

NIOSH: A Leader in Mining Rock Mechanics Innovation

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Summary:

NIOSH and its predecessor, the US Bureau of Mines, have significantly contributed to enhancing the safety of miners and to applying new technologies to the mining industry. Mining fundamentally depends upon pushing technological boundaries and adapting to new and uncertain ground conditions. The USBM/NIOSH, partnering with industry, have contributed significant rock mechanics research which has resulted in increased productivity and reduced hazards, particularly in the underground coal mining industry but in the metal/nonmetal sector as well. As an association focused on rock mechanics, ARMA applauds the work conducted by the USBM/NIOSH and encourages its continuation.

On December 6, 1907, the Monongah Coal Mine explosion claimed the lives of 364 miners (**Figure 1**). It was a devastating event during a decade of devastating events. Over the following years, new records of the most terrible kind were set. An all-time high 20 coal mine disasters with 5 or more fatalities occurred in 1909. The next year set a record for total mine disasters with 25. In 1911 there were 8 metal/nonmetal mine disasters, a record for that sector that still stands to this day.

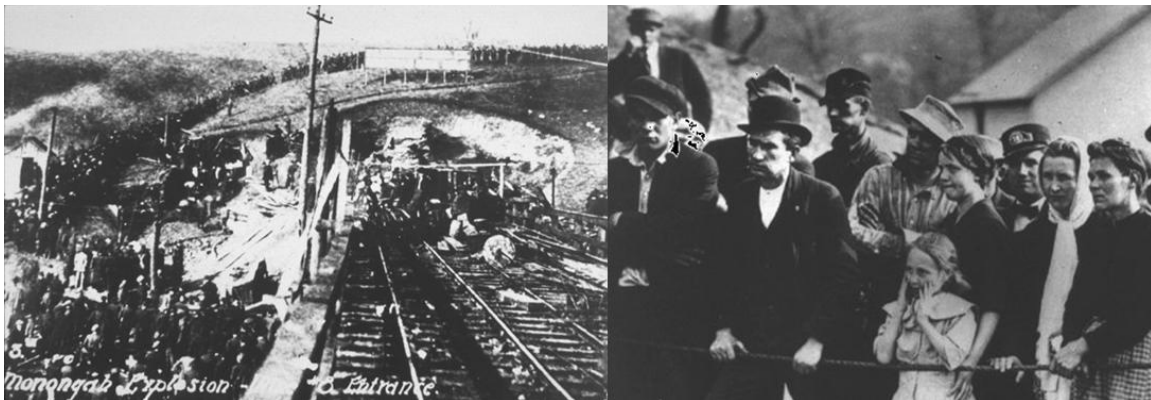


Figure 1 – Photograph of the destruction at the Monongah mine portal and shocked reaction of the local community.

Disasters had become commonplace. In a growing nation, dependent upon mining both at the community and national levels, Congress had to take action. In 1910, the US Bureau of Mines was born.

A century later, coal production had doubled to a peak in 2008 and mining, both coal and metal/nonmetal, had been totally revolutionized. Coal production per miner grew by a factor of ten (**Table 1**). The fatality rate had steadily and dramatically declined (**Figure 2**), achieving a total reduction by a factor of twenty (**Table 1**). There is often a misconception that safety

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and efficiency cannot be simultaneously achieved. Coal mining in the United States attaining a 200-fold reduction in the number of fatalities per ton of coal produced is perhaps the industrialized world's single most striking success story showing that efficiency and safety go hand-in-hand.

Table 1: Historical mining data for the USA including number of documented mine disasters (5 or more fatalities) [1], production [2,3], fatalities [4,5], and workforce size [4,5]. Number of miners and coal production is taken from an available year during the given range (with year noted), while number of disasters is cumulative for the period. Here “M/NM” refers to “Metal/Nonmetal”, which includes Mills (Metal, Nonmetal, and Stone), Sand and Gravel, Surface (Metal, Nonmetal, and Stone), Underground (Metal, Nonmetal, and Stone). Note US Department of Labor has included office workers in total number of coal and M/NM miners since 1973.

Historical Period	Coal Miners (thousands)	Coal Production (million short tons)	Coal Fatalities	Coal Mine Disasters (25 yr cumulative)	M/NM Miners (thousands)	N/MN Fatalities	M/NM Mine Disasters (25 yr cumulative)
1876-1900	449 (1900)	269 (1900)	1489 (1900)	101	N/A	N/A	4
1901-1925	725 (1910)	502 (1910)	2821 (1910)	305	N/A	883 (1911)	17
1926-1950	531 (1942)	643 (1942)	1471 (1942)	147	210 (1942)	361 (1942)	23
1951-1975	149 (1965)	527 (1965)	259 (1965)	35	263 (1965)	180 (1965)	9
1976-present	197 (1985) 134 (2008) 69 (2023)	883 (1985) 1172 (2008) 578 (2023)	68 (1985) 30 (2008) 9 (2023)	18	218 (1985) 258 (2008) 255 (2023)	57 (1985) 23 (2008) 31 (2023)	1

Metal/nonmetal mine statistics tell a similar story. Here the number of miners has remained relatively steady since the 1940s while the number of annual fatalities has been reduced by a factor of ten (**Table 1**). Additionally, metal/nonmetal mine disasters, which peaked at nearly 1 per year during the period 1926-1950, have been nearly eliminated.

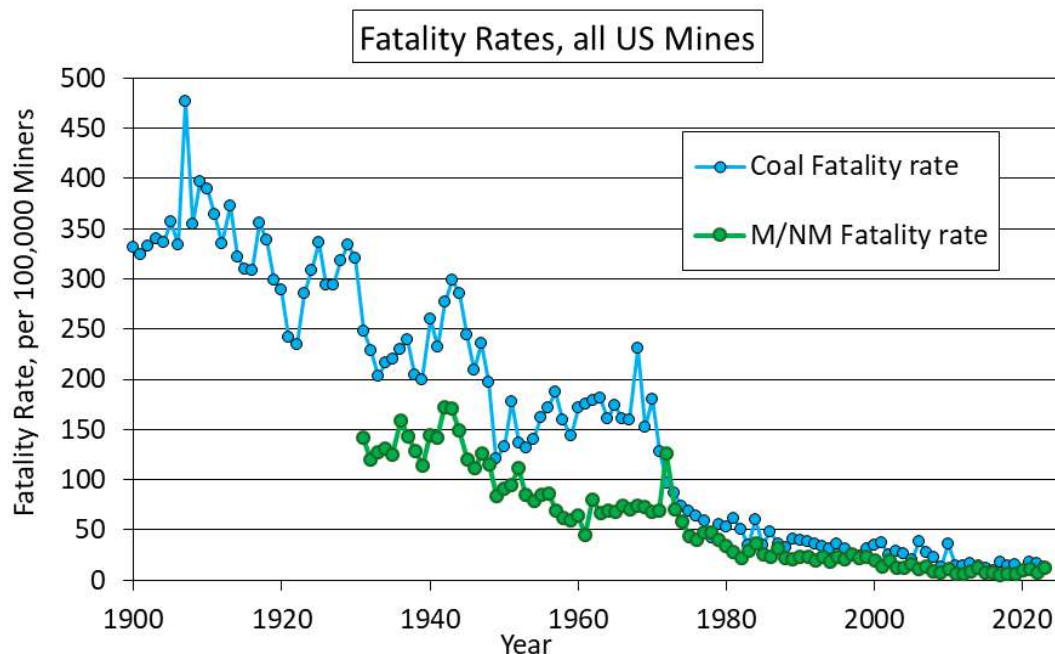


Figure 2 – Fatality rates for coal and metal/nonmetal U.S. mines [4,5].

It Turns Out, Innovation Matters

During this phenomenal century of increasing efficiency and safety, The National Institute of Occupational Safety and Health (NIOSH), and its predecessor the US Bureau of Mines (USBM), have been drivers of innovation. Almost immediately, the new agency set about to demonstrate that fine coal dust significantly raised the intensity of methane-initiated explosions. This was not broadly accepted at that time and had to be proven with experimental data. That data was produced at the USBM/NIOSH Pittsburgh Mining Research Laboratory. The realization that fine coal dust greatly magnified the destructive power of an isolated methane explosion led to the mandated practice of inert material dusting the inside surfaces of a coal mine along with guidelines for using explosives in gassy coal mines. Other important engineering interventions in the 1970's, such as ignition suppression systems and explosion proof bulkheads, led to even a more dramatic reduction in the threat of coal mine explosions (**Figure 3**).

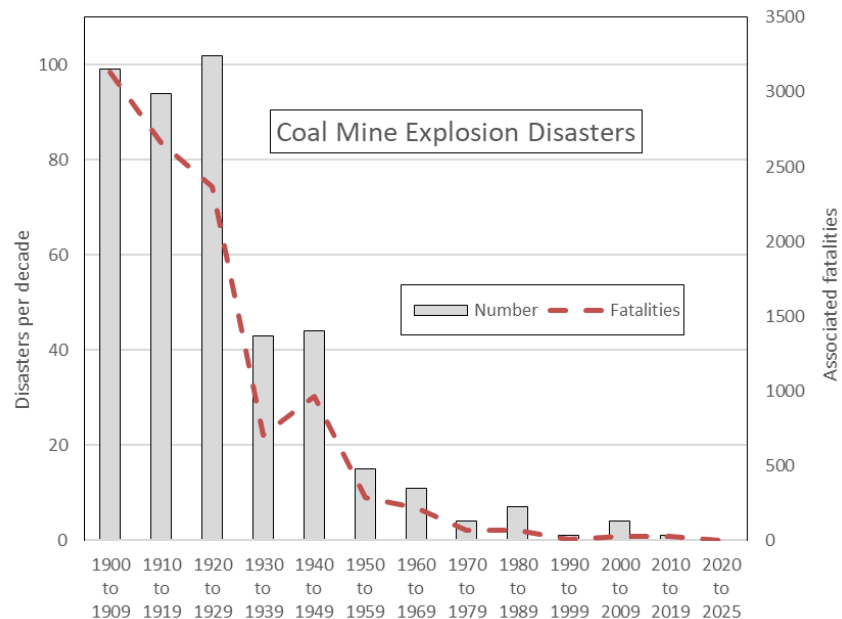


Figure 3 – The dramatic drop per decade in the number of coal mine explosion disaster (5 or more fatalities) and the associated fatalities [8].

A list of more recent accomplishments includes:

- Development of miner safety appliances such as the self-rescuer breathing apparatus that allows miners to continue to breathe in the event of fire or other disaster in underground mines. This device has saved many lives and is essential, required safety equipment at all US underground mines.
- Development of engineering methods for assessing stability of underground metal mines and in design of safe and efficient mining methods. For over 50 years, starting with the USBM, NIOSH has developed empirical and numerical methods for improving stable design of underground mines and instrumentation for measurement of in-situ ground stresses and the rockmass response to mining. These methods are

now widely employed by the US mining industry to ensure stable ground conditions for the workforce.

- Development of ground support methods such as the SplitSet rock bolt and other support methods such as rockfill and paste backfilling that are now mining standards for tunnel and mine excavation support.
- Development of mine seismic monitoring and interpretation methods to assist in managing mining-induced seismicity, which is a serious safety issue in deep mining.
- Development of the Virtual Reality for Mine Rescue Training where highly customized software and head-mounted displays are used by mine rescue teams allowing them to experience and respond to some of the many hazards found in the underground environment [9].
- Utilizing the Mine Roof Simulator (**Figure 4**), a one-of-a-kind instrument that simulates the stresses and displacements found in a wide range of mining conditions. Its purpose is to develop and test new, innovative strata support solutions. The culmination of this research is the computer design techniques referred to as Support Technology Optimization Program (STOP). The STOP program allows engineers to input information from their mines into the program and provides load-displacement guidelines and recommendations for over 100 different types of standing supports.
- Development of a wide range of methane control technology that allow coal mines to drain naturally occurring explosive gas from the coalbed prior to mining [6]. The two principal technologies include: a) the slant hole project (**Figure 5**) and b) foam and water stimulation of vertical boreholes (fracking) to enhance coalbed production. These techniques led to the “coalbed methane” natural gas category [7]. In 1989, the first year when data was reported, the industry produced 91 billion cubic feet of methane gas. By 2008, production rose to 1,966 billion cubic feet. With the arrival of the shale-gas industry in the mid-2000’s, coalbed methane production dropped to 980 billion cubic feet (in 2017). During its the peak years, coalbed methane was the largest supplier of natural gas in the Northern Appalachian Basin. The early work by the USBM helped to develop slant hole drilling technology, through the earth continuous telemetry and coalbed stimulation techniques. All of which helped to set the stage for the exploitation of this resource while reducing the risk of gas explosions in coal mines.

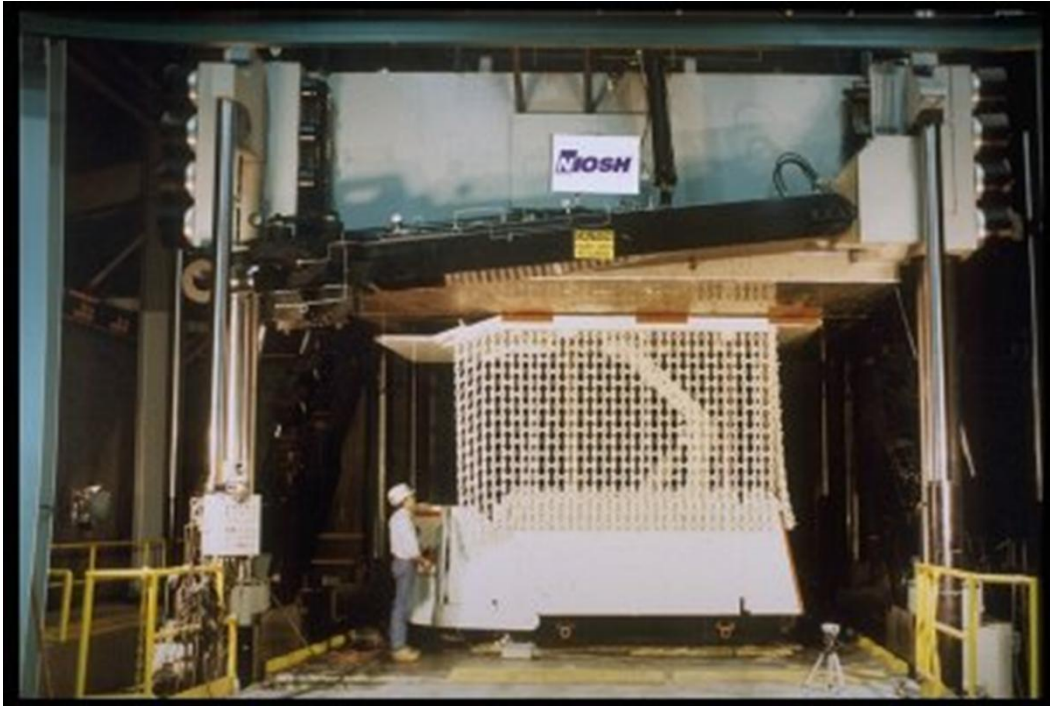


Figure 4 - Load and displacement testing of a Mobile Roof Support within the Mine Roof Simulator at NIOSH's Pittsburgh Research Laboratory.

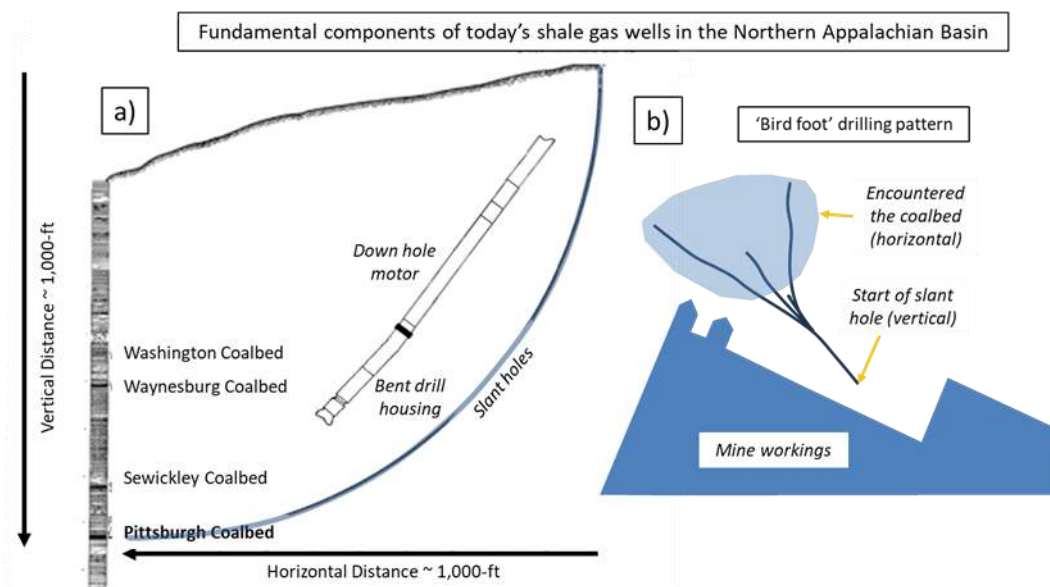


Figure 5 - Demonstration in 1978 of a directional surface borehole (adapted from USBM RI 8286 "Drilling a Horizontal Coalbed Methane Drainage System from a Directional Surface Borehole").

- Development and commercialization of the Personal Dust Monitor (**Figure 6**). This is one of dozens of interventions developed at the Pittsburgh Mining Research Laboratory to address one of the most debilitating worker health issues in coal mining. Pneumoconiosis or more commonly known as "black lung". NIOSH indicates

that coal worker pneumoconiosis was the underlying or contributing cause of death for 75,178 miners from 1970 through 2016 [10]. The PDM is a game changer because a miner can now monitor their exposure to dust in real-time and make adjustments within their work environment to lower exposure. Before this device was mandated by MSHA, miners had to wait several weeks for information on their dust exposure. Remembering work activities from several weeks ago is difficult and restricts positive changes in work practices.



Figure 6 - Miner safety product resulting from commercialization of the Personal Dust Monitor technology developed at NIOSH [11].

While the USBM/NIOSH accomplishments span many fields, rock mechanics has consistently played a central role. Over the last 40 years, our understanding of the cause of rock bursts and coal bumps has drastically reduced these dangerous occurrences. Meanwhile, building a mechanical framework for predicting and preventing pillar and roof-rib instabilities has led to the transformation of coal mine pillar design from an art to a science. Standardization of coal mine pillar design over the past 4-5 decades includes not only the development of approaches such as Analysis of Longwall Pillar Stability (ALPS) in 1990, LaModel in 1993, and Analysis of Retreat Mining Pillar Stability (ARMPS) in 1995 for underground coal, but, more recently, S-Pillar for underground stone mines.

The outcome has been a quantifiable, significant reduction in injuries and fatalities within the mining workforce. Of the various accident categories in underground mining, the one most specifically addressed by advances in rock mechanics is “Fall of Ground (from in place)”. These are accidents associated with unwanted, unplanned, and often sudden collapses or bursts of rock. The Mining Safety and Health Administration (MSHA) began assessing the accident class or category in 1983. Over the next 30 years, the number of

fatalities from Fall of Ground accidents reduced from 30-40 per year to only a few in a typical year (**Figure 7**).

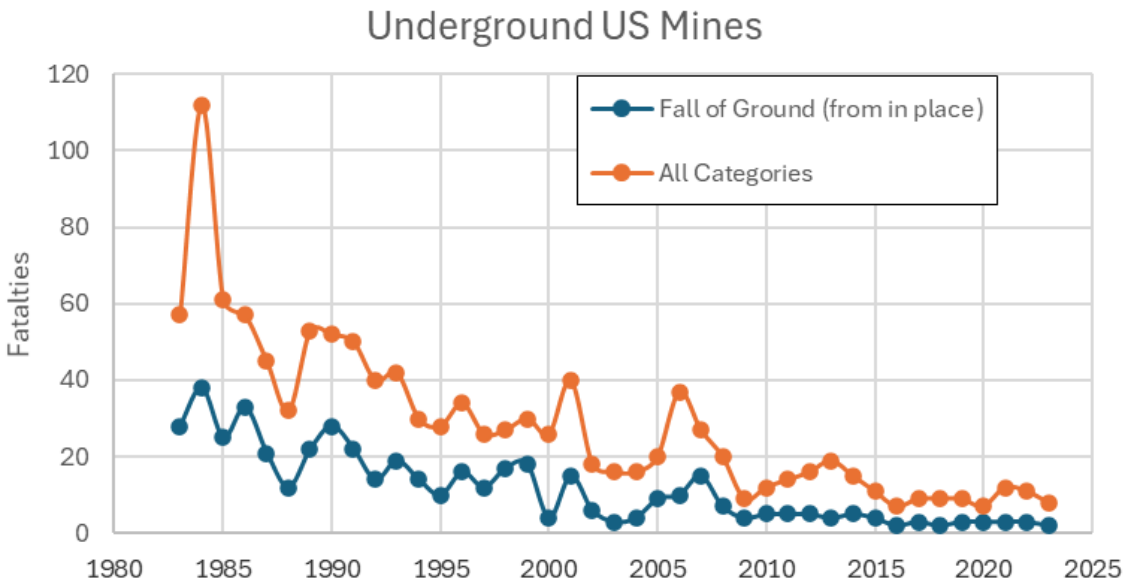


Figure 7 - Number of fatalities in underground US mines, including all categories as well as fatalities due to falls of ground [8].

The decline in Fall of Ground fatalities is striking. Furthermore, the reduction of Fall of Ground as a percentage of all fatalities in underground mining has reduced from 40%-60% during the 1980s and 1990s to 20%-40% today (**Figure 8**). The temporal correlation with the development of ground control science, as well as stricter government safety enforcement during the late 1980s and through the 1990s, is unlikely to be a coincidence, but rather it is another testament to the impact of innovation.

However, the fact that Fall of Ground fatalities still occur, comprising between 20%-40% of all underground fatalities points to a deeper truth, and a more profound and ongoing challenge, which is central to our closing argument. Rock mechanics is, at heart, a subbranch of engineering that addresses the inherent challenges associated with design and engineering in a natural, variable material. In mining, conditions change within a rockmass, because mining is always exposing new, previously unseen rocks, and because creating a mine opening can sometimes induce unexpected responses from the rockmass.

This is all to say, no two mines are alike. Mines are not factories that can be replicated from one location to another. Every mine requires a unique plan in order to be developed safely and efficiently.

A second part of the challenge is that mining practices are always being pushed to the limit. It is intrinsic to the field. Mining proceeds up to the edge of what is technologically and economically feasible to safely produce. Only innovation can take it farther.

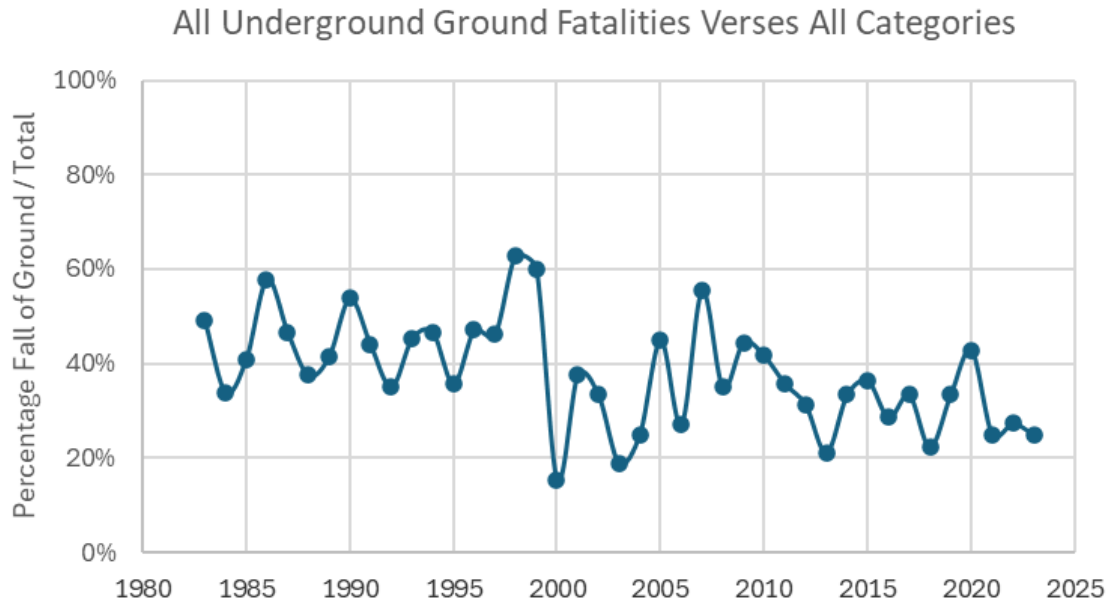


Figure 8 - Percent of fatalities due to falls of ground compared to total fatalities in underground US mines [8].

Currently, no other US government institution has been charged with performing research to advance the safety, efficiency, and operation of the nation's surface and underground mines. NIOSH is absolutely unique in this role. Furthermore, the research efforts at universities are dependent upon NIOSH's vision, oversight, and administration of externally-funded R&D projects. NIOSH personnel not only conduct research, partnering with industry, to improve mine safety, but they also oversee university research that is training the next generation of rock mechanics engineers. It is impossible to support mining without supporting the innovation needed to make mining safer and more efficient.

It is also impossible to expand renewable energy in this country without increasing production of critical minerals necessary for batteries and the copper that is needed to extend high transmission power lines to areas that are ripe for solar and wind power. Efforts from the mining industry that will provide these necessary minerals for the next generation can be strongly supported by mining research, specifically within rock mechanics.

As a rock mechanics community, we at the American Rock Mechanics Association (ARMA) celebrate the legacy of NIOSH and USBM and are proud of the role rock mechanics has played in the innovations that have transformed the mining industry in this country and beyond. But stopping there, considering efficiency and safety in mining to be a solved problem, part of our nation's past, would be a profound mistake, one that ignores the nature of underground engineering in the presence of uncertainty and that fails to recognize that future mining always depends upon pushing boundaries that are insurmountable with today's technologies. We therefore wholeheartedly support our members and colleagues at NIOSH, we express our appreciation for their efforts specifically in rock mechanics research, and we support the continuation of this important work.

About ARMA:

The American Rock Mechanics Association (ARMA) is a professional and international engineering and scientific association, which promotes interaction among specialists, practitioners, scholars, and educators in rock mechanics and geomechanics. For more information visit www.armorocks.org.

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Glossary of Terms:

Self-rescuer breathing apparatus – wearable respiratory device that provides a user with breathable compressed air

Backfill paste – a cementitious material place with mine openings to provide ground support and regional stability

Longwall mining – a form of underground coal mining where a long wall of coal is mined in a single slice several feet wide repeatedly to form a longwall panel

Room-and-pillar mining – a form of underground mining where material is extracted across semi-horizontal plan, leaving mine opening supported by adjacent pillars

Black lung – also known as pneumoconiosis is caused by long-term inhalation of fine coal dust in the lungs

SplitSet supports – a form of rock reinforcement also known as friction rock stabilizers capable of holding fractured strata in place

Intrinsic rock reinforcement – steel anchored bolts are inserted into boreholes drilled into the strata surrounding the underground opening

Free standing supports – engineered supports placed within the mine opening capable of resisting the deformation of the surround strata

Sources:

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