A Review of Mine Rescue Ensembles for Underground Coal Mining in the United States

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ABSTRACT

The mining industry is among the top ten industries nationwide with high occupational injury and fatality rates, and mine rescue response may be considered one of the most hazardous activities in mining operations. In the aftermath of an underground mine fire, explosion or water inundation, specially equipped and trained teams have been sent underground to fight fires, rescue entrapped miners, test atmospheric conditions, investigate the causes of the disaster, or recover the dead. Special personal protective ensembles are used by the team members to improve the protection of rescuers against the hazards of mine rescue and recovery. Personal protective ensembles used by mine rescue teams consist of helmet, cap lamp, hood, gloves, protective clothing, boots, kneepads, facemask, breathing apparatus, belt, and suspenders.

While improved technology such as wireless warning and communication systems, lifeline pulleys, and lighted vests have been developed for mine rescuers over the last 100 years, recent research in this area of personal protective ensembles has been minimal due to the trending of reduced exposure of rescue workers. In recent years, the exposure of mine rescue teams to hazardous situations has been changing. However, it is vital that members of the teams have the capability and proper protection to immediately respond to a wide range of hazardous situations. Currently, there are no minimum requirements, best practice documents, or nationally recognized consensus standards for protective clothing used by mine rescue teams in the United States (U.S.). The following review provides a summary of potential issues that can be addressed by rescue teams and industry to improve potential exposures to rescue team members should a disaster situation occur. However, the continued trending in the mining industry toward non-exposure to potential hazards for rescue workers should continue to be the primary goal. To assist in continuing this trend, the mining industry and regulatory agencies have been more restrictive by requiring additional post disaster information regarding atmospheric conditions and other hazards before exposing rescue workers and others in the aftermath of a mine disaster. In light of some of the more recent mine rescuer fatalities such as the Crandall Canyon Mine and Jim Walters Resources in the past years, the direction of reducing exposure is preferred. This review provides a historical perspective on ensembles used during mine rescue operations and summarizes environmental hazards, critical elements of mine rescue ensembles, and key problems with these elements. This study also identifies domains for improved mine rescue ensembles. Furthermore, field observations from several coal mine rescue teams were added to provide the information on the currently used mine rescue ensembles in the U.S.

Keywords: mine rescue ensemble; protective clothing; personal protective equipment; fire fighter; mining

INTRODUCTION

The mining industry is among the top ten industries nationwide with high occupational injury and fatality rates [1], and mine rescue operations are a relatively high risk activity in underground coal mining. Mine rescue team members must be prepared to respond when an emergency occurs and take the necessary precautions required to ensure worker safety. It is vital that members of the teams have the capability and proper protection to immediately respond to a wide range of hazardous situations. Their ensembles need to be able to protect them from hazards that they may encounter. In addition, mine rescue team members must know the limitations of their personal protective ensembles.

Mine Safety and Health Administration (MSHA) defines "mine rescue" as "the practiced response to a mine emergency situation that endangers life, property, and the continued operation of the mine".

The primary objective of mine rescue is described as preventing loss of life, and the secondary objective is the safe recovery of the mine and its return to normal production. In its earliest days, mine rescue was an unsystematic effort. Rescue "parties" were groups of miners and other volunteers who happened to be at the mine site at the time of the disaster. These groups had no training, no equipment, and no reliable breathing gear; and frequently, their names were added to the list of those who died in the disasters [2].

The history of anthracite coal mining in Pennsylvania was marked by an alarming increase in the number of fatalities in the late 1800s. One hundred and eight miners and two mine rescuers were killed in 1869 at the Avondale Mine in Plymouth, Luzerne County, PA when a surface fire blocked the exit of the mine. After increasing each year, the number of occupational coal mining fatalities in underground coal mines in the U.S. surpassed 500 by 1896. *Figure 1* highlights coal mining disaster incidents and the fatalities between 1900 and 2010 [3]. As a result of these fatalities, the first formal mine rescue teams were organized and trained in the 1900s [2,4,5].

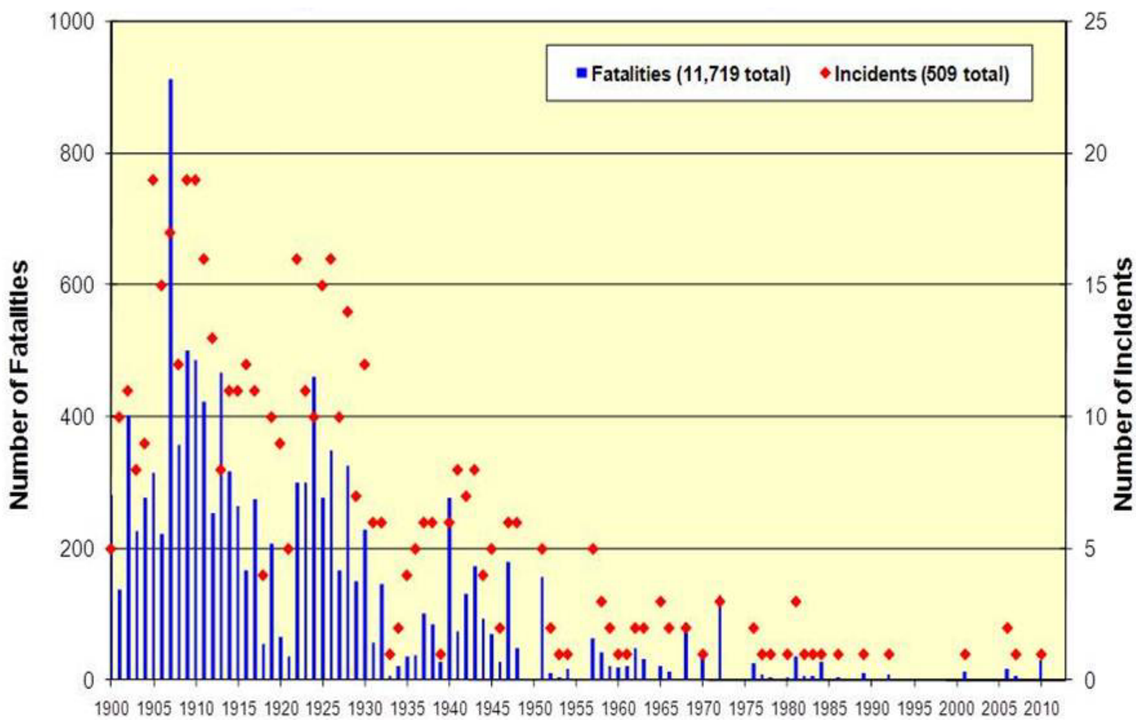

FIGURE 1. Coal Mining Disaster(*) Incidents and Fatalities[3]
(*): A mining disaster is an incident with 5 or more fatalities Data Source: MSHA

Right after its establishment in 1910, the United States Bureau of Mines (USBM) undertook a program of obtaining railroad passenger cars and modifying them into mobile stations for mine rescue and first aid training. These cars were equipped with breathing apparatuses and carried a crew of six men, each trained for a specific duty in regards to mine rescue and first aid [4].

While trying to save the lives of others, mine rescue team members have been injured and killed. Since 1900, 11,719 underground coal mine workers died in 509 U.S. underground coal mining disaster incidents, with most disasters resulting from explosions [3]. Also, since the Avondale Mine Disaster in PA in 1869, 125 rescue workers were killed during the rescue efforts (see *Figure 2*). The most common events of the incidents were, explosion, mine fire, inundation (the sudden inrush of water or toxic gases from old workings), seismic jolt, and mine collapse [6]. It should be noted that these rescuers were not all members of formal mine rescue teams. Many were other miners who happened to be at the mine or in the area and responded without donning any mine rescue ensemble.

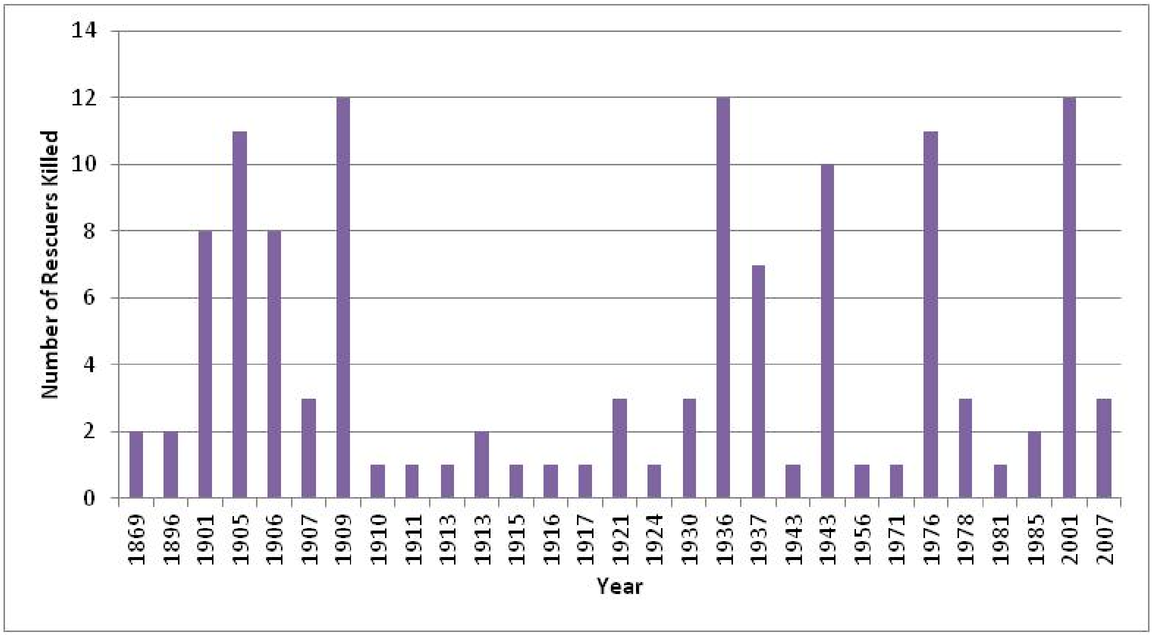

FIGURE 2. Mine Rescuers Killed at the Mine Accidents (**) [6]
Data Source: http://www.usmra.com/rescuer_deaths.htm#usa
(**) The United States Mine Rescue Association (USMRA) acknowledges that the disasters listed here may not be the only ones where rescuers were killed.

In 2006, there were three major underground coal mining accidents: Sago (January 2, 2006, explosion, 12 miners died), Aracoma Alma (January 19, 2006, belt fire, 2 miners died) and Darby Mine # 1 (May 20, 2006, explosion, 5 miners were killed). After three mine disasters in five months, the Miner Improvement and New Emergency Response (MINER) Act was signed on June 15, 2006 to improve accident preparedness and response [7, 8]. The other requirements of the MINER Act were in regards to the development of written emergency response plan, use of equipment and technology, additional mine rescue team training requirements, teams' response time, civil and criminal penalties, establishment of a competitive grant program for new mine safety technology, and an interagency working group to provide a formal means of sharing non-classified technology that would have applicability to mine safety. The MINER Act of 2006 introduced a significant change in mine rescue. However no information with regard to the minimum level personal protective equipment (PPE) required for mine rescue operations was included.

The most recent tragedy where mine rescue team members were killed, happened on August 6, 2007 when a catastrophic coal outburst accident occurred at the Crandall Canyon Mine, in Emery County, Utah. Two mine rescue team members employed by the coal company and one MSHA mine rescue team member died due to injuries received during the roof collapse. Six additional mine rescue team members, including one MSHA member, were also injured. Underground rescue efforts were suspended following these fatalities [9].

There is very limited information available in regard to the ensembles worn by the mine rescue teams during the mine disasters. However, it can be stated that in general, the ensembles used during the incidents include a typical mining coverall which is made of cotton or cotton/polyester blends and not fire resistant, helmet, cap lamp, boots, kneepads, facemask, breathing apparatus, belt, and suspenders [10]. During some of the mine disasters, such as explosions, it may be extremely difficult to protect mine rescue team members and prevent the injuries and/or fatalities through the use of a more encompassing ensemble or any kind of PPE; however, in other cases such as fire fighting, providing first aid, and recovering, the injuries or fatalities can be decreased by using ensembles designed to reduce exposures or the consequences of the exposures. These ensembles should also be ergonomically designed and aid mine rescue teams in their tasks. Thus, it can be stated that there is a room to improve the safety, health and performance of mine rescue team members by specifying the mine rescue ensemble elements and identifying the minimum performance and design characteristics of the mine rescue ensembles.

Today’s mine rescue efforts are highly organized and very cautiously managed operations carried out by groups of trained and skilled individuals who work together as a team[2]. Regulations require all underground mines to have fully-trained and equipped professional mine rescue teams available in the event of a mine emergency. Currently, there are 217 underground coal mine rescue teams with a total of 1888 members in the U.S.[11].

MINE RESCUE TEAMS and THEIR TASKS

Mine rescue and recovery involves a wide variety of tasks. The way that the mine rescue teams respond varies according to the type of mine emergency and the type of the mine being entered. Conditions within the mine also determine what the team will be required to do. MSHA defines some of the tasks that may be required during an actual emergency by mine rescue teams as [2]:

- Exploring the affected area of the mine
- Searching for and rescuing survivors
- Performing first aid
- Determining the extent of damage
- Determining gas conditions
- Mapping the team’s findings
- Locating and fighting fires
- Building temporary and/or permanent stoppings/bulkheads
- Erecting seals in a fire area
- Clearing debris, pumping water, and installing or erecting temporary roof supports

A mine rescue team for underground coal mines consists of a minimum of five members (see *Figure 3*), plus one alternate, who are fully qualified, trained, and equipped for providing emergency mine rescue response. The six team positions usually include [12]:

- captain who leads the team
- gas person who backs up the captain and checks for the presence of gas
- map person who maps locations of conditions in the mine and actions taken by the team
- stretcher person who pulls the stretcher
- tail person or co-captain who receives orders from the fresh air base briefing officer and relays information from inside the mine to the fresh air base, and
- briefing officer who remains at the fresh air base and directs the teams according to Command Center order, and also informs the Command Center of mine conditions found during exploration.

FIGURE 3. Mine rescue team members.

Prior to serving on a mine rescue team, each member of a coal mine rescue team must complete, at a minimum, an initial 20-hour course of instruction as prescribed by MSHA, in the use, care, and maintenance of the type of breathing apparatus which will be used by the mine rescue team. Upon completion of the initial training, all team members are required to receive at least 96 hours of refresher training annually [8]. This refresher training may include: a written test, bench testing of the breathing apparatus, first aid, fire fighting, locating miners, smoke training, and proper techniques for evaluating for noxious gases, mine mapping, ventilation controls, and proper techniques for examining the overall conditions of the mine. The type of clothing and equipment used by the team members do not differ by the member's role or the type of the activity (providing the first aid, fire fighting, or exploration.

RECENT RESEARCH/ CURRENT PRACTICES

MSHA regulates the PPE of miners and mine rescue personnel and accepts non-MSHA product safety standards or groups of standards [13]. The Code of Federal Regulations (CFR) 42 Part 84 which was updated on March 8, 2012, addresses National Institute for Occupational Safety and Health (NIOSH) and MSHA certification requirements for respiratory protective devices [14]. The American National Standards Institute (ANSI) and International Safety Equipment Association (ISEA) standard ANSI/ISEA Z 89.1-2009 [15] Type I, Class G contains requirements for helmets used in mine rescue. MSHA requires compliance with CFR 30 Part 49 – Mine Rescue Teams [16], which covers mandatory types of equipment, equipment maintenance, team membership and training. However, Part 49 does not specify requirements for the clothing elements of the ensemble used by mine rescue teams.

Although there have been many studies on respirators, communication devices, thermal and infra-red imagers, and training of mine rescue teams, research on ensembles for mine rescue teams in the literature is extremely limited. The only study available on mine rescue ensembles is a special report prepared for the USBM [17], although some studies are available on fire brigade teams and heat stress/heat strain issues of miners, mine rescue teams and fire fighters [11, 18-32].

Tuck reviewed the methods currently available for application of microclimate cooling garments within the mining industry and suggested a possible new design of a cooling jacket [19]. He also added that there is potential use of such garments in mine rescue applications where the normal means of cooling can be inapplicable and the thermal loading can be very high on rescue personnel. Kampmann and Bresser conducted a climatic exposure for the 52 mine rescue brigadesmen while they wore flame protective clothing [20]. They looked for individual parameters allowing prediction of tolerated exposure times in the climate tested and found that only body temperature at the end of the Stoklossa heat tolerance test and physical fitness show significant influence on the tolerated exposure time, although not very prominently. They found no significant influence of age, body mass, and Body Mass Index (BMI) on the tolerated exposure time. Additionally, the authors found during a longitudinal study that the tolerance time within the climate for four subjects shows considerable variations, and decided neither to take the result of the heat tolerance test as admittance criterion for the mine rescue service nor to perform a ranking of brigadesmen with respect to heat tolerance by this test. More recently, Kampmann et al. reported a similar study with four mine rescue brigadesmen performing three different standardized trainings in uncompensable heat stress with different equipment, clothing and climatic stress [27]. The strain during these trainings may be considered as typical for training and missions of firemen and mine rescue brigadesmen. The subjects repeated the diverse trainings each year for ten years and heart rate and body temperature were recorded throughout the exposures. The authors found a significant linear trend over time only for body mass (increase in three of the subjects). Also, specific physical fitness (fitness per body mass), heart rate, and body temperature showed no significant trend over time for initial or final values. Hardcastle et al. also recently reported a four year project which includes a review of heat exposure guidelines; mechanical and energy expenditure characterization of standard mining tasks; survey of the environmental conditions in Canadian mines; laboratory simulation of the tasks under controlled conditions; laboratory evaluation of heat guidelines, field validation; acclimation studies; and an instrumentation evaluation [25]. They showed a high level of variability in the duration and intensity of tasks performed within each mining job. It has been shown that the different mining jobs involve the execution of very similar tasks; however, the relative intensity of these tasks varies among jobs. Despite the large intervariability in energy expenditure and work intervals among jobs, they observed only small differences in average core temperature, suggesting that self-pacing may play a significant role in mitigating the level of physiological strain of miners in mechanized mines. They concluded that under hotter work conditions, workers in Canada's mechanized mines may be at an elevated risk of heat induced fatigue or injury [32].

The type and the level of the activities and protection needs of wildland fire fighters can be considered similar to underground coal mine rescuers. There have been a few research studies reported in the area of protective clothing of wildland fire fighters. Raimundo and Figueiredo showed that besides the improvement of personal protective clothing properties, the safety of wildland fire fighters is essentially related to good control of the exposure times to the high intensity radiation fluxes [29]. The authors used a mathematical multi-node thermoregulation model which enables the simulation of the dynamic response to the conditions that can occur when an individual is fighting a fire. They found that increasing the clothing vapor permeability has only a small influence on the times for the beginning of undesired reactions within the fire fighter, although higher values of vapor permeability are always advisable. Also, they reported that augmenting the clothing insulation increases the times for introversion (violent sweating, loss of judgment, amnesia, etc.), heat stroke and death, and ensembles with high values of insulation restrict movements of the wearer. Hockey and Rew summarized the simplified models more frequently used to calculate the probability of fatality from exposure to thermal radiation [30]. Richards and Fiala used a thermoregulation model to describe the physical response of men fighting fires [31]. The authors measured the clothing heat and moisture transport properties of three fire fighter suits using a sweating agile thermal manikin. With this data, the dynamic physiological responses obtained with a multi-node model of human thermo physiology were compared with 18 wear trials, and there was a good agreement between the experimental and calculated values.

HAZARD EVALUATION

Some of the dangers encountered in mines may include toxic gases or low oxygen levels, rotten timbering or no ground support at all, unseen dry-rot in bulkheads, invisible vertical shafts to lower levels, poisonous insects or snakes, frightened animals, and old explosives[33].

When rescue teams are called out in irrespirable atmospheres (toxic gasses or lack of oxygen) and under difficult climatic conditions, the following dangers may arise:

- Carbon monoxide and/or carbon dioxide poisoning
- Lack of oxygen
- Circulatory control failures
- Heat build up

Human error, self-overestimation, lacking physical conditions, nervous stress as well as leaking breathing tube connections and faulty equipment or accessories may lead to accidents [34].

From the literature review and meetings conducted with the mining personnel from extensive locations of U.S., it was determined that the main events for mine rescue fatalities and injuries of the 30 previous coal mine disasters include, coal bump/bounce (e.g., Crandall Canyon mine disaster), explosions (e.g., Scotia mine disaster), heat stress, slips and falls, roof falls, rib rolls (a slab of coal from a left over block of coal comes loose), asphyxiation (suffocation), burns from fire, overcome in a rescue, drowning during fire fighting, and overcome by carbon monoxide [5,8,9]. Sometimes rescue effort without PPE or adequate gas test equipment resulted in the injuries or fatalities. During some of the mine disasters, such as explosions, it may be extremely difficult to protect mine rescue team members through the use of any kind of PPE, however, in other cases such as fire fighting and providing first aid, the injuries or fatalities may be reduced by evaluating the hazardous conditions of the events and using ensembles designed to meet the needs.

It is crucial to understand the operating environment/hazards and duties to investigate the requirements for PPE for mine rescuers. According to a study report presented to USBM, environmental conditions for mine rescue operations can be summarized in the following categories [17]:

- *Toxic Gases, Smoke and Particulate Matter:* Methane, carbon monoxide, carbon dioxide, hydrogen, nitrogen oxide, sulphur dioxide, ethane, propane, butane, smoke, and other toxic and irritating material require the use of adequate respiratory protection [36].
- *Temperature:* The temperature in an underground coal mine varies with condition and location. Field study data show that a mine rescue team may operate in an environment ranging between 50°F and 150°F and on occasion may be exposed to even higher temperatures. The exposure time to the high temperature is usually no more than a few minutes because of the limits of human endurance.

- *Heat:* There are three modes of heat transfer: conduction, convection, and radiation. In mine rescue situations, the contact temperature can be as high as 1000°F-1200°F (conduction) and hot gas temperatures can range from 100°F-1500°F (convection). Flames are the greatest source of radiant energy but other materials may radiate too. At fire scenes, where direct contact is not made with a hot object, the heat load is comprised of both radiant and convective fractions, with convection being the small portion of the total heat loads.
- *Flame:* The rescue and recovery team is infrequently in direct contact with flame. Whenever contact is made with flame, it is usually the result of a falling ember and only lasts a few seconds. However, rescue teams called upon to fight fire will be directly exposed to flames.
- *Water:* The primary problems associated with water arise when the team gets wet, possibly soaked, all the way through their undergarments. The clothing becomes uncomfortable, and the weight of the water absorbed contributes substantially to fatigue. Also, a wet garment may result in steam burns, if the mine rescue team member suddenly comes in contact with a heat source.
- *Bloodborne Pathogens:* During the recovery of injured miners and providing first-aid, teams may be exposed to bloodborne pathogens from blood and body fluids.

CRITICAL ELEMENTS OF MINE RESCUE ENSEMBLES

The mine rescue ensemble is defined as the integrated elements of the rescue team's personal protection system. The function of the mine rescue ensemble is to improve the wearer's protection against hazards such as heat, flame, toxic gases, smoke, penetration, impact and water. The elements include (*Figure 4*):

- *Protective Garments and Equipment for Body Protection* - helmet and hood for head protection, ear protection (rarely used), coverall or pant/jacket for torso and limb protection, gloves for hand and wrist protection, kneepads for knee protection, and boots for foot and ankle protection
- *Respiratory Protection* - Closed Circuit Self Contained Breathing Apparatus with a full facepiece (SCBA)
- *Lighting System* - cap lamp with a cord and battery, or cordless
- *Communication Systems* – portable radios or hard-wired communication systems, etc.
- *Navigation Systems* - lasers and Infrared (IR) camera for navigation through smoke (not always)
- *Other*- life line, miner belt, gas detector, maps, tools, sounding stick, etc.

Some of the hazards faced in the mines may stemmed from team members having to spend long periods of time outside the mine, on the surface where climatic conditions may be cold winter conditions, or other seasonal conditions. In result, the range of hazards faced by team members may be broader than the mine conditions.

A typical mine rescue ensemble which is shown in *Figure 4* weighs approximately 50 pounds. Mine rescue team members generally carry approximately a total of 60 pounds of additional weight, with the added equipment needed to perform their tasks (portable radio, life lines, gas detector, miscellaneous tools, and sounding stick). This added weight reduces the mobility, increases the discomfort level and may lead to fatigue [36]. It has been found that the ensembles can trap body heat, leading to the risk of heat stress-related injuries. Similar issues are prevalent in the fire service [36-38].

FIGURE 4. Elements of a typical mine rescue ensemble.

PERFORMANCE REQUIREMENTS

The performance requirements of PPE for mine rescue ensemble can be grouped into four general categories [17]:

- *Protective Criteria*: This covers the first line of defense against the most destructive hazards. The specific properties needed from the protective clothing system include: resistance to impact, cut, abrasion, flame, heat, water, and bloodborne pathogens, durability, and static electricity dissipation.
- *Comfort and Human Performance Criteria*: This includes human factor related properties including comfort, design, fit, visibility, mobility, weight, dexterity, grip, and hearing ability.
- *Service Criteria*: This covers service related PPE properties, including launderability, maintainability, and reliability.
- *Other*: Other criteria which do not fit into any of the other categories, such as acceptance, compatibility, and visibility markings.

FIELD OBSERVATIONS

While improved technology has been developed for mine rescue teams, over the last 100 years, very little research in the area of ensembles has been conducted. Authors of this paper held a series of informal meetings with mine rescue teams and trainers at the nation-wide mine rescue competitions between 2009 and 2010 to further assess current practices in U.S. Mine rescue ensemble use and needs specific to garments, hoods, helmets, gloves, footwear, and eye/face protection devices were identified through these meetings and observations and specific hazards faced by mine rescuers during mine emergency operations were determined. Convenience sample selection method was used and information was gathered from approximately 100 mine rescue teams representing close to 50% of all underground coal mine rescue teams in the different geographical locations of the U.S. The collection of information was focused on details of each type of PPE used by the organization, in order to gain a better understanding for how an organization might choose different elements that comprise the ensemble: garments (regular work clothing vs. flame resistant (FR) clothing), helmets (high profile helmet vs. low profile helmet), cap lamps (incandescent vs. light emitting diode (LED)), hoods (6 oz/yd^2 Nomex® vs. 4 oz/yd^2 Nomex® or Nomex® vs. Nomex®/FR Rayon blend), gloves (regular work gloves vs. technical worker gloves vs. fire fighter gloves) and boots (leather vs. rubber). Information was gathered from teams selected by convenience in individual meetings as well as observations. Only qualitative data were obtained.

It was found that PPE practices for mine rescue teams differ by the type of operations (fire fighting, rescue, and recovery) and by the type of organization (federal, state, and private). It was observed that there was no consistency in mine rescue ensembles worn by different teams. In other words, different teams choose different levels of protection from regular cotton/polyester work clothes to fire fighter gear and different elements including, helmets, hoods, cap lamps, gloves and boots. One common observation was the need for guidance to select the most appropriate PPE for their activities. *Figure 5* shows pictures taken at these events and demonstrates that individual teams are wearing significantly different levels of protection. It was also found that different designs of garments (jacket and pants, coveralls, shirt and pants, overalls, etc.) made from different materials (cotton, cotton/polyester blends, Nomex®IIIA, FR cotton, and FR cotton/nylon blends) were used by mine rescue teams during mine emergency operations. Most commonly used mine rescue protective clothing are: regular mining coveralls made from cotton or cotton/polyester blends; single layer FR garments constructed from Nomex®IIIA¸ FR cotton, or FR cotton/nylon blend; and fire fighter turnout gear made of Nomex®/Kevlar®.

In terms of design, the majority of the garment designs observed in the field was coveralls and jackets/pants. It was also observed that a wide range of gloves are currently being used, including NFPA 1971[39] certified fire fighter gloves, gloves made from nylon with palms dipped in nitrile, and gloves made from polyester/spandex blends with nylon coating on palms, fourchettes and fingers. There were two main types of boots, metatarsal leather or rubber boots. Dräger BG4 SCBAs were overwhelmingly the most commonly used respiratory protection. The most frequently used hoods were made from Nomex® and Nomex®/FR Rayon ($4oz/yd^2$ and $6oz/yd^2$). ANSI approved miner hard hats, incandescent camp lamps, and knee pads were also used most commonly in the field. It was also observed that hearing protection is rarely used. The choice differences were mostly due to differences in cost, the common events that the team involved during the previous mine incidents (fire fighting, exploration, etc.), and the lack of guidance.

Detailed information has been also received in regards to the issues with the current mine rescue ensembles. Some of the issues that have been brought to the authors' attention were (from the most frequently reported to less frequently reported):

- Ensemble is too heavy
- Ensemble is too hot
- Helmets fall off
- Face mask and helmet interface problems
- SCBA hose location is not right
- Communication system ear piece problems
- Boots are too heavy
- Gloves are too hard to work in and dexterity is very low,
- Face mask melts
- Cap lamp location is not right

FIGURE 5. Example of different types mine rescue ensembles used in the U.S.

Furthermore, through meetings, field observations, and a literature review, it was found that the type of hazards, environmental conditions, the type and the level of the activities and protection needs of wild land fire fighters and technical rescuers (utility and rescue and recovery) are similar to underground coal mine rescuers. For example, the type of fire fighting in mining is found to be very similar to wild land fire fighting. Wild land fire fighters manage fires that take place outside, often in the forest or brush. These types of rescue workers often encounter very large fires, which can spread at great velocities. The difference between wild land fire fighters and their structural counterparts is that wild land fire fighters are not usually exposed directly to fire conditions under normal circumstances, but the risk of such condition does exist as in the case of mine rescuers. Since there is a ventilation system in underground coal mines, mine rescuers are typically not directly exposed to flames either. Also the type and level of the activity (crawling, climbing, etc.) of mine rescuers are also very similar to those in wild land fire fighting. In addition, activities of the mine rescue personnel often resemble the activities of technical rescue (utility and rescue & recovery) personnel. The mine rescue workers may also need protection from water as well as blood borne pathogens, similar to technical rescuers [40].

The NIOSH National Personal Protective Technology Laboratory (NPPTL) has recently started a research project to understand the comparative performance and thermal comfort of the most commonly used mine rescue ensembles in the U.S., and develop guidance documents that provide information on the minimum performance and design requirements [41-45]. In this two-phased project, fabric performance properties will be evaluated by bench-scale testing and thermal comfort will be evaluated by sweating thermal manikin testing coupled with bench-scale testing. These types of scientific studies and guidance documents on the mine rescue ensembles especially in the area of the protective clothing can help end-users to select the appropriate PPE for the tasks that they perform.

CONCLUSION

The mining industry trend toward reduced and non-exposure of mine rescue workers in hazardous situations should continue as the primary goal or direction. Mine rescue team members must be prepared to respond when an emergency occurs and take the necessary precautions required to ensure worker safety. It is vital that members of each team are provided with the proper PPE, and the mine rescue team members must know the limitations of their personal protective ensembles.

In this paper, a historical perspective on ensembles used during mine rescue operations was provided and environmental hazards, critical elements of mine rescue ensembles and key problems with these elements were summarized. In addition, field observations from several coal mine rescue teams were included to provide the information on the currently used mine rescue ensembles in the U.S.

While there are no minimum requirements or nationally recognized consensus standards for personal protective clothing worn by mine rescue teams in the U.S., there are current commercial PPE available to address emergency situations. Each mine rescue team should assess their specific needs based on their mine working conditions, the comfort of their existing mine rescue ensembles, what ensembles exist in the marketplace, and then select the appropriate PPE for the tasks that they perform.

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