were conducted at NIOSH's Lake Lynn Laboratory and operating mines during 1995 to 1999 and resulted in improved technology and training for mine rescue teams. For example, existing technologies were identified to help rescue teams during exploration. These included various chemical light shapes and laser pointers to identify team members and mark crosscuts and mine materials, strobe lights for mapping out escapeways and marking crosscuts, and thermal imaging systems to see through smoke. A hands-free communication system showed potential for enhanced communications between team members and the fresh air base. A new team lifeline that allows for flexibility of movement between team members was developed. A positive-pressure inflatable escape device (IED) was used to isolate the "hazardous" environment from fresh air and allow rescue team members to traverse through. An inflatable feed-tube partition that can rapidly block large openings such as underground passageways and simultaneously provide a feed-tube for high-expansion foam generators was also deployed for several simulations.

During the simulations, mine rescue team members donned self-contained breathing apparatuses (SCBA) and traversed more than 400-m of mine passageways filled with nontoxic smoke. Visibility ranged from 0.3 to 0.9-m. In one area of the mine, a kerosene heater was used to simulate a fire and reduce the oxygen concentration. In another area, a 1.5 pct methane zone was established. The team members searched for "victims," administered first aid, mapped the passageways, built temporary stoppings, and ventilated the smoke-filled entries. Advanced training included the extinguishment of a conveyor belt fire in a surface fire gallery. Two teams, each carrying charged

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waterlines, were escorted into the fire gallery through both doors. These teams controlled the rollback smoke and extinguished 7 to 9-m of burning conveyor belt. Team members indicated that the exercises were extremely beneficial due to the realism of the training simulations.

INTRODUCTION

Approximately 940 underground coal mines continue to operate in the United States. They employ a total workforce of 45,755 miners, 2,644 of which are contractors. These mines produce 419,660,986 tons of coal in 1998.

A recent survey conducted by the Mine Safety and Health Administration (MSHA) indicated that there are 281 state and company mine rescue teams in the United States; 157 metal & nonmetal mine teams and 124 coal mine teams with a total of 2,000 rescue team members. These statistics show a drastic decline in the number of teams over the last decade as the number of mines decrease. The largest representation of rescue teams for coal mines is in the eastern part and for metal/nonmetal mines is in the western part, of the Unites States.

This dedicated group of miners often put their lives in jeopardy to save others. It is important that team members are provided with the latest personal protective equipment, be well trained, physically fit, and fully understand the hazards that may await them during rescue, exploration and recovery operations. Very often, rescue teams receive hands-on training during actual emergencies, or in simulated mine environments with placards to identify objects and hazards. This paper deals with improved training simulations and new technology for mine rescue teams.

Mine rescue training began in the United States in 1910, the year the U.S. Bureau of Mines (USBM) was created. Joseph A. Holmes, the USBM's first director, sought a training vehicle (railroad cars) that would give the mining industry a cadre of mine rescue specialists who would be prepared to respond to mine disasters. The training efforts evolved into local and regional competitions and, a year later on October 30, 1911, the first national mine-safety demonstration was held at Forbes Field, in Pittsburgh, PA. The demonstration was planned and managed by engineers of the USBM, with the aid of miners and coal operators of the Pittsburgh district. It embraced exhibits that showed the character of nearly every branch of the USBM's investigative work in relation to mine accidents. The demonstration included first aid and mine rescue work, and special coal-dust explosions at the USBM's experimental mine at Bruceton, PA. Approximately 15,000 persons attended the demonstration. The field exhibits were witnessed by President William H. Taft, who presented Red Cross medals and first aid packages to rescue team captains, and many National and State government officials. Teams of miners trained in first aid and rescue work from every coal-mining state took part in this stimulating demonstration.

Mine rescue contests are still conducted on a regular basis to sharpen skills and test the knowledge of miners who may one day be called upon to respond to a real mine emergency. The contests require teams of six members each to solve a hypothetical rescue problem while being timed and observed by judges according to precise rules.

The simulated problem involves trapped miners who have to be found and rescued. State and Federal mine safety experts evaluate each team as they work through their rescue problem in a simulated mine environment as shown in figure 1. Teams are rated on adherence to safety procedures and how quickly they complete their task.

Figure 1.–An above ground mine rescue simulation.

Federal regulations, as spelled out in 30 CFR Part 49, Mine Rescue Teams, require that every operator of an underground mine will assure the availability of mine rescue capability for the purposes of emergency rescue and recovery. Part 49.8 discusses training for mine rescue teams. In particular, underground sessions will be conducted every 6 months and include the wearing and use of breathing apparatus; use, care, capabilities, and limitations of auxiliary equipment; advanced mine rescue training and procedures; mine map training and ventilation procedures, etc.

Over the past several years, the National Institute for Occupational Safety and Health's (NIOSH) Pittsburgh Research Laboratory has conducted mine rescue simulations at its Lake Lynn Laboratory (LLL) near Fairchance, PA. Memorandums of Understanding/Agreement were established between NIOSH and the Pennsylvania Bureau of Deep Mine Safety and several mining companies to increase the operational effectiveness of their coal mine and metal/nonmetal rescue teams and evaluate new and emerging technology [Conti et al., 1998]. These efforts have resulted in improved disaster recovery training drills and the development of new technology such as a new team lifeline, inflatable devices for fire suppression and personnel escape [Weiss et al., 1996; Conti and Weiss 1998]. Existing technologies, such as the use of chemical lightshapes, laser pointers and strobe lights for identifying team members, and thermal imaging equipment were evaluated. Current rescue protocols and strategies were also assessed.

The NIOSH, Pittsburgh Research Laboratory's LLL, formerly a limestone mine, is now a multipurpose research facility used to conduct mining safety and health research [Mattes et al., 1983]. The new entry dimensions of the underground mine range from 1.8 to 2.4-m high and from 5.3 to 6.3-m wide. The average dimensions are 2.1 and 5.8-m, for an average cross-sectional area of 12-m^2. The underground configuration of the new entries covers approximately 95-km^2, with an overburden ranging from 50 to 100-m. The unique nature of the facility allows it to be readily adapted for elaborate mine rescue team simulations in smoke-filled entries.

The LLL has installed a wireless signaling system that transmits an emergency warning which can quickly reach every underground miner. 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 low-frequency transmitter that can be strategically placed to create an electromagnetic signal that can completely envelop most mines without the use of repeater systems. The transmitter loop antenna is on the surface, and a receiver/ transmitter loop antenna is underground. The person-wearable receivers are small, lightweight modules incorporated into the miner's cap lamp assembly. Upon receiving an emergency or paging signal, the cap lamp begins to flash, which in turn alerts the miner to evacuate the mine or call the surface for a message, depending on which signal is received. 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 can be found in [Conti and Yewen 1997; Dobroski and Stolarczyk 1982].

A successful evacuation of miners during the Willow Creek mine fire, that occurred in Helper, Utah, on November 25, 1998, was attributed to a similar system, the Personal Emergency Device (PED) [Zamel 1990]. The paging system was activated when one miner 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 underground miners escaped in approximately 30 minutes.

EVALUATION OF MINE RESCUE TECHNOLOGY

Identifying Team Members

NIOSH attempted to address several issues raised by rescue team members that participated in the simulations. One of the main concerns of the rescue teams was identifying other team members and marking locations, such as crosscuts, brattice curtain, cribbing, and other items that may be found in the smoke-filled entries, or just maintaining a reference point. Chemical lightsticks, a technology that has been around for years, were found to be a valuable tool for underground rescue teams. The lightsticks are nonflammable and not a source of ignition, they are weatherproof, maintenance free, and nontoxic. To activate, just remove the stick from the package, bend, snap and shake. Instantly, a source of light exists that can vary in intensity and duration. The brightest lightstick lasts 5-min; the least brightest, 12-hrs. The cylindrical lightsticks were assessed by the team members during the simulations, both in white nontoxic smoke and black toxic smoke produced from conveyor-belt fires. Four lightstick colors were evaluated; clear, green, red, and yellow. Team members attached these lightsticks to the back of their helmets with plastic ties. They can be also placed on the floor at various critical locations and on obstacles during exploration. Figure 2 shows the responses of the rescue team members for the most visible color lightstick in these smoke-filled environments. Of 265 mine rescue team members participating in the white nontoxic smoke simulations, 77.3 pct identified green as the most dominant color seen, clear was the least visible color. Out of the 90 rescue team members that participated in fighting the conveyor-belt fire, 85.4 pct felt that green was the most dominant color; red was the least visible color. Lightsticks are now a crucial component for these team members. Other lightshapes were also evaluated by team members. Light-ropes were mounted on the back and around the brim of the helmet, and chemical circular light discs were mounted on the back of the SCBA’s. The various lightshapes are attached to the team members are shown in figure 3. The light-rope was found ineffective. Other chemical light shapes and intensities are currently being considered.

In other smoke training exercises, the lightstick was effectively used to negotiate travel through a smoke-filled passageway. The participants turned off their cap lamp and held a green light stick out in front of them, about waist high.

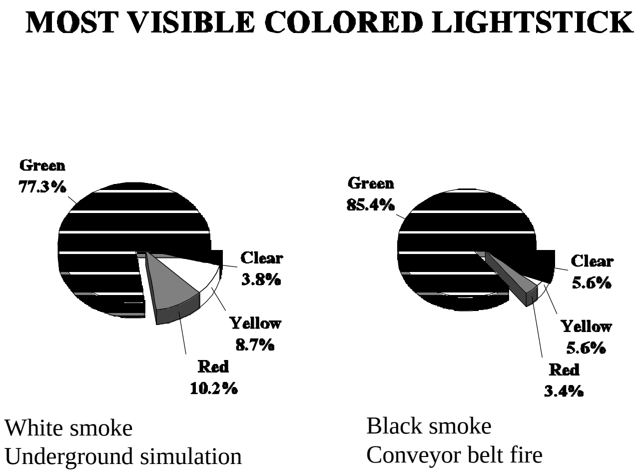

Figure 2.–Response of rescue team members for the most visible color lightstick in smoke filled environments.

Figure 3.–Various chemical lightshapes attached to team members.

Strobe Lights

Another area examined was utilizing high-intensity strobe lights (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 reflective lenses, are compact and lightweight (100 gm) and provide 180° of visibility. The triangular shaped (9-cm each side by 4-cm high), lithium AA battery powered strobe lights could be remotely activated by a wireless, through the earth signaling system such as the one installed at LLL. Ideally, underground sensors would monitor the gases and smoke in the passageways during a fire. By interfacing these data with a computer, the best escape route could be determined and the appropriate strobe lights remotely turned on.

During the in-mine rescue team simulations conducted at LLL, strobe lights were positioned in the center of the entry about 1.8-m from the floor and in the entry crosscuts predetermined to be the best escape routes. 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 felt that by keeping their cap lamps off, the strobe lights were easier to follow. Five strobe light colors (red, green, blue, amber, and clear) were evaluated by 271 miners. Figure 4 shows that the most visible color in the nontoxic white smoke was green and the least visible color was amber. Team members were asked which device (lightstick or strobe light) did they prefer to use in smoke-filled entries. Of the 78 members who responded to this question, 80.8% favored the strobe light.

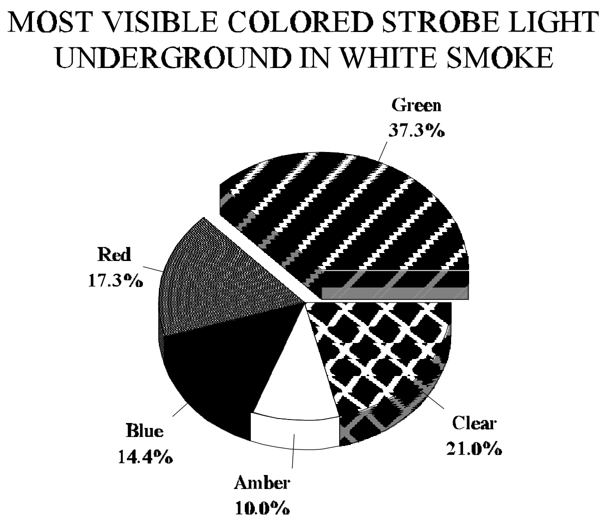

Figure 4.–Response of the rescue team members for the most visible color strobe light.

A similar simulation was conducted for underground mine personnel in a western mine. Miners, in groups of five, 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 mine (many for the very first time), but it gave them an opportunity to evaluate the strobe lights as an escape aid. Miners felt that the strobe lights at decision points were quite helpful and interfacing these devices with an audio output would enhance the use of strobe lights for mapping escapeways. The miners felt that the colored reflectors currently mounted in the center of their entries would not have helped them.

The concept of strobe lights to identify escapeways and marking mine obstacles was successful in experiments at the Lake Lynn Mine and several isolated passageways of a western mine. In a larger mine, the uncertainties inherent in a complex ventilation system would complicate this process considerably. Additional research would be required to evaluate the feasibility of using these devices in larger mines and incorporating audio output with each strobe light unit.

Laser Pointers

Commercial laser pointers are compact, lightweight, affordable, and have high quality beams. Some of these handheld battery powered pointers have ranges of up to 732 m. Two, class IIIa laser pointers, red and green, were evaluated by rescue team members. The red laser pointer, with a wavelength of 645 nm and output power of 3-5 mW, can operate continuously for 8 hrs. The green laser pointer, with a wavelength of 532 nm and an output power of 1-3 mW, can operate continuously for 2-3 hrs. The green wavelength appears brightest to the eye, so a high power is not required. Beam diameters are less than 1 mm.

These pointers, shown in figure 5, are mounted to the side of the miner's helmet with Velcro[4] or to their caplamps with hose clamps. The momentary on/off switch is modified to stay on. The captain is fitted with the green laser and the tailperson with the red laser. The laser beams were highly effective in the smoke-filled entries, allowing team members to easily determine the location of the captain and tailperson and to stay in better alignment across the entry during exploration. Figure 6 depicts the green laser beam cutting through the smoke-filled entry.

Figure 5.–Laser pointer mounted to rescue team member's caplamp.

Figure 6.–Green laser beam shining through smoke.

During other smoke training exercises, the laser pointer was effectively used to negotiate travel through a smoke-filled passageway. Approximately, 25 participants traveled 300-m in a nontoxic smoke-filled entry using a lifeline to lead them to fresh air. Visibility ranged from 0.3 to 0.9-m 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 them to the other end (no lifeline) and with their 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. The participant with the laser reached the fresh air base at the same time

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[4]Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

as the first participant who entered the smoke. The concept of laser pointers was successful in experiments at the LLL. Additional research would be required to evaluate the feasibility of using a higher power lasers to identify escape routes in smoke-filled entries or structures.

New Team Lifeline

Very often rescue team members are attached to a team lifeline connected to the main communication/lifeline that extends from the fresh air base. Team members are fixed along an 8.5-m length of rope at various distances between the captain and tail-person. Team members have reported that if one person would trip and fall, other team members would be pulled down with the falling team member. If the rope were entangled around debris, finding it was difficult.

These concerns were solved by using a high-visibility rope with filaments made of reflective material braided directly into the sheath. The reflective filaments, based on glass-bead technology, generate a return more than 1,000 times brighter than plain, white rope. Double-locking snaps were attached to both ends of the rope, with three or more snaps in-between both ends. D-shaped carabineers were then attached to the snaps. Team members, shown in figure 7, attach the carabineers to their mine belt and have freedom of movement to slide between the captain and tail-person, providing flexibility of motion to do activities such as carrying supplies, erecting temporary ventilation controls and supporting roof. This also alleviates tripping and falling problems.

Figure 7.–Rescue team members attached to new team lifeline.

Communications

Communication is a major issue and concern of rescue teams. Team members are often unable to hear other members, and at times the communication signal to the fresh air base is also faulty. This can be very frustrating to team members, especially in high stress situations.

The sound powered communication/lifeline system, developed many years ago, is the most typical system in use today. Although this type of system tends to be reliable, it does have problems. It requires the use of large cable reels (304-m of cable) and the communication usually gets scrambled as the electrical contacts in the cable reel wear. Also, good electrical connection to and along the lifeline cable is necessary. The current practice is that the tailperson, who has the earphones and microphone, talks to the fresh air base.

To address the communication concerns of mine rescue teams, the voiceducer two-way communication device was evaluated at LLL. The voiceducer, combined with a two-way radio, provides hands free two-way communications from a small device worn in the ear. Although it looks like an ordinary earphone, the earpiece contains both an accelerometer microphone and miniature receiver component. The ear microphone detects speech-induced bone vibrations via direct contact with the ear canal wall. The miniature earpiece leaves the hands free and face unobscured when worn by rescue personnel with breathing apparatus. When in high ambient noise, suitable earmuffs can be worn. The user consequently is afforded a much greater degree of freedom than has previously been possible with two-way radios.

At the LLL, a radiating transmission line, base station and repeater system along with two-way radios are used for daily communications between employees. The in-mine transmission line leaks a controlled amount of radio frequency energy over its full length so that two-way radio communication can be maintained for a considerable distance through the mine passageways and to the surface. Experiments with rescue teams at LLL indicated this system and the voiceducer showed potential. Both the captain and tailperson could communicate with the fresh air base. However, the earpiece slipped out of the ear canal at times and background noise was also a problem.

Additional research efforts could include inserting a wire antenna into the main line that extends from the fresh air base or wrapping the main communication line with a wire antenna. The latter example could serve as a backup communications system. During exploration, team members would have the antenna with them and can use the voiceducer. By having several channels on the radios, communications between team members or the fresh air base can be controlled.

Another new concept that will be evaluated with rescue teams is the head-contact microphone [Pittsburgh Post-Gazette 1998]. It is a hands-free radio microphone that can either be strapped onto the forehead or incorporated into a helmet headband. A rescue member need not speak into this microphone; it gathers sounds from vibrations transmitted through the skull and works whether the rescue member is wearing an SCBA or not. Little background noise is picked up by the microphone, so rescue members need not shout. Ear speakers are suspended on the helmet and a gloved hand can easily activate the system by touching a sensitive on/off switch.

The m-Comm communications system, developed in the United Kingdom [Operators Manual for m-Comm System 1998] was also evaluated with mine rescue teams at LLL. The m-Comm system is intrinsically safe and designed specifically for confined space and rescue applications. This system employs advanced low frequency (single wire) guide propagation techniques to achieve flexibility and dependability. The system consists of three handsets, a portable base unit, a dispenser reel holder and lightweight guide wire. The guide wire is payed out on entering a confined space. A button on the clip-on handset is pressed to talk. The handsets receive and transmit from any point along the guide wire. Experiments indicated exceptional quality of speech when one handset was used at distances of 300-m. However, when three handsets were used within the 8.5-m length of a rescue team, quality and reception degraded. The guide wire easily tangled, frayed and broke when used as intended. The same occurred when the guide wire was taped to the main team lifeline. For all practical purposes, the guide wire cannot replace the lifeline for mine rescue teams. Additional research is being conducted to see if the wiring from the current sound powered communication/lifeline system can be used for this system.

Vision Enhancement

Fire fighting and similar emergency response activities often impair vision due to dense smoke or darkness. Vision enhancement in such circumstances is a profound benefit for completing the assigned task. Infrared (IR) thermal imaging enhances the users vision when visible light is inadequate. Thermal imaging both restores vision and provides significant additional information to the user not otherwise possible to obtain. The technology increases the responder’s understanding of the environment, thus enhancing safety and the ability to accomplish the task. The first documented civilian life saved with thermal imaging technology was during a 1988 fire that occurred in New York City.

Recent improvements in the sensitivity and resolution of uncooled IR imaging sensors have provided the major enabling technology for the development of a practical helmet-mounted IR vision system [Miller 1997]. In 1995, Cairns & Brother Inc. introduced the first commercially available hands-free helmet-mounted IR imaging systems [Cairns IRIS 1995]. Firefighters can use the Cairns IRIS to see through dense smoke and darkness in structural fires. The system processes the signal and displays a black and white image that shows the hottest areas as white, the coldest as black and the temperatures between as varying shades of gray. It can detect 0.3° C differences in temperatures. The sensor is a specially coated 15-mm Germanium lens that filters out everything except 8 to 14-micron infrared radiation. A rechargeable nickel cadmium battery pack provides 30-min of continuous, uninterrupted use at ambient temperature.

The first demonstration of the Cairns IRIS in an underground mine was conducted at the LLL on February 8, 1996. The capabilities of the hands-free thermal imaging camera in the smoke-filled mine passageways suggested that it indeed had merit for reducing the time required for mine rescue exploration.

The Argus Thermal Imaging Camera (TIC) can also see through smoke and darkness. It is ergonomically designed for comfort and utility, handheld and has an angled viewfinder. Moreover, the TIC accommodates a variety of users’ positions from standing to lying prone. In low coal exploration, the innovative design reduces potential neck strain and when used in a stooping position, helps to prevent the back of the helmet from hitting the SCBA, which can occur with the helmet-mounted version. It can be easily passed on to other team members for viewing the thermal image.

Inflatable Feed-Tube Partition

When mine fires can no longer be fought directly due to heat, smoke or hazardous roof conditions, high expansion foam (HEF) may be one way to remotely quench the fire. The firefighters and HEF generator can be located away from the immediate vicinity of the fire at a less hazardous underground location. The HEF is a convenient means of conveying water to a fire [Conti 1994; Havener 1975]. It quenches or extinguishes a fire by diluting the oxygen concentration through the production of steam, blocking the air currents to the fire, and blocking the radiant energy from the fuel to other combustibles [Nagy 1960].

To effectively use the foam method for remotely fighting fires in underground mine entries, it is often necessary to construct, at some distance from the fire site, a partition or stopping in fresh air to separate the foam generator and its operators from the smoke and toxic fire products. If this is not done, the HEF could flow back over the foam generator, rendering the fire attack futile. This problem is especially acute when the fire is found uphill in a sloping entry. Concrete block, wood, plastic sheeting, mine brattice cloth or similar materials have been used for such partitions. Often, mine entries have irregular dimensions to which the partition must conform to avoid leakage around the periphery. Construction of such partitions can be a time-consuming process. After the partition is constructed, a hole must be cut through it to allow passage of the high expansion foam from the foam generator to the fire site. During a recent underground simulation for mine rescue teams and fire brigades in an operating coal mine, it required 77 min to construct a partition from wood, metal and brattice curtain, and start the foam propagating up the mine entry.

To address the drawbacks of constructing a partition for HEF generators, the inflatable feed-tube partition (IFTP) [Conti and Lazzara 1995; Conti 1994] was developed. The IFTP, shown in figure 8, is a lightweight, inflatable rectangular bag. The device can rapidly block large openings (within 15-min), such as those in underground mines, and simultaneously provide a feed-tube for high expansion foam. This allows firefighting foam to freely flow to the fire site and control or extinguish the fire.

The portable IFTP can be easily transported to a mine passageway leading to a fire area and then be inflated by a permissible fan/air blower, a compressed air line or an inert gas source (air or inert gas sources must be kept on to compensate for leakage). The fabric used for the IFTP is made from a water and heat resistant, lightweight fabric (0.076-mm thick), such as chemically treated, rip-stop nylon. The IFTP could also be fabricated from a material such as Mylar or fire-resistant materials. The shape and size of the IFTP depend on the passageway dimensions in which it may be used. For example, for a mine entry 2.1-m-high by 5.8-m-wide, the IFTP would take the shape of a slightly oversized rectangular bag approximately 2.6-m-high by 6.1-m-wide and 3.1-m-long. Experiments in the Lake Lynn Experimental Mine showed that a 2,800-L/s diesel-powered (fixed driving force), high-expansion foam generator with the IFTP could push a foam plug 245-m through an entry 2.1-m high by 5.8-wide with a 4.3 pct rise in

Figure 8.–Rescue team member wearing the Cairns IRIS and exiting the positive-pressure, inflatable escape device.

elevation, before the foam generator failed to push the foam plug further. Additional information on the use of foam and partitions can be found in the following references [Mitchell 1996; Conti 1995; Conti et al., 1998].

Positive-Pressure Inflatable Escape Device

Another conceptual use of an inflatable bag is a positive-pressure, inflatable walk-through escape device (IED). This rapidly deployed device, with its "pass-through" feature, allows extra time for personnel evacuation by isolating a smoke-filled entry from fresh air. The IED would be strategically placed in a mine entry, and then be either manually or remotely deployed during a mine fire. Evacuating miners would enter the IED from the smoke-filled entry and exit into the fresh air side. Figure 9 shows a rescue team member wearing the Cairns IRIS and exiting a smoke-filled entry through the IED.

Figure 9.–The inflatable feed-tube partition deployed in the Lake Lynn Experimental Mine.

To better maintain inflation when the IED doorways are opened, a third generation positive pressure, inflatable escape device was fabricated and successfully evaluated in the Lake Lynn Experimental Mine. The unit is a rectangular bag constructed from a heat resistant light weight fabric and is inflated by two fans, one of which is connected to an integral fabric tubing air distribution system. The IED can also be inflated by a compressed air. Large C-shaped zippered doorways on both sides of the IED allow easy entry and exit. Because the bag is under positive pressure, it is impervious too outside contaminants, such as smoke, if the air intake remains in fresh air. During a mine fire, the IED would be rapidly deployed to temporarily isolate a smoke-filled entry from fresh air. The inflating air was clean compressed air, the bag could be used as a temporary shelter [Baldwin 1996]. The use of a fan for inflation, however, would require that the fan remain in fresh air or that filters be installed on the fan to cleanse the mine air of any contaminants. Mine rescue teams could also use the IED as an airlock system during rescue and recovery operations and it could be rapidly advanced as mine recovery progressed. For this application, an inert gas source could be used to inflate the IED if necessary. The performance of the third generation IED was assessed during mine rescue team training simulations conducted in the Lake Lynn Experimental Mine. The IED was deployed in 5 to 10 minutes and isolated a smoke-filled passageway from the fresh air base. Fully equipped five to seven member mine rescue teams can enter or exit the IED without deflating the unit. The IED was also successfully demonstrated at an Open Industry Briefing on Mine Fire Preparedness held at the LLL. Briefing participants walked down a non toxic smoke-filled entry and passed through the IED to reach fresh air. This device successfully isolated smoke-filled entries from fresh air, and mine personnel effectively passed through the device to the fresh air base or back into the smoke-filled entries.

TRAINING SIMULATIONS MODULES FOR MINE RESCUE TEAMS

The "Muddy Creek" and "Red Creek" mine rescue team simulations, conducted in the Lake Lynn Experimental Mine, focused on fire fighting and ventilation techniques. The team members searched for "victims," mapped the passageways, constructed temporary stoppings, extinguished the fire and ventilated all smoke. Rescue team members donned Draeger BG-174 self-contained breathing apparatuses and traversed more than 305-m of mine passageways filled with nontoxic smoke. Visibility ranged from 0.3 to 0.5-m. The instructors' simulation map for "Muddy Creek," shown in figure 10, includes the locations of the two fatalities, an injured miner, and other pertinent information. The IED was used by rescue team members to enter the "smoke-filled" passageways from a fresh air base. Various colored chemical lightsticks identified team members and were used to mark strategic locations in the mine. In one area of the mine, a kerosene heater was used to simulate a fire and reduce the oxygen concentration to 18 pct. In another area, a 1.5 pct methane zone was established. Handheld sensors carried by the rescue team members alarmed when they entered these areas, alerting them

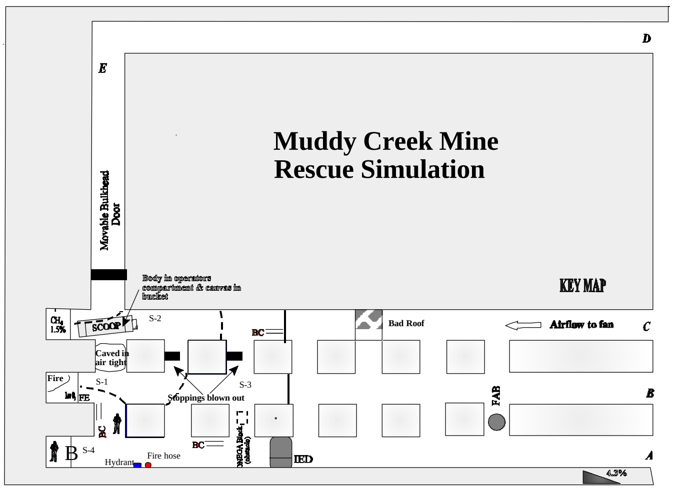

Figure 10.–Instructor's Muddy Creek Mine rescue simulation map.

to the “hazardous” condition. The “Triple R Coal Mine” simulation was one of the most aggressive mine rescue team exercises. A longwall panel fire resulted from an explosion and team members were instructed to find three missing miners. The team members moved the fresh air base, searched for “victims,” administered first aid, and mapped the passageways. In one area of the mine, a kerosene heater simulated a fire. A fiberglass duct, 81.3-cm in diameter by 6.1-m in length, was placed on the floor in one crosscut. Surrounded by an inflatable bag, the duct simulated a low roof and was the only means to enter the other entries. Two teams per day participated in the exercise. One team evaluated the Cairns IRIS helmet-mounted thermal imaging camera during exploration and the other team used conventional methods. The captain, tail-person and fresh air base from both teams used a hands-free, wireless communication system (voiceducer device). The simulation suggested that new protocols need to be developed when mine rescue teams explore with the Cairns IRIS because the team member with the thermal imaging camera can travel smoke-filled entries much more rapidly than other team members.

The “Rescue Team in Trouble” simulation focused on the backup team rescuing the exploration team. During exploration, a massive roof fall occurs behind the exploring team when the team approached a missing miner in a barricade. Communications to the fresh air base were severed. The team was trapped inby by the fall, and water to the roof sealed the only other way out of the mine. The backup team assembled, entered smoke-filled entries through the IED and determined that the rescue team was trapped. The backup team regrouped at the fresh air base and determined the only means to rescue the team was through the headgate of the longwall panel. After moving the fresh air base several times, and pumping out the water, they rescued the team and the missing miner.

One objective of the “Dog Lick” exercise was to evaluate the Cairns Iris, helmet-mounted thermal imaging camera, during exploration. Two dry stacked concrete block stoppings were built, one of which was coated with mortar on the heated side. Kerosene heaters were used to heat the back side of each stopping and simulate a fire. The missing miners stood in the center of the “hot” stoppings on the sides opposite of the heaters. The team member with the thermal imaging camera could see the person standing in front of the “hot” stopping; they appeared darker than the white wall. Wall temperatures of the coated and uncoated stopping when the missing miners were found were 35° and 44° C, respectively.

During the simulations, all problem tasks completed by the teams are tracked. For example, the data collected from “Red Creek” suggest significant differences in how teams go about exploring and solving the problems. Team-1 completed all eight tasks within 84-min. However, 85-min was required for Team-2 to complete only four tasks. The tasks for this problem included locating and extinguishing the fire, identifying the methane zone, finding the two missing miners and a mining scoop, setting up the brattice curtain, and ventilating the smoke-filled entries. The simulation suggested a wide variation in the way some teams go about mapping the entries during exploration. This includes differences within each team between the maps kept by the team map person and the fresh air base, and differences between the individual teams in deciding what information is important enough to map. Some teams document on the map everything they see and others are very sketchy; for example, the type of symbol used, or noting the location and visibility of smoke in the entry, or keeping track of the time and the lowest SCBA pressure when doing a team check.

For the conveyor belt fire training exercise, rescue team members were briefed on the protocol to be used during the extinguishment of a conveyor-belt fire. Three-person teams (under apparatus) on a short team lifeline were led into the Lake Lynn fire gallery, upstream of the developing belt fire. After 12-min, two teams of three members each carrying charged waterlines were escorted into the fire gallery through both doors. These teams controlled the rollback smoke and extinguished 7- to 9-m of burning conveyor belt.

Training simulations for rescue teams were also conducted in operating coal mines with varying seam heights (lowest of 81-cm) and metal/nonmetal mines. Various scenarios were developed depicting emergency disasters that could occur at the mine site. New rescue and exploration technologies were also used. Team members were cross-trained to perform different team duties and to work on other rescue teams. These onsite training simulations have identified issues that the mine operator must deal with during emergencies of which they otherwise would not have been aware. Key officials play a major role in the command centers as these simulations evolve and progress. The simulations offer an excellent opportunity for visiting rescue teams to become familiar with a mine for which they some day might provide emergency coverage. Training for rescue teams is also expanding into other environments, such as low and high coal seams, metal/nonmetal mines, preparation plants, etc.

At the end of each simulation, the team members answered a series of questions. These included demographics (age, mining and mine rescue experience, special training or routine tasks), usefulness of the fresh air base briefing, how the team members made decisions, anxiety levels and physical demands of the rescue operation. The rescue team as a whole was then debriefed. This open forum offers an opportunity for team members to engage in some lively conversation about the simulation. For example, how was the strategy developed for exploring the entries, and how good was the communication between team members and the fresh air base. Team members, company personnel, and State officials all agreed that the simulations are extremely beneficial. The program offers a unique opportunity to develop and conduct realistic simulations for mine rescue teams at the LLL and operating mines and evaluate technology for mine rescue operations.

Recommendations

Some recommendations to improve mine rescue team operations follow:

- Lifelines should be marked every 30-m to readily determine how much lifeline has been extended and how far the team has traveled. Perhaps, various colored tape representing the electrical resistor color code may be used for these markings.

- During exploration and mapping, the same symbols should be used by everyone. All teams, at the fresh air base and command center, should decide before hand how to identify entries and crosscuts so there is no confusion. When the backup team replaces the retreating team, this team would use both the fresh airbase and team maps of the retreating team.
- The backup teams listening to the exploring team at the fresh airbase should also be updating their maps to get a good idea of the scenario or emergency. Observations show that it is ineffective when two team members are used at the fresh air base, one member transferring the information from the exploring team to the other member who is mapping.
- The fresh air base person should use yellow markers when mapping to show explored areas for example. A green pencil may be used to show inby movements of the team and a red pencil to show the team retreating from those areas. The use of chart pack (drafting) tape in planning the ventilation scheme will eliminate the pencil markup and clutter of the map.
- When the face piece of the SCBA is not being worn by team members, it should be placed in a plastic bag for protection against the mine environment.
- An audible timer should be used at the fresh air base for 20 minute team checks (lowest team member SCBA pressure).
- Team members should carry an ample supply of first aid equipment to assist injured miners or team members.
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SUMMARY

This cooperative effort between NIOSH and the Pennsylvania Bureau of Deep Mine Safety and several mining companies offered an excellent opportunity to provide realistic training to mine rescue teams and evaluate new and existing technology that may be used for underground mine rescue operations. For example, rescue teams have identified green as the most visible colored lightstick in both white and black smoke. These teams have now added lightsticks to their cache of rescue team supplies.

Strobe lights were useful for mapping out an escape route for evacuating miners. Activation of the strobe lights by the wireless, through the earth signaling system was successful. Additional research would be required to evaluate the feasibility of using these devices in larger mines and to incorporate audio output with each strobe light unit.

During smoke training exercises, red and green laser pointers were effectively used to negotiate travel through smoke-filled passageways. The green laser pointer was the most visible color in white smoke.

By using the new team lifeline, team members have freedom of movement between the captain and tail-person. They can visually see the rope and are more flexible to do activities such as carrying supplies, erecting stoppings, and supporting roof. The team lifeline also alleviates tripping and falling problems.

Utilizing the voiceducer, with the present radiating transmission line at the LLL, has shown potential for improved wireless communications for mine rescue teams. Additional research is required to incorporate the antenna into the main lifeline.

The hands-free helmet mounted thermal imaging camera has merit for mine rescue exploration in the smoke-filled mine passageways in high entries. However, the simulations suggested that new protocols need to be developed when mine rescue teams explore with the Cairns IRIS, because the team member with the thermal imaging camera can travel smoke-filled entries much more rapidly than other team members.

Both inflatable devices have shown merit in providing a relatively rapid method for isolation of a mine fire and use with a foam generator for fire suppression, or for personnel escape and rescue. The inflatable partition can rapidly block large openings, such as those in underground mines, and simultaneously provide a feed-tube for high expansion foam. The inflatable escape device could be used as an airlock system during exploration by mine rescue teams and could be rapidly advanced as mine recovery operations progressed.

Since the onset of rescue team simulations at the LLL, several team members have decided that rescue work was not for them. Some rescue teams, who trained in smoke for the first time, were so confused that they gave up and had to be rescued. Overall, the strengths of the team and its members have improved since their initial exercise. For example, confidence levels have increased, and members are now working as a team, thinking through the problem together. Teams are successfully accomplishing their goals by replacing contest rules and placards with realistic hands-on-training exercises.

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