Recent Developments in Coal Mining Safety in the United States

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This paper briefly describes the progress in mine safety in the United States, with emphasis on recent events that have followed since the explosion at the Sago Mine in January 2006. Legislation following the mine accidents last year and areas of work carried out by the National Institute for Occupational Safety and Health (NIOSH) related to the accidents are discussed.

American coal production in 2006 was 1,150 million short tons. Most of this coal is consumed domestically, with annual exports of coal about 50 million tons. One third of annual production is produced at surface mines and the rest from underground. This coal is produced by about 82,000 miners working at 1,400 coal mines. Major improvements in coal mine safety have been made in the US since the Federal Mine Safety and Health Act of 1977. The fatal injury rate in underground coal mines between 1977 and 2004 was reduced by 47.8% to 0.036. The annual number of fatalities dropped from 112 to 14 during that period. Likewise, the non-fatal days-lost injury rate was reduced by 42.6% from 10.87 to 6.24.

The improvements in mine safety during this period can be seen in the graph of underground coal mine explosion fatalities and injuries from 1980 to present, which is shown in Figure 1. Between 1984 and 1993 (9 year period) there were 5 explosions and one major mine fire, for a total of 55 fatalities. Over the seven year period from 1993 to 1999 there were no fatalities from coal mine fires and explosions. However, in the six years since 2000 there have been 5 explosions and one fire, which have caused 37 fatalities.

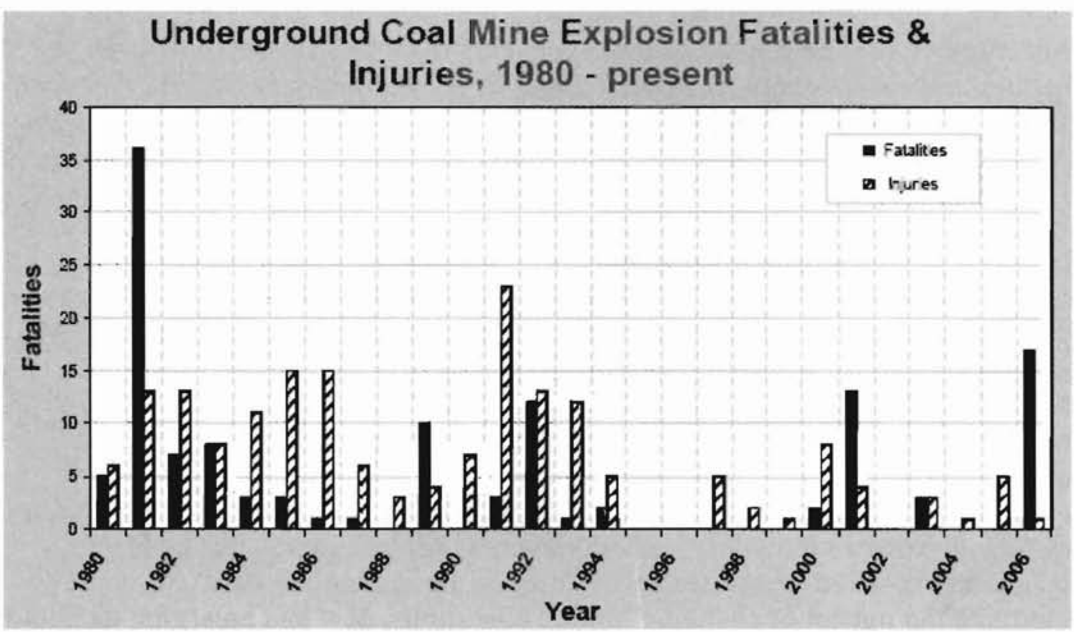

Figure 1. Underground Coal Mine Explosion Fatalities and Injuries, 1980 to Present.

The most recent mine incidents began last year with an explosion on January 2 at the Sago mine in West Virginia which killed 12 miners. A fire at the Aracoma Alma No. 1 Mine in West Virginia on January 19 caused 2 fatalities. On May 20 there was an explosion at the Darby No. 1 Mine in Kentucky which resulted in 5 more deaths. These major mine accidents caused great public concern and led the US Congress to pass the Mine Improvement and New Emergency Response Act of 2006 (MINER Act) on May 24, 2006. The Congress also passed an Emergency Supplemental Appropriation (ESA), which was signed in June. The ESA included funding of an additional $10 million to NIOSH to develop critical disaster response technologies in areas of oxygen supply, refuge chambers, and communications and tracking.

MINER ACT

The coal mining disasters in early 2006 and the MINER Act have had very significant effects on the coal mining industry in US. Some of the major provisions of the MINER Act include:

- Requires each covered mine to develop and continuously update a written emergency response plan;
- Requires wireless two-way communications and an electronic tracking system within three years, permitting those on the surface to locate persons trapped underground;
- Requires each mine to have available two experienced rescue teams capable of a one hour response time;
- Requires mine operators to make notification of all incidents or accidents which pose a reasonable risk of death within 15 minutes;
- Requires new safety standards relating to the sealing of abandoned areas in underground coal mines, increasing the requirements for strength of the seals;
- Establishes a competitive grant program for new mine safety technology to be administered by NIOSH;
- Establishes an interagency working group to provide a formal means of sharing Government-developed technology that would have applicability to mine safety;
- Establishes a Technical Study Panel for Belt Air to investigate the use of air from conveyer belt mine entries to ventilate the mine face;
- Raising the financial penalties for safety violations;
- Establishes a permanent Office of Mine Safety & Health in NIOSH, which helps ensure a viable and long-term focus on mining safety and health.

The Mine Safety and Health Administration (MSHA) has responsibility in the U.S. for promulgation and enforcement of Federal mine safety regulations. NIOSH is responsible for research to improve occupational safety and health for all workers including miners. NIOSH assumed the sole Federal responsibility for research on mine safety after the closure of the US Bureau of Mines in 1996. NIOSH inherited from the Bureau of Mines the mining research laboratories in Pittsburgh, PA and Spokane, WA. The NIOSH mining program currently has about 256 employees and a budget for 2007 of $31 million.

NIOSH does research in mining aimed toward seven major strategic goals. These are:

1. Reduce respiratory diseases in miners by reducing health hazards in the workplace associated with coal worker pneumoconiosis, silicosis, and diesel emissions.
2. Reduce noise-induced hearing loss (NIHL) in the mining industry.
3. Reduce repetitive/cumulative musculoskeletal injuries in mine workers.
4. Reduce traumatic injuries in the mining workplace.
5. Reduce the risk of mine disasters (fires, explosions, and inundations); and minimize the risk to, and enhance the safety and effectiveness of, emergency responders.
6. Reduce ground failure fatalities and injuries in the mining industry.
7. Determine the impact of changing mining conditions, new and emerging technologies, training, and the changing patterns of work on worker health and safety.

ON-GOING INTRAMURAL RESEARCH

The intramural research done by NIOSH related to prevention and response to mine fires and explosions is directed toward strategic goal number 5 above. This research is done primarily at the NIOSH Pittsburgh Research Laboratory (PRL). The NIOSH strategy in this area is in order of priority: prevention, escape, and rescue. Our research is aimed first a preventing explosions or fires that could endanger the lives of miners, second at technology to allow miners to escape if a serious incident occurs, and third at technology that would facilitate the rescue of miners who might be trapped underground.

Several of the current research projects at PRL have direct relevance to preventing the types of mining accidents which occurred last year. These include:

Mine explosion prevention: This project studies explosion propagation and explosion combustion mechanisms through full-scale tests at the Lake Lynn Experimental Mine (LLEM) and through laboratory tests. The LLEM research includes flame propagation in large volumes of non-uniformly mixed methane, the effects of non-uniform zones of coal and rock dust along an entry, and the effects of coal dust on the ribs/roof compared to floor dust. Researchers also study the amount of rock dust necessary to inert typical mine size dust for both high and low volatile coals. Basic research on the explosion mechanisms and flame propagation attempts to reach a more fundamental understanding of mine explosions.

NIOSH and MSHA conducted joint research to evaluate explosion blast effects on mine ventilation stoppings at the LLEM. After mine explosion accidents, MSHA conducts investigations to determine the causes as a means to mitigate or eliminate future occurrences. As part of these post-explosion investigations, the condition of underground stoppings, including the debris from damaged stoppings, is documented as evidence of the strength and direction of the explosion forces (Figure 2). These results assist investigators in determining the explosion forces that destroy or damage stoppings during actual coal mine explosions. (Weiss et al, 2006)

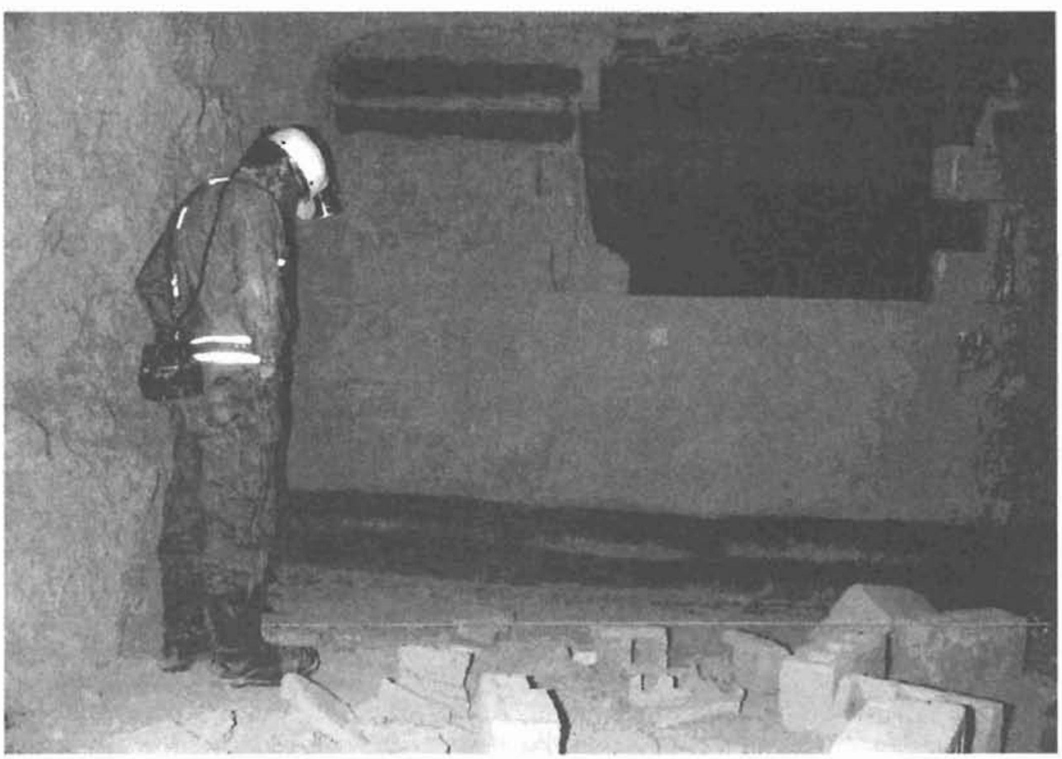

Figure 2. Ventilation stopping partially destroyed by explosion pressure.

Improving methane control practices in coal mines: The project goal is to identify and model methane emissions on longwall faces and continuous miner sections. This should improve the effectiveness of methane control technology, and reduce the explosion hazard for underground miners. The effectiveness of methane drainage on longwall and room and pillar face emission rates is assessed through underground methane emissions monitoring, borehole production evaluations and methane content measurements. Analytical, non-site specific algorithms are produced to predict face methane emission rates. Methane prediction methodologies are packaged for technology transfer to the mining industry. Methane drainage practices for continuous miner room and pillar operations are reviewed to evaluate potential application to abandoned or sealed workings. A surface borehole monitoring experiment is in progress for a Pennsylvania longwall panel. Figure 3 shows a surface borehole monitoring station. The adaptation of commercially available reservoir modeling software has successfully simulated gas flows for various borehole configurations and longwall mining scenarios. Two empirical methods for predicting longwall face emissions for increased face lengths have been developed and published. (Krog et al, 2006; Schatzel et al, 2006).

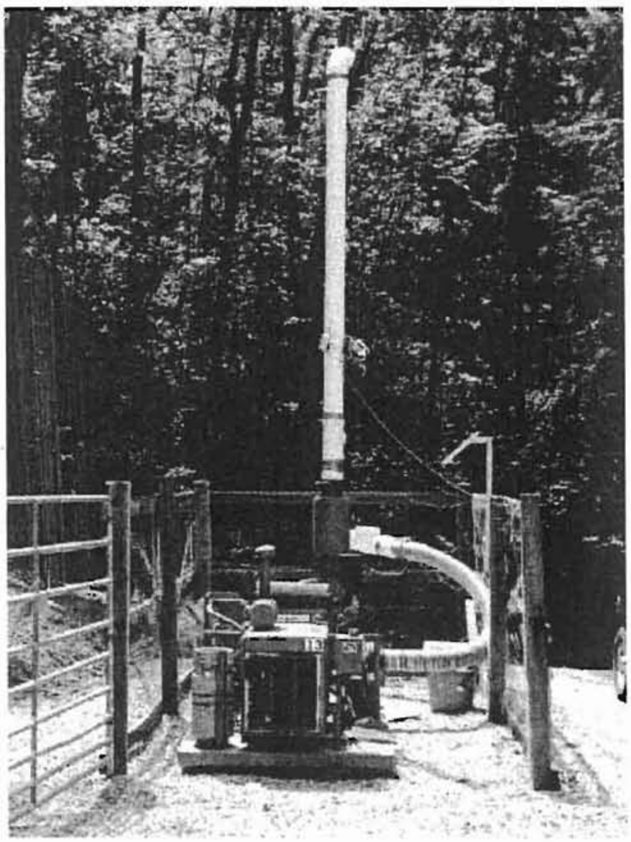

Figure 3. Instrumenting gob vent boreholes for monitoring.

Rescue Training and Technology: In cooperation with state mining agencies and mining companies, realistic training exercises for mine rescue teams have been developed, conducted, and evaluated at the LLEM. These training simulations require teams to make strategic decisions while they explore smoke filled entries, rescue injured miners, navigate around obstacles such as bad roof and water, conduct equipment checks, and reestablish ventilation controls. Mine rescue teams have evaluated a variety of rescue technologies during realistic training exercises at the LLEM. Technologies that have been evaluated with more than 50 different rescue teams include a lighted team linkline, lifeline pulleys, various communication systems, thermal imaging cameras, retractable stretchers, high-intensity LED lights, chemical light sticks, and handheld lasers. (Conti, 2001) Some of these technologies, such as lifeline pulleys and chemical light sticks, have already been adopted by many of the rescue teams. Further work is planned to make the lighting technologies and lasers intrinsically safe for use in mine rescue applications. Efforts are also continuing to find a licensee for the NIOSH patent on the lighted rescue linkline. (Conti and Chasko, U.S. Patent #6,742,909)

RECENT OOUTPUTS FROM INTRAMURAL RESEARCH

Some of the on-going research which was being done prior to the accidents in early 2006 have already produced relevant results which are ready for transfer to the coal mining industry. These include:

Coal Dust Explosibility Meter: The Coal Dust Explosibility Meter (CDEM), shown in Figure 4, is the first device that provides an immediate capability for determining if coal dust concentrations in active areas of underground coal mines have been sufficiently mixed with rock dust to prevent risk of explosion. This meter will quickly determine the explosibility and the incombustible content of coal and rock dust mixtures in coal mines, thereby improving sample analysis and rock dusting practices. The CDEM measures the explosibility of a coal and rock dust mixture by an optical reflectance method. Since rock dust is white and coal dust is black, the intensity of the reflected light depends on the concentration of rock dust in the mixture. The CDEM, when calibrated with actual mine dust mixtures, can be used to determine the approximate percentage of rock dust in the coal and rock dust mixture. PRL developed the theory and technology behind the device, and a prototype was developed in collaboration with the Geneva College Center for Technology Development. NIOSH and partners recently received the prestigious R&D 100 Award for the PRL-developed meter.

Figure 4. Coal Dust Explosibility Meter (CDEM).

Fine Coal Dust: NIOSH research has examined the adequacy of the 65% rock dust requirement for mine intakes. NIOSH and MSHA recently conducted a joint survey to determine the range of coal particle sizes found in dust samples collected from intake airways of U.S. coal mines. The last comprehensive survey of this type was performed in the 1920s. The size of the coal dust is relevant to the amount of rock dust required to inert the coal dust, with more rock dust needed to inert finer sizes of coal dust. Dust samples were collected by MSHA inspectors from underground coal mines throughout the U.S. Samples were normally collected in several intakes at each mine. The laboratory analysis procedures included acid leaching of the sample to remove the limestone rock dust, sonic sieving to determine the dust size, and low temperature ashing of the sieved fractions to correct for any remaining incombustible matter. The results indicate that particle sizes of mine coal dust in intake airways are finer than those measured in the 1920s. (Sapko, 2006)

Explosion Pressure Design Criteria for New Seals in U.S. Coal Mines: A new project was begun last year to study mine seals. Mine seals are structures built in underground coal mines to isolate abandoned mining panels or groups of panels from the active workings. Figure 5 shows a mine seal under construction. Recent explosions in the U.S. underground coal mining industry suggest that currently accepted seal construction and design methodologies are inadequate. Historically, mining regulations required seals to withstand a 140 kPa (20 psi) explosion pressure; however, the 2006 MINER Act requires MSHA to increase this design standard by the end of 2007. NIOSH has produced a new report that provides a sound scientific and engineering justification to recommend a three-tiered explosion pressure design criteria for seals in coal mines in response to the MINER Act.

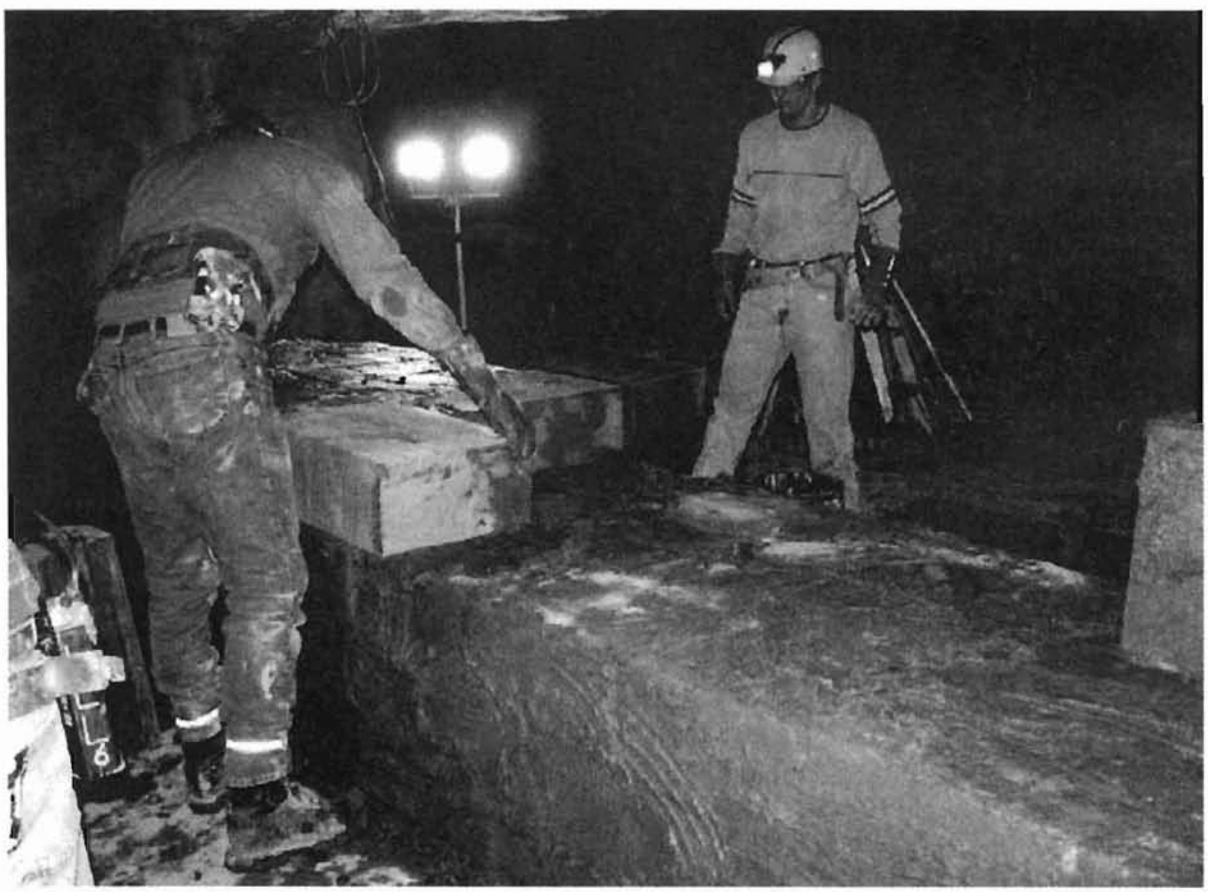

Figure 5. Construction of a mine seal.

NIOSH engineers considered various kinds of explosive atmospheres that can accumulate within sealed areas and used simple gas explosion models to estimate worst case explosion pressures that could impact seals. Three design pressure pulses were developed for the dynamic structural analysis of new seals under the three conditions in which those seals may be used. For the first condition, an unmonitored seal where there is a possibility of methane-air detonation behind the seal, the recommended design pulse rises to 4.4 MPa (640 psi) and then falls to the 800 kPa (120 psi) constant volume explosion overpressure. For unmonitored seals without the possibility of detonation, a less severe design pulse that simply rises to the 800 kPa (120 psi) constant volume explosion overpressure, but without the initial spike, may be employed. For monitored seals, engineers can use a 345 kPa (50 psi) design pulse if monitoring can assure that the maximum length of explosive mix behind a seal does not exceed 5 m (15 ft) and also that the volume of explosive mix does not exceed 40% of the total sealed volume. Use of this 345 kPa (50 psi) design pulse requires monitoring and active management of the sealed area atmosphere.

NIOSH used these design pressure pulses along with the Wall Analysis Code from the U.S. Army Corps of Engineers and a simple plug analysis to develop design charts for the minimum required seal thickness to withstand each of these explosion pressure pulses. These design charts consider a range of practical construction materials used in the mining industry and specify a minimum seal thickness given a certain seal height. These analyses show that resistance to even the maximum 4.4 MPa (640 psi) design pulse can be achieved using common seal construction materials at reasonable thickness.

NIOSH will continue research to improve underground coal mine sealing strategies and prevent explosions in sealed areas of coal mines. In collaboration with the U.S. National Laboratories, NIOSH researchers will further examine the dynamics of methane and coal dust explosions in mines and the dynamic response of seals to these explosion loads. This should lead to better understanding of the detonation phenomena and simple techniques to protect seals from transient pressures. Additional work will include field measurements of the atmosphere within sealed areas. This work will improve the monitoring of gob atmospheres to reduce the likelihood that an explosive methane/air gas mixture accumulates behind the seal line.

Methane Control Handbook: This is a summary handbook published last year that compiles in one document the results of several decades of research by the US Bureau of Mines and NIOSH on methods to control methane in underground coal mines. This handbook describes effective methods for the control of methane gas in mines and tunnels. It describes methane control methods primarily for U.S. coal mines, but also for metal and nonmetal mines and tunnels. (Kissell 2006)

NEW INTRAMURAL PROJECTS

NIOSH has initiated a pilot project to evaluate the potential for risk assessment and management in the US for disaster prevention. Recent mine disasters focused attention on the need to improve the operation and management of mine emergency response, from communications to rescue operations. Experience in other countries indicates that mine safety can be dramatically improved by implementing risk management methods, including hazard identification, risk assessment, implementation of controls, emergency response plans and a system to manage the process. The project time frame is approximately 15 months to conduct a series of case studies across mining sectors, with interim reports and evaluations to assess the need to continue or expand the effort. The case studies will lead mine personnel through a formal risk assessment of mine site hazards with the potential for multiple fatalities. The process will evaluate prevention, initial response, communications, escape, refuge and emergency response capacities and identify gaps in protection. The purpose is to build interest in and validation for the wider use of the risk assessment and management process and to identify any obstacles to its success in the US mining industry. To date, nine major hazard risk assessment case studies have been completed. A NIOSH report will soon be written detailing the strengths and weaknesses of this approach.

A Mine Emergency Communications Partnership was organized by NIOSH to facilitate the development, evaluation, and implementation of communication system technology that would allow workers in mines to communicate with personnel on the surface after an accident. Included is post-accident worker tracking technology. The primary goals of the Mine Emergency Communications Partnership are to: establish general performance expectations for mine emergency communications systems; establish uniform and fair criteria for testing and evaluating systems; conduct in-mine tests on systems under consistent conditions; and report the findings. A secondary goal is to identify gap areas that should be addressed through research. The Mine Emergency Communications Partnership includes representatives from state and national mining associations, labor unions, state and federal regulatory agencies, manufacturers, and university and government researchers.

PROGRESS ON THE EMERGENCY SUPPLEMENAL APPROPRIATION (ESA)

The Emergency Supplemental Appropriation (ESA) made available an additional $10 million to NIOSH with the goal to facilitate the adaptation and movement of oxygen supply, communications, tracking, and refuge chamber technologies from other industries or from prototype stage to commercialization, and into the mines as rapidly as possible. The intent of Congress was to overcome the small market barrier, by providing some government funding to solve unique application issues associated with in-mine use. The relatively small mining market in the US provides little incentive for expensive research and development of new safety technology for mining without some assistance from the government.

The ESA funds target technologies that could be available for mine use within 36 months. The focus is on moving demonstrated prototypes to commercialization, or adapting technologies from other military or civilian sectors into mining. While longer term R&D activities are important to develop new concepts and conduct experimental investigations of possible innovations, they aren't the focus of the ESA.

To address needs in a timely and cost-effective manner, the primary focus of the ESA has been on competitive contracts. The appropriated funds became available in September 2006. However, preliminary work had already begun. NIOSH scientists and engineers have been studying promising technologies that could meet the urgent needs of mineworkers. They continue to meet with manufacturers, inventors and innovators, trade and labor organizations, academia, and industry to discuss options, alternatives, and needs. They are examining installations in underground mines, and meeting with constituents and experts in the U.S. and other mining countries. Communications and tracking technologies are being tested in the lab and underground to evaluate the efficacy of systems purported to work in underground mines.

A number of opportunities were identified that have a reasonable likelihood of being commercialized and available for in-mine use within 36 months. However, it's unlikely that all of these are doable for $10 million. Therefore, a competitive process is being used to prioritize the most promising technologies based on significant positive impact on mine worker safety, and also on reasonable chance of commercial availability within 36 months.

Five new contracts are planned in the communications and tracking area. These include:

- Development of a "hardened" leaky-feeder-type system
- Development of a node or mesh-based system
- Study of communications standards for compatibility

– Agreement with Department of Defense to adapt military technology to mining communication systems
– Development of a general communication and/or tracking system.

Refuge chambers are one option for safety protection in the event of explosions or fires. In the United States, the use of refuge chambers in coal mines has generated debate. While refuge chambers can save lives, it is also argued that they may cause miners to seek refuge rather than attempt to escape their hazardous situation. There are a number of considerations involved with this approach, including the capabilities of stations, the type and location of structures, design criteria, and maintenance and training issues. Recent discussions have generated some consensus among stakeholder groups on refuge concepts as part of an escape strategy. Specifically, the merits of at least two concepts have emerged: inflatable, portable devices for use at the face, and "refuge rooms" for use outby the face. The refuge rooms could serve as "way stations" or "safe havens" as escaping miners make their way out of the mine. Being somewhat more permanent in nature, these rooms could in some cases be connected to the surface with a borehole, which would offer many other benefits. NIOSH plans to address the engineering issues associated with the construction and application of the various refuge alternatives through contract research. The knowledge developed through this contract will be used to develop recommended practices documents and other practical guidelines for mines, and to establish potential criteria for a possible approval and certification process for refuge chambers.

Researchers at NIOSH's National Personal Protective Technology Laboratory (NPPTL) will facilitate the development and commercialization of the next generation of selfcontained self-rescuers (SCSRs) through competitive contracts. The new SCSRs will provide more reliable oxygen supplies to miners in escape situations. The new and improved SCSRs could be developed, tested, and submitted for certification within the next 24 months.

Five contracts are planned for oxygen supplies and refuge chambers, including:
– A Hybrid SCSR
– A Dockable SCSR
– Development of overall escape strategies utilizing refuge chambers
– Survey and document refuge products, standards, and usage worldwide.
– Development of recommended practices for refuge rooms.

Some of these contracts have already been awarded and the last of these is expected to be awarded by June of this year.

SUMMARY

In conclusion, the provisions of the MINER Act and the funding provided by the ESA give us the best opportunity for "revolutionary" improvements to mining safety in nearly three decades. They can lead to potentially significant improvements for all of mining, not just coal. We are engaged in a mix of intramural and extramural activities to help realize the opportunities.

REFERENCES

Conti-RS (2001). Emerging Technologies: Aiding Responders in Mine Emergences and During the Escape from Smoke-Filled Passageways. In: Proceedings of Northwest Mining Association 107th Annual Meeting, Exposition and Short Courses (December 3-7, 2001; Spokane, WA); :14 pp

Conti-RS; Chasko-LL. Lighted Line. U.S. Patent #6,742,909

Kissell-FN (2006). Handbook for Methane Control in Mining. Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2006-127, Information Circular 9486, 2006 Jun; :1-184

Krog-RB, Schatzel-SJ, Garcia-F, Marshall-JK (2006). Predicting Methane Emissions from Longer Longwall Faces by Analysis of Emission Contributors. In: Proceedings of the 11th U.S./North American Mine Ventilation Symposium. Mutmanski JM, Ramani RV, eds. Leiden, Netherlands: Balkema Publishers, pp. 383-392.

Sapko-MJ, Cashdollar-KL, Green-GM, Verakis-HC (2006). Coal Dust Particle Size Survey of U.S. Mines. In: Proceedings of the Sixth International Symposium on Hazards, Prevention, and Mitigation of Industrial Explosions (Halifax, NS, Canada, Aug 27 – Sept 1, 2006). Halifax, Canada: Dalhousie University, 2006 Aug; 2:676-682

Schatzel-SJ, Krog-RB, Garcia-F, Marshall-JK, Trackemas-J (2006). Prediction of Longwall Methane Emissions and the Associated Consequences of Increasing Longwall Face Lengths: A Case Study in the Pittsburgh Coalbed. In: Proceedings of the 11th U.S./North American Mine Ventilation Symposium. Mutmanski JM, Ramani RV, eds. Leiden, Netherlands: Balkema Publishers, pp. 375-382.

Weiss-ES; Cashdollar-KL; Harteis-SP; Shemon-GJ; Beiter-DA; Urosek-JE (2006). Explosion Evaluation of Mine Ventilation Stoppings. In: Proceedings of the 11th U.S./North American Mine Ventilation Symposium, University Park, Pennsylvania, June 5-7, 2006. Mutmansky JM, Ramani RV. eds., London, U.K.: Taylor & Francis Group, 2006 Jun; :361-366.