



Coal mine safety achievements in the USA and the contribution of NIOSH research

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Synopsis

Over the past century coal miner safety and health have seen tremendous improvements: the fatality and injury rates continue to decrease while productivity continues to increase. Many of the hazards that plagued miners in the past, such as coal bumps, methane and coal dust explosions, ground fall accidents and health issues have been significantly reduced. The contribution of NIOSH research includes products for prevention and survival of mine fires, methane control measures, design procedure for underground coal mines, methods for excavation surface controls, methods and procedures for blasting, laser usage in underground mines and prevention of electrocution from overhead power lines that have reduced accidents and injuries in underground coal mines. Health research has produced products such as the personal dust monitor, noise abating technologies and ergonomic solutions for equipment operators. Research priorities at NIOSH are set by considering surveillance statistics, stakeholder inputs and loss control principles. Future research in coal mining is directed towards respiratory diseases, noise-induced hearing loss, repetitive musculoskeletal injuries, traumatic injuries, falls of ground and mine disasters. The recent spate of accidents in coal mines resulted in the Miner Act of 2006, which includes a specific role for NIOSH in future mine safety research and development. The mine safety achievements in the USA reflect the commitment of industry, labour, government and research organizations to improving the safety of the mine worker.

Introduction

The United States' coal mining industry employs about 75000 persons, producing more than 1.1 billion short tons of coal per year; approximately 60% is from surface mines and 40% from underground mines. Coal mining operations are concentrated in the eastern United States (Figure 1), with more than 70% of all operations located in Kentucky, West Virginia and Pennsylvania. Approximately 780 underground coal mines employ about 37000 persons (excluding office workers). Safety and health in the mines are regulated through the Federal Mine Safety and Health Act of 1977. The Mine Safety and Health Administration (MSHA) is charged with enforcing the act, while many states have their own state enforcement offices.

Miner safety and health in the United States has seen continuous improvement despite significant increases in productivity, more adverse mining conditions, and changes in mining methods and equipment. However, mining remains one of the high risk industries in the US with injury and fatality rates that exceed the national average. The societal expectation of 'zero accidents' maintains a continuous demand for further improvements (Kohler, 2005). The achievements in mineworker safety have been the result of concerted efforts of industry, government agencies, employee organizations, researchers and manufacturers.

The National Institute for Occupational Safety and Health (NIOSH) has an extensive research programme in coal mining safety and health which is coordinated through the Office of Mining and Construction Safety and Health Research in Washington DC. (NIOSH, 2006). The two main centres for mining research are the Pittsburgh Research Laboratory (PRL) in Pennsylvania and the Spokane Research Laboratory (SRL) in the state of Washington. Both the PRL and SRL were formerly US Bureau of Mines (USBM) research centres that were transferred to NIOSH in 1996, after closure of the USBM. This paper presents the contribution of NIOSH research to coal mine worker safety achievements since 1995, and includes a brief summary of NIOSH health related research outputs.

Safety achievement of the US coal mines

A series of mine disasters in coal mines during

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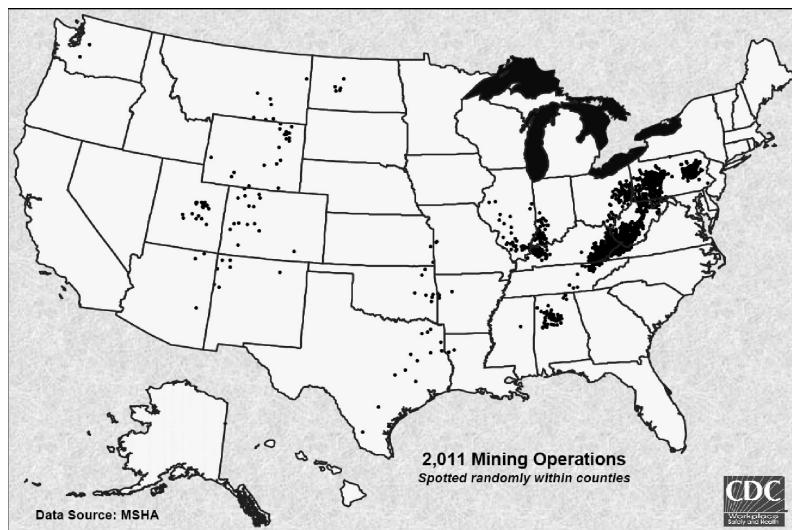


Figure 1—Coal mining operations in the USA

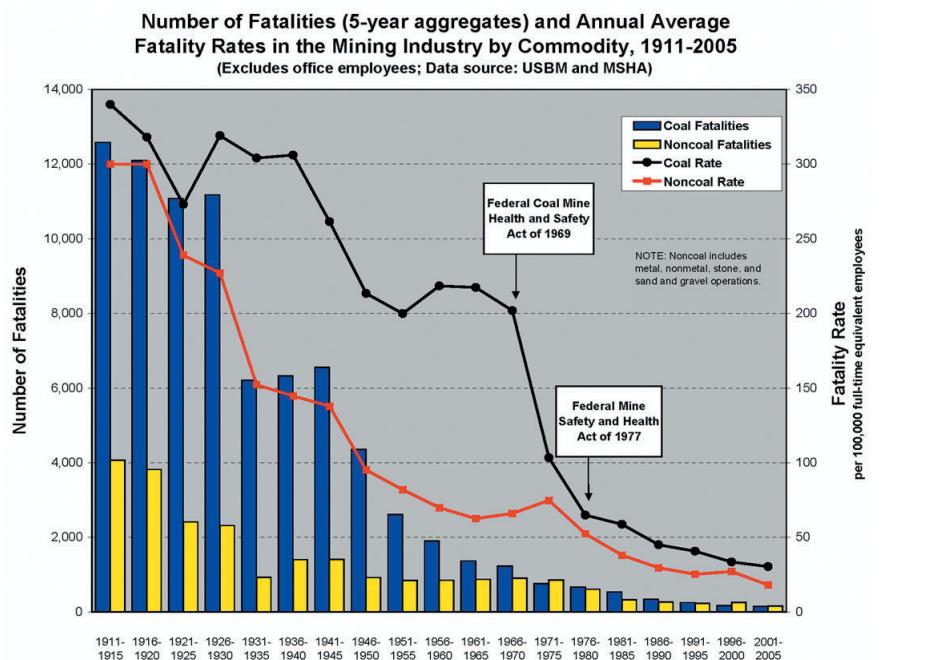


Figure 2—Trend in mine fatalities and rates (5-year aggregates) in the US mining industry by commodity, 1911–2005

the 1900s focused the public's attention on the loss of life in the mining industry. In 1907 alone, more than 3,000 lives were lost in coal mining disasters. Mine worker safety has seen significant improvements since 1911 when regular statistics were collected on a nationwide basis. Statistics presented in this paper were all retrieved from Internet sources (Bureau of Labor Statistics, 2005, 2006a/b; MSHA, 2006, Department of Energy, 2006). Figure 2 shows the historical trends in the aggregate number of fatalities and fatality rates in US coal and metal/non-metal (MNM) mines (MSHA, 2006). The chart also shows some of the major factors that affect the statistics. The introduction of the Federal Coal Mine Health and Safety Act of 1969, which mandated federal safety enforcement and called for expanded health and safety research, had a major impact on the safety achievements.

The historical reduction in mine accidents has made US mines some of the safest in the world. However, the fatality rate in the mining industry exceeds the national industrial rate, shown in Figure 3. Coal mining is the most hazardous, at about seven times the national rate. The primary causes of the fatalities in underground mines are falls of ground, powered haulage, explosions machinery and electrical, accounting for about 90% of all fatalities. In surface mines the primary causes of fatalities are: powered haulage, machinery, slip or fall of person and electrical, accounting for about 80% of all fatalities.

Non-fatal injury rates for 2004 (Figure 4), show that coal mining had the highest rate within the mining industry, at 5.3 injuries per 100 full-time workers compared to 4.5 for the national industrial average. The leading causes of injuries in

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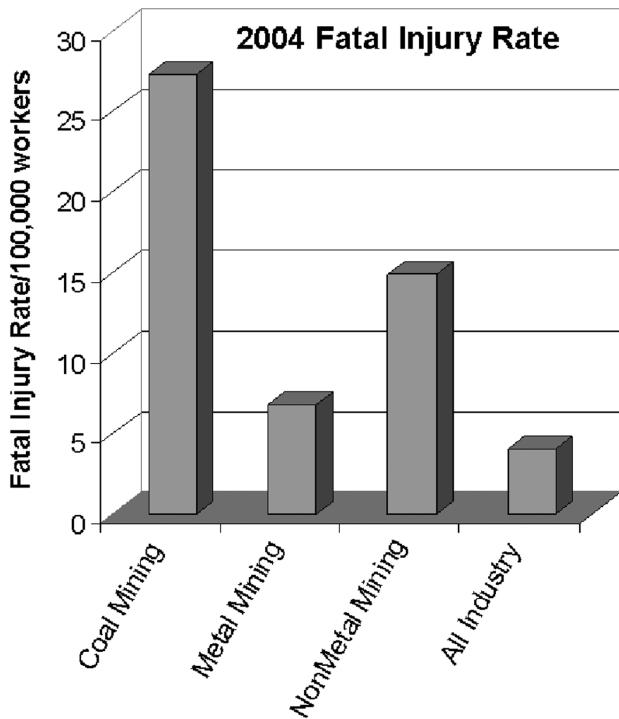


Figure 3—Fatal injury rate per 100000 workers

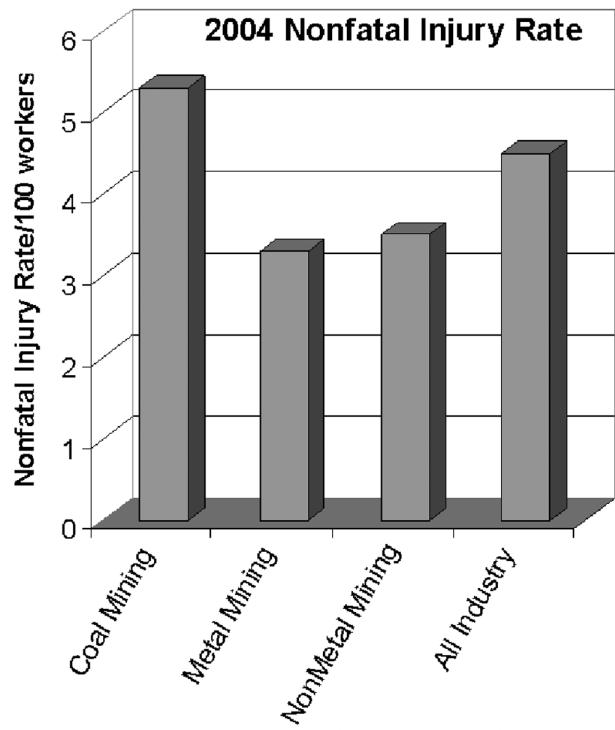


Figure 4—Nonfatal injury rate per 100 full-time employees

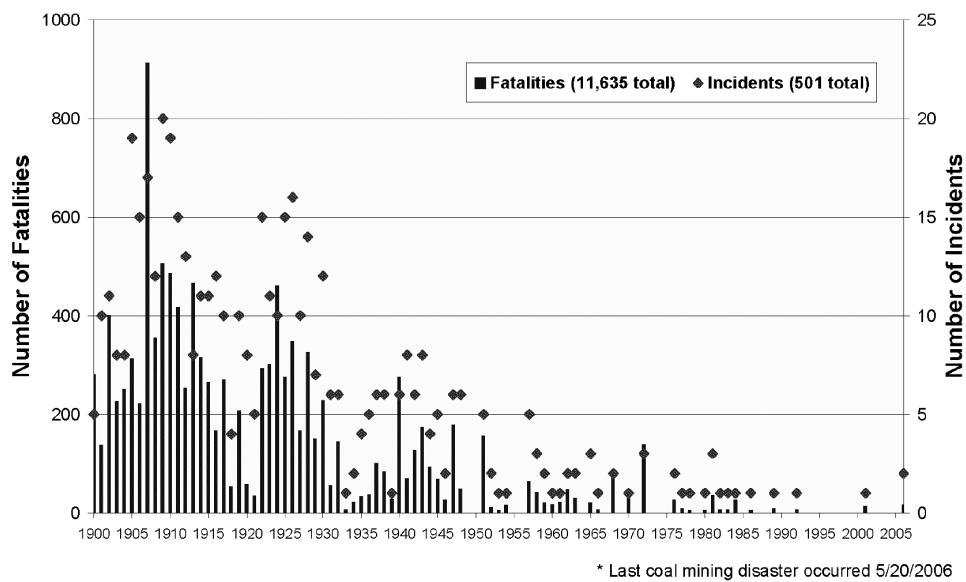


Figure 5—Coal mining disaster incidents and fatalities, 1900–May 2006

underground mines are: handling materials, slips and falls of person, falls of ground, powered haulage and machinery. In surface mines 90% of the injuries are accounted for by: handling materials, slip of fall of person, hand tools, machinery and powered haulage.

While annual fatality and injury rates provide insight into the causes and trends in mine safety, low probability but high impact events need to be considered over longer periods of time. Figure 5 shows the trend in coal mine disasters between 1900 and 2006. In the US mine disasters are defined as events resulting in five or more fatalities. Inspection of the disaster statistics for coal mines revealed

that eight out of the 10 disasters since 1981 were related to explosions.

In 2006 a series of unfortunate accidents in coal mines has resulted in an above average rate of fatalities. The United States senate proposed a bill called the Mine Improvement and New Emergency Response (MINER) Act, which became law in June, 2006. This bill addresses several aspects of mine safety, disaster response and enforcement. NIOSH was mandated in this bill to:

- Establish a permanent Office of Mine Safety and Health to enhance the development of new mine safety technology

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- Establish a competitive grant programme to encourage the development of mine safety equipment
- Chair an interagency working group to share technology applicable to mine safety and accident/incident management
- Expedite approval of new mine safety technology through review and testing contracts with third party laboratories
- Conduct research, including field tests in the NIOSH underground mine, on the use of refuge chambers in underground coal mines
- Establish a Technical Study Panel to provide independent scientific and engineering review and comment on the utilization of belt air and the possible use and integration of fire retardant belt components in underground coal mining.

The safety statistics demonstrate that coal mining, and particularly underground coal mining, poses the greatest challenge in terms of worker safety. The research programme at the NIOSH Pittsburgh Research Laboratory has been geared to address coal mining related issues, being located within the eastern US coalfields and having a historical tie to coal research since its inception. The location of the facility near operating coal mines has allowed cooperation with industry and labour organizations, and provided ready access to experimental sites in coal mines.

Research strategy at NIOSH

The ultimate goal of NIOSH mining research has been to improve health and safety through the elimination of harmful exposures and hazards. A structured approach has been followed to develop a research programme that addresses the important health and safety issues, provides practical outputs that can be implemented in the workplace, while maintaining the highest quality of scientific research.

Development of research goals

The scope of the research is determined through an interactive process in which surveillance statistics, stakeholder input and loss control principles are combined to develop strategic goals. Each of these components is discussed below:

- *Surveillance data*—Surveillance data is obtained primarily from the MSHA and Bureau of Labor Statistics databases, and then analysed to establish research priorities or assess the effectiveness of past research. The surveillance data are highlighted within the three categories of fatalities, injuries, and illnesses. The data are analysed across many categories including the type of commodity, geographic location, and in-mine parameters, among others
- *Stakeholder input*—Another major factor in setting research priorities is the input we receive from stakeholder groups, which have great knowledge and concern about the health and safety of miners. Some of the major customers/stakeholders who provide input are the following: labour: United Mineworkers of America, United Steelworkers of America, and International Union of Operating Engineers; industry:

Bituminous Coal Operators Association, National Mining Association, National Stone, Sand, and Gravel Association, and Industrial Minerals Association of North America. In addition, several state organizations, universities, manufacturers, and government agencies participate in research partnerships and provide important input to the list of priorities. NIOSH also maintains a standing advisory committee: the Mine Safety and Health Research Advisory Committee

- *Loss control considerations*—Low probability high impact events are identified as part of a loss control approach to mine safety. Statistics on mine disasters show that mine explosions, mine fires, mine collapses, and mine inundations are events that have a low frequency of occurrence, but can have a high impact. While these events have become much less deadly over time, they still do occur, albeit sporadically as shown in Figure 5. An increasing risk of disaster from explosions, fires, and inundations is expected, largely due to the worsening conditions as mines progress into gassier deposits, go deeper, and work under generally more adverse geologic conditions. The greatest risks were identified in underground coal mining, although metal/nonmetal mining entails significant risks as well. In addition to preventing these disasters, a concurrent priority is to develop safer and more effective response methods and technologies.

After consideration of the above components, the mining health and safety research programme was formulated through seven strategic goals as listed below:

- *Reduction of respiratory diseases*—Reduce respiratory diseases in miners by reducing health hazards in the workplace associated with coal worker pneumoconiosis, silicosis, and diesel emissions
- *Reduce noise-induced hearing loss (NIHL) in the mining industry*—Although NIHL is the most common occupational disease in the US, the problem is especially acute among workers in the mining industry
- *Reduce repetitive/cumulative musculoskeletal injuries in mine workers*—Musculoskeletal injuries, primarily to the low back, neck, knees, shoulders, and arms, are a continuing concern within the mining industry
- *Prevention of traumatic injuries*—The primary focus of the research is to prevent traumatic injuries related to electricity, machinery, powered haulage, and slips and falls in mining
- *Disaster prevention*—Reduce the risk of mine disasters (fires, explosions, and inundations); and minimize the risk to, and enhance the effectiveness of, emergency responders
- *Reduce ground failure fatalities and injuries*—Mining has the highest fatal injury rate of any US industry, at more than five times the national average, and ground failures have historically accounted for up to 50% of the fatalities in underground mines
- *Surveillance and training*—Determine the impact of changing mining conditions, new and emerging technologies, training, and the changing patterns of work on worker health and safety.

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Development of the research programme

The research programme is driven by the strategic goals. Each goal is assessed and the technology barriers and knowledge gaps are identified that prevent the achievement of the goal. Intermediate goals are developed, which have the objective of addressing the technology barriers and knowledge gaps. Research projects are then developed to address specific intermediate goals.

Performance measures have been established, which help to focus the research on a critical path, and also provide a method to assess progress. For example, the performance measure to reduce rock fall injuries by 50% in five years causes research managers and their staff to concentrate their efforts on projects that have the greatest likelihood to achieve the target.

The research programme is subject to various levels of external review to ensure its relevance and quality. Each project proposal is submitted for external review to ensure relevance, technical quality and the achievability of the outcomes within the budgetary and personnel constraints. All publications and other outputs are subject to an external peer review process, including all conference presentations. The entire research programme is reviewed from time to time by the National Academies of Science, a process that is currently underway.

Research products can have an impact only if they are implemented in the workplace. NIOSH has implemented a Research to Practice (r2p) initiative to increase workplace use of effective NIOSH and NIOSH-funded research findings. NIOSH is continuing to focus research on ways to develop effective products, translate research findings into practice, target dissemination efforts, and evaluate and demonstrate the effectiveness of these efforts in improving worker health and safety.

The NIOSH research programme has evolved over the years and is flexible to address new challenges as they arise, such as the recent spate of accidents in coal mines, which resulted in focused research into refuge chambers and belt air. The programme strives to address important safety and health problems and provide outputs that will be accepted by the mining industry and implemented in the workplace.

NIOSH research achievements in coal mine health and safety since 1995

The contribution of NIOSH to the safety and health in the US coal mining industry are best illustrated through the research achievements since 1995. Successful research outputs are products or methods that have 1) been implemented and accepted in the mining industry, and 2) have had an impact on the safety of mine workers. The NIOSH research achievements are grouped below in terms of the strategic research goals.

Preventing respiratory diseases

NIOSH research into respiratory diseases in miners addresses health hazards in the workplace associated with coal worker pneumoconiosis (CWP), silicosis, and diesel emissions. The last 35 years have seen major gains in the national effort to reduce CWP. The percentage of dust samples exceeding the 2

mg/m³ federal regulatory limit for continuous miner workers has dropped from 49% to 9%. For longwall workers, the percentage has dropped from 44% to 12%. Likewise, the prevalence of CWP category 1/0+ or higher has dropped from 28% to 8%.

Our research has resulted in dozens of new and practical ways to control dust that are now used in the coal mining industry throughout the United States. For example:

- Research for longwalls has identified optimum spray types and locations in cutting drums, developed directional spray systems for the longwall shearer, identified optimum operating pressures for different water spray types, demonstrated methods to control dust from crusher/stageloader units, and improved operating practices such as worker positioning and cutting practices.
- Continuous miner research showed that blocking sprays, if properly used, can reduce dust levels at the operator locations. Blocking sprays create a water barrier near the cutting face, which prevents dust from rolling back to the operator locations at the back of the machine and allows the dust to be captured by the scrubber inlets. A major continuous miner manufacturer now offers blocking sprays on its machines, and new continuous mining machines are underground with these sprays installed.
- NIOSH researchers also found that thinner filters were being used in flooded-bed scrubbers on continuous miners. Research showed that these thinner filters allowed 30% more dust back into the mine air. NIOSH recommended the use of thicker filters in a NIOSH Hazard ID flyer. MSHA requested 1,000 copies of this Hazard ID to distribute to mine inspectors as part of its initiative to lower silica dust exposure.
- A parallel research effort devoted to improved dust sampling has been ongoing for the past 10 years. These samplers use a size-selective cyclone to collect the respirable fraction of dust on a filter. The mass of dust, pump flow rate, and sampling time are used to calculate an average dust concentration for the shift. This concentration is not determined until the filter has been weighed at MSHA's Pittsburgh lab several days after the sample is collected. This sampling process has not changed in the past 36 years. In 1999, NIOSH began developing a mass-based, continuous dust monitor that could be worn as a personal dust sampler. This personal dust monitor (PDM), built into the miner's cap lamp system, provides a running average of dust exposure at any point in the shift, projects an end-of-shift concentration, and provides an actual end-of-shift concentration without any delay. This information will allow mine operators and workers to monitor the dust exposure during the shift. The PDM is now commercially available.

Preventing noise-induced hearing loss

Noise-induced hearing loss (NIHL) is the most common job-related illness in the United States today. It is especially

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common among miners. A NIOSH analysis of more than 60 000 audiograms showed that by age 51 about 90% of the coal miners and 49% of metal/nonmetal miners had a hearing impairment. By contrast, only 10% of the non-occupational noise-exposed population had a hearing impairment by age 51. A 2005 analysis of changes in noise exposure showed that the renewed emphasis on hearing loss prevention has already had a substantial impact. There has been a 40% reduction in the average coal miner's noise dose from 1997 to 2003. The rate of decline in exposures increased around 2000 when a new federal noise regulation took effect. Around the same time, the NIOSH Hearing Loss Prevention Branch became fully staffed. The NIOSH role in increasing awareness of NIHL and provision of testing facilities has contributed to the improvement of this illness.

Preventing musculoskeletal disorders

Mining is one of the most physically demanding occupations. It is also one of the most dangerous in terms of exposure to ergonomic hazards. Musculoskeletal disorders (MSDs) resulting from repetitive manual work have long been identified as a significant and costly problem for the mining industry. Strain and sprain injuries account for 24.0% and 25.2%, respectively, of all reported injuries for underground coal mining. They account for 19.4% and 20.4%, respectively, of all injuries for underground metal/nonmetal mining. In 2003, MSHA reported that 44% of all illnesses were joint, tendon, or muscle inflammation. Using a new process integration and interventions development approach in mining, NIOSH contributed to a 34% overall reduction in lost workdays due to repetitive-type injuries during 1998–2004. This approach focuses on incorporating the ergonomics process in existing safety and health programmes of the mining companies and empowering the workers to proactively develop injury prevention solutions to their tasks.

Research outcomes have addressed issues such as whole body vibrations and developing ergonomic processes through partnerships with mines. Examples are seat design for low-seam shuttle cars and collaborative research with coal mining companies to reduce overload conditions affecting the neck, back, forearms, arms, shoulders, fingers, and hands associated with coal mining operations.

Prevention of traumatic injuries

Research into the prevention of traumatic injuries has focused on injuries and fatalities related to blasting operations, electrical equipment and machinery accidents. The research achievements in each of these fields are listed below:

- **Blasting related injuries and accidents**—The frequency of blasting-related injuries and fatalities at mining operations has dropped significantly over the past 25 years. In 1978, 140 miners were killed or injured in US blasting accidents. By 1998, this number had dropped to 22 and continued to decline to 7 in 2001. Factors contributing to increased blasting safety include the development of nonelectric initiation systems; the change from the use of cartridge explosives to bulk explosives; increased use of safer, non-nitroglycerine

explosives; development of safer blasting practices; and an increase in the knowledge and professionalism of the average blaster. Industry, labour, and government all contributed to the improved safety record. Research products that have found acceptance and application at mine operations are:

- Modification of high-detonation pressure explosive boosters and initiation systems to reduce the potential for explosives accidents, in response to a request by MSHA
- Safe use of waste oil to make ammonium nitrate fuel oil (ANFO) blasting agent. MSHA regulations prohibited this practice because of concerns that contaminants in the oil could lead to the production of unusually sensitive, insensitive, or thermally unstable ANFO. NIOSH conducted research to evaluate the safety of waste oil-produced ANFO and help MSHA to develop safety guidelines for this practice
- Guidelines for prevention of CO poisoning near blasting sites. Cases of CO poisoning have been almost eliminated after a NIOSH investigation and recommendations for CO monitoring procedures
- Mines in the Powder River Basin of Wyoming asked for NIOSH assistance when concerns arose about the orange or red product clouds rising from large-scale surface blasts. NIOSH conducted in-house research to determine the factors that lead to excessive NO₂ and recommended practices that might reduce NO₂ production.

- **Electrical safety research**—The NIOSH programme in electrical safety research has focused on a variety of topics, including trailing cables, motors, trolley systems, ground fault protection, intrinsic safety, explosion-proof enclosures, overhead power lines, and lasers. Data from MSHA show that from 1990 to 2004 fatal electrical accidents decreased by 50%, lost workday electrical accidents decreased by 75%, and lost workdays decreased by 60%. Nevertheless, electrical accidents remained the fourth leading cause of on-the-job death in mining. Major research outcomes are:

- Feasibility of high voltage coal mining equipment. The demand for larger, more powerful mining equipment stimulated the need for increased voltages for coal mine face machinery. Several NIOSH studies showed that higher voltages were feasible. The resultant research reports provided technical information to MSHA that was used to help formulate new regulations. These regulations went into effect on May 10, 2002, and allowed the use of high-voltage longwall machines in coal mines. The reports also contributed to the formulation of proposed new regulations for high-voltage continuous miners. These are now in the formal rulemaking process
- Contact with overhead power lines. MSHA data show that nearly one-fifth of mine electrical deaths occur when workers contact overhead power lines. Research to protect workers from overhead power

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- line electrocution led to one patent and stimulated two US manufacturers to introduce stand-alone power line contact alarms
- Laser technology has become common in several fields, e.g., surveying and level detection. The use of lasers in potentially hazardous underground atmospheres was recognized as a new area of concern. Research was done to measure the risk of igniting flammable atmospheres by radiation from optical equipment. American National Standards Institute and International Electrotechnical Commission standards are now in process, based in part on NIOSH laser ignition research. These standards will result in safety guidelines for the safe use of lasers in gassy and dusty atmospheres.
- **Machine safety research**—Despite advances in mechanization, mining remains among the most physically demanding and hazardous of all occupations. Traumatic injuries resulting from machinery, powered haulage, and falls have long been identified as a significant problem for the mining industry. According to MSHA, during 1995–2004 there was a 42% decrease in days lost due to machinery injuries, a 51% decrease in days lost due to powered haulage injuries, and a 34% decrease in days lost due to falls. Examples of NIOSH research products that have contributed to these achievements are:
 - *A close-proximity warning device*—The research product (HASARD— Hazardous Area Signaling and Ranging Device) has been recently licensed to three firms that manufacture the system for their own use and commercial sales
 - *Technical guidance in the application of proximity warning systems*—MSHA and equipment manufacturers make use of NIOSH expertise to aid in decision-making on effective proximity warning systems and technologies to prevent accidents
 - *A set of best practices for system safety*—NIOSH collaborative research has developed a set of documents relating to the safety life cycle for programmable electronic mining systems. The research has been integrated into the national and international mining communities
 - A computer program that evaluates mine illumination systems: NIOSH-developed software (called the Crewstation Analysis Program) is routinely used by MSHA's Approval and Certification Center in the approval process for mine lighting systems.

Prevention of mine disasters

Since the mid-1990s, NIOSH research has led to the development of prevention, detection, control, and survivability technologies to reduce the probability of and fatalities from devastating fires and explosions. Many of these technologies have been adopted by the coal-producing and equipment manufacturing industry and are recognized in MSHA rulemaking. These technologies have also contributed to fire and explosion protection improvements in Australia and the Republic of South Africa.

The number of fatalities and injuries from mine fires and explosions declined greatly from 1970 to 1999. There were several 'zero' years during the late 1990s, despite a 700% increase in coal production during the same period. A rise in the number of injuries and fatalities since 2000 has prompted further NIOSH research into the causes and preventability of these accidents. These events, unlike other types of accidents where only a few workers are involved, often extend to every underground worker in the mine.

The significant research achievements in this area are listed below:

- Open industry briefings on mine fire preparedness conducted at NIOSH's Lake Lynn Laboratory, have enhanced the mining industry's awareness of the dangers of underground mine fires. Realistic rescue and response training exercises for federal, state, and mine rescue teams at Lake Lynn have improved the effectiveness of rescue teams during numerous mine emergencies.
- Development and implementation of a fire prevention checklist for profiling fire prevention and response capabilities at a mine site have played a key role in preventing and responding to incipient mine fires. NIOSH-developed discriminating fire sensors and optimum deployment strategies based on neural networks and combustion particle detection have reduced the number of false fire alarms when used in mining operations where smoke must be distinguished from normal diesel equipment exhaust.
- Implementation of automatic fire suppression systems on conveyor belt drives and underground diesel storage areas has successfully controlled the rapid spread of belt fires within mine entries. NIOSH research on flammability of noise control materials in operator cabs led to MSHA's acceptance of the American Society for Testing and Materials (ASTM) E-162 Radiant Panel Test as a major criterion in the selection and use of these materials.
- Fire and explosion safety expertise, test equipment, and test procedures that we developed for the mining industry have been transferred to other industries. The consensus standard test methods of the ASTM International committee E27 on the Hazard Potential of Chemicals apply to numerous other industries besides mining. Many of NIOSH's research findings were incorporated into the 2004 revised National Fire Protection Association (NFPA) mining fire protection standards (NFPA 120 (underground coal) and NFPA 122 (metal and nonmetal).
- NIOSH research to determine the risk of ignition of flammable atmospheres by laser-based optical and telecommunications equipment (fibre-optic networks) led to the development of ANSI standards governing the power thresholds for such lasers.
- Post-explosion accident investigation and forensics tools were developed and used by MSHA to help understand and identify the root cause of explosions. Blast-resistant seals and performance test methods were developed at Lake Lynn Lab and implemented in

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partnership with MSHA. Passive and active explosion suppression techniques developed at Lake Lynn are routinely used in underground mines throughout the United States and in other countries, such as Australia and the Republic of South Africa.

- Real-time, automated gob gas venthole monitoring and wireless data transmission permits continuous monitoring of individual gob gas ventholes to optimize methane drainage and reduce the potential for explosive methane-air mixtures.
- NIOSH testing showed that safety for roof bolter operators could be improved by sweeping the area inby the bolter with a methanometer in addition to the machine-mounted methane monitor. This requirement was implemented in MSHA's methane testing requirements.
- Based on data obtained by NIOSH, the Pennsylvania Bureau of Deep Mine Safety permits the use of powered haulage to evacuate a mine in case of a main mine fan outage. Prior to NIOSH's evaluation of worker safety during egress, the use of powered haulage was prohibited during main mine fan stoppages.

Reduction of ground failure fatalities and injuries

Ground falls in US underground mines (coal and nonmetal) caused more than 50000 deaths or about half of all mining fatalities during the 20th century. Over the past 10 years, there have been significant improvements in ground control safety. The roof fall fatality rate in US underground mines has averaged 0.001 per 200,000 hours worked in recent years, down 69% from its average during 1980–1995. In addition, the rock fall injury rate has fallen in each of the last 4 years to a level about 25% below its former plateau.

Important NIOSH research products in ground control that have been successfully transferred to and implemented by the mining community during the past decade include:

- Software for coal mine design that addresses nearly every aspect from coal pillar design, roof support and retreat mining to longwall panel layout
- The Support Technology Optimization Program (STOP) and Analysis of Longwall Pillar Stability (ALPS) programmes, which together have contributed to a virtual elimination of tailgate blockages
- Guidelines for coal pillar recovery and widespread use of mobile roof supports. These have helped make pillar recovery much safer
- Guidelines for designing deep-cover mines to prevent coal bumps (violent failures of highly stressed coal). These guidelines have contributed to 7 consecutive years with no fatalities due to coal bumps
- New standing roof supports. These have helped reduce the number of roof falls and the number of injuries to miners while installing roof support
- A research and educational campaign aimed at increasing awareness about rock fall injuries and the use of surface controls in coal mines. This has helped reduce rock fall injury rates
- Mine design technologies such as the Coal Mine Roof

Rating (CMRR) and Analysis of Horizontal Stress in Mines (AHSM), and guidelines for preventing massive pillar collapses. These have helped provide more stable mining environments.

An essential part of the success of the NIOSH ground control programme has been an effective technology transfer effort, which includes:

- Hands-on ground control software computer training workshops held in six US coalfield locations. These were attended by nearly 300 mine planners
- Open industry briefings on coal mine roof support. These were held in eight US coalfield locations and reached 750 mining industry personnel
- Ground control short courses conducted for Massey Energy and Peabody Energy
- Ground control training provided in eight sessions for all 400 coal mine inspectors from MSHA at the agency's request
- An annual response to an average of 200 technical requests and 40 visits at coal and nonmetal mine sites.

Conclusion

The remarkable improvements in mine worker safety and health have been made possible through the concerted efforts of the mining industry, manufacturers, labour organizations, government agencies and research organizations. NIOSH has contributed to the improvements since 1995 through a research programme that is directed to addressing important issues and providing practical outcomes. The NIOSH research achievements in coal mine safety have been described, showing impacts in traumatic injury prevention, mine disaster prevention and ground fall reduction. These achievements contributed to the significant improvement in mine worker safety and health over the past decade.

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