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National Institute for Occupational Safety and Health
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Comments to DOL

Comments of the National Institute for Occupational Safety and Health on the Mine Safety and Health Administration Request for Information Underground Mine Rescue Equipment and Technology

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

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The National Institute for Occupational Safety and Health (NIOSH) has reviewed the Mine Safety and Health Administration request for information *Underground Mine Rescue Equipment and Technology* published in the Federal Register [71 FR 4224] on January 25, 2006. NIOSH responses follow the italicized questions from the FR notice and are intended to assist MSHA in determining an appropriate course of action to improve mine rescue capabilities. NIOSH is available to assist MSHA in any other questions not specifically addressed below.

B. Breathing Apparatus

3. Do these apparatuses incorporate the best available technology? Can they be readily obtained? Do they meet U.S. approval and certification standards?

NIOSH-approved technology is the best available technology that we are aware of. NIOSH actively seeks alternative technologies but currently has no other breathing apparatuses to evaluate.

4. How can they be improved? How long would it take and at what cost?

Longer duration, lighter weight, and simplified refurbishment would all confer some advantages, but each of these would require a major breakthrough in technology. Barring such a breakthrough, it is difficult to conceive of devices that are significantly improved over those currently in use.

C. Self-Contained Self-Rescuers (SCSR)

1. *Is there more effective technology to protect miners than the SCSRs currently available? If so, please describe.*

Potential improvements to current SCSRs include the following:

(a) A hybrid system combines an SCSR with an air-purifying respirator. Prototypes of this type of respirator were discussed at NIOSH/MSHA sponsored Self-Contained Self-Rescuers Breathing System Workshops (June and December 2005) held in conjunction with the National Technology Transfer Center (NTTC) of Wheeling Jesuit University.

(b) A dockable (piggyback) SCSR includes additional SCSR units connected (snapped) to the initial SCSR, thus eliminating the need to make multiple donnings. This system has similar benefits to the hybrid system.

2. Should an SCSR be developed that provides more than one hour duration of oxygen? What duration is feasible considering that miners must carry the SCSR? Would it be desirable to require smaller and lighter SCSRs with less oxygen capacity to be worn on miner's belts while at the same time requiring longer duration SCSRs to be stored in caches?

Most one hour duration SCSRs are belt-wearable; longer duration SCSRs may be bigger and heavier. Reducing the duration requirement for the SCSR carried on the belt has the advantage of reducing weight; however, shortening the duration of the first-donned unit increases the chance that multiple donnings will be required to make an escape. In addition, different duration SCSRs will require different designs. Such systematic issues should be carefully considered when deciding whether to require SCSRs with either greater or lesser durations.

3. MSHA standards require each mine operator to make available an approved SCSR device or devices to each miner. Should mines be required to maintain underground caches of SCSRs for miners to use during an emergency, or should each miner have access to more than one SCSR?

A sufficient number of SCSRs need to be provided so that each miner can make an escape on foot and with enough oxygen from the deepest point of penetration in the mine to a point of safety.

4. SCSRs are currently required to be inspected at designated intervals pursuant to 30 CFR 75.1714-3. Should SCSRs be inspected more frequently than the current requirements?

Current MSHA regulations regarding the inspection of SCSRs are sufficient.

5. SCSR service life is determined by MSHA, NIOSH and the device's manufacturer. The service life can range from ten to fifteen years depending on the type of SCSR. Should the service life of SCSRs be reduced to five years or a different time limit?

Data collected through the NIOSH/MSHA Long-Term Field-Evaluation of SCSRs [NIOSH 2002] has not indicated that the age of the SCSR alone is the most important issue. Rather, more emphasis should be placed on the inspection of SCSRs in order to remove those that have suffered degradation due to other physical factors.

D. Rescue Chambers

NIOSH has the following general comments regarding rescue chambers ("emergency shelters") in underground coal mines, allowed for, but not mandated by 30 CFR 75.1500.

Deploying rescue chambers impacts mine rescue strategy and practices. Rescue chamber planning requires a systematic approach that includes a risk assessment of miner workplaces, escape strategies, potential entrapment scenarios, rescue team availability and approaches. Technical details of how to construct rescue chambers, as well as practical deployment considerations, are described in McCoy et al. [1983]. In the United States, rescue chambers in coal mines are almost nonexistent. An example of a rescue chamber is found in an underground coal mine operated by Peabody Energy, Twentymile Mine, which has used a stationary rescue chamber located in the middle of the headgate development entries of an exceptionally long longwall panel to provide shelter if crews could not escape by walking out. The chamber is connected to a surface borehole.

A comparable concept to a rescue chamber that MSHA may wish to consider is the "safe haven" which is meant as short duration shelter where escaping miners can rest, get a drink, replace their SCSRs, and communicate to the surface during their escape [Forster 1997].

1. *Should rescue chambers be required for coal mines?*

Escape from a mine is the primary survival strategy. If escape is impossible because all available escape routes are blocked, miners are trained to barricade and wait for rescue as a last resort. The presence of a rescue chamber may cause miners to wait there, possibly decreasing their chance of survival compared to escaping [McCoy et al. 1983]. A systematic risk assessment should be conducted at each mine site to evaluate the effectiveness of mine evacuation capabilities and plans, which would include, but not be limited to, the practicality of refuge chambers or safe havens. In summary, McCoy et al. [1983] may provide helpful information for conducting a risk assessment. In addition, NIOSH is available to assist MSHA in developing an approach for a risk assessment protocol for evaluating the effectiveness of mine evacuation capabilities and plans.

2. *What characteristics should they have? Should they be mobile? Should the rescue chamber be semi-permanent, or built into the mine?*

Work done by the Bureau of Mines has indicated a host of engineering difficulties with the refuge chamber concept [NRC 1981]. Highly productive coal mining sections (both development and longwall faces) advance at rates averaging 50 to 100 feet per day. If a fire, explosion or inundation threatens miners at or near the production face, a stationary rescue chamber located several thousand feet outby (away from the production face) may be of little use.

However, stationary chambers can be connected to the surface through a borehole, providing for fresh air and exhaust, food and water supply, waste disposal and communications. Through the borehole, fresh air in the chamber can be kept at an overpressure, preventing toxic mine gases and smoke from entering the chamber. Stationary chambers can be excavated to any desired height even in low coal seams.

A mobile chamber that is advanced with the production section can be kept close to the face crews. However, use of mobile chambers presents several problems:

- Sufficient quantities of supplies (oxygen, CO_2 scrubbing chemicals, water, food, lavatory chemicals, first aid) and equipment (communications, air quality monitoring) must be carried along as well.
- Mobile communication paths (wireless or wire-bound) are ultimately tied to mine entries and are therefore susceptible to damage from fires, explosions or roof falls. Prototype solutions exist for through-the-earth communications that may merit further development.

- Maintaining a breathable environment inside a mobile chamber requires provision of oxygen and removal of waste gases such as CO_2, as well as exclusion, absorption or neutralization of toxic gases (CO, NO_x, H_2S) that may be found inside the chamber after a fire or explosion, or that may enter the chamber as miners enter or exit the chamber even if an airlock is provided.
- If atmospheric conditioning requires electric power, such power must be provided independently from mine power. Mechanisms of air conditioning are discussed in Venter et al. [1999] and McCoy et al. [1983]. CO scrubbing is difficult, especially if positive pressure cannot be maintained inside the chamber, because of the possibility for CO to enter from the mine atmosphere [Brenkley et al. [1999].
- The available height of the coal seam presents an important consideration for mobile rescue chamber design, especially if miners are expected to use the chamber for multiple days.
- Mine explosions often occur as a consequence of a mine fire when explosive mixtures of methane and air exist in the mine. They can create shockwaves of excessive pressures that may damage rescue chambers and/or injure those inside the chamber.
- In case of inundation, the rescue chamber must be able to withstand water pressure.

4. How many people should they support?

If the chambers advance with the production faces, they need to support all crew members who normally work at the face plus those who may be present at the face occasionally, including but not limited to maintenance and outby support crews, firebosses, inspectors, and visitors. Also, consideration must be given to accommodating two full crews if they change shifts at the face.

Minimum required space for personal comfort is 15 ft^2 per person [McCoy et al. 1983], although no assumption about height is made since that is determined by the mining height and mobility requirements. To accommodate 15 people for comfort, an area of 225 ft^2 or 14 ft of entry, 16 ft wide, is needed.

5. How many rescue chambers should be required--how far apart should they be located?

In determining the number and spacing of rescue chambers, MSHA may wish to consider research by Forster [1997] in the United Kingdom. It was shown that a miner could reliably travel up to 2000 meters (m) with a 60 minute (min) SCSR at breathing rates of 40 to 45 liters/min. With good visibility and comfortable conditions, the average pace of travel while wearing an SCSR was 50m/min. However, when escape conditions were hot and humid, the experiments revealed SCSR operational times as low as 30 minutes for saturated environments above 32°C. Hot conditions combined with low visibility from smoke reduced travel distance to less than 600 m. The tests did not involve travel up a grade or the use of lifelines.

Besides the impacts of adverse conditions on the time required to escape and the operational times of SCSRs, other factors must be considered in determining the number and spacing of rescue chambers:

-mine layout,

-number of miners

-number of working sections in the mine,

-escapeway layout,

-distance to the nearest shaft or surface opening,

-accessibility by mine rescue teams,

-risks of flooding in case of pump or power failure,

-ventilation, and

-potential for accumulation of explosive gases.

NIOSH is available to work with MSHA to develop rescue shelter location guidelines.

E. Communications

1. What types of communication systems can be utilized in an emergency to enhance mine rescue?

During disasters, wire-based communications systems may fail due to fires, roof falls, explosions tearing down wires, power failure, or battery failure. A portable through-the-earth (TTE) system likely will have the best chance of providing contact with miners since it offers the best resistance to damage from roof falls, fires and explosions.

Another possibly applicable technology is a wireless mesh network based on wireless fidelity (WiFi) technology and employing transmission control protocol/internet protocol (TCP/IP)-based data protocols. Wireless modems would be strategically placed throughout the mine; each unit would receive, transmit, or act as a signal repeater. This multi-hop style network would be designed to be redundant and could automatically re-configure itself should one repeater or more fail due to loss of power or an event such as a fire or a roof fall. The application of this type of network could greatly enhance the reliability of a wireless coal mine network. A wireless mesh network can also provide monitoring of environmental variables throughout the mine. Continuous CO, CH_4, and temperature measurements could be provided along the path of the rescue team or in other desired areas.

If emergency communications depend on the existing mine communications system (e.g., a MESH network), all equipment would have to be powered independent of mine power and be able to survive a blast or fire. Research will be needed to harden this type of equipment, develop reliable redundant transmission paths, and provide intrinsically safe backup power solutions. A communication system independent of the mine infrastructure and connected directly to mine refuge areas may be an effective alternative for mines that cannot use TTE.

Miner tracking is an additional communications research need; existing systems do not pinpoint miner location or function if mine power is lost. Research is needed to develop systems that rescuers can use to quickly locate miners, especially those that are not able to communicate.

2. Current systems include permissible hand-held radios, hand-held radios using small diameter wires, pager systems, sound powered telephones, leaky feeder systems that ``leak" radio signals out of and into special cables, and inductive coupled radios that use existing mine wires as a carrier for radio signals. Are there other systems?

Additional systems include the following:

- Wireless radios afford the miners the most flexible, portable, and instantaneous communication. However, radios can require an elaborate support structure to compensate for the poor radio signal propagation environment of a coal mine. TTE radios do not require such a support structure; the predominant VHF and UHF band radio support structure is called a "leaky feeder."

- A new concept using radio in mines is WiFi, as mentioned in the response to question E1 above.

- Some systems no longer require the backbone infrastructure (Leaky Feeder). These systems require strategically placed wireless repeaters and are digital, which opens up new possibilities, including simultaneous delivery of voice (voice-over internet protocol [VOIP]), data, and video over the link.

- There has also been a merging of Leaky Feeder, Ethernet, and WiFi technologies. A few cell phone vendors now market a phone that combines standard cell phone communications protocols such as Global System for Mobile communications (GSM) and WiFi. With the appropriate software installed in a personal computer at the mine office, and a WiFi network installed in the mine, a miner can walk into the mine and continue to use his cell phone. Permissibility is still an issue for this equipment.

- Radio Frequency Identification (RFID) provides tracking and accountability of persons and other assets. RFID is provided by Leaky Feeder, WiFi, and other wireless system types used in mines.

New systems should be redundant to provide reliability and interoperable to provide the communication link necessary when one system or part of a system fails during a disaster.

4. What new communication devices or technology may be well suited for day-to-day operations and also assist miners in the event of an emergency?

Though not an electronic communication issue, verbal communications used in an emergency are critical. NIOSH developed the Emergency Communication Triangle safety talk, a training intervention designed to help miners giving a warning to provide the right information, and miners receiving a warning to ask the right questions [Vaught et al. 2000]. NIOSH researchers worked with safety professionals to determine what sorts of information are critical in a mine emergency. An extensive list of some 150 items was collapsed into six groups and a communication protocol was derived from these categories. The Emergency Communication Triangle was packaged as a short safety talk to be given by supervisors at the start of the shift. The package consists of a brief instructor's guide and an advance organizer to help workers remember the most important aspects of the safety talk. The objective of the talk is to inform miners about the importance of effective emergency communications and to teach them the six steps of the protocol.

6. How can the number of relay points be minimized in a rescue situation so that communications do not get garbled or misunderstood?

Reducing the number of relay points may not improve voice clarity; the greatest improvement to intelligibility may lie in the selection of microphones and earphones used by the particular system. Advances with systems used by firefighters are identified in the NIOSH [2003] contract report Current Status, Knowledge Gaps, and Research Needs Pertaining to Firefighter Radio Communication Systems.

7. How can communications be improved when a rescuer is wearing a breathing apparatus and talking through a speaking diaphragm in the mask?

The NIOSH [2003] contract report Current Status, Knowledge Gaps, and Research Needs Pertaining to Firefighter Radio Communication Systems provides additional information on devices to improve the intelligibility of voice while using a breathing apparatus. To counter problems with distortion and inaudible radio communications while wearing self-contained breathing apparatus (SCBA), some equipment manufacturers have designed integrated microphone and speaker systems into SCBA. Depending on the manufacturer, some of these systems use a bone microphone that is worn or integrated into the SCBA facepiece. Speakers are often a modified headset that fits in the ear, under the SCBA facepiece and other protective gear. Most include a large, easy to operate push-to-talk button for use while wearing gloves. These systems increase the clarity of radio transmissions, reduce the amount of feedback from radios being too close to one another, and increase the likelihood that the transmission will be heard and understood. Location of the microphone in relation to the mouth and SCBA can be important with some radio systems.

The clarity with which the transmitting person speaks, coupled with the volume of the transmission, will drive the audibility of the message at the receiving end. Well thought-out, clear, and concise messages are important characteristics to employ during radio transmissions. Noncritical messages increase the radio traffic and may prevent emergency messages from being transmitted. See the response to E4 for additional information on improving communication during a mine emergency.

G. Thermal Imagers and Infra-Red Imagers

4. Should all underground mining operations be required to have one of these devices available on-site?

NIOSH research has demonstrated the value of modern day thermal imaging cameras (TIC) during underground mine rescue team exercises at the NIOSH Lake Lynn Laboratory [Conti and Chasko 2002]. A rescue team member with a TIC was able to explore smoke-filled entries and detect "hot" spots or injured miners more rapidly than team members without the device, thus reducing the time for mine rescue exploration. The training simulations also indicated that new protocols are required to optimize the benefit of the TICs during search and rescue operations since they allow the team member with the device to travel through smoke-filled entries much more rapidly than other team members. One approach would be to have a retractable line attached to the person using the TIC. In this manner, the team member with the TIC could examine an area independent of the other team members while still being attached to the team life line and report back the findings. TICs were also useful during advanced fire fighting exercises for mine rescue teams and when fire brigades were extinguishing conveyor belt fires or diesel fuel fires in the Lake Lynn surface fire gallery. The black smoke from the fires was so dense that the team members could not readily locate the fire. The person using the TIC was able to view the fire and the hot smoke and gases at the roof, and better direct fire fighting operations.

TICs may also be used in mines for detecting potential fire problems in areas such as conveyor belt entries and power centers. TICs may aid miners during welding and flame cutting operations to ensure hot residue and slag is sufficiently cooled and the area properly inspected for incipient fires, and in detecting spontaneous combustion events.

Current TICs require too much power to meet intrinsically safe requirements. However, mine emergency responders should have access to TICs when lives are at risk. TICs could be used by mine rescue teams in exploring entries that do not contain flammable atmospheres as determined by hand-held gas detectors. Manufacturers should be encouraged to develop lower power, lower cost permissible devices. It is important that personnel using TICs be properly trained because seeing with a TIC is different than with natural vision, requiring some interpretation by the user.

I. Mine Rescue Teams

5. MSHA requirements for mine rescue teams are found in 30 CFR part 49. These requirements cover such topics as type of equipment, equipment maintenance, team membership and training. What other equipment, technology, membership requirements and training would facilitate or would better facilitate team preparedness?

In partnership with State agencies and mining companies, NIOSH is developing, conducting, and evaluating training exercises for mine rescue teams at the Lake Lynn Laboratory and operating mines [Conti et al. 2005; Conti and Chasko 2000; Conti et al. 1999; Conti and Chasko 2004]. Team members explore smoke-filled entries, erect roof supports and ventilation controls, combat fires, and rescue "injured" miners. Advanced fire fighting training is also conducted for mine rescue teams in the Lake Lynn surface fire gallery. Direct feedback from the participants indicates that this type of realistic training is the best preparation for actual emergencies.

The simulation exercises also allow for evaluation of technologies for improving the safety and effectiveness of mine rescue teams. Items that were highly rated by team members and that could assist mine rescue teams in mine emergencies include chemical light sticks, strobe lights, lighted team link lines, life line pulleys, hand-held laser pointers, TICs, and improved communication systems.

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