A century of mining safety and health research

The year 2010 will mark the 100th anniversary of the beginning of the research efforts by the U.S. government to improve the health and safety of miners working in the United States. This research began in 1910 with the establishment of the U.S. Bureau of Mines (the Bureau) and it has continued during the past 10 decades, even after the closure of the Bureau in 1996. The research on safer mining technology formerly done by the Bureau has now been combined with National Institute for Occupational Safety and Health (NIOSH) studies of miners' health to form a unified federal research program to improve the health and safety of miners. This article describes this research and places some of the accomplishments into perspective with other activities in the U.S. Mine Safety and Health Time Line (insert).

The time line shows years since 1900 along the horizontal axis. It has five sections vertically, which are:

- Catastrophic mining events — These are some of the more significant mining disasters that have occurred since 1900. As shown, there has been a noteworthy decline in both the frequency of mine disasters and the number of people killed in each incident.
- Fatality rates — These figures are the number of mining fatalities per 100,000 full-time employees. The data shown are averages during five-year intervals and are separated for coal and noncoal mines. The fatality rates have declined during the past century, but not at a steady pace. The coal mine fatality rates were two to three times higher than for noncoal from 1920 to 1970. The coal fatality rate declined sharply after the 1969 Coal Act and both rates have continued a steady decline since 1970.
- Significant congressional response — This section shows important mining legislation passed by the U.S. Congress and a few other significant federal organizational changes. Most of the federal safety and health legislation has followed major mining disasters that received significant public attention.
- Federal organizations — This bar shows federal agencies established to deal with mining safety and health problems and some of the organizational changes that have occurred.
- Significant safety and health advancements — This section includes notable achievements in mine health and safety technology. Most dates are only approximate as advances in mining usually take place over significant periods of time from initial development to acceptance and general use by the industry.

FIGURE 1

A miner is pictured in Monongah, WV where a pair of explosions in December 1907 killed 362 miners.

The rest of this article describes some of the highlights of the history of safety and health in the mining industry that are illustrated by the time line.

John A. Breslin

John A. Breslin, member SME, is Associate Director for Science, NIOSH, Pittsburgh, PA, e-mail jbreslin@cdc.gov.

FIGURE 2

Officials and rescue workers are pictured at the site of the Cherry Coal Mine in Cherry, IL, where a fire killed 259 miners in the second worst U.S. mining disaster.

Before 1910

In the years leading up to the establishment of the Bureau in 1910, there were a number of historic coal mining disasters with a large loss of life. A series of coal mine explosions in December 1907 killed more than 600 miners. The first explosion at the Naomi Mine, near Belle Vernon, PA, on Dec. 1, 1907 killed 34 miners. Five days later, on the morning of Dec. 6, 1907, explosions at the No. 6 and No. 8 mines at Monongah, WV, killed 362 more miners (Fig. 1). The Monongah explosions caused the worst mine disaster in the United States history. The third major disaster that month was on Dec. 19, when a gas and dust explosion killed 239 miners at the Darr Mine in southwestern Pennsylvania. Many of the miners killed there were Hungarian immigrants. A few were former workers from the Naomi Mine that had closed because of the explosion at that mine earlier in the same month.

The coal mine disasters of December 1907 led Congress to authorize research on the causes of mine explosions by the U.S. Geological Survey (USGS) in May 1908. The USGS organized a mine accidents division of its technological branch in 1908.

The second worst mining disaster in U.S. history, after the Monongah disaster, occurred on Saturday, Nov. 13, 1909 at the Cherry Coal Mine in Cherry, IL. A mine car full of hay was accidentally ignited by a kerosene lamp and the fire spread and burned its way up the timbers and stairs of the mine shaft. Many miners were saved by escaping up the hoist shaft. On the eighth day after the fire, 21 trapped miners were found. A total of 259 miners and rescuers died in the mine fire (Fig. 2).

1910-1930

As a response to tragedies such as those at the Monongah Mine and Cherry Mine, the sentiment in favor of government action increased and led Congress to pass an act in 1910 creating the Bureau of Mines in the Department of the Interior. The general aim of the Bureau under the original Organic Act of 1910 was "to increase health, safety, economy and efficiency in the mining, quarrying, metallurgical and miscellaneous mineral industries of the country." Dr. Joseph A. Holmes, who had been in charge of the technological branch of the USGS, became the first director of the Bureau (Fig. 3).

The initial mine safety research of the Bureau was in these areas:

- Explosibility of mine gas and coal dust and prevention of explosions and fires.
- Safety of explosives used in mines.
- Electrical safety in mines.
- Safety of mine lights and their use as gas detectors.
- Emergency breathing apparatus.

The research information gained by the Bureau was sent directly to mine operators and miners for increasing safety in coal mines. The Bureau sent engineers to visit every mine that had a significant explosion or fire to investigate the cause and give assistance where

FIGURE 3

Joseph A. Holmes (right), the first director of the U.S. Bureau of Mines, is pictured with President Taft at a safety demonstration at Forbes Field in Pittsburgh, PA, in 1911.

needed. These investigations were done "in cooperation with or the approval of the state or mine officials" (USBM, 1912). The Bureau at that time had no statutory authority to enter and investigate mines without permission.

Some of the highlights of the Bureau's work in its first five years included:

- The discovery that coal dust greatly increased the magnitude of mine explosions over those involving methane alone.
- Use of permissible explosives tested by the Bureau reduced the danger of coal mine explosions caused by the use of explosives.
- Bureau work led manufacturers to produce safer electrical apparatus and cap lamps for use in gassy coal mines, and recommendations of the Bureau led several states to enact stricter laws regarding electrical equipment.
- The Bureau's demonstration of rescue apparatus and training of miners in first aid led to the rescue of 200 men after mine disasters.
- A Bureau investigation in cooperation with the Public Health Service in Missouri revealed an excessively high mortality rate from tuberculosis and silicosis.
- The Bureau began compiling statistics on mine accidents and fatalities based on the data provided by the states.

In February 1917, as the U.S. was about to enter World War I, the Bureau offered its assistance to the War Department for the study of poison gases and gas masks. The Bureau did much of the work on poison gases and gas masks until the effort was transferred to the U.S. Army in June 1918. After the end of the war, the Bureau continued development of equipment for protection against mining and industrial gases and dusts. This work included development of gas masks that were effective against carbon monoxide and also of respirators that could be used in oxygen-deficient atmospheres.

An executive order by President Coolidge transferred the USBM from the Department of the Interior (DOI) to the Department of Commerce (DOC) effective July 1, 1925. By that time, the Bureau had 830 employees of whom more than half were based in Washington, DC or in Pittsburgh, PA. Almost 40 percent of the employees were classified as engineers, chemists or similar technical occupations.

As seen in the time line, fatality rates in coal mining rose in the 1920s after a decline in the period from 1910 to 1920. Mechanization of coal mines accelerated in the 1920s with the development of mechanical coal cutters and coal loaders (Fig. 4). These machines were allowed increases in coal mining productivity, but did not necessarily make mining safer. Notable technical safety advancements in this period were development of electric cap lamps, permissible explosives and rock dusting to prevent coal dust explosions.

FIGURE 4

Mechanization of coal mines in the 1920s increased productivity, but not necessarily safety in America's mines.

1930-1950

The time line illustrates that, in the 1930s and 1940s, the frequency of mining disasters declined, as did the fatality rates. Federal organizational changes included transfer of USBM back to the Department of the Interior from the Department of Commerce. USBM research declined in the 1930s with severe budget cuts during the Great Depression. Federal safety standards were established for coal mines in 1947, but were not enforceable. Technology advancements included permissibility for ventilation fans and the beginning of roof bolting in coal mines.

The 1933 annual report of the Bureau noted that 1,463 persons were killed in coal mines in 1931 and another 1,166 fatalities occurred in coal mines in 1932. This was compared to an average number of coal mining fatalities of 2,409 annually during the previous 25 years. In 1931, there were only 3.31 miners killed per million tons of coal produced, which was the lowest rate yet in the 20th century in the U.S. The report attributed much of the credit for what was then considered an "excellent safety record" to the activities of the U.S. Bureau of Mines (USBM, 1933).

The Bureau, along with the rest of the country, fell upon very hard times in the early years of the Great Depression. The budget of the Bureau was reduced from a peak of $3,444,595 in 1929 to about $1.1 million in 1934. As a result of these budget reductions, the Bureau reduced its staff from 755 employees in March 1933 to 501 employees in December 1933, a loss of about one-third of its staff in less than one year. The remaining employees were subjected to a salary reduction of 15 percent. Other budget restrictions forced the closure of five field offices and the termination of the Bureau's health division and all research on mine roof falls, explosives and mechanical equipment in underground mines (DOI, 1935).

The use of permissible explosives was a major factor in reducing explosions in underground coal mines. However, it required decades for the transition to permissible explosives to occur. In 1910, about 10 percent

FIGURE 5

Conventional timbering at the Isabella coal mine in 1949.

of explosives used in coal mines were permissible, while about 80 percent were black powder and the rest dynamite. It took until 1940 before more than 50 percent of the explosives used were permissible, although some of the nonpermissible explosives were being used in surface coal mining. Bureau research led to an increase in the authorized permissible charge limit from 1.5 to 3 lbs. This helped improve mining efficiency. Other improvements in blasting were the use of water-filled stemming bags, single- and multiple-shot blasting machines and short-delay detonators.

The Federal Coal Mine Inspection Act of 1941was passed by Congress following several mine disasters that year. The new law authorized the Bureau to enter and inspect coal mines to observe hazards and recommend safety improvements. Before the act, the permission of the coal mine operator had been necessary to enter a coal mine. In the first four-and-a-half years under this new law, the mining industry complied voluntarily with approximately 35 percent of the recommendations made by Bureau coal mine inspectors. By 1946, the Bureau had a field force of 157 coal mine inspectors and 10 explosives or electrical engineers.

After the Pearl Harbor attack in 1941, the Bureau research was redirected to war-related activities. During the war years of 1942 to 1945, 5,314 lives were lost in coal mines while more that 2.4 Gt (2.6 billion st) of coal was produced, which was a fatality rate of 2.04 deaths per million tons of coal produced. This compared with a total of 7,502 deaths in 1916 to 1918 at the time of World War I, during which more than 1.7 Gt (1.9 billion st) tons were produced, with a fatality rate of 3.91 deaths per million tons of coal. Thus, the fatality rate had been reduced by almost 50 percent between the two world wars.

FIGURE 6

Roof bolts installed at the Isabella coal mine in 1949.

1950-1970

Roof bolting was used extensively in U.S. metal mines by the 1940s. In 1947, Consolidation Coal Co. began testing roof bolting at Consol's Mine No. 7 near Staunton, IL. The Bureau was involved in the early roof bolt trials at Mine No. 7 (Figs. 5 and 6). As it gained confidence in the technique, the Bureau began to advocate roof bolting enthusiastically as an accident prevention measure and became involved with roof bolt trials in mines across the country. By 1957, more than half of all underground bituminous coal was produced in mines that were using roof bolts. Today, roof bolting is the universal primary roof support in American coal mines.

The time line illustrates that the period 1950 to1970 saw several major new federal laws affecting mining. On Dec. 21, 1951, an underground explosion killed 119 mineworkers at the Orient #2 coal mine in West Frankfort, IL. This mine disaster was the worst of its kind since 1940 (Fig. 7). The disaster drew national attention and resulted in passage of the Federal Coal Mine Safety Act of 1952. The Coal Mine Safety Act authorized the Bureau to enforce specific requirements aimed at the prevention of mine disasters and provided for annual inspections in certain underground coal mines. It also gave the Bureau limited enforcement authority, including the power to issue violation notices and imminent danger withdrawal orders.

The Federal Metal and Nonmetallic Mine Safety Act of 1966 was the first federal statute directly regulating noncoal mines. This act provided for the promulgation of standards, many of which were advisory and for inspections and investigations of noncoal mines. However, it gave very little enforcement authority to the Bureau.

On Nov. 20, 1968, an explosion at Consolidation Coal Co.'s No. 9 mine near Farmington, WV, resulted in the deaths of 78 miners (Fig. 8). By this time, medical studies by the Public Health Service were showing that pneumoconiosis or black lung disease in coal miners was a serious problem. The Farmington disaster and the publicity about the prevalence of black lung disease led to passage by Congress of the Federal Coal Mine Health

and Safety Act of 1969 (1969 Coal Act). The 1969 Coal Act was more comprehensive and more stringent than any previous federal legislation affecting the mining industry, and its impact on the industry was major.

The 1969 Coal Act included surface as well as underground coal mines, required two annual inspections of every surface coal mine and four at every underground coal mine, and dramatically increased federal enforcement powers in coal mines. The safety standards for all coal mines were strengthened, and health standards were adopted for the first time. The 1969 Coal Act also included mandatory health and safety standards, and provided compensation for miners who were totally and permanently disabled by coal workers' pneumoconiosis. Following the passage of the 1969 Coal Act, the coal mining fatality rate dropped almost 50 percent, from a five-year average of 202 fatalities per 100,000 full-time employees in the period 1966 to 1970, to 103 fatalities per 100,000 full-time employees in the period 1971 to 1975.

FIGURE 7

An explosion at the Orient #2 coal mine in West Frankfort, IL, that killed 119 miners drew national attention in 1951.

1970-1990

The 1969 Coal Act was the first federal law that dealt with the health of miners as well as safety. The law required mine operators to take accurate samples of respirable dust in underground coal mines. Dust levels were required to be no higher than 3.0 mg of respirable dust per cubic meter, and this level was required to be reduced to 2.0 mg per cubic meter within three years. In 1970, there were about 2,400 active underground coal mines operating in 22 states. In March 1970, the USBM had 327 mine inspectors, including 57 trainees. As a result of the 1969 Coal Act, the inspection force had increased to 1,000 by mid-1971. The 1969 Coal Act also authorized the establishment of the Mining Health and Safety Academy at Beckley, WV for the training of mine inspectors (CRS, 1976).

Congress extended broad safety and health protection to most other non-mine workers when it passed The Occupational Safety and Health Act (OSH) on Dec. 29, 1970. The OSH Act created NIOSH as well as the Occupational Safety and Health Administration (OSHA). NIOSH was authorized by the OSH Act of 1970 to conduct research, experiments and demonstrations relating to occupational safety and health. In the early 1970s, a substantial portion of the NIOSH budget was devoted to its responsibilities for protecting the occupational health of coal miners under the 1969 Coal Act. Some of this NIOSH work included the National Coal Workers' Health Surveillance Program and the Autopsy Study, as well as the long-term National Study of Coal Workers' Pneumoconiosis. Most of this work was done at the NIOSH laboratory in Morgantown, WV.

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The 1969 Coal Act created a statutory requirement that mine operators provide respirators for miners exposed to coal mine dust whenever the dust exceeded the established standard. A respirator testing and approval regulation, 30 CFR 11, was prepared jointly by the USBM and NIOSH in 1972. The new regulation imposed more stringent performance requirements on respirator manufacturers for approval of respirators. Later that year, NIOSH assumed sole responsibility for respirator testing.

In 1972, an underground mine fire at the Sunshine Mine in Kellogg, ID, resulted in the death of 91 miners. This disaster led to the immediate expansion in the research by the Bureau on prevention and control of underground mine fires. The Bureau began new research on test procedures for evaluation of fire resistance of materials used underground, fire detection instrumentation, computer models to predict the spread of fires and toxic gases and techniques for sealing and extinguishing underground fires. A new laboratory scale test procedure was developed to test the fire resistance of conveyor belt materials. The Bureau developed a mine fire simulation computer program called MFIRE that was used to model the spread of mine fires and continues to be developed and used today.

The attached time line includes major organizational changes occurring in the 1970s affecting federal agencies involved with mining. In 1973, Rogers C.B. Morton, the Secretary of the Interior, created a new mining agency within the Department of the Interior. It was named the Mining Enforcement and Safety Administration (MESA). Most of the health and safety enforcement functions were separated from the USBM and placed in the new regulatory agency. The functions transferred included mine health and safety inspection, technical support, assessment and compliance and education and training. The new Mining Health and Safety Academy being constructed at Beckley, WV was also eventually transferred to MESA. The mining health and safety research program and staff remained with the Bureau. Approximately half of the facilities and staff of the Bureau were thus transferred to the new agency (DOI, 1973). The reason for the creation of MESA was to eliminate the possibility of a conflict of interest within

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the USBM, because the Bureau mission to encourage the economic development of mineral resources might appear to conflict with the responsibility to enforce the mining health and safety laws. The Bureau lost more of its other functions in 1974 to the newly established Energy Research and Development Agency (ERDA) and in 1977 to the new Department of Energy (DOE).

The Federal Mine Safety and Health Act of 1977 (Public Law 95-164) extended most of the provisions of the 1969 Coal Act to all other mines and also increased the authorized funding for health and safety research. The 1977 Mine Act amended the 1969 Coal Act in a number of significant ways, and consolidated all federal health and safety regulations of the mining industry, coal as well as noncoal mining, under one law. It transferred MESA and its functions from the Department of the Interior to the Department of Labor, and changed the name of the agency to the Mine Safety and Health Administration (MSHA).

Bureau research was done in the 1970s and 1980s to help develop a self-contained self-rescuer (SCSR) to allow miners to escape from underground mines when the mine atmosphere contained toxic gases or insufficient oxygen. Previously, miners wore filter self-rescuers that were useful only to protect against low levels of carbon monoxide, but could not protect against other toxic gases or oxygen deficiency. Research by the Bureau and the private sector together led to the development of several SCSRs that could provide 60-minute supplies of oxygen to help miners escape in an emergency. Federal regulations were written to require SCSRs be available in the face area of underground coal mines, and they began to be deployed in mines in October 1982.

1990-2010

In September 1995, Congress made a decision to close the Bureau of Mines. The legislation that closed the Bureau transferred some of its functions, staff and facilities to other federal agencies. The health and safety research function and the mining research laboratory facilities and staff at Pittsburgh, PA and Spokane, WA were temporarily transferred to the Department of Energy. A few months later it was decided that these should be transferred to NIOSH. The mine safety and health research unit of the former USBM at Pittsburgh and Spokane has been maintained, with a separate and distinct identity for the mine health and safety program within NIOSH.

In 2001, NIOSH established the National Personal Protective Technology Laboratory (NPPTL), which is located at Bruceton, PA. The mission of NPPTL is to prevent and reduce occupational disease, injury and death for workers who rely on personal protective technologies, such as respirators, gloves and hard hats. Customers of NPPTL research include miners as well as firefighters, emergency responders, and health care, agriculture and industrial workers.

Several coal mining disasters have occurred in the past four years that have had major impact on mining in the United States. The recent major mine incidents began in 2006 with an explosion on Jan. 2 at the Sago Mine in West Virginia that killed 12 miners.

A fire at the Aracoma Alma No. 1 Mine in West Virginia on Jan. 19 caused two fatalities.

On May 20, 2006, there was an explosion at the Darby No. 1 Mine in Kentucky that resulted in five more deaths. These mine disasters led the U.S. Congress to pass the Mine Improvement and New Emergency Response Act of 2006 (MINER Act) on May 24, 2006.

The MINER Act required MSHA to act on new regulations and established deadlines by which some of the new regulations were to be finalized. On Aug. 6, 2007, six miners were killed by a coal outburst at the Crandall Canyon Mine in Utah, when pillars failed and violently ejected coal over a large area. Ten days later, two mine employees and an MSHA mine inspector were killed in a coal outburst during rescue efforts. The Crandall Canyon mine disaster increased pressure for action to improve safety and health for American miners.

As shown in the time line, some of the greatest recent advancements from the mining program under NIOSH have come in the areas of respirable dust, noise control and mine seals research. NIOSH developed a mass-based, continuous dust monitor that was small and light enough to be worn by the workers. This is called the personal dust monitor, or PDM. It has the ability to read out the gravimetric dust level during the work shift and to predict the full-shift dust level if nothing is changed in the mining situation. This allows workers and mine management to immediately correct dust controls to lower dust levels, thereby avoiding overexposure of the workers. At the end of the shift, the PDM data can be downloaded into a computer and stored for future reference. The PDM underwent an extensive field evaluation

that assessed its accuracy, reliability and acceptance by mine workers (Fig. 9). In September 2008, the PDM received approval from MSHA for use in underground coal mines and it is now commercially available.

A urethane-coated flight bar chain was developed by NIOSH to reduce excessive noise exposure for operators of continuous mining machines. It has demonstrated an eight-hour time weighted average exposure reduction of 3 dB(A). The urethane coating also extends chain life by preventing chain link failures. The dual sprocket chain is another technology that was developed for reducing noise overexposures of continuous mining machine operators. This control reduces noise by maintaining a constant level of tension and by decreasing chain slack that otherwise produces high-intensity noise. Underground results showed a 27 percent noise exposure reduction for the continuous mining machine operator. Both the dual-sprocket chain and the urethane-coated flight bar chain were categorized on the MSHA Program Information Bulletin (PIB) P08-12 as "technologically and administratively achievable."

Recent explosions in U.S. underground coal mines suggested that previously accepted seal construction and design methodologies were inadequate. One explosion resulted in the Sago disaster in which 12 miners died, and another caused the Darby disaster in which five more miners died. The new MSHA standard for sealing of abandoned areas raised the explosion pressure design criteria for seals from the old standard of 20 psi to 50 psi or 120 psi, depending on whether or not the mining company chooses to monitor and maintain the sealed area atmosphere inert. This new standard is based in part on the NIOSH report, "Explosion Pressure Design Criteria for New Seals in U.S. Coal Mines." This report established the scientific basis for these new seal standards based on the explosion pressures that could develop (Zipf et al., 2007).

Conclusion

One measure of the accomplishments and impact of a research program is recognition of its products by the R&D 100 awards program of *R&D Magazine*. These awards are presented annually for the 100 most technologically significant new products. Overall, the USBM received 33 R&D 100 Awards before being closed, and it ranked 13th in the world in the number of these prestigious awards (Kirk, 1996). The USBM health and safety research program received 16 of these awards, for innovations including: Trapped Miner Electromagnetic Transmitter (1979), Self-Rescue Breathing Apparatus (1980), Sheathed Explosive Charge (1982) and Personal Toxic Gas Alarm (1989). In addition, several more of these awards were received by the mining research program after it was transferred from the USBM to NIOSH, for accomplishments including: Portable Modified Direct Method Apparatus (1997), Personal Dust Monitor – PDM (2004) and Coal Dust Explosibility Meter – CDEM100 (2006).

As the U.S. Mine Safety and Health Time Line represents, there have been vast improvements in the safety and health of miners in the past 100 years. Changes in mining technology have led to great improvements in efficiency and productivity as well as safety and health. This progress has been enabled by technology developments resulting from research by the USBM and NIOSH. The research accomplishments range from safer best practices to innovative inventions and new products. Along the way, the goal of the USBM and NIOSH during the past century has always been the same — to protect the health and safety of our nation's miners. ■

FIGURE 9

Personal dust monitors have become standard gear for underground miners.

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