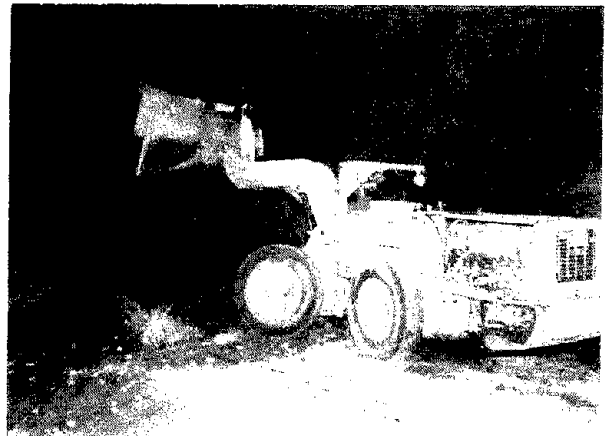




Office for Mine Safety and Health Research

Program of Mining Research 1998-1999



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health



NIOSH

**PROGRAM OF MINING RESEARCH
1998-1999**

**Dr. Larry Grayson
Associate Director for Mining
National Institute for Occupational Safety and Health**

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REFLECTIONS ON 1998

DR. LARRY GRAYSON, ASSOCIATE DIRECTOR

OFFICE FOR MINE SAFETY AND HEALTH RESEARCH

This has been a very busy year for the NIOSH Office for Mine Safety and Health Research. Just after the start of the 1998 fiscal year, I had the honor of being selected as the first permanent associate director. I had been very familiar with the work done by the former U.S. Bureau of Mines, and I found it truly exciting to become reacquainted with the research and the people that now make up this new NIOSH office. As I traveled about the country this year and met with you, our customers, I was impressed with both the reputation that our work has earned and with how much is left to do.

We have used a well-documented strategic planning process (described briefly in the Surveillance Activity section of this Program of Mining Research) to put together what we believe is an excellent research program. Most importantly, we reached out through both the Pittsburgh and Spokane Research Laboratories to our mining constituencies—miners, mine operators, mining associations, unions, academia—in a series of stakeholder meetings held in Colorado, Florida, Idaho, Kentucky, Pennsylvania, Virginia, and Washington, DC. Input was sought from industry management, labor, engineering and geology professionals, safety directors, associations—in short, an excellent cross section of the customers we serve. We listened to what we heard and used this information to help us develop research projects that would meet the needs of our customers, as perceived by our customers. The meetings focused on current research needs, future trends and potential needs, training deficiencies, and ways to disseminate research results more effectively.



Dr. Larry Grayson



Dr. Jeffery Kohler

Nineteen-ninety-eight was a year of change and growth as we completed the transition from the U. S. Bureau of Mines to NIOSH and the new Office for Mine Safety and Health Research. A major milestone was the naming of permanent directors at both the Pittsburgh and Spokane research labs. Ros Hill, who has a 27-year history with mining research in Spokane, was named director of the Spokane Research Laboratory. Dr. Jeffery Kohler, a well-known and widely respected professor from Penn State, was chosen as director of the Pittsburgh Research Laboratory. With such strong leadership in place, we are well poised to move ahead toward finding solutions to the safety and health problems that persist in the mining industry.

There are many challenges facing us all as we approach a new millenium. We look forward to continued interaction and partnering with you as we work to make mining safer for miners.



Ros Hill

PROJECT SUMMARIES

OBJECTIVES AND RESULTS

IMPROVED DUST CONTROL TECHNOLOGY FOR LONGWALL MINING

PRINCIPAL INVESTIGATOR: Jay Colinet

RESEARCH OBJECTIVE

Measure dust concentrations generated by major sources of dust found in longwall mining operations and identify control technologies that can be used to reduce the exposure of longwall workers to respirable dust.

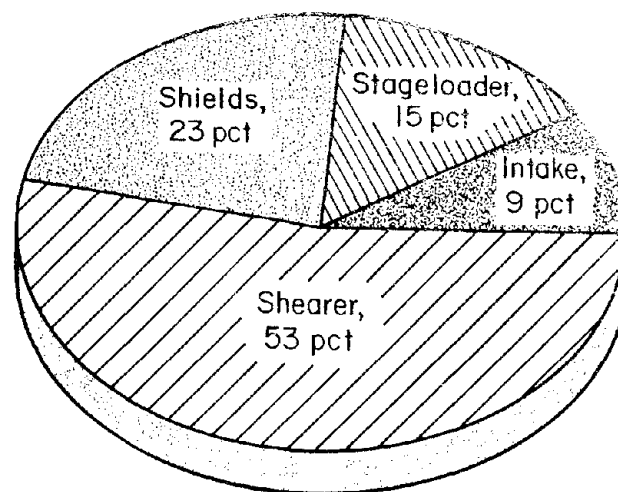
PROBLEM STATEMENT

Longwall mining is the most productive method of mining in underground coal mines; average shift production has increased fourfold over the past 15 years. However, longwall mining can also generate large quantities of respirable dust. Longwall operations typically have the most difficulty in maintaining compliance with the 2-mg/m³ dust standard. MSHA statistics show that approximately 20% of the dust samples collected from 1993 through 1997 in longwall mines exceeded the permissible exposure limit (PEL). The proximity of longwall workers to a number of significant dust sources exacerbates the problem of controlling worker exposure to excessive dust levels.

RESULTS TO DATE

A series of dust surveys were conducted in 13 longwall operations to measure dust levels generated by various sources, identify the types of control technologies being used, and determine the level at which these controls were being applied. Results from the surveys showed that the shearer, shields, and stageloader-crusher generated the highest levels of respirable dust. Ventilating air and water sprays remained the primary means used by longwall operators to control dust levels and reduce worker exposure.

Another task involved evaluating air-atomizing spray manifolds for their ability to split the ventilating airflow on longwall faces, which would confine dust-laden air to near the face while directing clean air over the worker walkway. These tests were conducted at



Average dust contributions from major sources on longwalls.

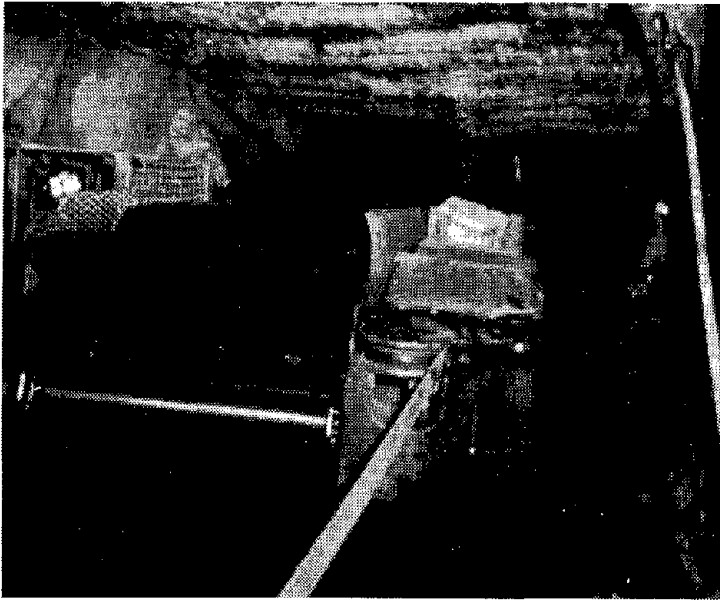
the Safety Research coal mine at PRL using spray manifolds spaced at 25-ft intervals along a simulated longwall face. Results indicated that the manifolds should be closer together to generate effective air splitting down the face. However, the quantity of compressed air and water required to supply additional manifolds at closer spacings would make the system impractical. Researchers concluded that air splitting would be a method of reducing worker dust exposure, but that an improved means of achieving splitting needs to be developed.

In the coming years, longwall dust control researchers will examine how high-velocity air streams entrain respirable dust, as well as investigate how novel control technologies can be applied. Stakeholders in industry and labor have indicated that they expect longwall mining production levels to continue to increase, but that current control technologies may be reaching practical limits. Longwall research remains a high priority, and new and/or improved control techniques are needed to ensure adequate protection for workers. Future research will address these stakeholder concerns and contribute to improved dust control techniques for longwall mining.

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KEYWORDS: Dust control, longwall mining



Operators of continuous mining machines and shuttle cars can be exposed to a range of dust concentrations and compositions.

SILICATE DUST GENERATION AND RARE ELEMENT BEHAVIOR IN COALS

PRINCIPAL INVESTIGATOR: S. J. Schatzel

RESEARCH OBJECTIVE

Investigate the relationship between the silicate component of a coalbed and silica dust concentrations produced by continuous miners during underground coal mining. The study will also incorporate an investigation of the geologic and biologic behavior of rare earth elements in coal and associated rocks.

PROBLEM STATEMENT

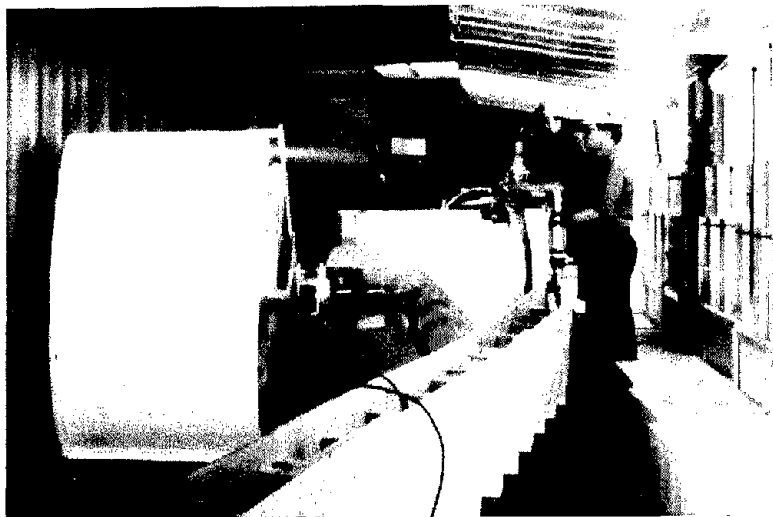
Silicosis is a disease that is harmful to human lung tissue and adversely affects the lives of many coal miners each year. The relationship between the mineral composition of samples of whole coal and samples of coal dust produced by mining is not clearly understood. Data on respirable silica dust reported by the Pittsburgh Research Laboratory suggest that concentrations of silica above the allowable limits may be occurring in mines with sandstone roof rocks. Other potential sources of silica dust are finely dispersed mineral matter within a coal unit and aluminosilicate clay materials, which can be present as discrete layers within the coalbed or in roof or floor rock.

Rare earth elements are regulated by "nuisance" dust standards. Consequently, the concentrations of rare earth elements in the diverse range of worker exposures have not been reported. Both laboratory experiments and studies on exposed human subjects have raised concerns about the behavior of certain rare earth oxide, chloride, and fluoride compounds with regard to the development of genetic abnormalities and respiratory illnesses. The types of exposures to rare earth elements are very broad and include dust from mining and processing of rock and glass; intravenous injections of rare earth compounds; and vapors from the use of molten rare earth elements in metal working, filaments, and carbon arc lamps. In 1996, a U.S. mine was the second-highest producer of rare earth elements in the world. In that year, there were 14 rare earth processing plants, producers of rare earth magnet alloys, or producers of rare earth magnets in the United States. About 20 cases of pulmonary disease caused by the inhalation of rare earth metal dusts have been documented. However, diagnosis of rare earth pneumoconiosis is not standardized; such diagnoses are made more difficult by the lack of postmortem studies, databases, and statistics on symptoms.

RESULTS TO DATE

This is a new project. However, specific sources of silica inhaled as a result of the coal mining process will be investigated at individual mine sites and across geographic basins. The capability of existing dust control measures to protect underground workers from hazardous levels of respirable silica will be evaluated during the experiments. The study of rare earth elements will examine their long-term behavior in nature and their concentration in coal and associated rock units. These results will be discussed with NIOSH health experts to assist in the evaluation of existing standards for rare earth elements in mining and other industries. This research will also provide new in-house capabilities for the analysis of rock-forming mineral components and can be applied to the NORA areas of mixed exposures and emerging technologies.

KEYWORDS: Rare earth elements, silica dust, underground coal mining, geochemistry



Tests of the efficiency of water sprays being conducted in the longwall dust gallery.

IMPROVED APPLICATION AND MONITORING OF DUST CONTROL PARAMETERS

PRINCIPAL INVESTIGATOR: Ellsworth R. Spencer

RESEARCH OBJECTIVE

Reduce the exposure of underground coal mine workers to respirable dust through improved application of ventilating air and spray water.

PROBLEM STATEMENT

Coal workers pneumoconiosis (CWP) continues to be a very serious health threat to underground coal mine workers. Results of the most recent round (1992-1995) of the Coal Workers' X-ray Surveillance Program show that approximately 9% of the miners examined who had at least 25 years of mining experience were in the initial stages of CWP. Most of these workers would have obtained their working experience and subsequent dust exposure after passage of the Federal Coal Mine Health and Safety Act of 1969, which established a respirable dust standard of 2 mg/m^3 . Sampling by MSHA showed that on the average, 10% of the underground dust samples exceeded the 2-mg/m^3 standard. For specific high-risk occupations, the percentage of samples exceeding the dust standard was even higher. From 1986 to 1995, the percentage of MSHA dust samples exceeding the 2-mg/m^3 standard were 29%, 23%, and 15% for shearer operators, longwall jack setters, and continuous miner operators, respectively. The continued development of CWP in coal mine workers and the extent of overexposure in these occupations illustrate the need for improved dust control technology in underground coal mining.

RESULTS TO DATE

Several tasks have been completed during this research project.

- A monitor was developed that records and displays dust control system parameters such as ventilation airflow and spray water pressure and flow continuously and in real time. The purpose of this joint NIOSH/MSHA study was to assemble a monitoring system and demonstrate how it could augment a coal mine's dust control plan. Monitoring dust control system parameters will help mine operators limit respirable dust levels in underground coal mines by keeping all dust control systems operating in concert and at optimum levels. MSHA has recently requested that this monitor be installed at a Western longwall operation.
- The use of exhaust ventilation and a scrubber at extended-cut continuous miner faces was evaluated. The promotion of extended-cut mining to achieve higher production rates can expose the operator of a continuous miner to higher levels of respirable dust. To reduce these dust levels, proven dust control methods are being evaluated. Tests in a full-scale continuous miner gallery that simulates an extended cut using exhaust ventilation showed that significant changes in ventilation levels did not substantially alter dust levels when the scrubber was operating. Significant differences in dust levels were observed when the sampling location was changed to simulate the movement of a remote continuous miner operator.
- The silica collection efficiency of flooded-bed scrubber filter panels was determined for six different types of filter panels. Results showed that collection efficiencies could range from less than 60% up to 95%. Selection of an inappropriate filter panel could significantly increase the amount of silica dust passing through the scrubber and back into the mine ventilating air.

Future research in the longwall gallery will evaluate changes in dust levels resulting from changes in airflow, water flow, water pressure, spray system design, and mining height at longwall faces. The results from the tests will illustrate interactions among the dust control parameters being evaluated. Longwall operators will be able to assess the potential impacts on dust levels that may result from changes in control parameters.

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KEYWORDS: Mining, coal dust, longwall, respirable dust

CONTROL OF SILICA DUST IN UNDERGROUND METAL/NONMETAL MINES

PRINCIPAL INVESTIGATOR: Robert J. Timko

RESEARCH OBJECTIVE

Investigate worker exposures in various metal/non-metal mining occupations to respirable silica dust and develop methods and technologies to reduce those exposures.

PROBLEM STATEMENT

Respirable dust is classified as an airborne particle having an aerodynamic diameter of 10 micrometers (μm) (0.000039 in) or less. Respirable dust is harmful when inhaled by workers because of its ability to become entrapped in the inner regions of the lungs. Crystalline silica, which is commonly found as dust where quartz and sandstone rocks are crushed, as well as in granular form as sand, is even more hazardous because of its ability to cause progressive deterioration of lung tissue. In fact, the International Agency for Research on Cancer has recently classified crystalline silica as a carcinogen.

In a recent study of gold miners, investigators concluded that exposure for 45 years to 100 micrograms (μg) of respirable quartz dust per cubic meter of air would increase the lifetime risk of silicosis between 35% and 47%. That amount is the current permissible exposure limit (PEL). MSHA is responsible for obtaining samples to ensure that a mine operator is complying with dust standards. Records collected from

1988 through 1992 show that between 25% and 53% of dust samples from silver, copper, uranium, vanadium, gold, crushed limestone, lead, and zinc underground mines exceeded the PEL. MSHA compliance data also show that certain occupations are at greater risk of overexposure to respirable quartz. Those occupations include scoop tram operators, crusher operators, jack-leg stoper drill operators, and load-haul-dump operators. For some of these occupations, existing technology already in place for controlling respirable dust in the coal industry may be applicable. For others, new technologies may have to be developed. Mining methods in metal/nonmetal mines can be significantly different from those in coal mines. For example, entries in some metal/nonmetal mines may be more than 60 ft wide and 100 ft high, dimensions that present unique dust control problems.

RESULTS TO DATE

This project was initiated in October 1997. MSHA compliance data were collected for various designated underground occupations in the metal/nonmetal mining industry. Also, MSHA officials were interviewed to see where they felt the respirable dust generation problems were most acute. These data will be used to decide where research will be most beneficial. Ultimately, this work will reduce miner exposure to silica dust in underground metal/nonmetal mines.

KEYWORDS: Respirable quartz, silica, metal/nonmetal, carcinogen, underground mines

SILICA DUST CONTROL IN METAL/NONMETAL SURFACE MINING

PRINCIPAL INVESTIGATORS:

Andrew B. Cecala and Robert J. Timko

RESEARCH OBJECTIVE

Determine effective control technology to reduce worker exposure to silica and other harmful contaminants in mineral processing plants.

PROBLEM STATEMENT

Crystalline silica is harmful because it causes progressive deterioration of the lungs once it has become embedded in tissue. In 1997, the International Agency for Research on Cancer contended that inhaling crystalline silica in the form of quartz or cristobalite can cause cancer in humans. MSHA's records show that since 1974, more than 82,000 of the 134,000 full-shift air samples collected by inspectors in the metal/non-metal mining industry contained at least 1% quartz. In a similar report, MSHA inspectors stated that at mineral processing facilities, the occupations with greatest exposure to silica are packaging, particularly bagging, loading, and laborer. Maintenance, cleanup, and utility workers are often overexposed because their mobility makes it hard to provide them with engineering controls.

RESULTS TO DATE

A study to evaluate respirable dust levels in portland cement operations is in its final stages. Two field evaluations have been completed, data analyzed, and a report drafted. This report summarizes the results of both field studies, one at a dry processing operation and the other at a wet operation. At both operations, respirable dust measurements were collected during all stages of the cement-making process. Each operation was evaluated during both summer and winter to compare dust levels under different weather conditions. The report provides some general recommendations for reducing respirable dust levels for plant personnel working in areas where dust exposure is high.

Work was also done to compare different types of building structural designs used in mineral processing

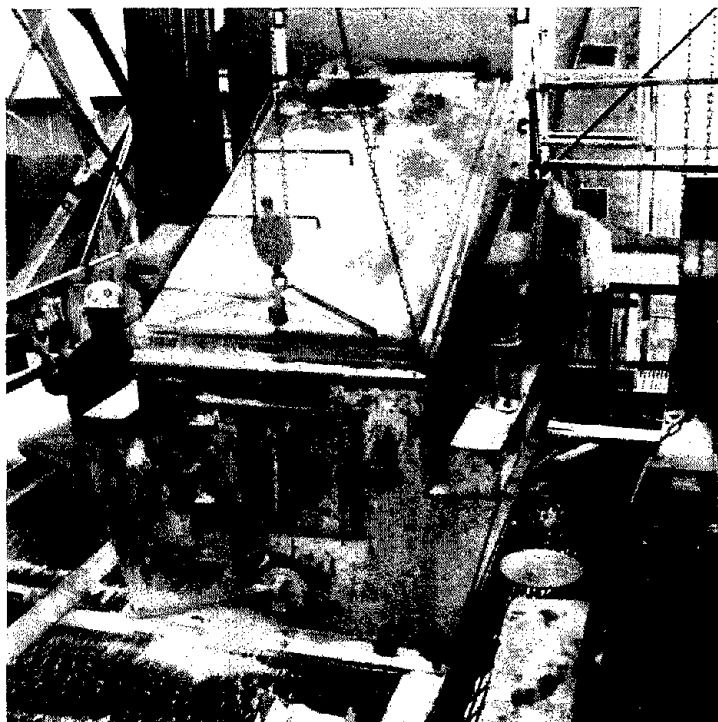
operations throughout the United States and to determine the impact of different designs on dust and noise levels. Three different structural designs were evaluated, all at silica sand plants. In September 1997, a pebble mill and screening tower were evaluated at an operation using a block-and-brick building design. In April 1998, an operation using an open-structure (no walls) design was evaluated. Respirable dust measurements were taken at a four-story screening tower with a steel beam shell and no sides. In September 1998, both the pebble mill and screening areas at a third operation were evaluated. The pebble mill was a metal-sided structure and the screening area was an open structure. The data from these evaluations are presently being analyzed.

This research should lead to a cleaner work environment for workers in the noncoal mining industry, lower respirable dust exposures, and reductions in the potential for life-threatening lung diseases.

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Respirable dust measurements being taken near screening area as part of structural design evaluation.

DUST CONTROL IN SURFACE COAL MINING

PRINCIPAL INVESTIGATORS:

John A. Organiscak and Steve J. Page

RESEARCH OBJECTIVE

Reduce exposure to silica dust at surface mining operations through examination of existing dust control technologies and development of new ones where deficiencies exist.

PROBLEM STATEMENT

As of 1995, 44% of all coal miners (47,467) worked at surface coal mines. In 1992, NIOSH reported 23 cases of silicosis in miners ranging in ages from 25 to 60 and who had from 3 to 20 years of drilling experience. Most of the cases involved operators in their 30's and 40's, suggesting that high silica exposure levels were associated with their occupation. A more recent study of a 664-volunteer population of surface coal miners showed that the prevalence of silicosis-like abnormalities was 9%. The two most significant factors associated with these silicosis-like abnormalities were increasing age and years of drilling experience. MSHA dust exposure data also show that the two most frequently designated work positions (DWP's) over the permissible exposure limit (PEL)

are drill and bulldozer operators. Therefore, the focus of this research is to reduce the exposure of drill and bulldozer operators to silica at surface coal mines through assessments of current dust control technologies and development of new ones where deficiencies exist.

RESULTS TO DATE

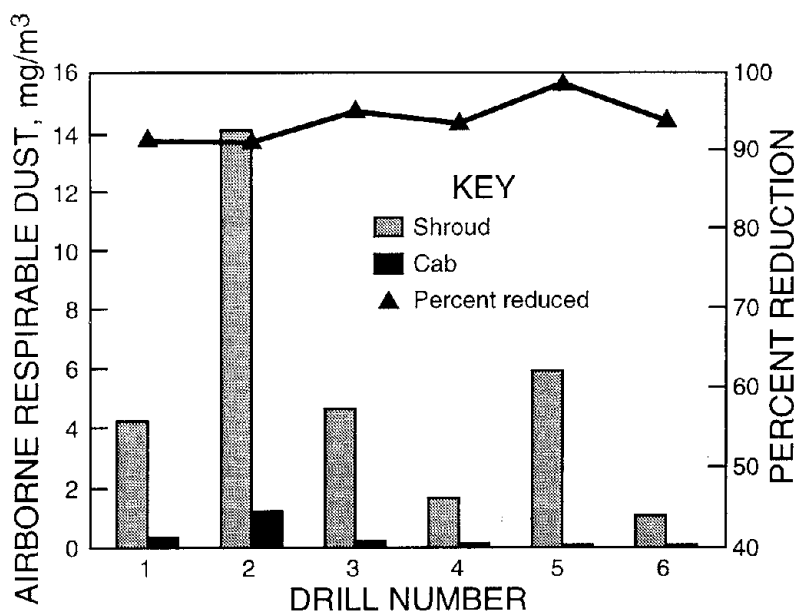
Six rotary rock drills and five bulldozers were evaluated at six surface mines. Airborne respirable dust (ARD) was measured inside and outside enclosed operator cabs. All the drills used dry dust collector systems as the primary means of dust control, with enclosed cabs for additional operator protection. The drill dust data show that a drill can generate large amounts of ARD near the collector shroud, while the cab provides good dust protection for the operator. ARD was commonly more than 90% lower in the cab than next to the shroud. However, collecting primary dust at the drill shroud is the key, because ARD levels in the cab are directly related to the dust levels generated by the drill. Without an effective dust collector near the drill, dust would rise to levels beyond the capability of the cab to provide protection.

The bulldozers studied had enclosed cabs as the primary means of dust control for the operator. Bulldozer data showed that reductions in ARD inside the cab were more variable than near the drills, varying between 40 and 100%. However, the amount of dust generated by the bulldozers was an order of magnitude lower than dust generated by drills, so dust levels in the cab rarely exceeded 0.2 mg/m³.

Since this study showed that drills have a much greater problem with silica dust than do bulldozers, future research will focus on developing new engineering control technologies to reduce drill-generated dust. Development of such new technologies will lower the exposure of drill operators to silica dust and reduce their likelihood of contracting silicosis.

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Dust levels measured at rotary drills at surface coal mines.

KEYWORDS: Surface mining, dust control, silica, surface drills

MINING DUST CONTROL APPLIED TO OTHER INDUSTRIES

PRINCIPAL INVESTIGATOR: Ed Thimons

RESEARCH OBJECTIVES

Task 1: Conduct surveys of tunnel construction practices that impact dust levels and evaluate the need for NIOSH involvement in development of control technology. Task 2: Provide drill operators with concise information on how to reduce their exposure to silica dust. Task 3: Demonstrate how to improve surface mine equipment cabs to protect equipment operators from exposure to respirable dust.

PROBLEM STATEMENT

Task 1: Survey of Tunneling Practices That Impact Dust Levels

Results of dust sampling at hard-rock tunnel construction sites showed that dust levels often exceed the legal exposure limit. Tunnel construction workers have a high risk of developing silicosis. However, the basic dust control information commonly available for all types of mines is not available for tunnels. For example, at some tunnel operations, conveyor belts are used to transport broken rock out of a tunnel. At others, rail cars are used. Conveyor belts are thought to be dustier, but nobody knows for sure. How much spray water and ventilation air is really necessary to control dust, how to best design a dust collector for use underground, or even how to measure dust in a reliable and consistent way are also unknowns.

Task 2: Pocket Guide for Control of Construction Drill Dust

In both the highway construction and surface mining industries, large truck-mounted drills are used to drill holes for placing explosives. Drilling these holes generates large quantities of silica dust, which can represent a serious silicosis hazard to drill operators. A pocket guide on how to control construction drill dust would take the knowledge we have obtained from surface mining dust control research and put it in an easy-to-follow format that could be used by both the mining and the construction industries. Such a pocket guide would be a concise handbook written in nontechnical language and small



Rock drill with type of dust shroud recommended by pocket guide



Enclosed cab at surface coal mine

enough to fit in a pocket. The proposed guide would summarize all the dust control information developed for mining drills for a construction-related context. While the intent of the guide is to encourage technology transfer to the construction industry, it would serve similar objectives for the mining industry.

Task 3: Improve Surface Mine Equipment Cabs

Recent MSHA survey results show that 33% of the bulldozer operators at surface coal mines had respirable quartz exposures in excess of $100 \mu\text{g}/\text{m}^3$ of air. In autopsies, 6.4% of surface miners had silicosis. MSHA has recently declared that dust protection afforded by mining equipment cabs is a priority issue. Much of the mining equipment used in surface mining is old, and the operators' cabs fail to protect against exposure to respirable dust either because of poor structural integrity or inadequate filtration efficiency. Even many cabs on new equipment do not provide good dust protection because the design of the filtration system is poor.

RESULTS TO DATE

Task 1: Survey of Tunneling Practices That Impact Dust Levels

Surveys have been conducted at four tunnels near Las Vegas, New York City, and Boston. These surveys consisted of measuring relevant dust and ventilation parameters and dust levels and then making recommendations on how to reduce dust. In future work, these surveys will be used to build the information base necessary for making generalizations about various tunneling practices and their effects on dust control. If this project is successful, tunnel contractors will be able to do a much better job of controlling silica dust.

Task 2: Pocket Guide for Control of Construction Drill Dust

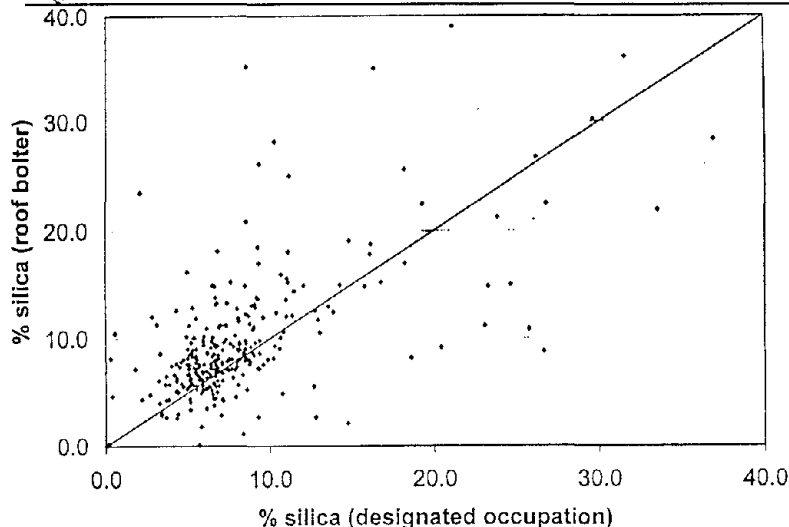
During the fiscal year, a pocket guide for the control of construction drill dust was written and sent out for review. The main topics are (1) Why should rock drillers worry about silica dust? (2) How do they know if there is a dust problem? (3) How can dust exposures be cut? (4) What are the top three actions to take? If this project is successful, fewer drillers will be exposed to the hazard of silica dust.

Task 3: Improve Surface Mine Equipment Cabs

This project was started in March 1998. Progress has been in two areas. First, laboratory tests are underway to see how wind speed affects the protection provided by enclosed cabs. A series of tests was run at the Clean Air Filter facility in Defiance, IA. In these tests, a simulated cab with known air leaks was pressurized with filtered clean air, and dust levels were measured using particle counters inside and outside the simulated cab. Further testing is planned for 1999.

Second, a partnership has been established with Clean Air Filter, Red Dot Corp., and Al Hamilton Construction Co. to demonstrate how older cabs can be improved to provide better dust protection at a very reasonable cost. A service contract that provides 50% cost-sharing has been issued to Clean Air Filter to do the actual cab refurbishing. Two old cabs, one on a drill and the other on a loader, will undergo both structural and filtration improvements. Red Dot is providing and installing the air conditioning-heating units at no cost to the project. Clean Air Filter will provide the filtration media. Al Hamilton Construction is providing the mine equipment along with on-site support for the project. NIOSH personnel will evaluate how the cabs have been improved. The results of this research will show that cost-efficient modifications can be made to equipment cabs to provide better protection from respirable dust.

KEYWORDS: Dust control, rotary drills, silica control



Relationship between designated occupation and roof bolter before silica percentages for all operations are selected.

CONTROL OF SILICA DUST EXPOSURES IN UNDERGROUND COAL MINING

PRINCIPAL INVESTIGATOR: Gerrit V. R. Goodman

RESEARCH OBJECTIVE

Identify occupations with high silica dust exposures and improve methodologies for controlling such exposures during underground coal mining.

PROBLEM STATEMENT

MSHA limits exposure to respirable coal dust to 2 mg/m^3 . If the silica content on the sampling filter exceeds 5%, the respirable dust limit is reduced using a formula of 10 divided by the percentage of silica. When in compliance, the 2-mg/m^3 - and reduced-dust standards limit silica concentrations to $100 \text{ }\mu\text{g/m}^3$.

The respirable dust standard for a production machine is adjusted by silica exposures measured using the occupation designated as the dustiest. This designation assumes that using such a "worst-occupation" standard will protect the workers in other occupations on the production unit (i.e., roof bolter, shuttle car operator, etc.). In continuous mining operations, the continuous mining machine operator generally receives this designation. However, experience shows that a roof bolter operator can be exposed to higher silica levels than the designated occupation. To limit silica dust exposures, the roof bolter machine is termed a designated area and receives its own dust standard adjusted by silica levels measured in this occupation. Like the designated operator, the designated area is subjected to a more rigorous sampling scheme.

MSHA data show that most of the violations issued for excessive respirable silica dust are in MSHA districts 4, 5, 6, and 7. These districts comprise southern West Virginia, northeastern Kentucky, southeastern Kentucky, and southwestern Virginia. Not surprisingly, the concentration of underground coal mining operations is high in these areas, representing nearly 530 mining operations out of a national total of 700.

RESULTS TO DATE

MSHA offices in districts 4, 5, and 6 were visited to review the coal mine inspector's dust sampling records for the period from January 1, 1997, to June 30, 1998. These records provided a factual and reliable account of mining and operating conditions during respirable dust sampling. Data were obtained on dust concentrations for all sampled occupations, amount of rock mined, coal tonnages, and measured operating levels for fresh air flow, air flow through the dust collector, water spray pressure, and water spray count. To control the scope of the investigation, only those mining operations that had silica dust levels in excess of 5% were selected, because this percentage suggests a potential problem with silica exposure. One group unsuccessfully maintained silica dust levels at or below $100 \text{ }\mu\text{g/m}^3$, while the other group successfully maintained the $100\text{-}\mu\text{g/m}^3$ level. To further control the amount of data collected, only the worst of the first group and best of the second group were considered. This led to comparisons of silica dust exposures for "problem" and "good" operations.

The results showed that occupational overexposure to respirable silica dust continues at the roof bolter, and that a roof bolter is not always protected by a standard based on designated-operator-adjusted silica dust levels or a separate standard based on a designated area. Future work will investigate technologies for reducing roof bolter exposures to respirable silica dust.

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KEYWORDS: Silica dust, coal mining, respirable dust, ventilation, surveillance

PERSONAL DUST MONITORING

PRINCIPAL INVESTIGATOR: Jon C. Volkwein

RESEARCH OBJECTIVE

Develop an inexpensive personal dust monitor based on the correlation of increasing pressure restriction of a filter with increased mass loading of the filter.

PROBLEM STATEMENT

Current methods to measure exposure to respirable coal mine dust do not provide timely results to operators or workers. Major stakeholders, namely the National Mining Association, the United Mine Workers of America, and MSHA, have all expressed keen interest in the development of a real-time, cumulative personal respirable-dust monitor. This approach to dust monitoring can be used by companies to control dust exposures administratively and by miners to empower the workers with knowledge of their daily exposures.

Improving assessment of respirable dust concentrations in the workplace is a NORA priority area.

RESULTS TO DATE

NIOSH, in partnership with MSHA, has been developing an extremely accurate but expensive tapered-element oscillating microbalance for mine use. The personal dust dosimeter provides an alternative approach through the use of a less accurate but inexpensive method for routine monitoring of respirable dust levels. The new sampler correlates filter back-pressure with mass accumulation to provide midshift and end-of-shift determinations of cumulative exposure. The sampler uses a small, low-flow-rate pump that draws dust through a small detector tube containing a porous urethane foam section. The foam captures large, nonrespirable particles, and a glass fiber filter collects respirable dust.

This new type of dust sampler was compared side by side with personal gravimetric samplers. In the laboratory, the new instrument compared favorably with currently used sampling systems. Assessment of the device under field conditions is in progress. To date, the dosimeter has been compared with personal samplers in five different mines. Preliminary analyses

show that results from nondiesel mines correlate well with the laboratory data.

The personal dust dosimeter is just one of the new tools that NIOSH is developing to monitor the dust exposure of workers. The application of this technology to the workplace promises to give workers and companies alike the information they need to monitor and control exposures to hazardous dust.

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KEYWORDS: Respirable dust, monitoring, pneumoconiosis, aerosols



The new pressure-differential-based personal dust dosimeter and a gravimetric personal dust sampler being evaluated in underground side-by-side comparisons.

FIXED SITE DUST MONITORING

PRINCIPAL INVESTIGATOR: Bruce K. Cantrell

RESEARCH OBJECTIVE

Develop new technologies and instruments that can measure and characterize respirable coal mine aerosols continuously and accurately.

PROBLEM STATEMENT

In 1991, the Secretary of Labor directed MSHA to review its respirable dust enforcement program and recommend improvements. Because of that directive, a Coal Mine Respirable Dust Task Group was formed. In June 1992, a task group report called for the accelerated development of two mine dust monitors: (1) a fixed-site monitor that could provide continuous information about dust levels to a miner, mine operator, and to MSHA, if necessary, and (2) a personal sampling device capable of providing both a short-term personal exposure measurement as well as a full-shift measurement. The task group recommended continuous monitoring to ensure that environmental dust levels would always meet the applicable respirable dust standard.

In October 1996, the Secretary of Labor's Advisory Committee on the Elimination of Pneumoconiosis Among Coal Mine Workers also examined when continuous monitoring of coal mine dust concentrations would be appropriate. The committee's recommendation was, in part, that

"MSHA should complete research (in consultation with other agencies such as NIOSH) to study the relation between indices collected from continuous monitors and the traditional methods of assessing exposure to respirable dust when these different methods are applied to the function of hazard surveillance as well as when developing other potential uses of continuous monitoring data (for example, compliance activity)."

RESULTS TO DATE

NIOSH has engaged in an aggressive research effort to develop mineworthy devices to monitor respirable coal mine dust mass concentration continuously. The primary dust sensor technology chosen for development is the tapered-element oscillating microbalance (TEOM), manufactured by Rupprecht &

Patashnick Co., Inc. Ten prototype machine-mounted continuous respirable dust monitors have been fabricated, and their performance and reliability are being evaluated in underground coal mines in collaboration with MSHA. The results will be used to develop strategies for using the monitor as an active component of a mine's dust control procedures. As a follow-on to this work, NIOSH has embarked on development of a person-wearable version of this dust monitor. It is also investigating pressure differences across a filter as part of work to develop a personal dust dosimeter.

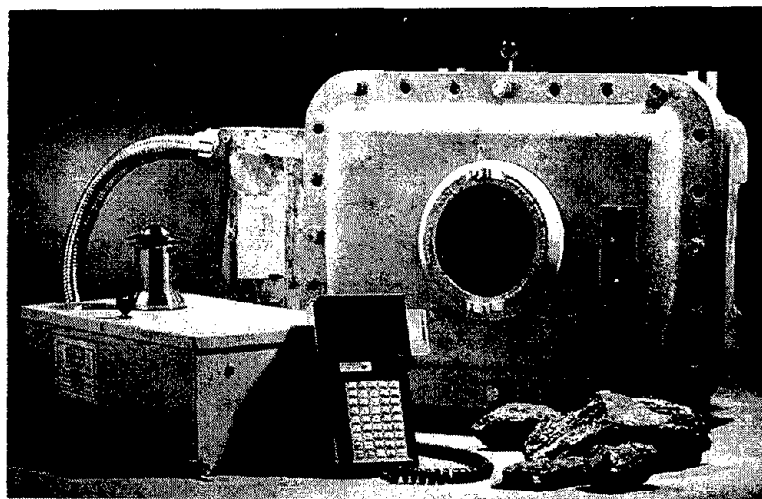
Besides the effort to develop continuous dust monitors, improved methods for analyzing silica in dust samples are being studied. A workable, on-filter quartz analysis technique, based on Fourier transform infrared spectroscopy, has been developed. Although this method is no more accurate than methods now in use, it will enable rapid analysis of filter samples. Software to optimize and automate the procedure is currently being written.

Each of these project efforts is focused on providing a quick assessment of exposure to hazardous dusts. Such information can help protect workers by providing quick feedback for optimization of dust control systems.

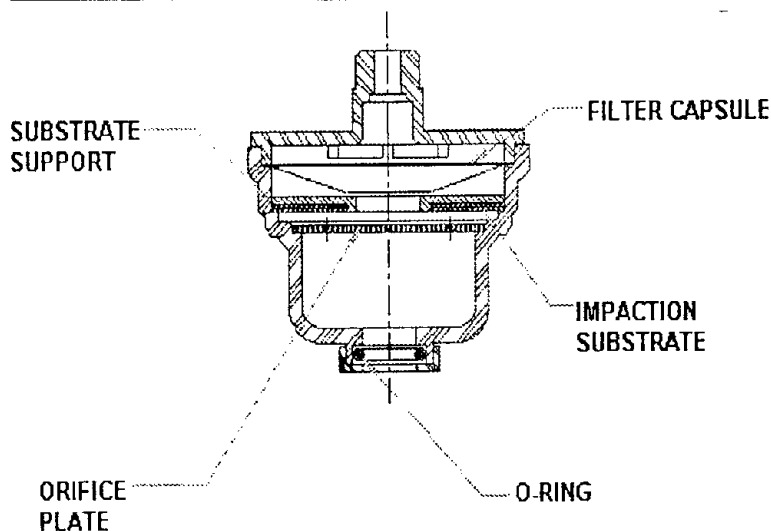
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KEYWORDS: Respirable dust mass monitor



Preproduction MMCRDM used in the phase 2 in-mine evaluation



Commercial diesel exhaust sampler

DIESEL ENGINE EMISSION MEASUREMENT AND ANALYSIS

PRINCIPAL INVESTIGATOR: Bruce K. Cantrell

RESEARCH OBJECTIVE

Develop techniques to measure emissions from diesel engines accurately.

PROBLEM STATEMENT

Diesel exhaust consists of noxious gases and diesel exhaust aerosols. Approximately 30,000 underground miners are potentially exposed to high concentrations ($>0.5 \text{ mg/m}^3$) of diesel exhaust, and another 200,000 surface mine workers are exposed to lower concentrations. In 1995, the American Conference of Governmental Industrial Hygienists recommended a threshold limit value (TLV) of 0.15 mg/m^3 based on a relative lung cancer risk of 1.4. MSHA has proposed a permissible exposure limit (PEL) for diesel exhaust aerosols in metal/nonmetal mines. If the proposed value is adopted by MSHA as a PEL, nearly all underground mines using diesel equipment would be out of compliance.

Accurate measurements of emissions are necessary to reduce exposure effectively and to ensure compliance with standards. Consequently, measurement technology is being developed to evaluate diesel emission control techniques and provide the industry with a means to assess worker exposure to regulated exhaust components. The NIOSH research program on diesel emissions has developed and evaluated exhaust control technology to reduce exposure to diesel exhaust emissions without creating unsafe conditions.

RESULTS TO DATE

- A size-selective personal diesel exhaust sampler originally developed by the U.S. Bureau of Mines is being commercialized by SKC, Inc., under a joint effort by NIOSH and MSHA.
- Field comparisons of techniques for measuring diesel exhaust aerosols (i.e., size-selective, respirable combustible dust, and the NIOSH elemental carbon sampling/analytical method 5040) are being conducted. A report on the first such comparison is available in the proceedings of the Canadian Ad Hoc Diesel Committee held at the Oct. 1997 plenary conference, Toronto, ON.
- A new passive cassette sampler has been developed for workshift NO and NO₂ measurements. Direct reading cards and continuous monitors are being evaluated for this application.
- An emissions-assisted maintenance procedure was developed, and a report on the procedure is available on the NIOSH Internet Web page. MSHA will use this procedure to implement current diesel regulations. MSHA has distributed 1,500 copies of the report and is currently developing a maintenance manual based on the material presented there.

Collectively these reports and hardware will enable the mining industry and MSHA to determine diesel exhaust gas and particulate exposures and take the first steps to controlling that exposure with appropriate maintenance procedures.

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KEYWORDS: Diesel exhaust aerosol mass measurement

REDUCING DIESEL PARTICULATE EXPOSURE IN WESTERN MINES

PRINCIPAL INVESTIGATOR: Art Miller

RESEARCH OBJECTIVE

Reduce the exposure of workers in Western mines to potentially dangerous levels of exhaust from diesel engines. Products of this research will be information and tools that the mining industry can use to help meet Federal mandates and reduce worker exposure levels.

PROBLEM STATEMENT

Exposure to diesel exhaust, especially diesel particulate matter (DPM), has been recognized as a health concern for some time. The problem is far worse in underground mines than in other industries because of low ventilation. The issue appears as a research gap in the Phase III strategic planning document for all underground categories. The lack of surveillance data on current exposure rates is confounded by the limited sensitivity of measurement technologies and the confusion surrounding what constitutes a standard data collection protocol. MSHA has recognized DPM as a potential hazard and anticipates putting new regulations in place to help reduce worker exposure in underground mines. Several entities, including the Environmental Protection Agency, have produced studies that suggest diesel exhaust should be labeled as carcinogenic. If this takes place, health concerns will be amplified



Many miners are regularly exposed to some level of diesel exhaust in their work environment.

and fuel a new thrust to eliminate exposures to diesel exhaust. With these developments in mind, we are initiating this NIOSH research to bring mining science and engineering expertise to bear on this emerging issue.

A fully successful program has the potential to reduce exposure to diesel particulates by 90% or more. If implemented in underground mines, almost 100,000 workers would see significant reduction in DPM exposures. Research results could also be implemented in other industrial sectors where diesels are used in close quarters, i.e., factories and warehouses. The transfer of technology to these sectors could easily result in reduced exposure for hundreds of thousands of employees in nonmining industries.

RESULTS TO DATE

The project was organized into three phases: identification of potential interventions, selection of interventions for further evaluation, and implementation of interventions to reduce worker exposure. Only work on phase 1 has been initiated.

Identification of Potential Interventions

This phase entails identifying and evaluating as many interventions and solutions as possible through an extensive literature search. The result will be a document outlining each intervention and discussing its pros and cons, and creation of an evaluation matrix for systematically assessing the relative feasibility of each intervention.

Contracts: Two contracts have been let. One employs a physical chemist at St. Mary's University to complete a literature review on the topic of combustion chemistry. The second contract, to complete a search on technology to reduce diesel particulate exposure in underground mines, is with Idaho National Engineering and Environmental Laboratories.

Collaboration: Personnel from the Pittsburgh Research Laboratory have extensive experience in this field, and we are working with them to determine the direction of this research. A North American consortium called DEEP has been a clearinghouse for funding diesel research for several years, and it will be a good source of information. A European group called VERT has been doing extensive R&D on this topic using the many large-scale tunneling projects in Europe. Interaction

with this group has been and will be of great benefit. Another potential partner is the staff at the Colorado School of Mines, who are interested in cooperative work to adapt recent fuel cell technology to mining. Other collaborators will include NIOSH researchers in Cincinnati, OH, who have developed the elemental carbon method for analyzing diesel exhaust, as well as personnel in Morgantown, WV, who are studying the health effects of diesel exhaust.

KEYWORDS: Diesel exhaust, diesel particulate matter, worker exposure, mine health and safety.



Dust being emitted during drilling operations in an underground nonmetal mine

EXPOSURE TO TOXIC SUBSTANCES IN DUST AT NONMETAL MINES

PRINCIPAL INVESTIGATORS:
Pamela L. Drake and Greg G. Miller

RESEARCH OBJECTIVE

Identify toxic substances in dusts from nonmetal ores to evaluate their potential for worker exposure.

PROBLEM STATEMENT

There are approximately 25,000 workers employed in nonmetal mines. Although metals and other trace toxic substances can be present in nonmetal ores, the extent to which toxic substances occur in dusts from nonmetal ores and whether exposure levels constitute a hazard have not been studied extensively. Neither are the health effects of exposure to dusts in these mines addressed under the current NIOSH mining safety and health research program except where significant amounts of silica are present.

The mineralogic content of nonmetal ores is highly variable because this classification includes a wide range of commodities and because separate occurrences of each commodity are very different. Analyses of trona samples from the Solvay Mine in Wyoming indicate copper, zinc, and chromium are common, while nickel, arsenic, and lead are present in some samples. Trona (sodium sesquicarbonate) can be an irritant to the respiratory system, mucous membranes, and skin because of its alkalinity. Health effects can be worsened because trona and many other nonmetal ores dissolve readily in the lungs, leading to rapid uptake of toxic substances. In other mines, asbestos is often associated with talc and can affect respiratory function. The National Occupational Health Survey of Mining identified anomalous concentrations of chromium in dust from phosphate and trona mines.

The largest sources of dust at nonmetal mines are drilling and blasting operations in underground mines and crushing operations in surface mines and mills. Haulage traffic is a source of dust at all locations. Stakeholder input from a talc mine in Montana and anecdotal accounts from workers in trona mines in Wyoming indicate there are concerns about exposure to dust in nonmetal mines. A better understanding of the occurrence and exposure pathways of toxic substances in dust is needed.

RESULTS TO DATE

This is a new project.



Collecting a short-term sample of silver while the precipitate containing the silver is being transferred to the furnace.



Collecting a sample of silver fumes during a pour of molten slag.

CHEMICAL HAZARDS AT ACTIVE METAL/NONMETAL MINES

PRINCIPAL INVESTIGATORS:

Pamela L. Drake and Russell L. Levens

RESEARCH OBJECTIVE

Investigate and evaluate potential chemical hazards in mining workplaces to enable development of control or mitigation methods.

PROBLEM STATEMENT

Exposure to metals and other chemicals in mining workplaces, particularly in milling and refining facilities, may adversely affect thousands of workers. Mercury and silver are examples of potentially hazardous metals found in ore deposits in the western United States.

Mercury is not an important commodity, but it is retained during processing and refining because of its similarity to gold in chemical complexing and adsorption behavior. The potential for exposure is enhanced because mercury has a high vapor pressure, which means that whenever ore concentrates containing mercury are heated, the mercury is vaporized.

Occupational exposure to silver and mercury can occur during numerous refining processes. Dust containing mercury or silver can be stirred up while handling dry concentrates and while cleaning silver bars (doré bars) after smelting. Also, metal fumes can be released when concentrates are heated during retorting and during smelting. Mercury or silver from the refinery can be spread to other areas on shoes or clothing.

RESULTS TO DATE

Exposure to mercury vapor and silver dust and fumes have been the focus of this project. Site surveys have been conducted at three gold and silver mines. Personal breathing zone samples and area air samples were collected in the refineries in order to detect excessive exposures and to identify potential sources of mercury and silver. Air velocity measurements were taken in exhaust ventilation systems with the purpose of assessing their effectiveness and making recommendations for design changes where needed. Two al-

ternative designs for ventilation hoods in the refinery at one site were completed. The new hood designs were presented to the mine personnel as a relatively inexpensive means of reducing worker exposures to silver during the doré bar cleaning process. Modifications were subsequently made to the doré bar cleaning hood. A follow-up survey consisting of ventilation measurements and personal and area air samples shows that these modifications may have reduced silver exposures slightly; however, silver concentrations continued to exceed the MSHA permissible exposure limit (PEL).

A team of researchers from NIOSH and a team from the Center for Toxicological Investigations of the University of Carabobo, Venezuela, conducted a site survey to determine if overexposure to mercury exists in El Callao, Venezuela. Included in this survey were an industrial hygiene study, a medical study, and an examination of mining processes at the site.

Different threshold limit values (TLV's) have been set for metallic silver and soluble silver compounds by the American Conference of Governmental Industrial Hygienists. Currently, the accepted protocol measures only total silver; therefore, laboratory tests were conducted to measure the amount of water-soluble silver compounds and the amount of total silver on air filter samples collected at three silver-gold refineries. The analysis of the air filter samples suggests that the water-soluble concentrations of silver are less than the MSHA PEL of 0.01 mg/m³.

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EXPOSURE TO TOXIC SUBSTANCES IN MINING

PRINCIPAL INVESTIGATORS:

Gerrit V. R. Goodman and Pamela Drake

RESEARCH OBJECTIVES

Identify high-risk toxic substances in the mining environment, assess risks and measure exposure levels associated with these substances, and develop strategies for controlling such exposures.

PROBLEM STATEMENT

NIOSH has identified exposures to many potentially toxic substances in the mining workplace. Chromium and nickel exposures can arise from welding with stainless steel filler metals. Previous studies on the health effects of welding showed that welders ran a 30% to 40% increase in the risk of lung cancer. Exposures to cutting fluid aerosols and metal dusts can arise from cutting and abrasive grinding processes employed in surface shop areas. Long- and short-term exposures to these agents may adversely affect respiratory health.

RESULTS TO DATE

Many potentially toxic substances are present in the mining industry. It is most practical to first consider those substances and occupations representing the greatest risks to mine workers, i.e., substances and occupations having the highest toxicity or affecting the largest number of workers. Risk assessment will be based upon morbidity and mortality data, exposure data from other Federal agencies, information from medical screenings and interviews, medical testing data to evaluate organ function, x-ray surveillance data, and the results of previous surveillance activities. Measuring personal exposures to toxic substances in the mining industry is also necessary.

Contacts with industry will be used to establish studies measuring exposures to the substances of interest. Exposures will be categorized according to occupation, facility (mine, mill, shop), ore type, mining region, and operational characteristics such as ventilation flow, ventilation type, worker positioning with respect to the toxic agent source, and the presence of existing controls. This task will also identify possible limitations in the use of such controls.

This project started in October 1998. Preliminary work has begun with industry searches of available literature and consultations with personnel from the Physical and Toxic Agents group in MSHA. Data gathered in this early stage will be used to identify

those toxic agents and occupations presenting the greatest risk to mine workers.

KEYWORDS: Toxic agents, surveillance, measurement, occupational health



NIOSH has identified exposures to many potentially toxic agents in the mining environment.

COMMUNICATIONS AND TECHNOLOGY TRANSFER FOR HEARING CONSERVATION

PRINCIPAL INVESTIGATOR: Roy Bartholomae

RESEARCH OBJECTIVES

Raise the mining industry's level of awareness about the problem of noise-induced hearing loss and create a sense of urgency to preserve the hearing of miners.

PROBLEM STATEMENT

In spite of progress during the last two decades, overexposure to noise in the mining workplace remains a serious problem for many mine workers. A sustained communication effort to educate the mining industry about the problem of noise-induced hearing loss and the solutions currently available are critical components of a strategy to eliminate hearing loss among miners. A base of technical information already exists, but it needs to be reviewed and expanded. Four major activities have been identified to date.

- Update the Noise Control Handbook.
- Develop a series of noise control manuals.
- Develop guidelines for the selection and use of personal hearing protectors.
- Implement an industry outreach program.

RESULTS TO DATE

This project was initiated last year. Two workshops were held. Plans are being developed for a NIOSH Web page on noise-induced hearing loss, so that the Internet can be used to make information easily and readily available to the entire mining community (workers, mining companies, machinery manufacturers, and others). The Web page and future workshops will be used as a forum for technology transfer of current information and to examine the question of why miners are still losing their hearing after 25 years of regulation. A primary goal of the Web page will be to solicit feedback from stakeholders to assist in defining a research agenda that is responsive to their needs.

MODEL HEARING CONSERVATION PROGRAM FOR MINERS

PRINCIPAL INVESTIGATOR: J. Alton Burks

RESEARCH OBJECTIVE

Demonstrate the efficacy of a model hearing conservation program in preventing hearing loss among miners.

PROBLEM STATEMENT

When safety and health regulations for metal/nonmetal mining were enacted, it was already recognized that the high noise levels generated by mining machines posed a serious threat to the health of miners. In 1976, NIOSH published the results of a cross-sectional survey of hearing levels that confirmed the severity of hearing loss among coal miners. The study found that over 70% of miners had a hearing impairment by the time they retired. To combat this problem, regulations were adopted to limit the overexposure of miners to harmful noise, and a program of research was undertaken to develop engineering noise controls for mining equipment.

Unfortunately, a recent analysis of a large audiometric database on noncoal miners revealed that the majority of miners are still losing their hearing. Over 70% of the miners who retired around 1990 had experienced high-frequency hearing loss. So why are miners still losing their hearing after 20 years of regulation and intervention? In the simplest terms, this outcome can be explained by the lack of a systematic plan of intervention; such a plan would also have included a mechanism to evaluate the impact of intervention activities continuously.

RESULTS TO DATE

This is a new project. A program announcement to identify a cooperator to work with NIOSH and labor in implementing a model hearing conservation program at a coal mine was prepared. In response to the announcement, several proposals were received and evaluated. A cooperator has been selected, and contract funds will be awarded in January 1999.

Critical elements of an effective hearing conservation program include—

- Measurement of worker exposure to noise and identification of noise sources.
- Intervention strategies to reduce noise exposures.
- Periodic audiometric evaluations.
- Educational and motivational programs.

- Record keeping.
- Monitoring to assess efficiency of program elements.

KEYWORDS: Noise, noise-induced hearing loss, hearing conservation, noise control, exposure monitoring

INVESTIGATION OF TECHNOLOGY FOR HEARING LOSS PREVENTION

PRINCIPAL INVESTIGATOR: David C. Byrne

RESEARCH OBJECTIVE

Evaluate practical technological advances in level-dependent hearing protectors and inexpensive personal acoustic monitors.

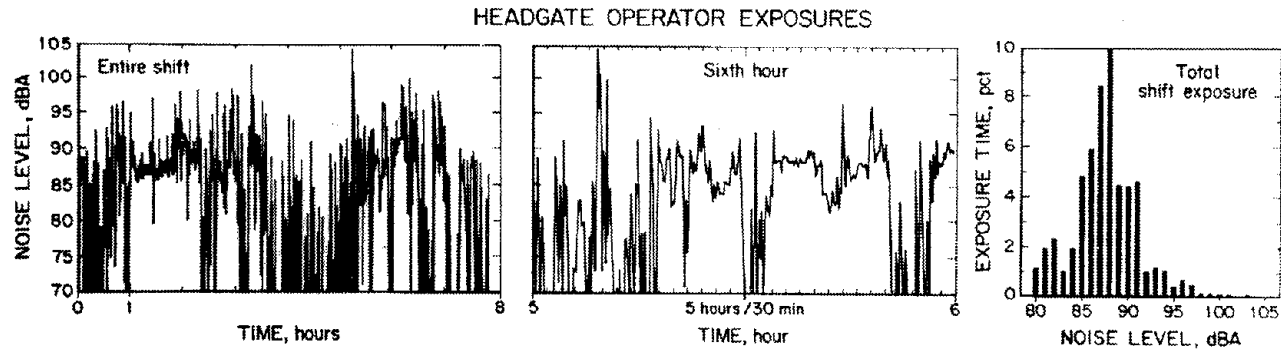
PROBLEM STATEMENT

There are numerous barriers to preventing hearing loss among miners. It is anticipated that increased on-the-spot awareness of hazardous noise levels and the availability of more suitable hearing protectors will provide a degree of protection beyond what is currently attained.

RESULTS TO DATE

This investigation will consist of at least two multi-part studies involving the evaluation of practical technological advances in level-dependent hearing protectors and inexpensive personal acoustic monitors. In each case, projects will involve analysis of this new technology under both laboratory and field conditions. Laboratory work will consist of controlled studies using human subjects to evaluate the adequacy and effectiveness of various hearing protection devices, as well as electroacoustical performance tests of new noise monitors. Field studies will determine the actual usefulness and practicality of the personal protection and monitoring equipment as used in different mining situations.

KEYWORDS: Hearing, noise, acoustic, protection



Full-shift noise exposure history for a headgate operator

CROSS SECTIONAL SURVEY: NOISE EXPOSURE PATTERNS/SOURCES

PRINCIPAL INVESTIGATOR: J. Alton Burks

RESEARCH OBJECTIVE

Establish baseline noise exposure profiles for mining occupations so that optimal intervention strategies can be identified and implemented.

PROBLEM STATEMENT

Overexposure to noise in the mining workplace remains a serious problem for mine workers. Eighty percent of the country's miners go to work every day in an environment where the time-weighted average (TWA) noise level exceeds 85 dBA. Even worse, 25% of the miners are exposed to a TWA noise level that exceeds 90 dBA. The risk of developing a hearing impairment when exposed to these workplace noise levels is significant.

Much of the existing noise and worker-exposure data is dated and has limited value for research purposes. In many cases, the data are specific to machine type and were obtained for source diagnoses rather than exposure assessment. MSHA has collected over 60,000 full-shift dose measurements on coal miners and almost 200,000 measurements on metal/nonmetal miners, but these data cover only the daily noise dose (or equivalently, the TWA noise level) for a shift and provide no information as to either the specific noise contribution of each source nor the cumulative effects of exposure during the shift.

There also is a great range in noise levels for a given occupation. For example, noise levels for a continuous miner operator have a modal value of 90 dBA and a range that varies from

80 to 105 dBA. A noise level of 80 dBA translates into a daily noise dose of 0% while a 105-dBA level represents a daily noise dose of 800%. Yet at present we have neither the information nor the technical insight to explain this extreme variation in exposure for this typical occupation. The source of this variability must be understood if we are to be successful in identifying appropriate solutions. Specifically, we need noise level data that provide a time exposure history for workers in addition to information on sources. This information will provide a basis for attacking the exposure problem using engineering controls in combination with administrative controls and personal protection equipment.

RESULTS TO DATE

A cross-sectional field study of exposure of mine workers to noise will include consideration of a variety of mining methods, equipment, range of geographic locations, and different mine sizes. The primary task is to establish representative noise exposure profiles for various occupations. The results of a study of the intermittency and patterns of noise exposure of long-wall coal miners were presented to the Acoustical Society of America. These results will form an integral part of the project.

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KEYWORDS: Noise survey, time-resolved noise survey, cross-sectional noise survey, noise-induced hearing loss

TECHNICAL ASSISTANCE FOR HEARING CONSERVATION

PRINCIPAL INVESTIGATOR: James Rider

RESEARCH OBJECTIVES

Provide information and conduct on-site measurements for engineering solutions to noise-control problems and participate in retrofitting noise-control technology.

PROBLEM STATEMENT

Prolonged exposure to noise over a period of several years generally causes permanent damage to the auditory nerve—the greater the noise exposure, the more rapid the loss. Unfortunately, loss of hearing acuity occurs gradually and is so subtle that an individual may not realize that he or she is losing their hearing until a substantial amount of hearing is lost. This damage, known as noise-induced hearing loss (NIHL), is a permanent, chronic, irreversible health effect. Once the damage has been done, there is no known medical treatment that will restore lost hearing acuity.

In the mining industry, overexposure to occupational noise remains a widespread health hazard. The use of heavy equipment, rock drilling, and confined work environments are just a few characteristics that contribute to high levels of noise exposure.

Noise-induced hearing loss has been recognized by NIOSH as one of the 10 leading work-related diseases and injuries in the country, and its importance is expressed as a NORA research priority.

RESULTS TO DATE

To provide the mining industry with quantitative information on hearing loss and help guide the industry in assessing the potential acoustical benefits of facility design, PRL researchers studied two silica sand processing plants having similar operating conditions but different designs. The two facilities relied on essentially the same processing equipment to screen and classify silica sand material by size. One facility consisted of a metal frame structure without any walls or roof, while the other was constructed with cement block walls and a metal roof. Experiments to measure the spatial distribution of sound levels were conducted at silica screening towers at the two facilities. To minimize background noise, plant operations were suspended during all tests.

An external sound source with a known sound power level was used to measure the acoustic environment. Forty-five seconds of noise were recorded at different locations throughout the four-story structure for each octave band between 125 and 8,000 Hz. The recorded noise was subsequently analyzed in the laboratory with a digital frequency analyzer. A 32-sec linear averaging time was used in calculating the one-third octave band spectra from 63 Hz to 8 kHz (see table). The results showed noise fields at both facilities decreased with increasing distance from the source. The level of the sound field at the screening tower tended to be 5 to 8 dB higher than the sound field at the open environment facility at comparable distances from the source. The sound field associated with the open-environment facility appears to approximate, acoustically, that of a free field.

Sound pressure levels in reverberant environment, decibels. Locations are feet from noise source.							
Octave band center frequency, Hz	Second floor		Third floor		Second floor	Fourth floor	
	Location 3, 28 ft	Location 2, 38.25 ft	Location 1, 45 ft	Location 2, 59.75 ft	Location 1, 60.25 ft	Location 2, 67.5 ft	Location 1, 79 ft
125	84.3	84.8	82.7	81.3	79.3	77.9	77.8
250	81.3	82.6	81.4	78.1	78.9	76.7	76.0
500	80.7	79.4	78.8	76.3	76.8	77.3	72.9
1000	80.1	77.7	76.6	73.8	73.4	70.9	68.5
2000	77.4	74.8	75.7	70.8	71.2	69.6	65.7
4000	76.3	73.4	72.9	68.5	69.4	66.6	63.6
8000	75.2	71.4	71.9	65.6	66.6	66.7	59.1

AUDIOMETRIC AND NOISE SURVEY IN THE SAND AND GRAVEL INDUSTRY

PRINCIPAL INVESTIGATORS:

Deborah Landen and Gail McConnell

RESEARCH OBJECTIVE

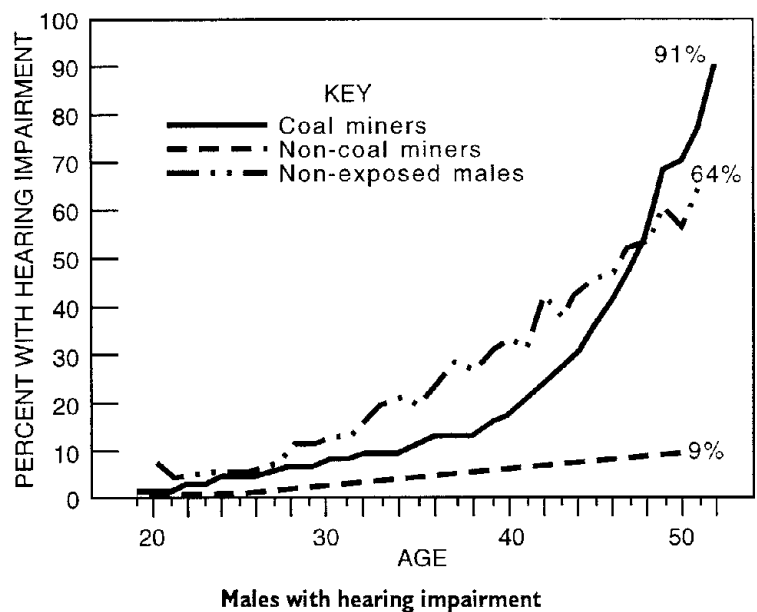
Obtain surveillance data on hearing and noise exposures in the sand and gravel industry. Data will be used to (1) estimate the prevalence and severity of hearing loss among workers employed by sand and gravel operators and contractors regulated by MSHA, (2) estimate workshift noise exposures by occupation, and (3) assess the relationship between work shift noise exposures and temporary threshold shifts in hearing.

PROBLEM STATEMENT

Noise-induced hearing loss has been identified by NIOSH as an area of high priority for research and intervention. The last survey of occupational hearing loss was initiated by the Public Health Service in 1968 and completed by NIOSH in 1972. This survey excluded workers with noncontinuous noise exposures and included few individuals with exposures below 85 dBA. Recent research indicates that *all* noise above 80 dBA should be included when estimating noise exposures.

Noise-induced hearing loss is of particular concern for the mining industry. Although survey data are not available for more recent years, in 1996 Franks analyzed data from a large sample of audiograms obtained by a commercial company from metal/nonmetal mines and coal mines. The results of the analysis showed that at age 50, 49% of metal/nonmetal miners and 90% of coal miners had a hearing impairment. By contrast, only 10% of the nonoccupational-noise-exposed persons had a hearing impairment at age 50. However, more detailed analysis of the data by mining commodity, occupation, and level and type of noise exposure was not possible.

This survey is anticipated to be the first of a series of surveys covering all mining commodities (including coal, metal, nonmetal, and stone). The sand and gravel industry has operations in all 50 states, and these operations are usually quite accessible to a mobile testing van. Workers to be tested include all those work-



ing in strip or dredge operations, and in associated processing plants and mills. Office workers are to be excluded. The survey results will provide a baseline for future surveys and allow targeting of high-exposure occupations for further assessment of noise exposures and possible engineering interventions.

RESULTS TO DATE

This is a new project.

KEYWORDS: Noise-induced hearing loss, mining, audiogram, occupation

REDESIGN OF THE INCIDENT COST INDICATOR MODEL

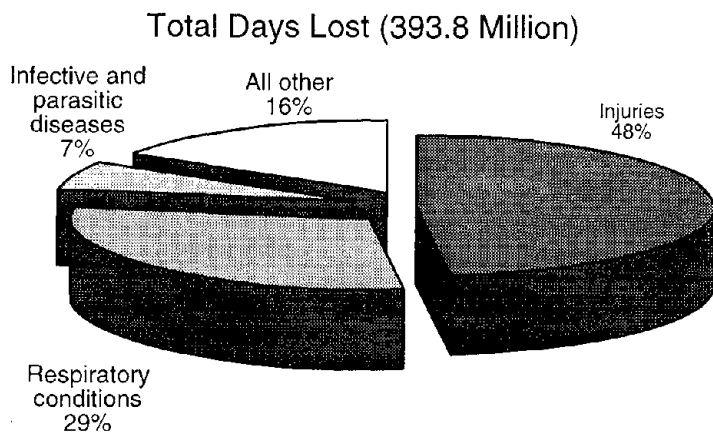
PRINCIPAL INVESTIGATOR: H. K. Sacks

RESEARCH OBJECTIVE

Design an economic model and write a computer code to calculate the economic costs for all mining injuries requiring medical treatment. The model will include data on coal, noncoal and independent operators and will be based on the information provided in MSHA's Mine Accident, Injury and Illness report (form 7000-1).

PROBLEM STATEMENT

The Accident Cost Indicator Model (ACIM) is a computer-based model that estimates the tangible costs of work-related injuries and illnesses in the U.S. coal industry. It was developed for the U.S. Bureau of Mines in the late 1970's for the purpose of using published statistics on injury and death to calculate costs on medical treatment, worker's compensation, lost production, lost wages, investigations, etc., and to allocate these costs to the public, private, and family sectors of society. Assigning a relative cost to a fatality or injury is a powerful method of ranking research projects. It also provides compelling evidence for encouraging employers and employees to invest in preventative measures.



Data from 1994 National Health Interview Survey (all occupations)

The current ACIM code can run only on a DEC VAX system, which is no longer available, and uses numerous databases and assumptions that are no longer available nor valid. In addition, the code does not calculate costs for nondisabling injuries or injuries involving noncoal or independent contractors. The current project is intended to correct these problems.

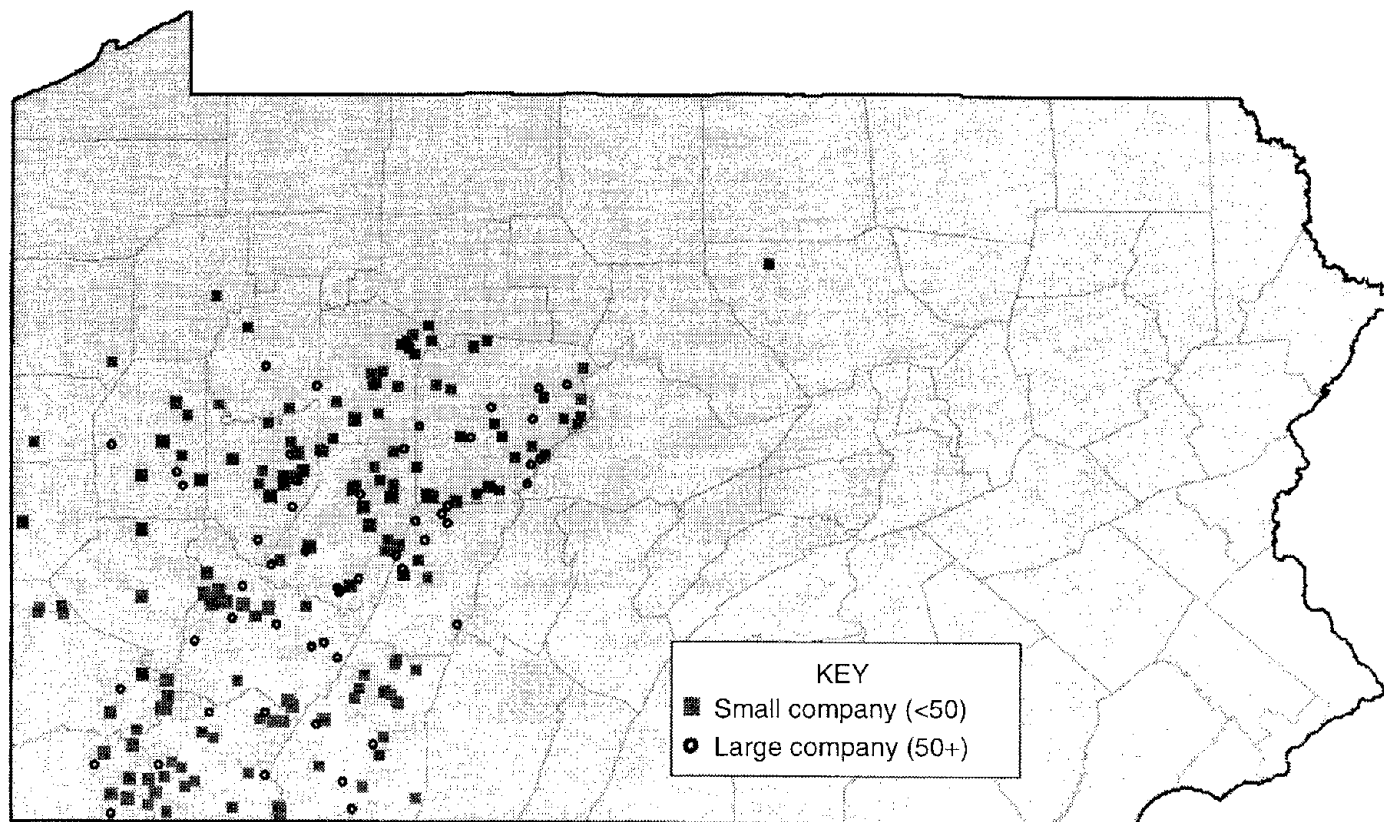
The project directly supports the NORA priority on social and economic consequences of workplace illness and injury.

RESULTS TO DATE

Discussions have been held with other NIOSH researchers working on industry-wide cost models, and all have agreed to make their models compatible wherever possible and to collaborate on model assumptions and sources of data.

The National Medical Expenditure Survey (NMES), developed by the Agency for Health Care Policy and Research of the Dept. of Health and Human Services is being considered as a possible way to calculate injury costs. The expenditure survey relies on ICD-9 codes, and one of the team members has completed a short course that will help team members evaluate the possibility of converting MSHA accident codes to the ICD-9 code. It now appears that the NMES data can be used for certain frequently occurring injuries that don't result in lost work days. The National Council for Compensation Insurers (NCCI) is another source of information on medical costs. NCCI data are compiled only for cases that involve lost work days and provide a good match to the NMES database. Data for 3 years were purchased, and a crosswalk between NCCI and MSHA accident data was completed. Data for union and nonunion wages and benefits have been purchased from Western Mine Engineering, Inc. Work remains on matching job occupations with standard descriptions in the MSHA database.

KEYWORDS: Mining, injury, costs, models



Small mining companies tend to have fewer resources for addressing safety and health issues. This map of surface bituminous coal operations was used by MSHA and the Pennsylvania Small Mines Committee to identify small company mines in Pennsylvania.

IMPROVED SAFETY FOR SMALL MINES

PRINCIPAL INVESTIGATOR: Robert F. Randolph

RESEARCH OBJECTIVE

Help meet the special safety and health needs of small mining operations.

PROBLEM STATEMENT

The safety record at small mines has been alarming. Statistical analyses show that fatality rates and some types of serious injury rates are higher at small mines than at mines employing 50 or more workers. The mining community has responded by making this issue a high priority. For instance, MSHA sponsored a spring 1994 summit that assembled individuals from industry, labor, state agencies, academic institutions, and Federal agencies to share concerns and propose solutions to the problems faced by small mines.

RESULTS TO DATE

Researchers on this project completed the most sophisticated surveillance analysis of issues concerning small mines available. These studies identified the nature of fatalities and injuries at small underground coal mines. We also evaluated the hypothesis that low working heights underground may be responsible for the poor safety record of small mines. This analysis found that risk varied by seam height, but that the relationship differed depending on the type of incident. For example, low seams were related to higher risks of some types of machinery-related incidents, while high seams were related to slip and fall injuries, falling rock, and certain other types of machinery incidents.

Project members were involved in several activities to assist small mines.

- Project members coordinated a feasibility study done by the University of Kentucky. This study identi-

fied some of the technology transfer media that would be most effective for small mines. For instance, Internet and CD-ROM technologies were found to be preferable to video conferences via satellite transmission and dispersed training centers.

- The project team participated in the Penn State Committee for Small Mines' Health and Safety. To address the needs of different types of small mines, several statistical and graphical analyses were provided. For example, the locations of mines associated with small companies were mapped.

- We also teamed up with local mining organizations and MSHA to set up seminars and workshops in areas where small mines predominate. These included the first New England Mining Health and Safety conference in April 1997, the Mid-States Mining Safety conference in September 1997, and the Mid-Atlantic Mining Safety conference in February 1998.

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KEYWORDS: Small mines, communication, surveillance

PREVENTING SLIPS AND FALLS— A SYSTEMS APPROACH

PRINCIPAL INVESTIGATOR: T. Michael Durr

RESEARCH OBJECTIVES

Protect miners (and others who work under highly variable environmental conditions) from injuries related to slips, trips, and falls by developing a systems-oriented prevention program that considers all factors in the traditional hierarchy of controls; testing this module at selected work sites in both the eastern and western United States; and, based upon field test results, designing and distributing an intervention program to industry.

PROBLEM STATEMENT

The National Safety Council puts the average cost of a fall- or slip-related claim at \$23,000. This figure suggests significant pain and suffering by the person who has fallen. It also means that an employer will be without the worker's contributions for some time. Yet fall prevention is one of the most underdeveloped programs in industry. Those programs that do exist tend to focus on only one or two factors in the hierarchy of controls (usually elimination of the hazard or engineering remedies).

In mining, where 6,543 falls resulting from slips and trips have made this one of the largest categories of lost-time injuries for the period between 1992 and 1997, a holistic approach is needed. This is because mines are complex systems in which workers, machines, and the environment all interact under conditions of continual change. Workers move about the mine and from job to job, equipment wears out and is replaced, and geological conditions vary over time. Thus, traditional interventions might have limited application in a mining environment.

NORA priorities support research leading to (1) intervention effectiveness, (2) organization of work, and (3) the effective use of personal safety equipment.

RESULTS TO DATE

- Researchers compiled MSHA accident narratives in which slips, trips, and falls were implicated for the 5-year period of 1990-1994.
- A questionnaire was designed to assess workers' attitudes toward injuries resulting from slips, trips, and falls.
- A table-top simulation that deals with how to investigate a fall-related injury is being assessed. This simulation was developed

independently of this project and is being studied for its efficacy as a possible intervention tool.

- A risk assessment instrument has been identified for use with focus groups.
- Two research sites (an underground bituminous coal mine in the eastern United States and a surface mine in Pennsylvania's anthracite region) were identified, and oral agreements have been concluded with the proper officials at these operations. The two mines already have self-reported protocols in place to record noninjury falls from slips and trips. The resulting information is being used to construct a database that can be applied to both sites. Investigations at the bituminous mine were successfully concluded this past year, and the results of the investigation will be presented to the company this fall.
- This year, the team will evaluate the most current (1995-1997) MSHA accident narratives in which slips, trips, and falls were indicated. The compiled data will be used to isolate the occupations and activities that have the most slips, trips, and falls associated with them. The team will also begin the on-site intervention and assessment of the surface anthracite mine this spring.

SYSTEMS APPROACH TO REDUCE MANUAL TASK INJURIES

PRINCIPAL INVESTIGATOR: Sean Gallagher

RESEARCH OBJECTIVE

Evaluate the effectiveness of participatory ergonomics committees in reducing the risk of musculoskeletal disorders in the mining industry and provide the industry with resources in support of this effort.

PROBLEM STATEMENT

Mine workers experience a higher incidence and prevalence of musculoskeletal disorders than workers in other industries. According to an analysis of data from the National Occupational Health Survey of Mining, both coal miners and metal/nonmetal miners are exposed to a higher number of ergonomic risk factors than workers in nonmining occupations.

This project is related to several NORA research priorities, including low-back disorders, musculoskeletal disorders of the upper extremities, traumatic injuries, emerging technologies, and intervention effectiveness research.

RESULTS TO DATE

As part of the NIOSH/OSHA conference entitled "Ergonomics: Effective Workplace Practices and Programs," a mining breakout session was arranged in which participants discussed what types of ergonomics practices seemed to be effective in the mining environment, as well as those that did not work well in mining. In general, mines tended to find the following interventions successful: use of hoists to assist manual handling of materials; reduction in weight of objects requiring lifting; improved seating for mantrips and shuttlecars; and development of both specialized tools for specific mining tasks and specialized vehicles to assist in maintenance and materials-handling tasks.

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KEYWORDS: Ergonomics, mining, musculoskeletal disorders, low-back pain

ERGONOMICS INTERVENTIONS IN MINING

PRINCIPAL INVESTIGATORS: Fred Turin and Lisa Steiner

RESEARCH OBJECTIVE

Assess exposures to musculoskeletal disorders in mining environments and evaluate the effectiveness of ergonomics interventions

in terms of lowering risk factor exposure and reducing musculoskeletal injuries.

PROBLEM STATEMENT

Studies have shown that miners experience more disabilities from knee and back pain, more absenteeism, more osteoarthritis, and more disk degeneration than comparable industrial populations. Exposure of mine workers to musculoskeletal overload conditions clearly plays an important role in the development of musculoskeletal disorders in both coal and metal/nonmetal mines. This project is a collaborative two-phase effort between MSHA and NIOSH. The first phase will be concerned with establishing baseline data on musculoskeletal disorders and identifying means to reduce risk factors. The second phase will involve development, implementation, and evaluation of ergonomics interventions at one or two cooperating mine sites.

RESULTS TO DATE

This is a new project.

KEYWORDS: Mining, ergonomics, musculoskeletal disorders, intervention effectiveness



Roof bolter operator in stressful working position

MATERIALS HANDLING ACCIDENT REDUCTION IN UNDERGROUND MINES

PRINCIPAL INVESTIGATORS:

Bill Stewart and Ted Williams

RESEARCH OBJECTIVE

Improve methods and procedures to reduce or prevent repetitive trauma and accidents associated with materials handling in underground mines.

PROBLEM STATEMENT

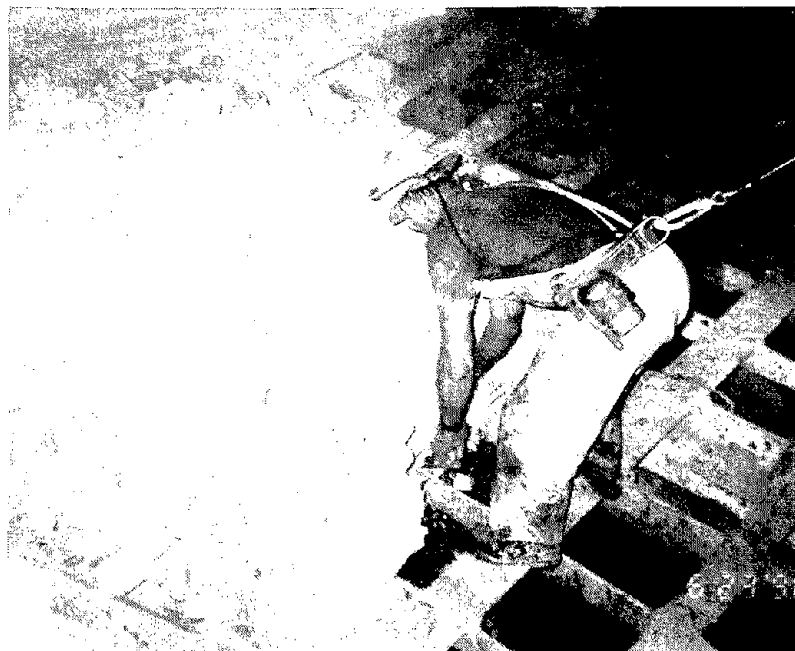
Repetitive trauma and materials handling accidents continue to be a problem in underground mines because of limited space, poor footing, inadequate materials handling equipment, and the weight and bulk of the materials themselves. The NIOSH Phase III report identified repetitive trauma and materials handling accidents as problems in all underground mines. The two subjects are combined in this proposal because they are closely related in mining.

A search of the MSHA database for the period between 1987 and 1996 identified 78 accidents out of 392 (20%) as being due to breaking or cleaning rock manually from the top of a grizzly. Another major cause of accidents involved removing the belt conveyor frame and rollers during longwall operations in Western underground coal mines. The rock and coal dust under and around the belt is often wet, creating a very poor surface for maintaining one's footing while removing heavy conveyor parts. Identifying state-of-the-art procedures for removing the structure and developing improved engineering designs for the workplace may reduce the repetitive trauma and accidents associated with doing this common job.

RESULTS TO DATE

This is a new project for FY99. Project goals for the year include (1) a review of MSHA accident statistics to identify underground mines with both good and bad materials handling records, (2) visits to several mines to get an understanding of general materials handling approaches, problems, and needs, and (3) definition of materials handling problems and focus areas that may be common to most mines.

KEYWORDS: Materials handling, accidents, equipment



Miner cleaning waste rock off grizzly manually. This type of materials handling procedure in underground mines resulted in 78 accidents between 1987 and 1996.



Hand-held pneumatic scaler

SAFETY ENHANCEMENTS FOR ROCK SCALING PERSONNEL

PRINCIPAL INVESTIGATOR: Art Miller

RESEARCH OBJECTIVES

Study present methods of scaling and their associated safety risks and develop interventions that will reduce the number of injuries caused by scaling-related accidents.

PROBLEM STATEMENT

In MSHA accident reports, 12% of the accidents in underground mines were classified as being caused by material falling from above. Most of these accidents were the direct result of scaling loose rock from roofs and walls. In addition, researchers noted that many otherwise-classified accidents could be linked to scaling processes, such as prying or barring down, or to loose material falling. These injuries were often classified as "hit by rock" or "strain/back injuries." Thus, the process of scaling was identified as a major source of injury to miners and was targeted for investigation.

RESULTS TO DATE

The project was organized into three phases—problem assessment, designs for safer methods and equipment, and tests of methods and equipment.

Phase I - Problem Assessment

Searches of the MSHA mine accident database, MSHA fatalgrams, and engineering databases were completed. Extensive interviews and brainstorming with mine personnel over the phone and during mine visits resulted in many good comments about scaling safety issues and how scaling problems might be addressed. Two possible interventions were selected: development of a hand-held, powered scaling tool and a safety training package focusing on rockfall hazards and scaling techniques

Phase II - Design Concepts for Safer Methods and Equipment

A prototype scaler modeled after an off-the-shelf pneumatic scraping tool was constructed and tested. The tool was designed to minimize weight, maximize reach, and allow chisel bits to be changed easily. A second-generation pneumatic scaling scepter was designed to make scaling a roof easier by placing an upward bend 5 ft in front of a hand-operated throttle valve. However, when scaling a rib, a cantilever beam effect caused the scepter to be un-

wieldy. Therefore, a third-generation pneumatic scaling scepter was designed. In this scaler, a section of a pole-vaulter's pole was used for the body to reduce weight. A hand-guard similar to those used on jousting lances was mounted close to the middle of the body and a shoulder harness was added. A smaller pneumatic head replaced the previous one, which also helped to reduce the weight of the scepter. Arrangements have been made to test the most recent design in an underground hard-rock gold mine.

A literature review was completed on the topics of adult learning and training curricula for unique populations such as underground miners and a summary report is being written. Based on the results of the review, a video-based format was selected as the best one for our purposes. Key concepts for the training were derived from numerous mine visits and interviews with mine personnel.

Video sessions will be scheduled in two to four mines in the next 2 months. Three peripheral modules will accompany the video and will focus on such topics as identification of geological and other hazards, scaling techniques, and knowledge of roof-fall prevention strategies.

Mine safety officers and trainers will help in reviewing the video script as well as the format for the auxiliary modules. When the video-based training package is complete, four hard rock mines will participate in evaluating it for use in mandated annual refresher training.

KEYWORDS: Scaling, barring down, rock falls, ground control, mine safety

INJURY PREVENTION FOR METAL/NONMETAL DRILLING AND BOLTING OPERATIONS

PRINCIPAL INVESTIGATORS:
Robert McKibbin and Curtis Clark

RESEARCH OBJECTIVES

Identify the causes of injuries related to the human-equipment interface in drilling and bolting operations in metal/nonmetal mines and develop the technology to reduce or eliminate the risk of injury.

PROBLEM STATEMENT

MSHA-based statistics show that there were 10 fatalities and over 1,000 injuries in drilling and bolting operations in metal/nonmetal mines during the most recent 5-year period (1992-1996), accounting for 5% and 4% of all fatalities (233) and injuries (25,693), respectively. A significant percentage of these accidents were lower back injuries, which, when coupled with the fatalities, addresses two NORA priorities—traumatic injuries and low-back disorders.

RESULTS TO DATE

The first year of this project involved problem identification and highlighted a number of areas where reductions in accidents might be realized. These include crushing injuries on carriage and jumbo drills, getting caught in rotating drill components, the excessive weight of jackleg drills, slips and falls while getting on or off drills, rock falls while barring down or bolting, and handling steel or supplies. The MSHA-based statistical findings were confirmed during various stakeholder meetings and discussions with industry personnel.

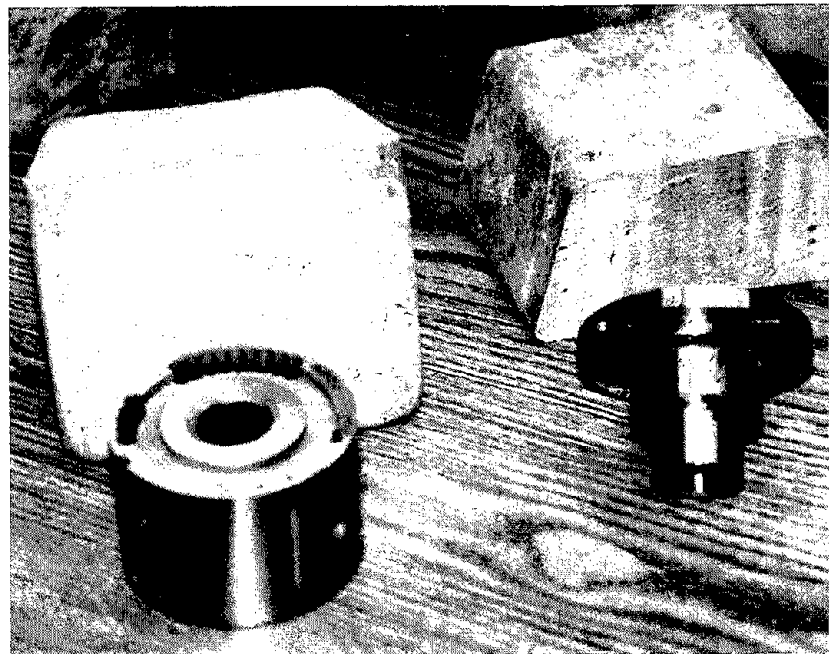
A significant finding was the number of injuries related to the weight (about 103 lb) of jackleg drills. Such injuries result in about 35 lost-time injuries per year, or about 17% of drilling and bolting injuries. Almost all of these are low-back injuries.

Project staff decided that one possible course of research offering a better probability of short-term success would be the fabrication and testing of a

lightweight jackleg. The goal is to reduce the weight to 70 lb without a reduction in the specific energy of drilling.

Work began on this drill in August 1998. Initial work will be to replace nine components on a standard steel jackleg with aluminum or titanium components of identical size, thereby reducing the weight of the drill by 21.3 lb. When completed, the drill will be tested in the laboratory for function and reliability. If successful, additional components will be examined to see if they can be constructed of lightweight materials to realize the overall goal of 33 lb of weight savings. This goal can be realized through the experience of the staff at the Spokane Research Laboratory. The project team and support staff includes engineers and technicians with extensive experience in mechanical system design, machining, instrumentation and electronics, control system design, and analytical modeling. All members have been involved in field activities throughout the western United States in all phases of the metal/nonmetal mining industry and are thus uniquely qualified to perform this work on an intramural basis.

KEYWORDS: Underground mining, surface mining, mining health and safety, low back disorders, materials handling, jackleg



Lightweight valve components of A356 aluminum. Weight savings: 2.46 lb.

IMPROVING CODE OF FEDERAL REGULATIONS SAFETY EVALUATIONS FOR MINE VENTILATION SEALS

PRINCIPAL INVESTIGATOR: T. M. Barczak

RESEARCH OBJECTIVES

Develop alternative safety evaluation requirements for mine ventilation stoppings and seals that more realistically simulate actual mine conditions and examine emerging lightweight materials that currently fail existing regulatory statutes.

PROBLEM STATEMENT

Nearly all commodities in underground bedded deposits use stoppings and seals to control ventilation. Hundreds of thousands of these critical structures are placed each year in underground mines. Failure of these structures can lead to disastrous mine explosions and fires. Two problems have been identified relative to the construction of these critical structures.

First, the current Code of Federal Regulations does not allow proper simulation of actual conditions in large-scale structures. For example, Part 75.333 requires underground coal mine stoppings and permanent ventilation control structures to pass ASTM standard E-72 tests for transverse loading capability. This criterion was actually designed for evaluating a free-standing wall. In a mine, ventilation structures (i.e., stopping walls and seals) are restrained on all four sides by roofs, floors, and coal pillar ribs and are slightly preloaded by wedging the wall in place. Transverse loading capabilities are significantly enhanced under these conditions as compared to conditions for a free-standing structure. The addition of pressurized grout bags can be used to increase the transverse loading capacities of ventilation structures.

Second, most mine ventilation stoppings are constructed from concrete blocks weighing between 50 and 60 lb per block. Blocks of this weight are classified in the National Occupational Health Survey of Mining as constituting a heavy lifting risk factor. About 40% of underground coal miners and 30% of metal/nonmetal miners lift blocks of this size and as a result could be at high risk for musculoskeletal repetitive trauma disorders.

While several new materials would provide a block weight reduction of up to 50%, they have failed to meet the ASTM E-72 transverse loading requirements and cannot be presently used underground. A theoretical analysis of a wall constructed of these lightweight materials indicates that they all would have passed the transverse load requirements had they been tested in a realistic

setting. Thus, existing test standards are eliminating new materials that could dramatically reduce materials-handling injuries in mines.

Materials-handling injuries are identified in NORA and the Phase III Strategic Plan as a research priority and as a gap area in underground metal and nonmetal mines.

RESULTS TO DATE

Current E-72 testing specifications for stopping wall constructions have been obtained and analyzed. A theoretical assessment of the impact of preloading on masonry wall constructions is continuing. This analysis clearly indicates that a small amount of preload should make a big difference in side-loading capability.

The first step toward full-scale tests is to design a test fixture. Ideas for this fixture are being developed. The goal is to have a final design completed in January 1999 and construction of the test fixture completed in the spring.

KEYWORDS: Stoppings, seals, ventilation controls, coal mining, lightweight materials

HUMAN FACTORS ISSUES IN EXTENDED-CUT MINING

PRINCIPAL INVESTIGATOR: Lisa Steiner

RESEARCH OBJECTIVE

Assess the ergonomics considerations of remote-controlled continuous mining operations by evaluating the interaction of mining sequence, equipment, and mine characteristics. The primary goals are to determine safe operating positioning and work procedures for face crew workers.

PROBLEM STATEMENT

Room-and-pillar mining accounted for 72% of employee hours worked in underground coal mines from 1993 to 1995. Sixty percent of the injuries and 83% of the fatalities in mining occurred in room-and-pillar sections. The face or inby area where coal is extracted is considered to be the most hazardous area, resulting in 45% of all underground mining injuries.

Over 49% of all mines have MSHA approval to use extended-cut methods, which have become increasingly popular because they allow increased production rates at relatively low costs. However, there are implications that extended-cut mining has a high potential for unplanned roof falls, human-machine interface problems, and face crew hazards. Research will provide information that will assist the operators of continuous mining machines in making better decisions as to where to stand while operating the machine. Several different mining plans, operating procedures, operator mining techniques, and safety precautions will be compared.

RESULTS TO DATE

- Technology transfer seminars on the extended-cut mining method were presented at Evansville, IN, and Charleston, WV. Three papers based on field interviews and observations conducted over 5 years were presented.
- Training tools associated with remote-controlled and extended-cut mining were developed and tested in the field.

- Fatality scenario and related safety evaluation interviews were completed, and a report summarizing the data collected from Mapco and Cyprus mines was presented to each mine.
- Development of a device to warn miners about unsupported roof was completed.

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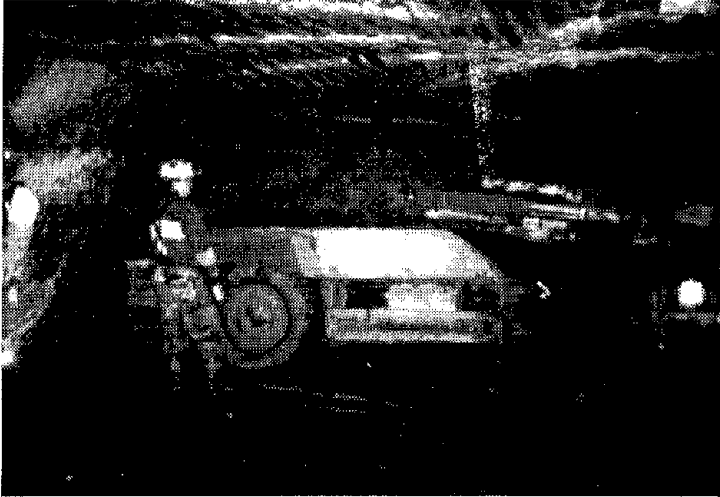
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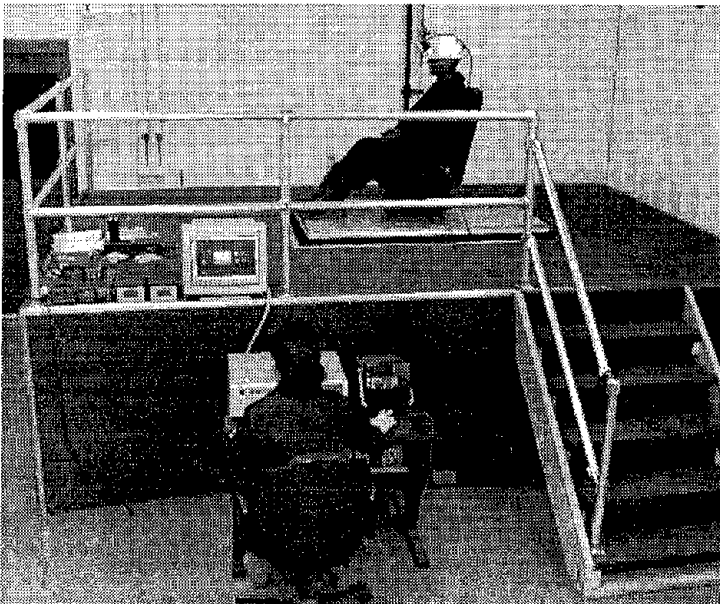
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KEYWORDS: Coal mining, extended-cut mining, remote-controlled technology, ergonomics, human-machine-environment interaction



Observing a continuous miner operator during coal cutting



Vibration testing of improved operator seat

HUMAN FACTORS DESIGN FOR MACHINE AND HAULAGE SAFETY

PRINCIPAL INVESTIGATOR:

August J. Kwitowski

RESEARCH OBJECTIVE

Identify and prevent hazards associated with underground mining machinery through the application of human factors design principles considered either alone or in combination with simple engineering controls.

PROBLEM STATEMENT

Mining machinery accidents continue to be a leading cause of fatalities and injuries in underground coal mines. Much of the research conducted to date has attempted to completely redesign the equipment or develop experimental remote-control technologies in an attempt to remove workers from the vicinity of the hazards. The application of human factors design principles has been underutilized and needs to be considered, either alone or in combination with simple engineering controls, as a means of decreasing machinery accidents in underground mines.

RESULTS TO DATE

Progress continued on reducing injuries caused by vibrations among underground equipment operators. In-mine data were collected and analyzed on seat pads featuring NIOSH-recommended viscoelastic foam. The analysis showed impact energy was reduced by 88% to 95% for shuttle car operators. Also, mine safety managers reported that complaints of back and neck problems were reduced to zero after a year of using the seat pads. All shuttle cars at this mine are now equipped with viscoelastic foam seat pads. Furthermore, a major mining equipment manufacturer plans to offer ergonomic seats for low-coal equipment based on NIOSH's recommended materials and features standard.

A laboratory vibration testing facility was completed. This facility will be used to improve seating design and to study whole-body vibrations. Such a laboratory will allow re-creation of the shocks and vibrations that equipment operators receive while performing various tasks. A single-axis actuator, base, and hydraulic power unit were obtained from another

research facility and connected to a new, state-of-the-art controller and data acquisition system. New data recorders and accelerometers were purchased to enable personnel to record shocks and vibrations while they are on site.

Two working models of mining machinery controls were designed and fabricated to demonstrate good and bad ergonomic features. These features included activation forces, control spacing, control orientation, and joysticks in lieu of single control levers. One model included computer-generated feedback to display activation forces. These models were used during a seminar and a mine training session on human factors related to equipment control design. The control modules were also displayed at PRL's open house and to approximately 20 groups of visiting students.

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KEYWORDS: Machinery safety, human factors, machine control, design guidelines, computer-based modeling

EQUIPMENT SAFETY ANALYSIS USING COMPUTER SIMULATION

PRINCIPAL INVESTIGATOR: Dean Ambrose

RESEARCH OBJECTIVES

Develop an accurate three-dimensional computer graphics model of mine incidents. Using this model, analyze incidents to determine problems in equipment operation, function, and structure and the ways in which their interaction with human operators may have contributed to the incident. Provide engineering information

to carry out practical improvements for safe mine equipment.

PROBLEM STATEMENT

Mining equipment plays a major role in mining incidents. The second leading cause of death in underground mines is the use of powered equipment in confined spaces. At surface mines, the use of large, fast-moving haulage vehicles is the leading cause of fatalities. Despite new mining methods and technological improvements in equipment, worker injuries and fatalities continue. Currently, there are no analytical methods or ingenious devices (i.e., recorded data from a "black box") to assist either mine operators or NIOSH and MSHA representatives in envisioning underground and surface mine incidents.

There is a need to view underground and surface mining incidents as a gradually developing sequence of multiple events, rather than in terms of an immediate, last factor in an emergency situation. The intent of this research is to re-create and analyze mine incidents involving mining equipment using three-dimensional computer graphics simulation to examine, evaluate, and determine changes that need to be made to mining equipment or to human interactions with this equipment to improve worker safety.

RESULTS TO DATE

Studies continued with computer-based modeling and simulation for experiments to improve safety related to roof bolter machines. Information obtained from Fletcher Mfg. Co. and Pro/Engineering CAD software were used to complete models of keyboard- and joystick-type bolting stations. Also, a preliminary computer model that uses Jack software to simulate a human roof bolter operator installing a resin bolt was completed in a three-dimensional virtual environment.

The Jack software was also used to execute a computer code that generates random events relating to safe and hazardous acts performed by a roof bolter operator. The randomness of a hazardous event was defined using information from a contract report written by West Virginia University entitled "Accident Risk During Roof Bolting Cycle, 1993." The code is written so it can be expanded and enhanced to collect statistics on objects in the simulation environment.

KEYWORDS: Accident analysis, ergonomic, mining machine, modeling, simulation, roof-bolter safety

ENGINEERING CONTROLS FOR REDUCING JOLTING AND JARRING INJURIES IN SURFACE MINING

PRINCIPAL INVESTIGATORS:
Fred R. Biggs and Rusty Miller

RESEARCH OBJECTIVE

Devise and promote the use of engineering controls to eliminate or minimize jolting and jarring injuries among haulage truck and other heavy equipment operators in metal/nonmetal surface mines.

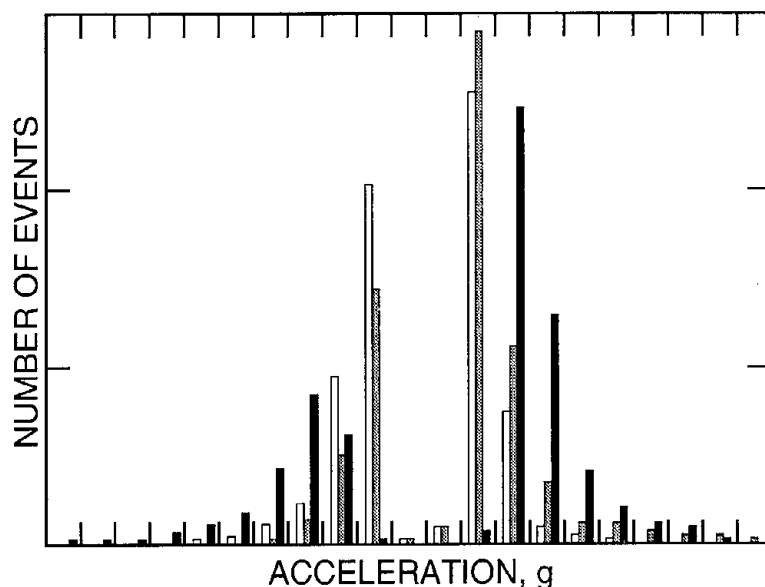
PROBLEM STATEMENT

Shock trauma injuries, as they relate to surface mining heavy equipment operators, fit into two areas of the National Occupational Research Agenda's (NORA) top 10 disease and injury list for priority research, namely lower back disorders from repetitive exposure to low levels of jolting and jarring, and traumatic injuries from a single, high-level jarring incident. Very little research has been done related specifically to jolting and jarring injuries caused by surface mine haulage trucks, nor to the development of engineering controls to reduce such injuries.

During the last several years, the number of surface mines in the West has increased. This increase has resulted in a larger work force, increased production demands, and larger haulage trucks, which in turn has led to more worker fatalities and injuries. Between 1986 and 1997, truck drivers accounted for approximately 63% of the fatalities in surface mining truck haulage and 60% of the lost-time injuries. The Spokane Research Laboratory's engineering expertise in newly developed engineering control technologies can be applied to characterize jolting and jarring through bench and field tests to isolate elements that could lessen shock loads to an operator.

RESULTS TO DATE

An IMPACT Mark II free-fall shock test machine was acquired from the USBM's Twin Cities Research Center and shipped to Spokane. This machine can subject a test specimen (dummy) to a wide range of acceleration pulses and simulate shocks similar to those felt by the operator of a piece of heavy machinery. This



allows engineering controls to be tested in the lab before they are used in the field.

A memorandum of understanding (MOU) is in place with a Western surface mine that will enable SRL researchers to gather field data on jolting and jarring. Three-axes accelerometer modules were installed in the cab of a haulage truck to record shocks to the operator during vehicle operation, thus generating a shock history. The shock data are then compared to shock simulations generated on the MTS IMPACT machine. The shock data from both sources are plotted as histograms to show the distribution and amplitude of jolts over a shift. Additional accelerometer hardware and software were purchased to enable researchers to place instruments on the operator's seat at the same time as jolts to the truck are being recorded so as to gain insight into the number and intensity of the shocks that are transferred to the operator through the seat.

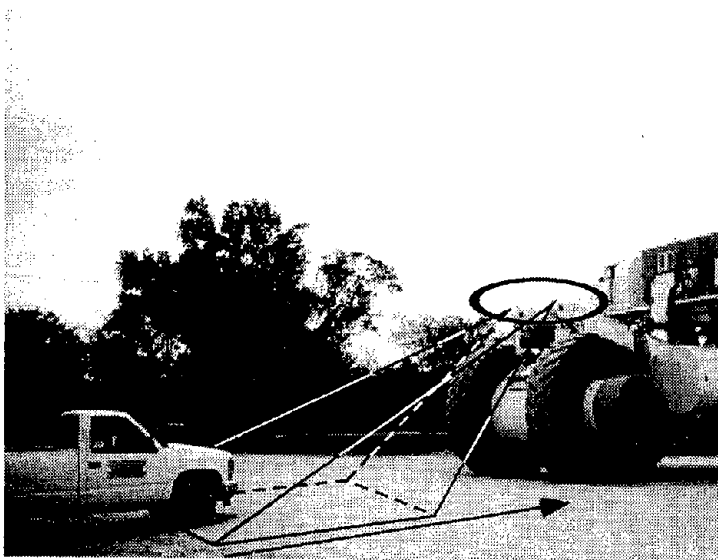
At the mine's request, SRL researchers are also working with mine personnel to coordinate shock event data using the mine's Global Positioning System (GPS). This will enable researchers and mine personnel to monitor truck activities and record the locations where severe shocks are experienced. These exceptions to normal truck operation would be investigated and an explanation given as to what caused the jolt. Some of the causes of an abnormal jolt could be excessive speed for road conditions, truck maintenance problems, roads in need of repair, or collisions with other pieces of equipment or with berms.

Initial observations during field tests indicate that minimizing injuries to operators has not been a focal point in designing trucks. Additional studies are needed on equipment design, placement of instruments, and operator posture before lower back injuries can be reduced. Another goal is to identify how long-term exposure to low-level jolting and jarring and fatigue affects incident rates.

KEYWORDS: Vibration, shocks, haulage trucks, jolting, jarring



Shakedown tests using Doppler radar device.



Detection zone of "focused" Doppler radar sensor on 240-ton chassis

HAZARD REDUCTION FOR SURFACE MINING HAULAGE EQUIPMENT

PRINCIPAL INVESTIGATORS:
Ron Backer and C. M. K. Boldt

RESEARCH OBJECTIVES

To investigate, evaluate, and develop technological tools to reduce haulage-related accidents and injuries at surface coal and metal/nonmetal mines.

PROBLEM STATEMENT

Task 1

In the past 5 years, powered haulage accounted for 43% of the fatalities in surface mines and was among the top five sources of injuries. Limited visibility from the cab of large trucks was cited as a major cause of these accidents.

Accidents and injuries can be reduced by improving ways to recognize hazards, providing restraint devices for operators of haulage trucks, finding better ways to enter and leave trucks, and providing feedback to operators when driving. Equipment manufacturers are working to incorporate alarms, improve vision, and improve ergonomics on large pieces of equipment. Other approaches involve the development of remote-controlled or autonomous vehicles for specific, extremely hazardous, repetitive, and/or simple tasks. Improvements in sensing technology, such as radio frequency, radar, laser, and infrared devices, offer other opportunities to introduce technological improvements to vehicle operation and/or control.

Task 2

There is little in the literature quantifying costs associated with various methods of truck dumping procedures (end-dumping materials over a spoilpile versus dumping and bulldozing the materials over a dump edge, known as short-dumping). The latter procedure is considered safer, but it is intuitively more expensive because it requires a bulldozer and its operator in addition to haulage trucks and drivers. However, intuition may be misleading because a bulldozer and operator may already be spending time

on the dump constructing dumping berms. Knowing what is actually involved in various procedures would give safety professionals a more measurable means of evaluating the true costs of an activity and incorporating safety.

RESULTS TO DATE

Task 1

A contract was awarded for a custom-made, ultrawide-band radar device to be used as a proximity warning system for haulage vehicles. This unit uses range gating, that is, it can be adjusted to sense obstacles within prescribed distances. Also, a radar device currently manufactured by Eaton-Vorad for over-the-road highway trucks was obtained. The device will be evaluated for mining haulage trucks.

Task 2

Economic studies of various dumping practices (end-dumping versus short-dumping) have been initiated. This work is being coordinated with the Pittsburgh Research Laboratory as a cost-modeling approach to studying the economic effects of injury prevention. Initially, it was thought that the use of short-dumping instead of edge-dumping would save cycling time at the dump site. However, site visits and discussions with mine engineers indicated that there is essentially no difference between the two methods in the time it takes for trucks at the spoilpile. In most instances, the dumping phase is a small segment of total truck cycling time, and there is no significant difference between edge-dumping or short-dumping.

Instead, the main advantage of the edge-dumping method is the amount of dozer work required. Often, a rubber-tired dozer is of sufficient size to maintain the berm adequately. At smaller operations where hauling distances are short, a rubber-tired dozer can sometimes split time between maintaining the spoilpile and performing cleanup duties at the shovel. This dozer would not be available for cleanup work if the mine was short-dumping.

Thus, the main cost difference between the two methods is the use of a dozer. Where a mine can use a rubber-tired dozer for edge-dumping, a larger track dozer would be necessary for short-dumping. If a track dozer were already in use, the switch from short-dumping to edge-dumping would probably require a larger size dozer (a D11 instead of a D10, for

example). This change would increase operating and ownership costs. In addition, the effective operating life of a dozer is greater when the edge-dumping method is used, since the dozer moves less material a shorter distance.

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KEYWORDS: Surface mining, trucks, safety, alarms, sensors

HAZARD REDUCTION IN THE SURFACE MINING OF SAND AND GRAVEL

PRINCIPAL INVESTIGATOR: C. M. K. Boldt

RESEARCH OBJECTIVE

Reduce worker fatalities and injuries in surface sand and gravel operations.

PROBLEM STATEMENT

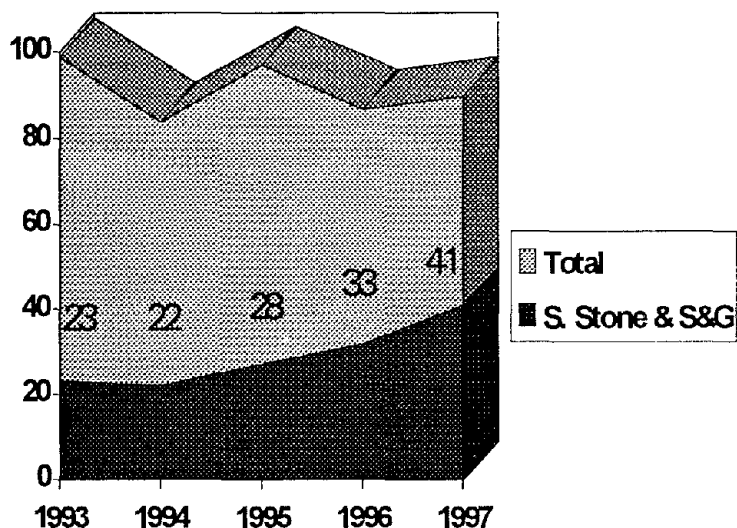
The sand and gravel and surface stone quarry industries have been underrepresented in mine safety research. A cursory look at the MSHA accident data, however, shows that surface stone and sand and gravel operations had 34 fatalities in 1996 and 41 out of a total of 90 fatalities in 1997. These figures are nearly half of the mining industry fatalities for the year. According to the *MSHA Metal-Nonmetal Monitor* (July 1, 1996), there were 34,379 employees working 59 million hours at 6,162 sand and gravel mines in 1994 with an average of less than 6 employees at each mine.

RESULTS TO DATE

From the information gathered to date, some conclusions can be drawn. These will be used throughout the year to further refine the efforts of the project personnel.

- There are twice as many sand and gravel and stone sites as sites in all of the rest of mining.
- Over 40% of U.S. mine workers are employed in sand and gravel or stone.
- Sand and gravel production is highest west of the Mississippi. Stone production is highest in the East. It is believed that as alluvial deposits are depleted, stone operations will become more numerous. Urban and suburban areas will be loathe to permit surface sites; therefore, underground operations will be more palatable.
- Fatalities in sand and gravel and stone are increasing. Employment levels for sand and gravel are leveling off, and crushed stone employment figures are increasing.

Fatalities



Surface stone and sand and gravel workers have been experiencing an increasing number of fatalities during the past 5 years.

- Fatality classifications in the sand and gravel and surface stone industries show similarities with surface mining in general; that is, powered haulage, slips and falls, and machinery are the prevalent injury categories.
- In both sand and gravel and surface stone, the top three injury categories for powered haulage fatalities involve off-highway ore haulage trucks, front-end loaders, and conveyors.

Sand and gravel, crushed stone, and dimensional stone are the only mining segments in which MSHA does not enforce miner training requirements. Congress has exempted Part 48 training enforcement from MSHA's yearly budget since 1979. What this means is that, while the stone industry is required to train its workers in accordance with 30CFR, Part 48, MSHA is not funded to issue citations and/or fines against companies who do not train their workers.

KEYWORDS: Surface mining, sand and gravel, safety

REDUCING GROUND FALLS IN UNDERGROUND STONE AND NONMETAL MINES

PRINCIPAL INVESTIGATORS:
R. H. Grau, III, and L. J. Prosser, Jr.

RESEARCH OBJECTIVE

Prevent injuries and fatalities to workers employed in the underground stone and nonmetal industries.

PROBLEM STATEMENT

Incidence rates are higher and severity of accidents are greater among miners in the underground stone and nonmetal industries than among workers in other segments of the mining industry. About 62% of all roof, face, and rib accidents in underground limestone mines were designated by MSHA as some type of lost-time accident.

Ninety percent of the fatalities in underground limestone mines were associated with failure of a main roof beam. In addition, loose or failed roof rock within the roof beam accounted for 80% of the accidents that did not result in injury. In general, roof support or monitoring techniques used by mining personnel are not designed in an engineering sense, but are based on past experience that does not take scientific information into account.

RESULTS TO DATE

Data concerning mine characteristics, support and monitoring methods, and roof fall incidents have been collected from over 60% of the limestone mines in the United States. Data analysis shows that most failures were caused by deterioration of the mine's main roof beam. Field work has been conducted at several sites to determine the effectiveness of monitoring strata stability and study how a mine's physical characteristics affect strata stability. A roof monitoring safety system (RMSS) has been developed and installed at the field sites. Some of the advantages of RMSS are its low cost, easy fabrication, and capability to acquire readings from a location away from unstable roof conditions. A safety seminar conducted in December of 1997 provided information on roof failure and hazard recognition to 165 stone industry workers.

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KEYWORDS: Fatality, miner, underground, roof, hazard

WARNING SYSTEMS TO REDUCE TRAUMATIC INJURIES IN UNDERGROUND MINES

PRINCIPAL INVESTIGATOR: Todd Ruff

RESEARCH OBJECTIVE

To reduce traumatic injuries in underground metal/nonmetal mines by providing better workplace information to workers and rescuers.

PROBLEM STATEMENT

MSHA accident statistics show 82 fatalities and 12,333 injuries in the past 10 years in the underground metal/nonmetal mining industry. Of the 82 fatalities, 39 were caused when a worker was hit by falling rock and 16 were directly related to the operation of equipment. This work falls under the "traumatic injuries" priority research area of NORA. The project will address the major causes of injuries in this type of mining—falls of ground and collisions with mobile equipment.

RESULTS TO DATE

Navigation and Warning Aids for Mobile Equipment

Research on available collision avoidance sensors has shown that existing back-up alarms and sensors have excessive technical limitations and are not being used effectively. The most promising technologies are radio frequency identification (RFID) transponders and radar.

For RFID, each worker in the mine would wear a small RFID tag. A tag reader would be mounted on each vehicle. If a tag is identified within the reader's sensing range, the operator of the equipment would be warned. This solution eliminates false alarms and the possibility that back-up alarms associated with other systems would be ignored.

Evaluation of off-the-shelf RFID systems indicated that the technology is promising. However, because these systems were not designed for the harsh environment of a mine or for collision avoidance, the

Two-part radio-frequency identification tags, one carried by a pedestrian and the other mounted on the vehicle.



systems will have to be redesigned. A contract was awarded to ID International Holdings of Concord, MA, to design an RFID system specifically for mining equipment. A prototype was tested on a front-end loader at SRL's surface test facility. The tests showed that the tag antenna needed to be redesigned to eliminate its sensitivity to orientation.

The new tag antenna design uses two orthogonal coil antennas, and the reader can now detect the tag in any direction. However, the redesign also increased the range of the system so that the new tag can be detected as far as 100 feet away. It is desired that the tag be detected between 0 and 40 feet behind the mining equipment. Modifications are underway to decrease the range.

New developments in radar are also being studied in cooperation with the Hazard Reduction for Surface Mining Haulage Equipment project. Field tests showed problems with conventional Doppler systems, and new types of radar are being investigated. An ultrawide-band radar unit is being developed for underground and surface mining equipment. This technology was originally developed for collision avoidance between helicopters.

Injured Worker Locator System

The complexity of deep underground mines and the limited ability to communicate make it difficult to know when and where an accident has occurred. Many MSHA accident narratives describe injured workers lying for hours before they were discovered, often too late to prevent their deaths.

This task has been limited to one particular problem because of limited funds. Rock bursts in the Coeur d'Alene Mining District raise concerns for the safety of miners, especially as mines reach deeper levels in the earth. A system is being tested to provide instantaneous information about a rock burst, including its location, so that rescue personnel can be sent to the area immediately and assist workers who might have been injured. The first phase of this project was to determine the most effective means of detecting and locating a rock burst in a stope. Three sensors were tested, including an air velocity gauge to detect the air blast from a rock burst, a dust sensor, and an accelerometer that measures localized vibrations. The dust sensor has proven to be the most reliable, although because of the time it takes for the ventilation system to blow dust past the sensor after a rock burst, the signal is delayed.

An alarm system using the dust sensor was built and tested in two stopes of an underground lead/silver mine. Researchers collected a year's worth of data on the performance of the dust sensors for detecting rock bursts. This method of detecting damaging bursts has been effective but does have the potential for producing false alarms. For example, if a source such as a passing vehicle raises dust levels to an alarm level, a false alarm can be generated. False alarms have been minimized by raising the alarm threshold so that only those bursts that create a large amount of dust are detected.

If the possibility of some false alarms is acceptable to mine management, a system will be built that incorporates a dust sensor, an alarm unit, and an alarm light in each stope. The alarm light could be placed at the entrance to the stope, or somewhere where other workers can be alerted.

KEYWORDS: Underground mining, mining safety, equipment, collision avoidance, rock burst

INVESTIGATE PROXIMITY DETECTION AND COLLISION AVOIDANCE

PRINCIPAL INVESTIGATORS:

Gary L. Mowrey and William H. Schiffbauer

RESEARCH OBJECTIVE

Develop and evaluate various proximity detection and collision avoidance systems to minimize the likelihood that miners could become pinned or crushed by mining equipment.

PROBLEM STATEMENT

One of the main safety problems in underground and surface mining is that of personnel being killed or permanently disabled by machinery (average 40.4/yr) or powered haulage (43.7/yr). Between 1992 and 1994, there were 4,658 nonfatal days lost due to machinery and 4,302 days lost due to powered haulage out of a total of 34,555 nonfatal days-lost accidents in all mines. Since 1995, at least four fatalities and many injuries have occurred involving miners being crushed or pinned by remote-controlled continuous mining machines. Both fatalities and injuries could be significantly reduced if effective, low-cost, reliable proximity warning systems were available to the mining industry.

This project was initiated at MSHA's request. It involved developing an in-house proximity warning system called HASARD, acquiring and evaluating commercially available proximity warning devices, determining what areas around mining equipment are dangerous, and studying the habits of mining machine operators.

RESULTS TO DATE

A prototype of the HASARD system based on electromagnetic principles has been designed, constructed, tested, and modified. This prototype consists of a transmitter that generates "warning halos" around the dangerous areas surrounding a mining machine and a miniature radio receiver worn by an operator and helper(s). The receiver detects these halos and warns miners if they are too close to the mining machine. This system is presently undergoing surface and underground tests at PRL prior to being

tested at a nearby underground coal mine. Critical issues such as antenna directionality and noise susceptibility have now been resolved. Warning devices such as vibrators, lights, and audible alarms are being investigated to determine which ones would be most beneficial for use in a mine. Antenna placement, geometry, and air gap spacing are also being studied to maximize system performance.

Several commercially available proximity warning systems (e.g., Radio Fence, Proxagard, and ultrasonic devices) were also tested, but none were found to be suitable for underground coal mine use. Project personnel also visited an underground Canadian metal mine that had a system made by Mintronics, but this system was determined to be unsuitable for coal mines; it was also very expensive.

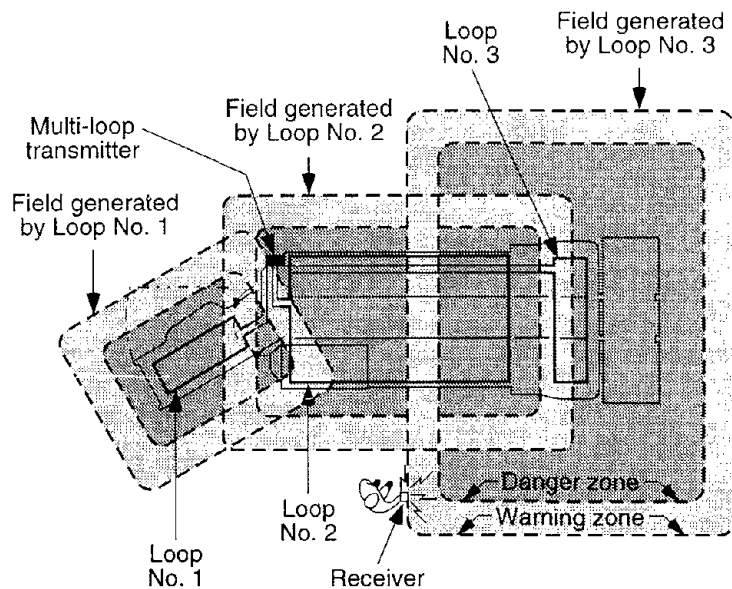
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KEYWORDS: Hazard, HASARD, proximity, warning, detection, collision, avoidance



The HASARD system. A multiloop transmitter mounted on the mining machine generates safety zones that are recognized by a receiver worn by a miner. The miner must remain outside the danger zones to operate the machine safely.

DESIGN ANALYSIS OF ORE PASSES

PRINCIPAL INVESTIGATORS:

Michael J. Beus and Bill Stewart

RESEARCH OBJECTIVES

Improve ore pass design criteria to prevent hangups and structural failure and provide enabling technology for detecting and remediating blockages in ore passes in hard-rock mines.

PROBLEM STATEMENT

Research on ore pass designs will include measurements of static and dynamic loads, predictions of loads using particle flow models, studies of the influence of ore pass inclination on loading, tests of innovative methods to determine fill levels and hang-up locations, and development of safer hang-up removal methods.

RESULTS TO DATE

The field test on an ore pass chute and gate system at the Lucky Friday Mine in northern Idaho has been completed, and a second site at the Stillwater Mine in south-central Montana has been selected for continuing analysis of static and dynamic loads on ore pass chutes and gates. The advantage of the Stillwater Mine is that the ore pass is 300 ft long (compared to 50 ft at the Lucky Friday), which is a more typical depth in underground mines. Much higher static and dynamic loads are expected. To date, eight strain gages have been installed on the support structure of a new chute and gate assembly at the discharge end of the ore pass. Temperature sensors, load cell washers, and a new data acquisition system are currently being calibrated and will be installed in early FY99.

This new system has been adapted specifically to collect information from individual strain gages and is capable of high-speed data collection and event storage with less background noise. Stillwater personnel have approved video recordings of ore pass loading and pulling events, and will allow us to use their existing transmission system to send data on ore chute loads to the surface.

Construction of the ore pass support structure was completed and the discharge chute and gate assembly was installed. The 3.5-ft-diam by 17-ft-high ore pass was positioned on the support structure and connected to the chute and gate assembly. Extensive modifications include a new and safer skip, a new skip discharge chute, extension of the skip guides, installation of a permanent ladder in the shaft, and installation of a new knife gate that closes by pulling up through the material.

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KEYWORDS: Ore pass, field measurements, computer analysis, materials handling, ground control



Ore pass test facility can be inclined up to 15° in 5°-increments from vertical. Dynamic loads dropped from a height of 50 ft are measured on the loadout chute and gate assembly.

MINE HOIST AND ELEVATOR SAFETY

PRINCIPAL INVESTIGATOR:
Jeffrey Shawn Peterson

RESEARCH OBJECTIVE

Address specific MSHA concerns regarding the improvement of hoist and elevator safety inspection equipment, methods, and procedures.

PROBLEM STATEMENT

Despite periodic testing required by MSHA, mine hoist and elevator accidents resulting from electrical, mechanical, and structural failures do occur. For example, shaft accidents associated with the hoisting cycle may happen when the conveyance is empty or lightly loaded. Survey data show that the car is empty or lightly loaded during 90% of a hoist's cycling time. This creates a situation where the counterweight is heavier than the car. If a brake fails, the car will accelerate upward and crash into the headframe, a condition termed "overspend" and "overwind." In the time since this project was initiated, at least four accidents with injuries have occurred in the United States that fit the above description.

Downtime for inspection, maintenance, and repair significantly decreases the number of production shifts available for hoisting. Data suggest that much of the Nation's existing mine hoisting infrastructure is simply not capable of continuing to function in a safe and economical manner without the construction of new facilities, major rehabilitation of existing facilities, or the application of new technology. Injuries and fatalities can result from exposure of maintenance and operating personnel to the hazardous hoisting environment. Thus, research to improve and increase information flow about the operational status of a hoist and/or allows personnel to be removed from hazardous locations near the hoist is crucial.

RESULTS TO DATE

- A model elevator has been built to train MSHA hoist and elevator inspectors.
- An exhaustive survey of sensing techniques that can monitor cage position and velocity was conducted.

Results showed that a dc tachometer, accelerometer, and microwave devices proved reliable and accurate.

- A computerized data acquisition system has been developed that monitors and digitally records pertinent electrical signals from sensors on hoists and elevators. The information transmitted includes hoist cage acceleration, cage velocity, hoist motor armature voltage, armature current, and field current. Field experience proved that the system was reliable. In addition, math functions available with the system allow certain electrical data (such as cage acceleration or velocity) to be calculated in situations where sensors are unavailable.
- MSHA personnel have visited PRL twice to link a LMA-75/125 wire rope tester with the data acquisition system. Several tests were successfully conducted using the elevator in Building 23. MSHA suggested additional work be done so that this type of data collection could be incorporated into our research.
- Two software packages have been developed. The first assists in the calibration of the LMA-75/125 wire rope tester, and the second will, based on data provided by the user, generate an elevator inspection list for routine, 1-year-, 5-year, and acceptance inspections. It will also assemble relevant installation information into a database.

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A presentation on the uses of the data acquisition system was given to roughly 120 mine electrical inspectors at the National Mine Health and Safety Academy, April 29, 1998.

KEYWORDS: Electrical safety, mine elevators, mine hoists, elevator safety, monitoring systems.

MINE HOIST AND ELEVATOR SAFETY

PRINCIPAL INVESTIGATORS:

Michael J. Beus and Stephen Iverson

RESEARCH OBJECTIVE

Improve the safety of hoist and elevator operations by using sensor and computer technology to increase the amount of information and efficiency of flow to hoist operators and inspectors.

PROBLEM STATEMENT

This project was initiated at the request of MSHA because of increasing concern about hoist and elevator safety. According to accident statistics, mine hoist maintenance workers and hoist operators are exposed to many hazards in hoisting environments. MSHA, mine hoist operators, and maintenance personnel have expressed an interest in better technology to monitor these hoist conditions.

RESULTS TO DATE

A state-of-the-art hoisting and ore pass research facility has been constructed. This facility allows assessment of mine hoisting and elevator safety and control systems, including hoisting machinery (hoist room controls, motors and gear boxes, and winders) and shaft infrastructure (support frameworks, guides, wire ropes, and skips and cages). Sensors and real-time data acquisition interfaces to monitor hoisting operations have been developed. Limit switches have been designed and installed on the hoist headframe and in the loading pocket. A Windows-based program called Wonderware and a flat panel touch screen monitor are used for process control and automation. These systems allow personnel to assess critical hoist operating parameters, such as hoist position, speed, and acceleration; conveyance loads; rope tension; and shaft guide alignments. A load cell has been developed to measure rope tension and has been patented.

Validation of various data protocols is complete. A computer program written in Visual C++, called "On-board," has been developed for data collection and visualization on a stand-alone process screen that can be used with desktop or laptop computers. A handheld computer has been developed to read sensor data via wireless data transmission during shaft inspection and sensor calibration.

The final mine prototype of the hoist monitoring system has been built and installed at the test facility. This system further integrates a customized signal processing board to minimize size

and increase transmission speed. An in-shaft generator circuit charges the monitoring system's power supply. Methods and modification of modems to transmit voice and data to the hoist room are being finalized. Integration of conveyance monitoring data into the hoist room computer is in progress. Plans are to field test the complete hoist monitoring system at a selected mine site.

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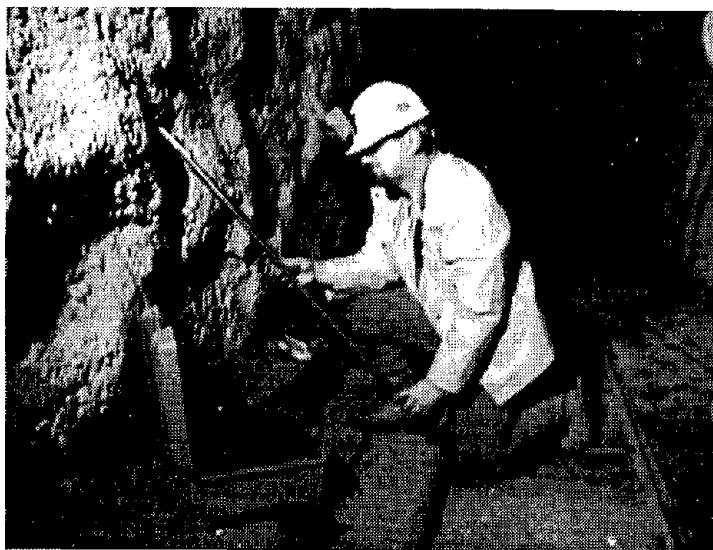
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KEYWORDS: Mine hoisting, wire rope tension, conveyance monitoring, wireless data transmission



Data acquisition equipment installed at test facility on Kimberly-styled mine skip complete with safety dogs.



Scoping a rock bolt hole prior to bolt installation. The small-diameter borescope offers several advantages over conventional borescopes. The cost is low because the borescope relies on off-the-shelf components; miniaturized components keep the system portable, which enables it to be operated by one person; and it can be used to depths up to 100 ft, far deeper than fiber-optic borescopes.



View in the borescope as seen by an operator. The view screen shows a fracture in the rock mass; such a fracture may affect the choice of ground control strategies in this particular area of the mine.

MINING UNDER ADVERSE GEOLOGIC CONDITIONS

PRINCIPAL INVESTIGATORS:

Jeffrey K. Whyatt, Brian G. White,
and Timothy J. Orr

RESEARCH OBJECTIVE

Develop methods to recognize and respond to adverse geologic conditions that markedly increase the potential for ground falls and rock bursts.

PROBLEM STATEMENT

Ground falls and rock burst hazards vary widely within and among hard-rock mines. While this is not surprising, it is not readily apparent in the MSHA statistical database, largely because exposure rates are not tracked. However, project personnel are developing independent estimates for special circumstances, particularly those involving adverse geologic conditions. For example, the deep mines in the Coeur d'Alene Mining District of northern Idaho are operating in highly stressed quartzites. The fatal accident exposure rate for rock bursts in these mines has been estimated to be eight times the national average for all types of mining-related fatal accidents over the past 10 years. Anecdotal evidence from other mines and other districts suggests that this experience is not unusual. Highly hazardous working environments created by adverse geologic conditions need to be identified so working conditions can be improved.

RESULTS TO DATE

A ramp development study was completed that showed that rock burst hazards and accidents during development were related to geology, particularly where conditions suddenly changed for the worse.

Field investigations of rock burst mechanics in the Coeur d'Alene district continue to help researchers refine their understanding of rock burst phenomena. For instance, rock bursting has been documented in silicified siltite-argillite rock in the vicinity of the Gold Hunter vein. Siltite-argillite rock has been viewed as too soft to support brittle failure, but silicification of this rock, which is common near veins in the district, appear to change rock properties sufficiently to allow

bursting. Samples of silicified siltite-argillite are being collected for laboratory testing. Valuable in situ measurements were obtained of slip on a bedding plane fault associated with a 3.1-Richter magnitude event at the Lucky Friday Mine. These measurements should provide a basis for evaluating models that relate seismic energy, stress drop, slip magnitude, and slip radius in seismic events caused by slip along a discontinuity. A set of seven in-depth field studies of geologic conditions documented the relationship between geology, in situ stress, mine operations, and rock burst hazards. A detailed investigation of how the in situ stress field varies naturally, and how these variations may be addressed in numerical models, is being conducted.

A valuable result of this research has been new insight into the relationship between economic veins and geologic structures in the Coeur d'Alene district. This new insight has been integrated into exploration programs throughout the district and inspired a new USGS effort to update its model of district ore deposits. These ideas have been disseminated through informal contacts, a cover article in *Mining Engineering*, a paper at the SME annual meeting, and a number of presentations to other interested groups.

Detection of specific adverse geologic conditions is essential to avoid unexpected hazards. Since exploration holes are drilled well before excavation begins and are routinely drilled into mine roofs and ribs, these holes provide an important opportunity for direct observation of geologic conditions. An Employee Invention Report has been filed on an inexpensive video borescope being developed to gather information from boreholes, and a company has been retained to manufacture several copies of these instruments and demonstrate how they can be used to inspect roof strata, examine Split-Set bolts for corrosion, and assist with quality control. In addition, teams of students from the Center for Engineering Design (CED) at Gonzaga University in Spokane assisted project personnel in designing a number of advanced features for a video borescope that will allow inspection of deep boreholes. A CED team addressing the design of a navigation system for determining the location of an image within a borehole won a regional ASME student presentation contest in May 1997 and presented its project at a nation-wide contest held in December at the annual national meeting of ASME in Dallas, TX. A second CED team designed a cooling system for exploration of hot boreholes.

In cooperation with the Fundamental Studies of Rock Mass Deformation project and Silver Valley Resources, project researchers developed a link for displaying daily seismic information along with current mining progress and geology. The link was installed on a networked commercial mine information visualization system called GEMCOM, which can send daily readings to underground terminals to be used by shift supervisors and miners. Other project work involves the protocol VRML and solid modeling capabilities. VRML allows a solid model to be viewed and manipulated with plug-ins to Web browsers, greatly increasing the potential for distributing virtual models of mine geometry, geology, and seismicity. Visualization of these features is essential for efficiently spotting and responding to adverse geologic conditions.

Project burst-monitoring capabilities were expanded when three seismic monitoring stations were established near the Stillwater Mine (in cooperation with Stillwater Mine and Montana State Bureau of Mines Office of Earthquake Hazards) and a system was developed for setting up additional stations around the Gold Hunter vein (in cooperation with Hecla Mining Co.). Existing cooperative work at the Lucky Friday and Sunshine mines is continuing.

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PATENT

Employee invention report EIR 1-001-98/0 has been filed for the "Borehole Video Inspection Tool for Determination of Geologic Conditions in Small-Diameter Boreholes," and a patent application is being processed.

MINE DEFORMATION MONITORING FOR GROUND HAZARD ASSESSMENT

PRINCIPAL INVESTIGATORS:

Peter Swanson, Mark Larson, and Doug Scott

RESEARCH OBJECTIVE

Develop effective methods to describe mining-induced fracturing and deformation in order to reduce ground control hazards for miners.

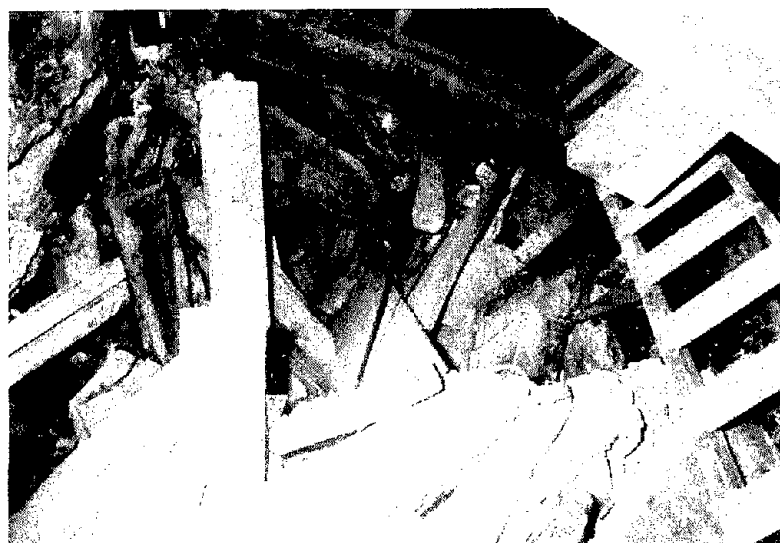
PROBLEM STATEMENT

Underground miners are exposed to a variety of different hazards (e.g., coal bumps, rock bursts, ground falls, pillar collapses) resulting from uncontrolled or unplanned deformation of the ground surrounding underground openings. While numerical modeling tools have become very sophisticated and have ample capability to simulate expected deformation, overly simplistic rock mass deformation (constitutive) laws and ineffective methods of describing spatially variable and time-varying material properties and field boundary conditions limit their use. These limitations reduce the effectiveness of the modeling approach to identifying and predicting ground control hazards. Conventional methods of monitoring deformation are restricted by the expense and difficulty of making stress and displacement measurements at a few discrete points. Simple tools are needed to provide miners and mine operators with a means of characterizing stability when mining under difficult and/or unusual conditions.

This project seeks to overcome current limitations in estimating and forecasting ground control hazards by developing more realistic rock mass deformation laws and more effective methods of monitoring hazards from a remote location. Joint efforts with industry partners are focused on field and laboratory studies that address hazards associated with rock bursts, coal bumps, and mine collapses.

RESULTS TO DATE

In a joint project with Silver Valley Resources, work has begun on the second phase of an automated PC-network-based seismic monitoring system at the Galena Mine near Wallace, ID. This system gathers



View of raise before (top) and after (bottom) a rock burst in a hard-rock mine.

seismic event location information in real time and automatically distributes it via a computer network to mine personnel on the surface and underground. In the phase 2 expansion of the seismic array coverage, a second data acquisition system and array of sensors were deployed in other parts of the mine. The technology to merge and process seismic data automatically from several autonomous data acquisition systems was developed and tested.

In cooperation with PRL's Coal Bump Reduction Through Advanced Mine Design project, the initial components of a combined surface and underground seismic monitoring array have been installed at Cyprus Plateau's Willow Creek Mine (Helper, UT).

This system is being installed as part of a joint NIOSH/industry investigation into the mechanics of coal bumps in multipanel longwall sequences. Eleven roof-mounted and borehole geophones were installed and connected with cables for transmitting the signals to an underground data acquisition trailer. Nine remotely powered geophone stations were installed on the mesa top above the mine. Signals from six of these surface stations are digitized and telemetered to a digital data acquisition system in the engineering office via spread-spectrum radio links. Signals from three of the surface stations and a strong-motion seismometer are digitized and stored locally for periodic retrieval. GPS receivers provide the time base to synchronize the data acquisition systems. A fiber-optic network connects the underground and surface data acquisition systems with an automated processing and display workstation in the engineering office. Preliminary estimates of seismic event locations are automatically displayed on a mine map in the engineering office.

Exploratory seismic measurements were initiated at the Alchem trona mine (Green River, WY) in a joint effort with General Chemical Corp. to examine remote methods for monitoring the stability of large excavated areas. Several different seismic sensors and signal-conditioning modules were installed at the edge of one of these areas, and signals are being input into an underground data acquisition system. The objective is to determine if these types of remote measurements can be used to provide a baseline against which accelerating deformation can be observed.

Efforts have also been made to determine more realistic constitutive relations for use in modeling studies pertinent to improved rock mass support technology. As part of this effort, a new time-dependent constitutive model for joints has been written in the FISH language for use with the numerical code FLAC. Numerical simulations of deformation and failure are being compared with measurements made at the Shoshone longwall mine (Hanna, WY). Results of these numerical tests are being studied to learn how creep time-step and equilibrium condition interact to shape deformation history. Direct-shear laboratory tests on core taken from the roof at the Shoshone Mine suggest the presence of a static fatigue phenomenon, but results are limited. Additional laboratory tests are planned.

Progress has been made in an experiment designed to characterize the relationship between rock stress and seismic velocity. An initial tomographic seismic velocity survey was completed on a pillar under the controlled conditions of the Colorado School of Mine's experimental mine (Edgar Mine, Idaho Springs, CO). Installation of a flatjack for the stress measurements is in progress. Upon completion, a series of seismic surveys will be made as pressure in the flatjack is increased.

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KEYWORDS: Rock bursts, coal bumps, mine collapse, mining-induced seismicity, rock mechanics

SLOPE STABILITY HAZARD RECOGNITION FOR METAL/NONMETAL MINES

PRINCIPAL INVESTIGATORS:

**Jami M. Girard, Ron Mayerle, Ed McHugh,
and Doug Scott**

RESEARCH OBJECTIVE

Minimize hazards associated with unstable mine slopes through an aggressive research approach involving engineering controls, geotechnical design, advanced monitoring equipment, computer models, and hydrogeologic investigations.

PROBLEM STATEMENT

Whether underground or on the surface, unanticipated rock movements create the potential for a mine catastrophe. In 1997, three surface mine workers (or 9% of the surface mine fatalities reported in 1997) died in slope-failure-related accidents, and 20 workers have been killed by slope-failure-related accidents in the past 5 years.

Basically, there are four types of slopes that may fail at an open-pit mine: highwalls, dumps, stockpiles, and tailings embankments. An understanding of slope failures related to mining activity and the technology available to prevent these types of failures will assist engineers in designing the best preventive measures for unstable ground. Better design and control of slopes will reduce the number of fatalities and injuries. Results of this research can be transferred to a number of other applications, including landslide control, design of roadcuts, railroads, canals, refuse disposal sites, and earth dams.

RESULTS TO DATE

Researchers assisted the Bureau of Land Management with an analysis of a proposed slope design. The mine plan proposed permanently diverting a stream drainage to a bench on the mine highwall. Recommendations were sent to the BLM and to the mining company.

Several novel techniques for slope design and monitoring have been examined. An overview of these



Tension cracks (above) and water seepage (right, as indicated by researcher) can be indicators of potential slope failure

technologies was presented to attendees at the 17th Ground Control in Mining conference. SRL researchers are working with many universities and private companies to develop new instruments to enhance safety at open-pit mines. Examples of this technology include—

- Imaging spectrometers to map geology, locate hydrothermally altered zones (weak areas) within a rock mass, and delineate structures that may influence stability,

- Interferometric synthetic aperture radar to monitor small displacements and generate digital elevation models,
- Subsurface imaging tools to search for unknown underground workings, locate water-bearing structures, and map geologic contacts.

Data from an airborne imaging spectrometer has been gathered and an analysis completed for a mine site in Arizona. Samples of several different rock and mineral specimens, including some samples of rare-earth minerals, were tested with a spectrometer being developed by Carnegie-Mellon. Subsurface imaging field tests were completed at a mine site in Nevada. Design modifications for some instruments at the Carnegie-Mellon Research Institute and Brigham Young University have been discussed and some of these modifications have been started.

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SAFETY DESIGN FOR UNDERGROUND MINE STABILITY

PRINCIPAL INVESTIGATORS:

Tom Brady, Jeff Johnson, and Mark Larson

RESEARCH OBJECTIVES

Develop systematic analytical methods for assessing the safety of mine operations, particularly the stability of underground mine workings, and promote the routine application of these methods in the mining industry.

PROBLEM STATEMENT

Loss of ground stability, either locally or across large sections of a mine, is a serious problem for the mining industry. Recent examples of major instabilities include a chain reaction of rock mass failure at the Macassa Mine in Ontario that devastated the bottom half of the mine and a 0.75-square-mile collapse at the Solvay Mine in Wyoming. Smaller sequences of pillar collapse receive less attention, but they are quite common. Over the last 15 years, 30% of the mine fatalities in underground metal/nonmetal mines and 42% of the fatalities in underground coal mines are caused by failures of ground.

Analytic methods, by their nature, require a great deal of computational effort, as does obtaining the geophysical and geomechanical data needed to support the analyses. Recent dramatic progress in the cost effectiveness of computational power, however, have brought these analyses into the realm of personal computers. This project seeks to develop engineering tools for the design and analysis of stability in underground mines.

RESULTS TO DATE

Earlier project work concentrated on analyses of the most critical of mine structures, the shaft pillar. Loss of a shaft pillar, like that experienced at the Macassa Mine, can threaten an entire shift of miners with entrapment, injury, and death. Loss of a shaft pillar can also result in the closure of major portions of a mine or even all of it, resulting in significant economic and social losses. In this project, the major

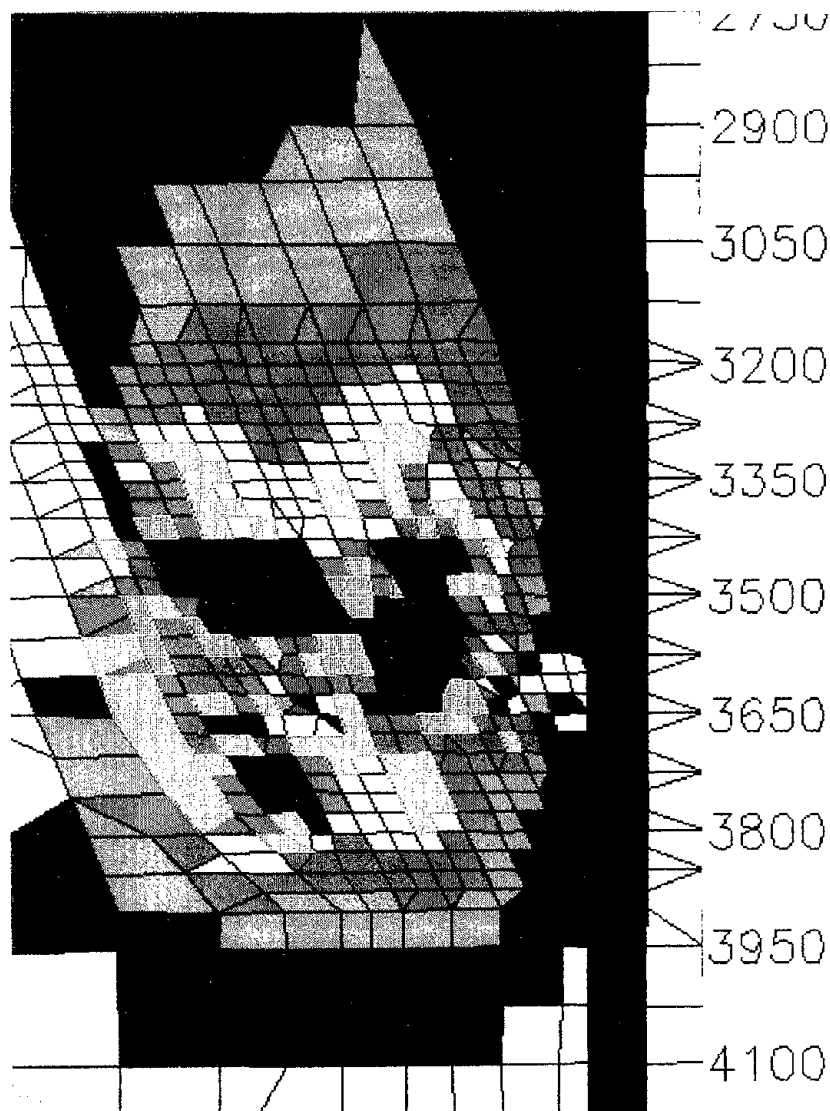


focus was to develop, improve, and evaluate elastic finite-element tools for assessing the stability of the Ross pillar at the Homestake Mine during mining of high-grade ore in the pillar. When unexpected shaft deformation occurred, creating considerable concern for miner safety, SRL researchers were asked to establish a monitoring and analysis program to evaluate the stability of the pillar. Continued monitoring has shown that, although the pillar is stable in the short term, there is also significant long-term creep that was not accounted for by available analytical methods. The effect of creep on shaft pillar stability over time is difficult to discern and requires new analytical tools.

Ideally, stability analyses should be done early in a mine's life so that problems can be avoided entirely. A cooperative arrangement among the Stillwater Mining Co., Montana Tech, and the Spokane Research Laboratory will investigate how a stability analysis can best be integrated into the design of an expansion at the Stillwater Mine and address a number of safety concerns. SRL efforts are being complemented by geo-physical investigations of rock mass properties by Montana Tech and a substantial contribution of resources from the mining company. To this end, SRL and Montana Bureau of Mines personnel established a geophone station and accompanying relay stations at the end of the summer to monitor rock bursts.

A new method involving the use of instrumented rock bolts was developed this year to measure rock mass response to drifting and blasting. In this method, two sets of bolts were placed at the start location for production mining. A CSIRO hollow inclusion cell was placed ahead of drift advance. A three-dimensional, finite-element model was then developed for the drift. The results from the model and the field strain data were compared and found to be in agreement.

All of these analyses, instruments, and tests have been conducted with an eye to developing tools and training materials that can be transferred from research to the work site in a cost-effective manner. The goal is better and safer mines through the use of rock mechanics.



Computer-generated display of stress in a deep underground mine. Solid black indicates the shaft and "open" mined-out areas. The darker the color, the greater the safety factor. Numbers to the right are mine levels below the surface.

MINE ROOF AND ESCAPEWAY SAFETY FOR WESTERN LONGWALL COAL

PRINCIPAL INVESTIGATORS:

Eric Zahl and John Dunford

RESEARCH OBJECTIVES

Identify and evaluate the hazards associated with longwall coal mining in the West. Select focus areas and develop best practices for escapeway safety in Western longwall coal mines. One selected focus area is the development of assessment strategies for violent failures of supporting coal in underground operations.

PROBLEM STATEMENT

There are 90,000 underground coal miners in the United States, and the proportion of longwall mining to all underground coal mining has grown from 20% in 1983 to 47% in 1996. Competitive coal prices have forced the industry to develop more productive methods of extracting coal. These methods will involve larger automated machinery, larger coal panels, new support systems, and work areas that are much farther from mine portals. New coal mines also tend to be deeper and in less stable ground. These factors create a mining environment that is changing so fast that

reliance on historical accident data to determine hazards is inappropriate.

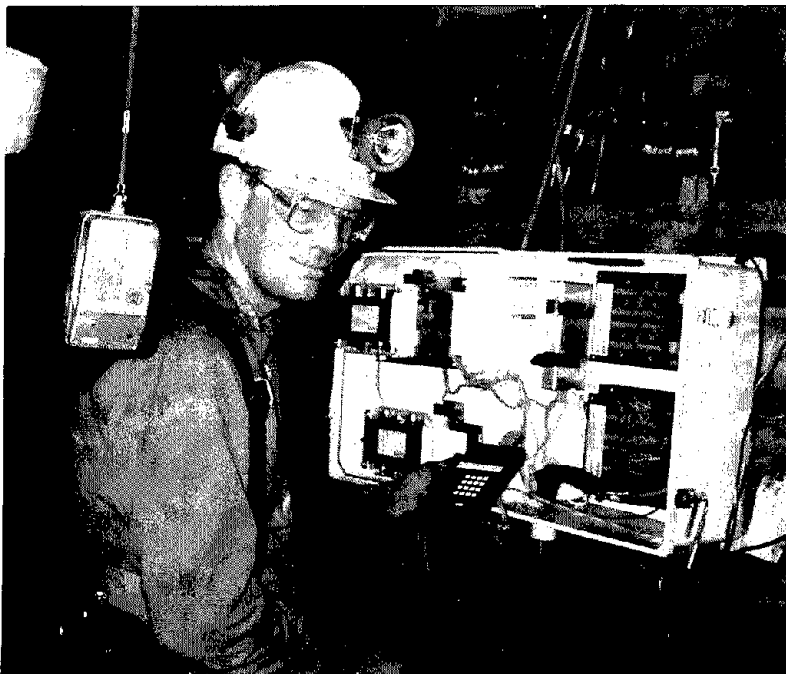
Integrating the potential hazards of the newer longwall mining environments with a continuing focus on the structural integrity of escapeways is the focus of this project.

RESULTS TO DATE

The project team established a working relationship with Cyprus Plateau Mining Co. and NSA Engineering to perform field studies at the Willow Creek Mine, a longwall coal mine near Price, UT. This site was selected because it is under deep cover and faces challenging ground conditions that are becoming more characteristic of newly developed mine properties. For this field study, 20 instruments were placed in the coal to measure stress and displacement. These instruments were coupled to a data acquisition system that provides near-real-time data on changes in global stress and strain in the mine. Of particular interest to us was the ability to monitor ground conditions over the long term in a new mine where there are significant stability concerns, i.e., coal bumps and roof failures. Such failures have led to fatalities and injuries to miners in nearby mines.

The total instrument package and data acquisition system have been installed and made operational. Results have been used by the mine to track stress redistributions and caving characteristics for the first production panel. Spokane Research Laboratory researchers will use these data to evaluate the potential for coal bumps, including location and magnitude in the short term, and to develop methodologies for assessing and reducing bump potential in the long term.

KEYWORDS: Coal, longwall, geotechnical, escape-way, instrumentation, support, modeling, data acquisition systems, monitoring, stress, strain



A data acquisition system used to monitor stress and strain changes in the mine.



Earth pressure cells and strain gauges being installed to monitor the stability of backfill



Backfill composed of cement, fly ash, cycloned mill tailings, and waste rock placed between remnant ore pillars at a mine in Missouri. Backfill trucks are used to place most of the fill in the 20-ft-high, 30-ft-wide opening between pillars, and then the remainder of the opening is filled tight to the back using slinger trucks and a similar backfill mix with minus 2-in crushed waste rock.

SAFE MONITORING OF ENGINEERED BACKFILL

PRINCIPAL INVESTIGATORS:

J. B. Seymour, D. R. Tesarik, and T. J. Williams

RESEARCH OBJECTIVES

To improve the safety of underground miners by developing new backfill evaluation methods and innovative instruments for monitoring mining-induced stresses and displacement in backfill and the host rock.

PROBLEM STATEMENT

Roof and rib falls accounted for approximately 46% of the underground metal/nonmetal mine fatalities in the United States over the last 10 years. Many of these traumatic injuries and fatalities might have been avoided through the use of backfill mining techniques. Backfilling with an engineered fill material provides excellent long-term ground support that improves the safety and stability of underground workings. However, the use of backfill mining methods is limited by a lack of information regarding the ground support characteristics of placed fill.

The use of modern backfilling techniques in the United States has traditionally lagged behind that of other countries, particularly Canada, Australia, South Africa, and Finland. However, over the past few years, backfill mining methods have gained a more widespread acceptance in the U.S. mining industry. Because of its support capabilities in weak ground and its high extraction rates, backfill mining methods are being used extensively in the underground gold mines in Nevada. Backfill is also being used to reduce the incidence of hazardous rock bursts in deep metal mines, recover remnant ore pillars in room-and-pillar mines, and provide stability for in-panel entries during longwall mining in underground coal mines.

Because backfill is being used in new situations and in increasingly weaker ground, the Mine Safety and Health Administration has requested that backfill research be given a high priority. Recent backfill-related accidents illustrate the continuing need for better quality-control measures for backfill batching and placement, improved techniques for monitoring and evaluating the safety and stability of placed fill.

RESULTS TO DATE

In cooperation with Cyprus Twentymile Coal Co., the safety and stability of underground working conditions in the Foidel Creek Mine, an underground coal mine in Colorado, were monitored as a longwall mined through a series of backfilled cross-panel entries. To maintain the stability of these in-panel entries during subsequent mining of the longwall panel, the entries were backfilled with an air-entrained mixture of fly ash and cement. Instruments installed in the cross-panel entry pillars, backfill, longwall panel, and adjacent headgate entry were continuously monitored by a computerized data acquisition system as the longwall approached and mined through the backfilled section of the panel. Data collected from these instruments were analyzed to determine the magnitude and direction of secondary principal stress changes ahead of the longwall face, deformation and closure of the headgate entry, and stability of the cross-panel entry pillars and backfill. A three-dimensional, boundary-element model was calibrated to predict mining-induced stress changes and the distance they occurred ahead of the longwall face accurately.

A second study was conducted in cooperation with Hecla Mining Co. to investigate the cause of recent backfill roof failures in ramp-stope intersections at the Lucky Friday Mine, a deep silver mine near Mullan, ID. Because these backfill roof failures pose serious hazards to miners working in the intersections, instruments were installed to monitor deformation of the backfill and host rock during subsequent mining of undercut stopes beneath the intersection and to measure mining-induced loads on trusses and reinforcement within the fill. The instruments showed that as mining progressed beneath the intersection, the walls converged, transferring mining-induced loads first to the cemented backfill and then to steel reinforcement within the fill. As additional undercut stopes were mined beneath the intersection, the mine walls continued to converge, further crushing the fill. At failure, only two of the four legs of the truss carried load. The mine staff then decided to install 10- by 10-in by 10-ft wood beams rather than trusses to support the backfill in the intersections.

Instruments were also installed to measure mine wall convergence above cemented sandfill in an undercut-and-fill stope in the Gold Hunter vein, a newly developed deposit at the Lucky Friday Mine. Because the rock surrounding the Gold Hunter is much softer than the brittle formations around the Lucky

Friday vein, baseline information is needed about the interaction between cemented backfill and the wallrock. Preliminary studies indicate that the mine walls are converging at about one-half the rate measured in the Lucky Friday vein and that the backfill is undergoing a safe level of horizontal compression.

In cooperation with the Doe Run Co., borehole extensometers were installed in ore pillars at the Fletcher Mine, a lead-zinc, room-and-pillar mine near Bunker, MO. Doe Run is currently placing cemented backfill composed of cement, fly ash, cycloned mill tailings, and waste rock to provide roof support during mining of remnant ore pillars. By measuring vertical and horizontal deformation in selected pillars as adjacent ore pillars are mined, the extensometers will provide critical information regarding the stability of the pillars and the safety of underground working conditions. The instruments are currently being monitored by a computerized data acquisition system temporarily set up near the instruments. After Doe Run's backfilling and pillar recovery plans are finalized for the northern part of the Fletcher Mine and an adjacent section of the West Fork Mine, additional instruments will be placed to monitor the stability of the backfill, mine roof, and support pillars during mining of remnant ore pillars.

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KEYWORDS: Backfill, instruments, modeling, stability, cement

MOBILE ROOF SUPPORT TECHNOLOGY

PRINCIPAL INVESTIGATORS:

John K. Owens and Wayne L. Howie

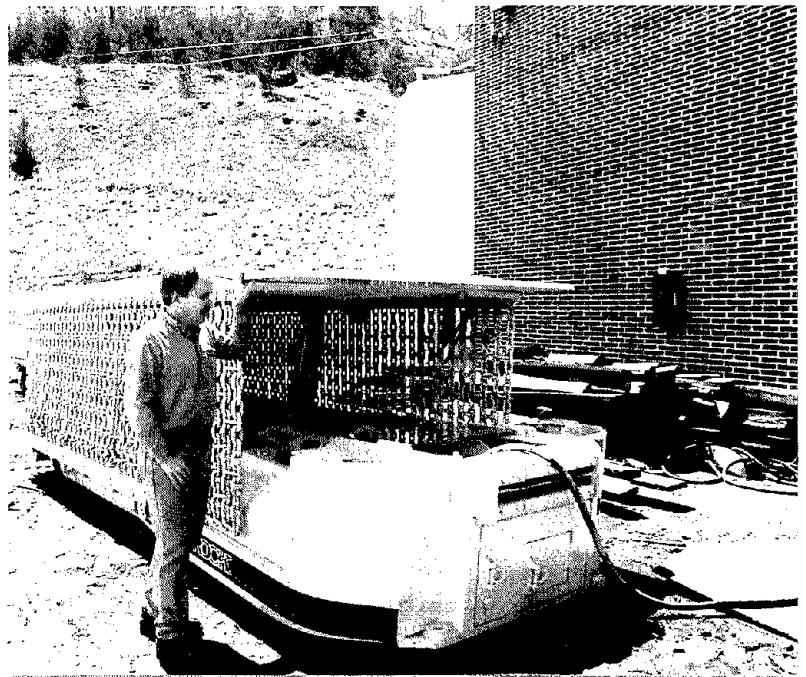
RESEARCH OBJECTIVES

Assess how loading on mobile roof supports (MRS's) can be used to indicate impending roof failure and provide data that MSHA can use to improve safety in retreat mining operations utilizing MRS's.

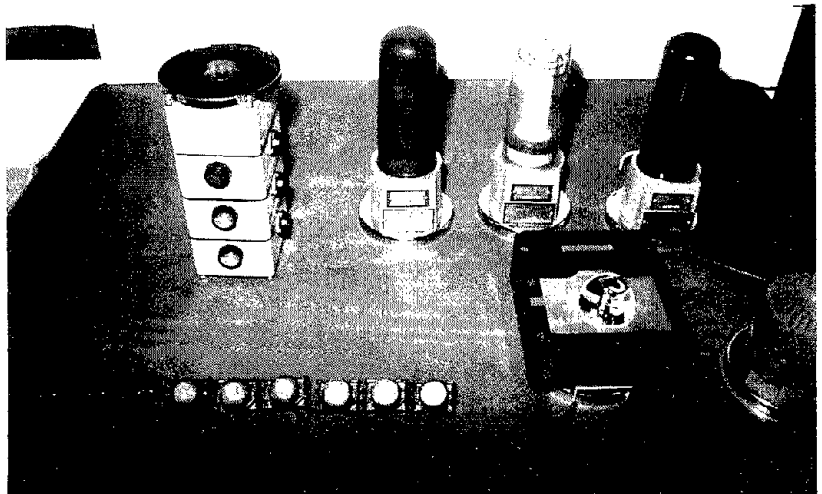
PROBLEM STATEMENT

Recent years have seen a resurgence in pillar extraction in underground coal mines where MRS's are used for support instead of posts, and to date, approximately 40 U.S. coal mines have adopted this technology. It is estimated by major manufacturers that there will be 150 machines in operation by the end of 1998. Along with the increase in the number of MRS's, MSHA has received requests to approve roof control plans that involve novel approaches to the use of these machines. However, MSHA does not have the technical information needed to approve these plans, nor is agency approval consistent from one subdistrict to another. As a result, MSHA requested that research be performed to (1) develop an understanding of how these machines interact with mine strata and provide support during coal extraction and (2) acquire the data needed to develop guidelines for the safe use of MRS's. Topics of concern include optimum setting pressure, critical loading rates that could signify imminent failure of the mine roof, and optimum location of MRS's during specific operations.

Another problem is the lack of a warning system. In the past, post and cap noises, ground and post displacement, and failure allowed miners to "read" unstable ground, but with the increasing use of MRS's, such an early warning system is no longer available. Thus, during the investigation of a fatality that occurred in a mine section where MRS's were used, the West Virginia Board of Coal Mine Health and Safety requested that research be performed to determine the feasibility of developing a warning system for MRS's that would alert miners to unstable ground conditions during pillar removal so that miners and equipment could be removed before a fall occurred.



Low-seam mobile roof support with hydraulic cylinders fully extended.



Types of warning devices that can be installed on a mobile roof support.

RESULTS TO DATE

The mechanics of load transfer from an MRS to mine strata was analyzed using field data, boundary-element modeling, and closed-form analytical solutions. Two mines in West Virginia and two in Utah were visited to observe MRS use, verify the results of numerical analyses, and investigate miner safety during pillar-pulling operations.

- Using three-dimensional, boundary-element analyses, two common pillar-pulling methods (Christmas tree and outside lift) were studied. The results showed that MRS's support roof rocks near the machines, but do not have the capacity to control overall roof-floor convergence, overall stress distributions, and strata movement because the MRS's are considerably less stiff than the rock. The Christmas tree method results in more deformation and entry closure than the outside lift method because in the Christmas tree method, more coal is extracted. This study shows the importance of careful mine layout design and proper mine orientation for optimizing roof stability and improving caving in operations where MRS's are used.

- In a second study, analytical closed-form solutions were used to determine the area immediately influenced by MRS's. Two conditions were analyzed, one in which a pair of MRS's were set side-by-side in an entry, and the other in which two pairs of MRS's were positioned 18 ft apart in an intersection. In both cases, the MRS's were shown to play a critical role in controlling the stability of the immediate roof and the middle roof for distances up to 60 ft above the seam. It was also found that higher MRS capacities and setting pressures are useful for stabilizing upper strata but may contribute to differential loading on the immediate roof, failure of mechanical bolts, and a reduction in the stability of the immediate roof. Other findings were that (1) the existing setting pressure standard of 1,500 psi (one-third of capacity) is reasonable because MRS's work in areas where significant deformation occurs and (2) MRS's should not be used to induce caving because the maximum stress that can be applied to the mine roof by the canopy (90 to 250 psi) is considerably less than the strength of typical coal-measure rocks (8,000 to 16,000 psi). The practice used at some mines to cycle MRS's at high setting pressures to induce caving may only lead to failure of mechanical bolts and localized failures of the immediate roof. The best method for inducing a cave is through proper orientation with respect to geologic discontinuities.

- A field test plan was developed to evaluate the influence of MRS's on roof stability. An instrument package consisting of a Campbell data acquisition system, pressure transducers, and string potentiometers was assembled to monitor loading and canopy closure during pillar-pulling operations and sent to MSHA's Triadelphia, WV, office for explosion-proof testing. These packages will be installed on four MRS's used for support during pillar removal. Information to be collected includes load history on

the MRS's, effect of leg staging of the hydraulic cylinders on the accuracy of support load measurements, optimal location of MRS's for pushout removal, and how unloading on one MRS affects load transfer to neighboring MRS's.

A prototype load-rate monitoring (warning) device has been developed for MRS's. The device dynamically monitors pressure in the hydraulic cylinders of the MRS, calculates changes in pressure over time, and converts these pressure changes to loading rates. Warning lights mounted on the MRS canopy are then activated: bright green for low loading rates, yellow for medium loading rates, and red for high loading rates. The red light is programmed to flash continuously when the yield pressure of the hydraulic cylinders is reached. The performance of the load rate monitoring device will be evaluated during a field test, after which a protocol will be developed on how to use the device to alert miners to dangerous conditions during pillar extraction. Critical load rate settings will also be determined for geological conditions at the mine. An experimental permit has been obtained from MSHA to field test the device on a MRS.

Several mines have been contacted and have expressed an interest in participating in the field study. J. H. Fletcher has agreed to assist SRL researchers in retrofitting the load-rate monitoring device onto one of its machines and installing the instrument packages to monitor the machine's loading behavior during pillar-pulling operations.

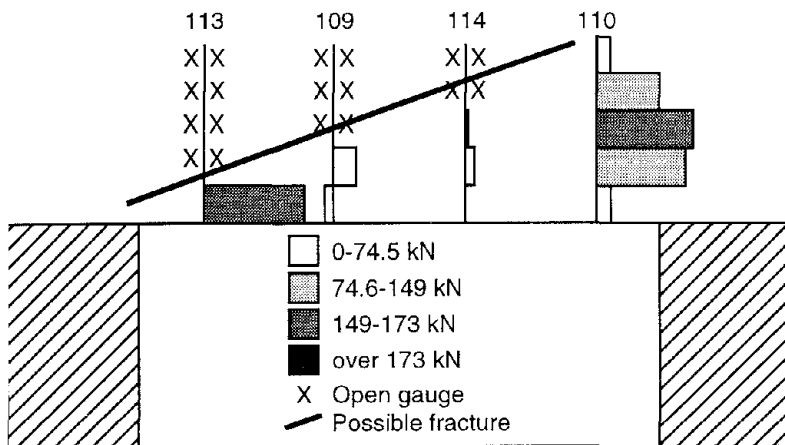
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PATENT

Howie, W. L., and J. K. Owens. U.S. Provisional Patent Application No. 60/083, 678, Method and Apparatus for Load Rate Monitoring, filed with U.S. Patent and Trademark Office on April 30, 1998.

KEYWORDS: Retreat mining, mobile roof supports, load rate warning system, mine safety



Axial loading on instrumented bolts show shear failure of the immediate roof.



Installing roof bolts is the most hazardous job in an underground mine.

METHODS FOR THE PREVENTION OF MINE ROOF SUPPORT FAILURE

PRINCIPAL INVESTIGATORS:
Steve Signer and Lewis Martin

RESEARCH OBJECTIVE

Develop methods for the prevention of roof support failures that cause roof falls.

PROBLEM STATEMENT

Over a hundred million rock bolts and cable bolts are installed in U.S. mines each year. Many of these supports fail, resulting in more than 400 injuries and 10 fatalities a year. Rock falls that block ventilation or escapeways can pose additional safety hazards. Recent NIOSH studies showed support load levels exceeding the yield point of the steel. These load levels can produce unstable conditions that pose safety hazards for mine workers.

Despite the importance of entry stability, there are no adequate methods to relate roof bolt diameter, length, and spacing to mining conditions such as geology, geometry, and in situ stress fields. Development of methods and tools to assist in the evaluation and selection of rock supports could reduce the number of unplanned rock falls significantly.

The approach taken in this project is to install both fully grouted bolts and cable bolts instrumented with strain gages in mines having variations in geology, opening geometry, and in situ stress fields to study the effect of these factors on support loading. Laboratory tests are designed to study the effects of both bending and shear forces on the behavior of rock supports. This information is critical because steel is weakest in shear, and field observations show high shear stress can be the primary mechanism of failure. Using the results of both laboratory and field tests, a tool will be developed that can estimate roof support requirements more accurately to prevent rock falls.

RESULTS TO DATE

- Forty-eight instrumented resin bolts and nine instrumented cables have been installed at test sites in six mines (four gold mines, one coal mine, and one

trona mine), and tests have been completed at four coal mines and one trona mine. The purpose is to study the effects of geology, geometry, and in situ stresses on roof and/or cable bolt loading.

- Fourteen fully grouted bolts instrumented with strain gages were installed in a longwall recovery room at the Emerald Mine to monitor roof stability. When the longwall approached the recovery room, an unplanned roof fall occurred. The strain gages showed that there had been a significant buildup of shear stress that contributed to failure of the roof support.
- Tests at site 1 in General Chemical's trona mine were completed. The mining method is pillar retreat with a low extraction ratio to prevent caving. Forty instrumented, fully grouted roof bolts had been installed in five rows at various bolt lengths, bolt spacings, and entry widths. Results showed that entry width had a significant effect on bolt load levels, and in most cases, loading increased after second-pass mining.
- Ten instrumented bolts and eighteen sagmeters were installed at the Deer Creek Mine. Shear stress measurements taken after the pass of the first longwall panel showed that bolt loading increased at many locations. The concrete-filled cans used as secondary support had a significant effect on reducing bolt loading as the second panel approached the test sections. Bolts installed in the cross-cuts showed higher load levels than bolts installed at mid-pillar.
- Tests at site 1 in the Trail Mountain Mine showed that large rock movements were taking place within the bolted zone. Approximately 25% of the normal supports (bolts and cables) had broken by the time the first longwall panel had passed. Geology appeared to be a significant factor in localized roof degradation. A very weak rock layer in the immediate roof contributed to the development of shear planes that had a significant effect on roof supports. Instruments consisted of 16 fully grouted, strain-gaged resin roof bolts, load cells on both full and partially grouted cable bolts, and vertical-deflection, multipoint extensometers. These instruments were installed on-cycle to measure bolt loading on existing supports and to determine if cable bolts could be used to improve roof stability. Only one instrumented bolt measured a maximum strain less than 2,000 microstrain, the yield point of the steel. The average maximum strain of all of the bolts was 20,000 microstrain. However, electrical continuity was lost to many gages, and a pattern was produced that indicated bolt failures.

An initial series of laboratory tests was completed in which instrumented roof bolts were tested to quantify bolt response to shear forces over a range of tensional loads. Paired, opposing strain gauges were mounted along the length of the bolt so that both axial and shear loads could be monitored. For this set of tests, the bolts were pretensioned in high-strength concrete blocks to as much as 80% of their yield strength, then, with the failure plane controlled, the bolts were subjected to direct shear loads in a hydraulic test frame. Data from the tests will permit characterization of the relation of axial load to shear load and determination of the distribution of shear strain along the length of the bolt. The object of the study is to better predict the behavior of roof bolts that are already carrying axial loads as they respond to shearing forces.

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KEYWORDS: Roof supports, bolt, cable, rock reinforcement

REDUCING INJURIES FROM THE FAILURE OF COAL MINE ROOF SUPPORT SYSTEMS

PRINCIPAL INVESTIGATORS:
D. Dolinar and G. Molinda

RESEARCH OBJECTIVES

Develop methodologies and/or guidelines for the selection of support for coal mine roof. The design of safe support will lead to lower numbers of unplanned roof falls and reduce the number of associated injuries.

PROBLEM STATEMENT

Over 100 million roof bolts are installed each year in underground coal mines to prevent falls of ground. Yet during any given year, nearly 55% of operating mines will experience at least one reportable roof fall accident. For example, in 1996, nearly 2,824 roof fall accidents from 892 underground mines resulted in 711 injuries and 8 fatalities in 1996. Of these roof falls, about 80% were caused by failure of the primary support system.

Over 350,00 intersections are excavated each year. NIOSH data reveal that over 71% of the roof falls reported in known locations had occurred in intersections. Because of large roof spans, intersections are significantly more likely to fall than entries, which exposes the underground work force to unstable roof even where the roof is supported and supposedly safe. The high number of accidents indicates that either the selection or design of the support system (or both) are inadequate for the conditions. In practice, roof support systems have been traditionally been designed on past practices or personal experience, trial-and-error, the choices of a neighboring mine, or the persuasiveness of a roof bolt vendor.

RESULTS TO DATE

The approach is to use experience of mine personnel to determine the most important factors in the stability of coal mine roof and develop guidelines based on the influence of these factors. Therefore, we are constructing a nationwide database of roof control experience in underground coal mines. During the last year, data have been collected from 14 mines. At each

mine, extensive interviews were conducted with knowledgeable personnel to collect information on roof bolt performance, roof fall characteristics, and mine geology and load history. The mines were then visited to characterize and quantify different roof geologies through use of the Coal Mine Roof Rating (CMRR), measure intersection diagonals, verify roof bolt data, and document roof damage. This information is being analyzed to use as input into the database. A multivariate statistical model will then be applied to the data, and a model and/or guidelines will be developed for the selection and design of roof support systems and mine openings. So far, data have been collected from mines in Alabama, Colorado, Kentucky, Illinois, Indiana, Ohio, Pennsylvania, West Virginia and Wyoming.

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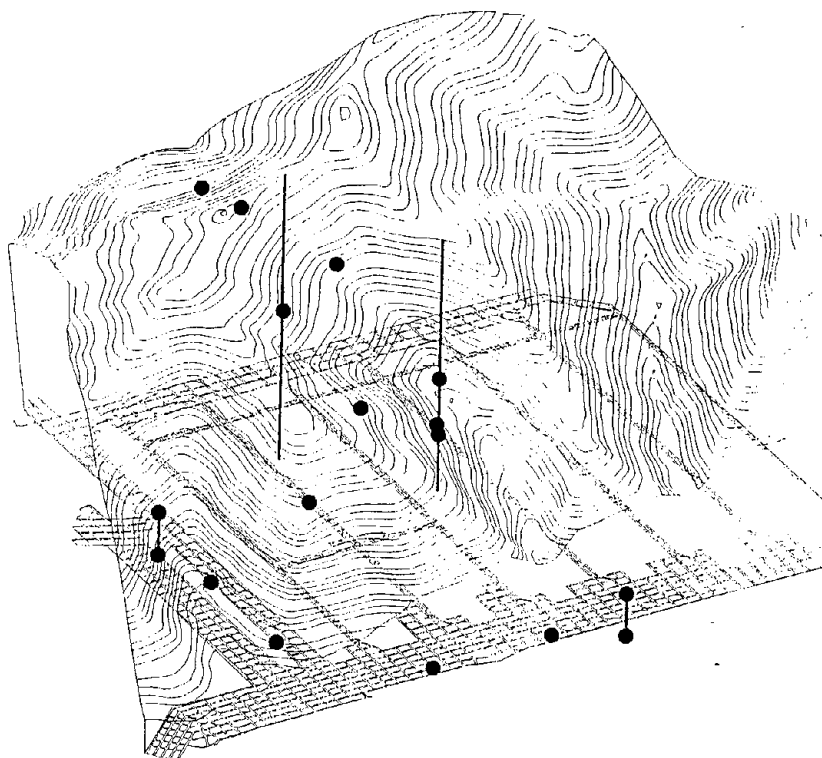
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KEYWORDS: Roof bolts, support system design, intersections, roof falls



Roof fall caused by failure of roof support system



Field location of geophones in a microseismic system

COAL BUMP REDUCTION THROUGH ADVANCED MINE DESIGN

PRINCIPAL INVESTIGATOR: Keith A. Heasley

RESEARCH OBJECTIVE

Reduce the incidence of bump fatalities and injuries through the development of improved coal mine design concepts that are solidly based on the actual mechanics associated with caving of massive main roof, compaction and load acquisition of the gob, failure of the floor, and abutment stress redistribution in the seam and surrounding strata.

PROBLEM STATEMENT

Coal bumps are the sudden violent expulsion of coal from a pillar or rib into an adjacent entry. On the average, two coal miners are seriously injured every year and a miner is killed every other year because of a coal bump. The exact mechanics of coal bumps is still not completely understood, and we believe that this lack of fundamental knowledge is the primary hindrance to further bump mitigation.

The approach taken in this project is to place instruments in a deep, bump-prone longwall mine and determine the behavior of the main roof, gob, and floor using a real-time microseismic system to "listen" to the rock. By determining the timing and location of rock strata failure around a longwall and analyzing this failure, the mine can be better designed to reduce dangerous bumps.

RESULTS TO DATE

A microseismic system consisting of 11 underground geophones (microphones for listening to the rock) and six surface geophones has been installed in and on top of a deep Utah coal mine. The underground geophones were typically attached directly onto the mine roof every 1,000 to 2,000 ft around a longwall panel and then wired to a central underground shed. On the ground surface, six geophones wired to solar-powered telemetry stations were installed above the active longwall panel. Data on rock failure from both the underground and surface geophones are radioed from the telemetry stations to a data analysis workstation at the mine office. The data are analyzed and the locations of rock failures calculated. These locations are then displayed in relation to a mine map on the computer screen for use by mine personnel.

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KEYWORDS: Bumps, bounces, coal mine, ground control, rock mechanics

PREVENTION AND SUPPRESSION OF EXPLOSIONS

PRINCIPAL INVESTIGATORS:
K. L. Cashdollar and M. J. Sapko

RESEARCH OBJECTIVES

Improve worker safety through research on the prevention and suppression of mine explosions; obtain basic data on the explosibility and ignitability of dusts, gases, and vapors from mining and other industries; develop instruments and procedures for characterizing explosion hazards; and assist in the forensic investigation of explosion accidents.

PROBLEM STATEMENT

Research on the causes and mechanisms of gas and dust explosions is needed as a basis for the development of techniques and strategies for explosion prevention, suppression, and mitigation in underground mines and aboveground processing plants. The results of this research are also applicable to other industries that manufacture, generate, process, use, or transport flammable gases and combustible dusts.

This project is related to the NORA priorities of emerging technologies and control technology.

RESULTS TO DATE

- In November 1997, PRL sponsored a forum on the problems of frictional ignition in mines to increase communication among mining companies, mine equipment manufacturers, and MSHA. Progress on this topic was reviewed, particularly regarding the commercial availability of wet-head mining machines.
- In September 1998, NIOSH co-sponsored the International Symposium on Hazards, Prevention, and Mitigation of Industrial Explosions to disseminate results of PRL and other explosion experts' research to the industrial community. The papers presented at this symposium are available in two proceedings volumes.
- In a cooperative effort, research personnel at the Experimental Mine Barbara in Poland will evaluate a prototype of the PRL-developed reflectance rock dust meter.

- Test procedures developed at PRL to evaluate the explosion hazards of dusts and gases will be promulgated as standard methods by the American Society of Testing Materials E27 committee.
- Another goal is to obtain basic laboratory data on the explosibility and ignitability of dusts, gases, and vapors. Basic data on explosion propagation will be obtained as part of research being funded by South Africa under a memorandum of agreement. Assistance to other NIOSH centers or MSHA in the forensic investigation of explosion accidents will continue as requested.

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KEYWORDS: Explosions, ignitability, methane, dust, flammable

PREVENTION AND EXTINGUISHMENT OF MINE FIRES

PRINCIPAL INVESTIGATOR: A. C. Smith

RESEARCH OBJECTIVE

Develop improved and novel fire prevention and suppression systems to reduce the risk of severe underground mine fires and enhance fire safety.

PROBLEM STATEMENT

Underground mine fires are one of the most serious threats to the safety of the Nation's miners. Mobile diesel-powered equipment has been identified as one of the largest sources of fires in underground mines. Of particular interest is the fire risk associated with the storage of large quantities of diesel fuel in underground storage areas. Research by NIOSH and other agencies has shown that water-mist technology, developed as a possible replacement in above-ground halon extinguishing systems, may be applicable for fighting diesel fuel fires. NIOSH is investigating the use of this technology for controlling and extinguishing fires in underground diesel fuel storage areas. Water-mist suppression systems may also be applicable to other types of fires in underground mines, particularly in haulageways, and to the protection of stationary equipment such as compressors and electrical substations.

RESULTS TO DATE

A large-scale fire suppression facility was constructed to simulate an underground fuel storage area. The facility consists of a fire-proofed main tunnel (entry) and a test area perpendicular to the main tunnel (crosscut) where fire tests are conducted. The dimensions of the facility are typical of entries and crosscuts in an underground coal mine. The facility is equipped with a variable-speed mine fan to control the ventilation rate of airflow through the tunnel, a self-contained water supply and drainage system to prevent environmental contamination, temperature and gas measurement systems, and a computerized data acquisition system to monitor the progress of the experiments.

Experiments were conducted on diesel fuel tray fires to determine if a water-mist suppression system would extinguish these types of fires and if the droplet size of the mist, the location of the fire, the type of nozzle, and the size of the fire had an effect on the time it took to extinguish the fires. The results showed that water-mist suppression systems did extinguish these fires and that there was an optimum range of droplet sizes for extinguishing the fires in the shortest time. Experiments were also carried out using 4-ft steel plates placed at various locations around and above the tray fires to determine if obstructions lessened the effectiveness of the water mist. Researchers found that the water mist was able to extinguish the fires under these conditions, but more time was needed. These results will be used to write engineering guidelines for the design, installation, maintenance, and inspection of water-mist suppression systems in underground diesel fuel storage facilities.

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KEYWORDS: Fire suppression, mine fire, water mist, diesel fuel fire.

EXPLOSIVE HAZARDS SURVEILLANCE AND EVALUATION FOR MSHA

PRINCIPAL INVESTIGATOR: J. H. Rowland

RESEARCH OBJECTIVES

In cooperation with MSHA, identify hazards associated with explosives and blasting practices through a review of explosive accident statistics and investigations of explosive and blasting accidents conducted. Test new candidates for permissible explosive status for MSHA. Determine the quantities of toxic fumes generated by explosives and blasting agents and study the potential for these fumes to injure miners.

PROBLEM STATEMENT

Once or twice a year, an explosives manufacturer will develop a new candidate for permissible explosive status and submit a request to MSHA to have it approved as a permissible explosive. Historically, the Pittsburgh Research Laboratory has tested candidate permissible explosives for MSHA because the facilities and expertise for conducting these tests (as required in the Code of Federal Regulations, Title 30, Part 15) exist only at PRL. Also, several times a year MSHA will ask for technical assistance in the investigation of an accident involving explosives. Toxic fumes produced by explosives and blasting agents are a special problem deserving study. Between 1978 and 1993, 90 workers in the mining industry were killed or injured by explosives fumes.

RESULTS TO DATE

During FY98, PRL assisted MSHA in the investigation of an explosives-related fatality at an anthracite mine in Pennsylvania. Assistance involved conducting permissibility tests on the explosives cartridge and evaluating the detonators and detonating cord to find



out if they were unusually sensitive. The investigation is continuing. PRL also assisted in the investigation of a fatal explosives-related fumes incident that occurred during excavation for new sewer lines in Atlanta, GA.

In the experimental study of toxic fumes, a number of commercial blasting agents have been examined, as well as a series of ammonium nitrate-fuel oil (ANFO) mixtures having widely varying oxygen balances. The ANFO series clearly points out the role of oxygen balance in the production of toxic fumes. CO increases and NO_x decreases as the oxygen balance decreases (fuel oil increases from 1 to 10%). The sum of the fumes is at a minimum at about 6% fuel oil (i.e., the basic ANFO composition). Using the basic ANFO mixture, a cursory study was made of the effects of changes in explosive containment, water content, and aluminum content. The preliminary results suggest that there will be significant effects on toxic fume production when (1) combustible carbon is contained in the casing material, (2) formulation changes lead to changes in the degree of nonideality of the detonation, and (3) expanding detonation products (particularly solid carbon) are prevented from interacting with atmospheric air (e.g., underground detonations).

Progress is being made in developing a computer model to predict fumes production by explosives and blasting agents. For the explosives and blasting agents tested to date, agreement between experimental and predicted fumes production is reasonably good.

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KEYWORDS: Permissible, fumes, explosives, blasting agents, mining

PREVENTING FLYROCK INJURIES AND FATALITIES

PRINCIPAL INVESTIGATOR: T. S. Bajpayee

RESEARCH OBJECTIVES

Develop a scientific understanding of the factors involved in generating flyrock during blasting. Develop pertinent methodologies, procedures, or computer codes that may be used by the mining industry to reduce the incidence of flyrock during blasting.

PROBLEM STATEMENT

Blasting is considered a very hazardous component of mining operations. Surveillance studies have indicated that flyrock accidents are still a very serious problem faced by the Nation's miners. Fatalities or serious injuries occur each year from blasts that throw rocks beyond expected bounds. A related but somewhat different type of accident occurs when rock is not thrown beyond the expected bounds, yet still injures or kills someone. This type of accident was responsible for numerous fatal and nonfatal injuries in the mining industry. Several accidents involved bystanders.

Reduction of injuries and fatalities from flyrock would make a significant impact on the safety of the Nation's miners. A thorough analysis of blasting procedures, including blast design, explosion factors, rock types and geologic conditions, and safety awareness of employees is needed. Once the causes are known, the needed research can be defined and a methodology to address the problems can be developed and implemented. This research will also aid in reducing blasting flyrock injuries and fatalities in the construction industry.

RESULTS TO DATE

This is a new project.

KEYWORDS: Flyrock, explosive, blasting



MINE FIRE PREPAREDNESS

PRINCIPAL INVESTIGATOR: R. S. Conti

RESEARCH OBJECTIVE

Enhance the current state of fire preparedness and response in underground mines by identifying, evaluating, and integrating optimal systems, equipment, and protocols to detect, respond to, control, and suppress underground fires.

PROBLEM STATEMENT

The prevention of a serious underground mine fire often requires extinguishing a small fire before it becomes a danger to mine personnel. The success of this operation depends on several factors, including an awareness of fire hazards, the availability of effective firefighting equipment and trained personnel, and sufficient response time.

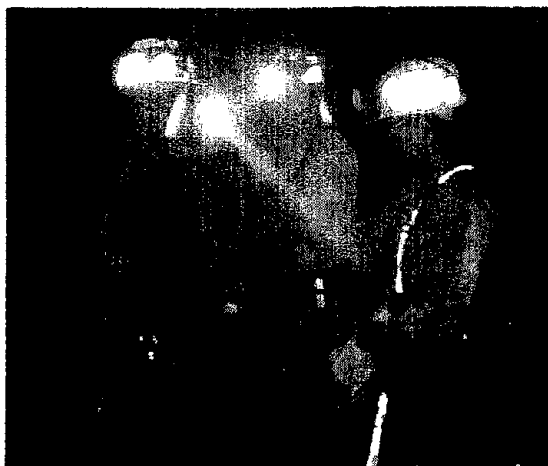
The state of fire preparedness for underground mines can be enhanced by employing large-scale tests and evaluations of current technology. Improved training protocols for miners and mine rescue teams need to be developed and evaluated. Recent fire research and actual mine fires have shown that the fires can spread very rapidly. For example, full-scale gallery experiments have demonstrated that conveyor belt fires can propagate at rates over 20 ft/min. Yet, many in the mining industry still believe fire-resistant belting will not burn. Modern firefighting equipment is available, but is not often found in underground mines. In many instances, mine personnel and mine rescue teams were put at risk during a

mine fire because of poor training, inadequate water supplies, plastic nozzles that melted, water lines that burst, suppression systems that failed, and improper personal protective equipment. Often, too, miners were forced to escape through smoke-filled entries.

RESULTS TO DATE

To address the various issues pertaining to personnel escape and fire suppression, a third-generation positive-pressure inflatable escape device was developed and evaluated during mine rescue team exercises. In a subsequent version of the escape device, C-shaped doorways were used on both sides of the device to allow easier entry and exit. The internal space was inflated with one blower, and air ducts were inflated with a second blower to maintain inflation of the escape device for longer periods when the doorway was open and several people entered. Rescue team members successfully entered the escape device from the fresh air side of the mine entry and left to "smoke-filled" passageways. Experiments were also conducted on an inflatable feed-tube partition. This device can rapidly block large openings, such as underground passageways, and simultaneously provide a feed tube for high-expansion foam generators during fire-fighting activities.

Mine rescue team training simulations were developed and evaluated. During these training simulations, rescue team members donned self-contained breathing apparatus and explored more than 1,000 ft of mine passageway. They also traversed an additional 1,000 ft of nontoxic smoke-filled entries in which visibility ranged from 1 to 3 ft. Team members searched for "victims," mapped passageways, and built temporary stoppings. They extinguished



Chemical lightsticks attached to the back of the helmets of mine rescue personnel

liquid fuel fires in a quarry and a conveyor belt fire in the surface fire gallery. More than 80 mine rescue teams participated in these training simulations; participants indicated that the exercises were challenging and very informative.

Other work includes—

- Development of technologies such as chemical lightsticks for identifying team members and marking crosscuts and mine materials, strobe lights for mapping out escapeways and marking crosscuts, and thermal imaging systems for seeing through smoke. These technologies are designed for use by mine rescue teams.
- Construction of wireless receivers that interface with strobe lights that emit a high-pitched sound. These devices are being developed under a CRADA with TeleMagnetic Signalling Systems and will be used to map out escape routes in smoke-filled entries. They will be evaluated by mine personnel.
- Continuation of briefings on mine fire preparedness at the Lake Lynn Laboratory. This technology transfer program offers a unique opportunity to pass on NIOSH technology to the mining industry. Impact studies indicate that participants have an increased awareness of fire hazards and significantly improve their preparedness for mine fires.

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KEYWORDS: Fire detection, control and suppression, emergency response, escape and mine rescue

LIFE SUPPORT AND SURVIVAL

PRINCIPAL INVESTIGATOR: J. Kovac

RESEARCH OBJECTIVES

Develop the technology to increase the chances for miners to survive and escape a mine fire, explosion, gas outburst, or water inundation and improve the safety and effectiveness of mine rescue, recovery, and fire-fighting efforts.

PROBLEM STATEMENT

After a mine fire or explosion, the atmosphere inside a mine may become oxygen deficient or filled with smoke and toxic gasses. Respiratory protection is necessary if miners are to escape from the mine. Fire brigades try to fight a mine fire while wearing breathing apparatus. If the situation deteriorates, mine rescue teams wearing long-duration breathing apparatus are mobilized to reenter the mine to reach trapped miners, suppress the fire, or reestablish the ventilation system.

Escaping from a mine (the only circumstance in which a miner should don a self-contained self-rescuer or SCSR) means that a miner must go on foot and breathing oxygen from the deepest point of the mine to the surface. An important concern expressed by miners, mine operators, and manufacturers is—How many SCSR's does a miner need to make such an escape? The answer is that the number depends on many factors, including the miner's body weight, escape distance and slope grade, condition and height of escapeways, how much useable oxygen an SCSR stores, SCSR readiness, and expectations.

RESULTS TO DATE

The results of a joint MSHA/NIOSH project in which mock escapes at 145 underground coal mines throughout the United States were monitored are being analyzed. The purpose is to quantify the effect or impact of different real-world factors (see above) on mine escapes.

The sixth phase of the long-term field evaluation of SCSR's has confirmed the finding in the fifth phase of the evaluation that early CO₂ breakthrough (inhaled CO₂ of 4% in as few as 12 min of use) is occurring in model CSE SR-100. The CO₂ breakthrough is

attributed to chemical bed degradation resulting from the SCSR being worn on a belt instead of being stored. The manufacturer has proposed a course of action to remedy the problem, and the proposal is now being reviewed by MSHA and NIOSH. The sixth phase report has been written and is being reviewed.

There has been continuing confusion and a number of field complaints about SCSR's because of flaws in current certification regulations (42 CFR 84). The result has been to put increased pressure on Federal agencies to change the regulations. A report has been written describing the failings of the present regulations in detail and containing recommendations for replacement. Quantitative tests involving continuous monitoring of stressor levels until the oxygen source is exhausted are recommended. This report is being reviewed.

A report has been written on a comparison of the performance of 14 breathing apparatus used in mine rescues, one prototype, and one open-circuit fire-fighting apparatus. All apparatus were compared on PRL's breathing and metabolic simulator.

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KEYWORDS: Respiratory protection, closed-circuit breathing apparatus, mine rescue, breathing and metabolism simulation, oxygen cost



Selecting SCSR's during long-term field evaluation program

SMART FIRE SENSORS

PRINCIPAL INVESTIGATOR: J. C. Edwards

RESEARCH OBJECTIVE

Develop "smart" fire sensors and deployment strategies to provide adequate warning to miners about an incipient combustion event before it develops into a life-threatening fire.

PROBLEM STATEMENT

Product-of-combustion sensors currently used in underground mines, as well as sensors currently not used in mines, are being examined to develop a smart fire sensor technology that has the capability of detecting a mine fire, discriminating the combustible source, and providing a strategy for locating the fire. A mathematical model will be developed that predicts how the fire will grow and how the smoke will spread so that guidelines can be developed for fire control and smoke management in a mine.

RESULTS TO DATE

A series of experiments were conducted in PRL's Safety Research Coal Mine to determine the response of smoke and CO sensors and a CO-NO diesel exhaust discriminator. One experiment was conducted in which no diesel equipment was present, and three experiments were conducted in which diesel equipment was operated in a steady-state condition. Some of the results were that—

- A commercial optical path fire sensor currently not approved for in-mine use set off an alarm earlier than the diffusion-mode CO sensor at an optical density of less than 0.022 L/m.
- Transient emissions associated with starting the diesel engine could be discriminated from emissions from a slowly developing fire using a combination of an optical path smoke sensor and a CO sensor. This result involved interpreting the rate of change of the smoke sensor's response signal associated with diesel emissions as a characteristic to be differentiated from sensor response associated with increasing products-of-combustion from a developing fire.

- A commercial CO-NO diesel-discriminating fire sensor failed to detect a slowly growing fire that had a CO production rate of 0.00141 ppm/s.

Future research will involve developing a methodology based on a CO sensor and an optical-path smoke sensor that will eliminate false alarms set off by an atmospheric mine monitoring system when diesel equipment is running.

A prototype optical diesel discriminator fire sensor was designed, fabricated, and tested in a series of small-scale laboratory tests. The results indicated that where levels of optical density were less than 0.04 to 0.05 L/m, no optical scattering was measured for diesel smoke while relatively intense scattering was measured for smoldering coal smoke. The device showed promise in a series of in-mine coal fire experiments in which diesel exhaust was introduced into the mine atmosphere.

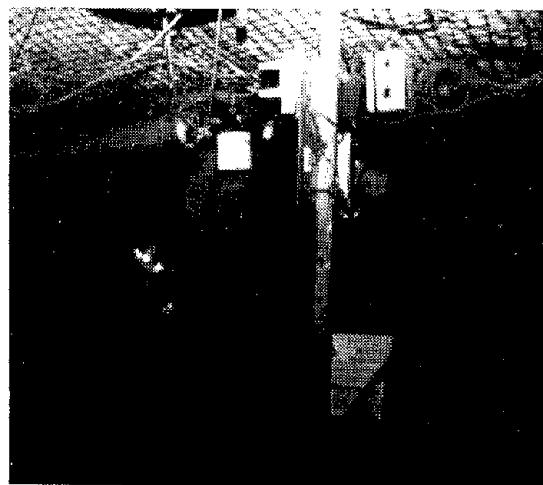
A computational fluid dynamics program was used to model CO spread from an in-mine fire under zero airflow and predict smoke reversal from a fire in a ventilated mine. Results of the computations agreed with measurements from the in-mine fire. This research can be used to develop smoke management strategies in the event of a fire.

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KEYWORDS: Mine, fire, detection, smoke, carbon monoxide, neural network



Sensors for monitoring exhaust and smoke in an underground mine

HYDROSTATIC EVALUATION OF MINE SEALS

PRINCIPAL INVESTIGATORS:

M. J. Sapko and N. B. Greninger

RESEARCH OBJECTIVES

Develop improved apparatus and procedures to better characterize strength properties of mine seals, evaluate equivalence hydrostatic and explosion testing of seals, and identify models for possible use by MSHA in approval actions regarding seals.

PROBLEM STATEMENT

Mine seals are used extensively in mining to isolate worked-out areas of a mine, isolate active fire zones, and control water inundation. It is most important to know a mine seal's strength safety factor. Before seals can be erected, their design must be deemed "suitable for use" by MSHA. The pressures at which seals have been tested range from 20 psi to over 50 psi, although MSHA's test requirement is 20 psi. This pressure assumes that no float coal dust accumulations occur.

No single seal design is suitable for all possible scenarios. For example, depending on specific conditions, seals must withstand excessive convergence, cure quickly, resist attack by acid mine water, or hold back water. They must provide a fire barrier and low gas-leakage rates. Some require special anchoring because of conditions in adjacent strata and need steel reinforcement and high-strength cement. Some are needed for very wide or high roadways and must perform for years.

Unfortunately, explosion tests rarely allow a seal's ultimate strength, failure mechanisms, or long-term performance at applied pressures to be determined. Although much research on mine seals has been done by NIOSH and foreign mining research establishments, there are important unresolved research problems remaining. MSHA has a compelling need to evaluate geometric scaling criteria for seals and alternative designs for high-convergence conditions and conditions in which adjacent strata are friable. In addition to improved seal designs, data to facilitate modeling efforts are needed. Improved test procedures that would simplify and improve evaluations of alternative seal designs are of great importance to MSHA, NIOSH, seal makers, and mining companies.

RESULTS TO DATE

The contract for the construction of the two hydrostatic chambers for testing seals has been awarded and construction will begin in late 1998 at the Lake Lynn Laboratory. Labview, a software package to be used in the data acquisition system for the

hydrostatic test chambers, is being installed on a notebook personal computer. Relevant foreign literature on mine seals is being examined.

KEYWORDS: Seals, mine seals, explosion-resistant stoppings, inundation

REMOTE METHANE MEASUREMENTS

PRINCIPAL INVESTIGATORS:

C. E. Lucci and R. A. Cortese

RESEARCH OBJECTIVE

Explore the development of an infrared absorption instrument that will allow measurements of methane concentrations in the area near the working face to be made remotely from permanently supported roof areas. Methodologies will be explored to improve upon current point-type methane measurement techniques.

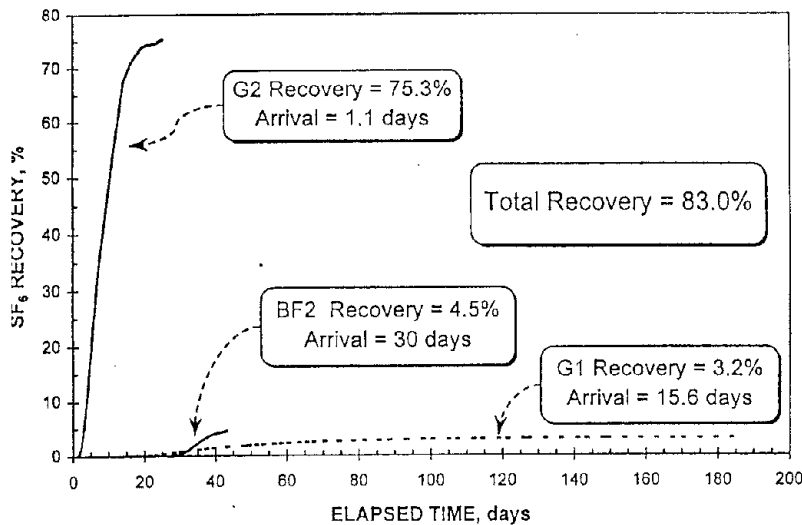
PROBLEM STATEMENT

Methane accumulation in the vicinity of a working face where coal has been freshly mined is a significant hazard and can lead to gas and coal dust explosions. As mines begin to make deeper cuts in coal, thereby creating longer distances to the coal face, forced air ventilation systems become less efficient in diluting methane, which then increases the probability for the formation of explosive mixtures of methane and air. These longer distances also make measurements of methane more difficult when using conventional measurement practices.

RESULTS TO DATE

It is the intent of this research to improve methods and sensors for the remote measurement of methane. The algorithm required to resolve the problem of measuring methane concentrations over distances has been contracted out, and work is scheduled to begin in the fall of 1998. The instrument's optical system has been designed, and the prototype system is being developed.

KEYWORDS: Methane, instrumentation, gas detection



Cumulative tracer gas recoveries and arrival times at adjoining gob gas ventholes G2 and G3 and bleeder fan BF2 after G2 went off production.

CHARACTERIZATION AND MITIGATION OF MINE GAS EMISSIONS

PRINCIPAL INVESTIGATOR: W. P. Diamond

RESEARCH OBJECTIVE

Characterize the geotechnical and engineering factors influencing the release and migration of methane and other hazardous gases into the underground workplace so that more efficient control strategies can be developed.

PROBLEM STATEMENT

Unexpected increases in methane emission levels resulting from the unpredictable interactions between geology and mining practices may lead to an underground mine explosion. The trend to increase mining productivity by increasing the size of longwall panels is an important development that has led to elevated methane emissions in some underground coal mines.

RESULTS TO DATE

Tracer gas studies are a valuable tool for studying air flow associated with longwall gobs, bleeders, gob gas ventholes, and other inaccessible areas in underground coal mines. Evaluations of eight tracer gas releases of sulfur hexafluoride (seven underground and one borehole injection) and gas from gob ventholes at a longwall mine operating in the Pittsburgh Coalbed have been completed. Major findings from this series of experiments were

(1) Flow paths for tracer gas in both the bleeders (former gate roads) and the longwall gob were to the back (start-up) end of the panels, indicating that the bleeder fans on the back of the panels were operating as designed.

(2) Gob gas ventholes at the start-up end of the panels produced methane at higher rates for a longer time than holes in the central or completion end of the panels.

(3) In the borehole injection study, it was found that all three gob gas ventholes on the tailgate side of the panel were connected, as shown by injected tracer gas flowing through the gob (a) 2,500 ft horizontally to the adjacent venthole in only 1.1 days and (b) 6,800 ft horizontally to the most distant hole in 15.6 days.

(4) Tracer gas injected into the gob stayed in the gob until gas production was interrupted at one gob gas venthole, which allowed the tracer gas to escape from the gob into the ventilation system.

Borehole injection tracer gas experiments will be conducted in FY99 at the same mine to investigate the degree of compaction and associated reduction in fracture permeability along the centerline of the 1,000-ft-wide longwall panels. This will be accomplished by injecting tracer gas into specially drilled holes on the headgate side of the new study panel to see if (and how much) gas migrates across the panel to the operating gob gas ventholes on the tailgate side. Data generated by the tracer gas experiments will be used to optimize methane control strategies for wide longwall panels.

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KEYWORDS: Tracer gas, gob gas, coal mine safety, reservoir engineering, unconventional gas reservoirs

EXTENDED-CUT AIR DELIVERY SYSTEMS

PRINCIPAL INVESTIGATOR: Charles D. Taylor

RESEARCH OBJECTIVE

Develop better ventilation techniques that will increase airflow distribution at the working face of entries and improve monitoring of potentially explosive methane gas.

PROBLEM STATEMENT

Motivated by production gains, almost half of those mines using continuous mining methods have received approval for making extended cuts before installing roof bolts to support the roof. In extended-cut mining, the distance from the last row of bolts to the face, where the coal is extracted, is 20 ft or greater. Regulations require that methane be monitored at the face during mining and roof bolting. Since these readings must be taken under permanently supported roof, probes or other acceptable means must be used to position methanometers. The greater the distance to the face, the more difficult it is to measure methane. None of the techniques currently used to position a methanometer at the face during bolting or mining of an extended cut are easy to use or are generally accepted by the mining industry. Alternative sampling techniques are needed to improve methane monitoring during extended-cut mining.

RESULTS TO DATE

Laboratory and underground studies were conducted to evaluate alternative methane monitoring strategies for use during mining and bolting at the face of an extended cut. A simulation of an extended-cut roof bolting operation was conducted at the Pittsburgh Research Laboratory's ventilation test gallery to evaluate alternative methane monitoring strategies. Methane concentrations were measured at the face and at several other locations farther from the face under a range of operating conditions (intake flow, curtain and tubing setback distance, equipment configuration). Concentrations at all locations were used to develop models for estimating concentrations of methane at the face. Criteria for selecting alternative sampling locations were recommended.

A separate study was conducted underground to evaluate the long-term performance of a methanometer placed on a mining machine. Performance criteria were based on periodic measurements of instrument calibration and response times. Results showed that the effects of airborne dust and water droplets on methanometer performance were negligible. A related study, conducted on a mining machine in the ventilation test gallery, evaluated the effect of intake air flow direction on methane concentrations at the sampling point. The results showed that the intake flow direction had no significant effect on methane concentrations as long as the water sprays and scrubber were operating.

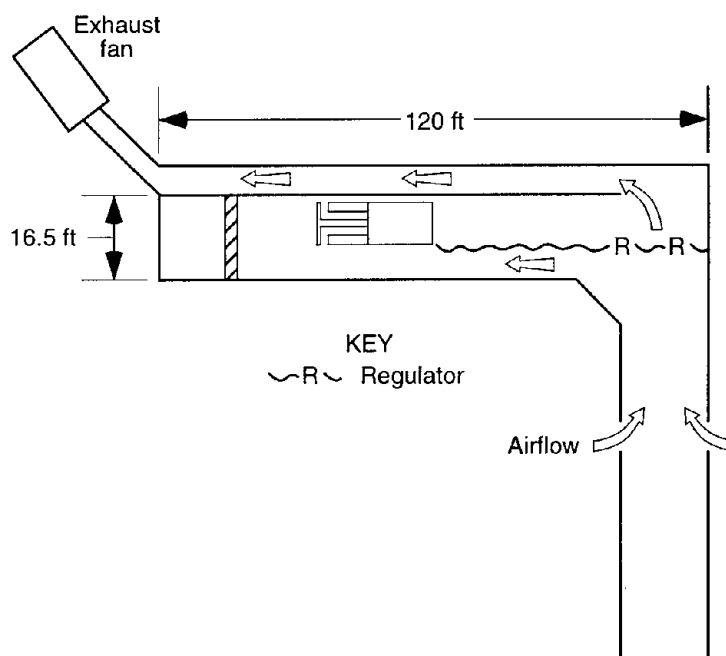
The improved sampling techniques developed by this program will help maintain safety for workers during extended-cut mining and allow the most productive use of this mining method.

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Measuring Low-Level Methane Concentrations with an Air Bag Sampling System, *J. Mine Vent. Soc. of S.A.*, vol. 50, no. 2, April/June 1997, pp. 47-56

KEYWORDS: Roof bolter, methane, extended cut



Bolter test in ventilation gallery

ELECTROMAGNETIC FIELD EXPOSURE IN THE MINING WORKPLACE

PRINCIPAL INVESTIGATOR:

Michael R. Yenchek

RESEARCH OBJECTIVE

Extend the scope of NIOSH studies on exposure to industrial electromagnetic fields (EMF) by measuring electromagnetic fields in mines and related facilities to determine (1) time-weighted exposures in various mining occupations and (2) field profiles of electrically powered mine equipment.

PROBLEM STATEMENT

Electric and magnetic fields are present anywhere electrical equipment is energized. It is estimated that about half the underground mine population, or about 30,000 workers, may have significant exposure to these fields, particularly while performing maintenance on or working around large machines. Deleterious health effects from exposure to electromagnetic fields have been suspected for 20 years. In 1991, investigators at a workshop conducted by NIOSH concluded that identifying and characterizing occupations exposed to electric and magnetic fields should be considered a high research priority. Concerns about field exposure were recently heightened by the findings of the EMF working group of the National Institute of Environmental Health Sciences in June 1998. Conducting a thorough review of literature on electromagnetic fields with respect to occupational exposures, the group concluded that power-frequency electromagnetic fields are a possible carcinogen (Group 2B as classified by the International Agency for Research on Cancer). A characterization of field exposures in the mining industry will augment the NIOSH occupational database and will facilitate future development of mitigation strategies for this potential health hazard.

RESULTS TO DATE

This is a new project.

KEYWORDS: Exposure, electromagnetic fields



Miners working near large machinery may be exposed to significant electromagnetic fields.

FUNDAMENTAL STUDIES IN ELECTRICAL HAZARDS

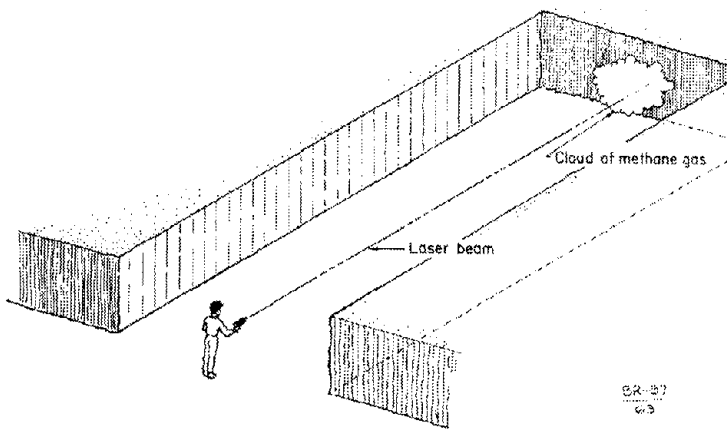
PRINCIPAL INVESTIGATOR: Thomas Dubaniewicz, Jr.

RESEARCH OBJECTIVE

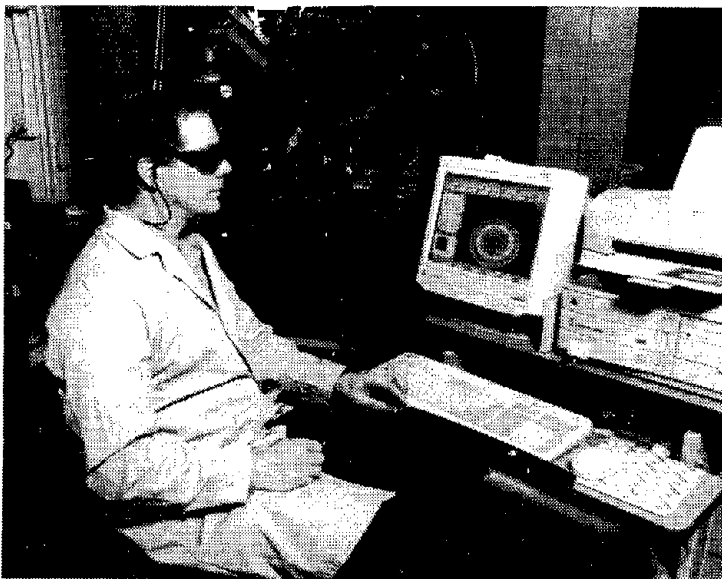
Develop safety recommendations for lasers used in the presence of explosive methane gas or coal dust.

PROBLEM STATEMENT

The United Mine Workers of America has expressed concerns over the difficulty of measuring dangerous levels of methane gas with conventional instruments during extended-cut operations. In response to these concerns, a laser-based, remote methane monitor has been proposed as a better way of taking critical measurements. However, above certain power levels, the laser itself poses the risk of igniting methane or coal dust. Already fatalities have been reported during medical operations as a result of laser-ignited gases inside the human body. The goal of this project is to ensure laser ignition fatalities never occur in coal mines. A fundamental understanding of the ignition process supported by experimental evidence will provide sound scientific justification for eventual safety recommendations.



Concept of a remote laser-based methane monitor.



Researchers conduct laser ignition experiments in the laboratory.

RESULTS TO DATE

Researchers have conducted over 150 experiments attempting to ignite methane-air mixtures using lasers. Of this number, 45 ignitions were observed. By analyzing the data graphically, researchers were able to gain a better understanding of what power levels pose a significant ignition risk under certain test conditions. A theoretical model of the ignition process was developed that may help to explain experimental results. These findings were shared with other safety professionals through two symposia publications and presentations.

Project personnel are also collaborating with a newly formed international working group charged with making safety recommendations for optical equipment used in hazardous locations. Cooperation with the working group will help this project, as well as ensure that eventual safety standards will be coordinated at the international level and help instrument manufacturers to build competitive and safe products.

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ELECTRIC SHOCK PREVENTION

PRINCIPAL INVESTIGATORS:

Peter Kovalchik and Gerald Homce

RESEARCH OBJECTIVE

Provide scientifically valid recommendations for protecting workers from electrocution.

PROBLEM STATEMENT

Electrocutions cause approximately 10% of all mining fatalities each year. Over 17,000 workers in underground coal mines are at risk from hazards associated with improperly rated electrical cables. Cables on reels are especially hazardous because overheating of the cable leads to premature failure of the insulation. Current MSHA rating practices have been shown to underrate round cables and overrate flat cables. The Insulated Cable Engineers Association (ICEA), which writes cable ampacity standards for the National Electrical Code, and MSHA recently collaborated with the Pittsburgh Research Laboratory to devise a test program to supply ICEA with appropriate data for reevaluating reeled cable ratings for mining.

Overhead electric power lines present a serious hazard to workers in a variety of industries. An estimated 2,300 accidental line contacts occur each year in the United States, resulting in severe shocks, burns, and electrocutions. Mining is one of several industries where there is a significant risk of line contact, with approximately 175 serious incidents reported to MSHA between 1980 and 1997. Over half of these cases involved workers touching mobile equipment (such as cranes and dump trucks) that were in contact with overhead lines or hoisted loads that touched powerlines.

RESULTS TO DATE

Experiments were conducted to measure the conductor temperature of a No. 4-3 conductor, G-GC round trailing cable. Temperature data were obtained from one to four layers. Each layer had a temperature profile similar to the others; the maximum temperature occurred in the center of each layer. A summary

Comparison of Ampacities Measured by ICEA and NIOSH

No. of layers	ICEA, amps	NIOSH, amps
Open air	122	130
1	104	82
2	80	60
3	59	48
4	42	38

of test results is shown in the table. Results from the NIOSH study are compared with the ICEA ampacity ratings as a function of the number of layers on the cable reel. These are the current values that will cause the conductor temperature to reach 90° C. This information was presented to the ICEA at its annual meeting on September 15, 1998, at Niagara-on-the-Lake, ON.

A large number of MSHA investigative reports on line-contact accidents in the mining industry have been compiled and reviewed. The focus was primarily on those incidents in which mobile equipment contacted power lines. This information has been complemented by an analysis of similar incidents in the construction industry, as well as a review of currently available intervention strategies. The findings of this study will be used to formulate practical recommendations for reducing powerline-contact injuries in the mining industry.

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KEYWORDS: Electrical safety, trailing cables, electrical shock, overhead powerlines, shuttle cars, derating factors, ampacity

POTENTIAL HAZARDS IMPOSED BY EMERGING TECHNOLOGIES IN MINING

PRINCIPAL INVESTIGATOR: Julie Mitchell-Dubaniewicz

RESEARCH OBJECTIVES

Identify technologies that have been recently introduced in mining, that are beginning to be implemented, or that are on the horizon. For the emerging technologies identified, determine known or potential health and safety hazards posed to the workforce.

PROBLEM STATEMENT

There are numerous technologies being introduced and implemented within the mining industry. Emerging technologies can take the form of new products, materials, equipment, processes, or methods. Many of these technologies have been introduced to address safety and health hazards through measurement, control, or personal protection. Other technologies are introduced as the push for increased efficiency and productivity in mining continues. However, with the introduction of new technologies comes the potential for new safety and health hazards. Hazards created by these new technologies have the potential to affect the entire mining workforce, but most definitely those who are directly involved with a mining activity. As emerging technologies continue to be implemented, there is a need to better understand their effects, so that intervention strategies can be developed to reduce the hazard created.

RESULTS TO DATE

This is a new project. A literature and information search is being conducted. Contacts and interviews are being made with stakeholder groups (industry organizations, manufacturers, mining companies, unions, academia, and government agencies) to help with the identification of emerging technologies, methods, and issues. Many of these same contacts will assist in conducting hazard analyses of the identified technologies.

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KEYWORDS: Emerging technology, mining, equipment, processes, new materials

SYSTEM SAFETY: PROCESSOR CONTROL APPLICATIONS

PRINCIPAL INVESTIGATOR: John J. Sammarco

RESEARCH OBJECTIVES

Improve the safety of the processor-based control and monitoring systems used in mining. Provide a set of recommendations that establish processes, methods, and tools that apply to development, testing, approval and/or certification, operation and maintenance of hardware and software used in mining.

PROBLEM STATEMENT

The emerging technology of processor-based control and monitoring systems brings new hazards to mining because of the added complexities and ambiguous nature of software. Between 1992 and 1995, use of processor-based control of mine monitoring equipment more than doubled. Increased complexity is evident in radio-remote-controlled longwall equipment, shearer-initiated supports, and shearer auto-steer. Yet, the industry lacks extensive experience with the application of processor technology, and no guidelines or standards exist for its safe use in mining.

If no action is taken, incidents may increase as the complexity and quantity of processor-based control increases. Seven incidents occurred during 1996 and 1997 in which processor control was a contributing factor. Four of these incidents were fatal, including one in metal/nonmetal mining. There is a need to address functional safety as well as permissibility before this technology proliferates in mining.

RESULTS TO DATE

A set of five recommendation documents is being written. These documents will form the safety framework for processor-based control and monitoring throughout the life cycle of mining systems (system development, testing, approval/certification, operation, and maintenance). These documents are—

(1) *Programmable Electronics in Mining: An Introduction to Safety*. Provides fundamental information about system and software safety and includes a description of the benefits of a system safety program.

(2) *System Safety Program Plan (SSPP)*. How to design in safety for the system.

(3) *Software Safety Plan (SWSP)*. How to design "safe" software.

(4) *Safety Case*. How to document that the system and software meet the appropriate level of safety;

(5) *Safety Audit*. How MSHA would "certify" or "approve" proof of safety.

An industry safety panel has been established to assist in identifying safety issues and review project direction. At the third meeting of the panel, presentations on technical issues on system and software safety were given.

Two world-renowned organizations with interests in the safety of processor systems—Underwriters Laboratories and Feltronics—have agreed to provide technical assistance on the project. These organizations will bring experience and resources to the project as we formulate the recommendations on safety for processor-based control systems.

Some successes have already been achieved. A longwall equipment manufacturer adopted our key process for software configuration and version control to address an incident of longwall shield ghosting that was caused, in part, by a software modification. This key process will help reduce the likelihood of an accident occurring when software is modified. A second success is that our risk-based safety process was adapted by MSHA in its study of accidents involving remote controllers.

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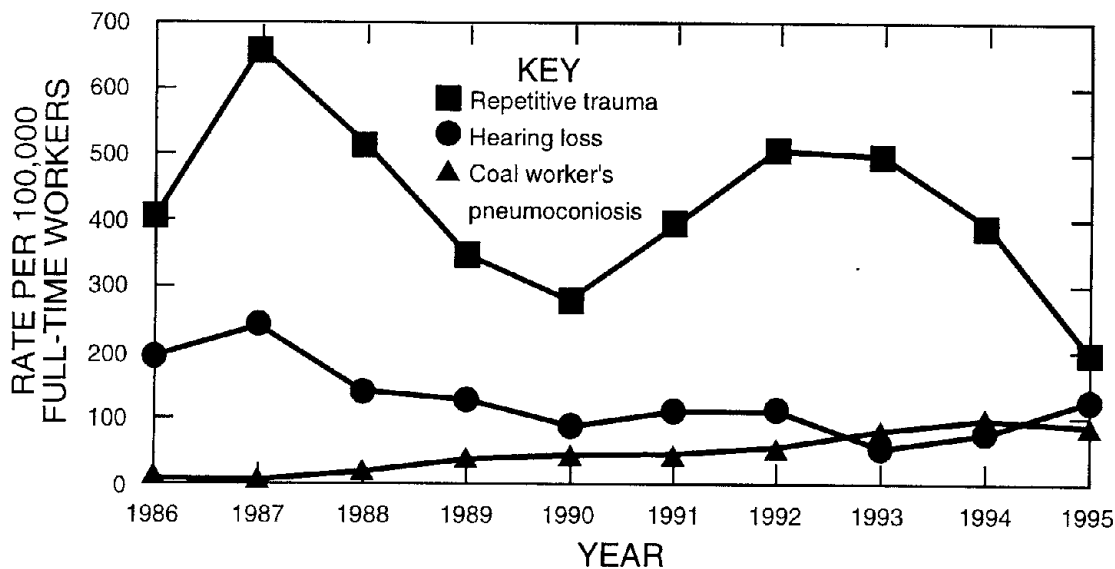
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KEYWORDS: System safety, equipment safety, processor control, software, functional safety



Longwall mining is one of the most complex applications for computer control.



Rates of selected conditions in coal mine operators per 100,000 workers by year

STATUS OF MINERS' HEALTH: AN ANNUAL REPORT

PRINCIPAL INVESTIGATOR: Gail McConnell

RESEARCH OBJECTIVE

Develop an annual document that reports progress toward fulfilling the mission of the Office for Mine Safety and Health Research with regard to health outcomes and possibly injuries.

PROBLEM STATEMENT

In the section on Research Tools and Approaches, Surveillance Research Methods, NORA addresses a need for "Periodically reviewing and communicating the progress and successes of partnership teams, NIOSH intramural and extramural activities, and the overall role and effectiveness of NORA in occupational safety and health." Fulfillment of this need is hampered by the widely scattered sources of the available data. The development of an annual report is an essential element in program planning and evaluation. The Office's FY99 Phase III Strategic Planning document states that

Impact can only be measured by better surveillance data, particularly for occupational health issues....A high priority for future strategic planning should be the development of more direct surveillance measures of mining illness....Health surveillance data for mining is much more limited than incident (safety) data. Existing health data sources should be compiled by our surveillance activities so that they are accessible to planning and research teams. New data should be collected to fill important gaps in exposure and illness information, especially for identified problem areas (noise, silica and coal dust, repetitive trauma, toxic substances, etc.).

The intended outcome of this project is a compilation of existing and current health (and possibly injury) data into a concise document specifically for the mining industry.

RESULTS TO DATE

Numerous sources and existing databases will be used to devise a concise database and subsequent report that will provide a snapshot of national health statistics and health concerns of the nation's miners. This document will also describe ongoing progress towards mission goals. Anticipated sources of data include MSHA's Accident/Injury/Illness Database and PRL's Mine Surveillance Report. Additional data will be obtained from the Bureau of Labor Statistics, the NIOSH Division of Respiratory Disease Studies, the NIOSH Hearing Loss Prevention Branch, and SENSOR or other state-based databases. Accomplishments and impediments to progress will be identified and documented. The report will emphasize NIOSH efforts and its collaborations and partnerships with other Federal and state agencies. The anticipated format will lend itself easily to a 30- to 45-min presentation. This format can be tailored to many internal and external audiences. The anticipated audience for this report will be NIOSH, CDC, other Federal agencies such as MSHA, Congress, state agencies, universities, industry groups, health organizations, research and development groups, and labor organizations. Additional dissemination of information can be through periodicals and agency Web sites.

KEYWORDS: Mining, occupational safety, occupational health, NORA

RISK-RELATED CHARACTERISTICS OF THE MINING WORKFORCE

PRINCIPAL INVESTIGATORS:

Robert F. Randolph and Barbara Fotta

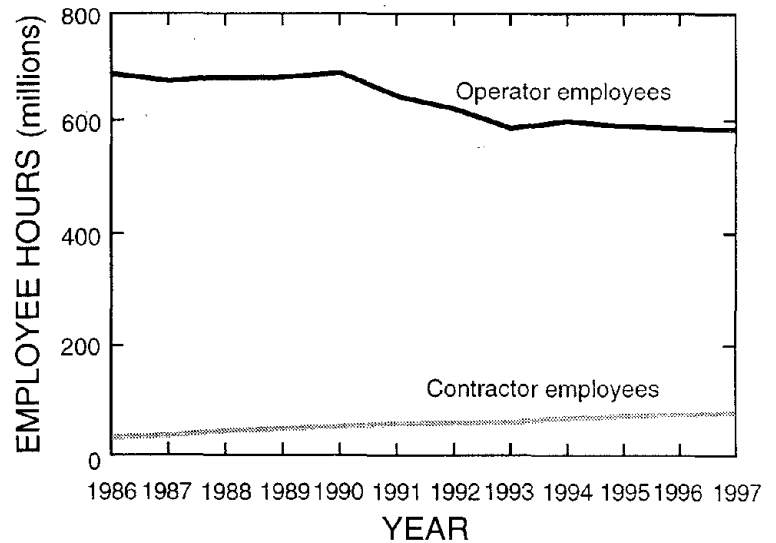
RESEARCH OBJECTIVE

Gather statistical information about miners that can be useful in reducing their risk of injuries and illnesses.

PROBLEM STATEMENT

Our ability to identify risks and hazards in mining is sharply limited by a lack of information about the workforce. MSHA and other agencies collect gross statistics on the size and distribution of the workforce, but these data lack the specificity needed to resolve important safety and health questions. For instance, one such question is "Which jobs are most likely to result in a fatality?" Although we know the job titles of all fatally injured miners, we do not know how many workers in each job were *not* injured. Without this crucial denominator data, it is impossible to compute the risk ratio of injured versus uninjured workers in specific subpopulations.

In addition to job type, other useful information would include job experience, education, training levels, age, work sites, and machinery exposure. A now-outdated source of this information is the USBM's 1986 *Demographic Survey of the Miner Population*. Mining companies showed exceptional interest in the findings, and over 2,200 requests were received for the study's publications. These data gave other safety researchers unprecedented capabilities to test safety hypotheses. They were also useful for customizing interventions to the needs of different subpopulations. For example, data on miners' educational levels were used to match training materials to reading proficiency in different areas of the country. Unfortunately, the 1986 data have limited utility in generalizing results to the current mining population because of changes in that population since 1986. For example, while the size of the overall mining workforce has declined since 1986, the independent contractor subpopulation has grown steadily, from 4% to 12% of the workforce. Other workforce changes have undoubtedly resulted from new technologies, societal shifts, and economic forces, but these changes have largely gone unmeasur-



While the size of the mine operator workforce declined during 1986-1997, the independent contractor workforce has increased.

ed. This study will help close this critical knowledge gap and provide an important tool for future improvements in safety and health.

RESULTS TO DATE

This is a new project. At completion of the study, a database of mining workforce demographics will be made available to safety and health researchers. No interim products are currently scheduled.

KEYWORDS: Demographics, risk, occupation, mining

ANALYSIS OF RISK TO FACE WORKERS USING MINING MACHINERY

PRINCIPAL INVESTIGATOR: William H. Lewis

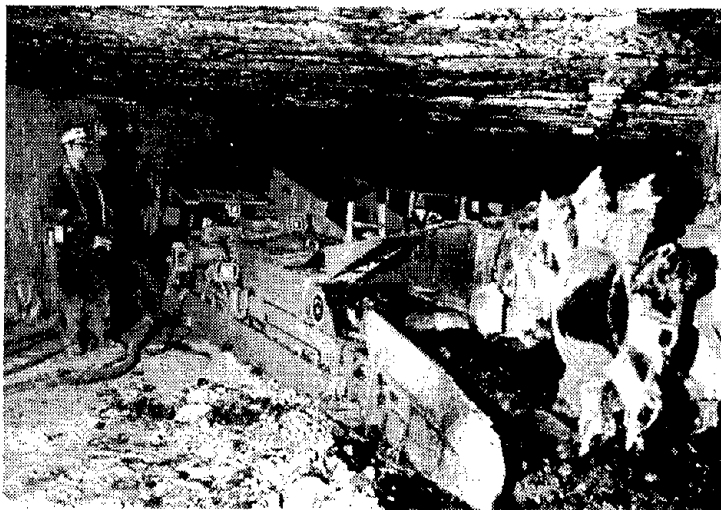
PROJECT TEAM: Suresh Bhatt, James C. Cawley, and
Richard Wang

RESEARCH OBJECTIVES

(1) Provide an in-depth overview of the fatality and injury data from underground coal mines; (2) assess the impact of emerging technologies involving the control of mining equipment with regard to these data; (3) recommend workplace interventions and future areas of research to reduce underground coal mine fatalities and injuries; and (4) prepare a model surveillance database and report on underground coal mining.

PROBLEM STATEMENT

Approximately 50,000 miners work in U.S. underground coal mines. About 16,000 of these miners operate equipment full time at the mine face, where they are exposed to a wide range of safety and health hazards. Another 17,000 miners routinely enter the face area for supervisory, inspection, maintenance, and other activities. Between 1985 and 1994, the U.S. underground coal mining workforce experienced 361 fatalities, 1,178 disabling injuries, and more than 72,000 lost work days. Approximately one-third of all serious injuries occurred at the mine face where the population density of worker and machine is greatest.



A remote-controlled continuous machine

Today's mining scene at the face area is changing. New technologies involving the control of mining equipment offer the potential to reduce risks in this hazardous area. To assess the impact of these new technologies, an in-depth study of the fatality-injury data is needed. Presently, MSHA accident data are categorized by type of accident rather than by root cause. This study will review MSHA accident data and narratives and attempt to classify accidents by root causes. At the same time, a detailed task analysis will be performed to determine what tasks miners are doing underground and the relative time spent doing these tasks.

It is hoped that the combination of these two approaches, while difficult, will lead to greater insights into the fatality-injury picture and the formulation of new workplace interventions and future areas of research to reduce fatalities and injuries.

RESULTS TO DATE

The project outlined above is an ambitious undertaking and a relatively new start. Development of a program methodology has been completed, and development of a root cause classification system for the analysis of MSHA data has begun. The MSHA narratives are being recoded according to the new system. Three visits were made to mining companies to ascertain time study data on underground workers. Work has been initiated on collecting and compiling profiles of underground coal mines and demographic data.

KEYWORDS: Coal mining, accident, surveillance, demographics



Miners performing construction-related activities at a coal mine.

SURVEILLANCE OF INJURIES RELATED TO CONSTRUCTION, MAINTENANCE, AND REPAIR ACTIVITIES IN THE MINING INDUSTRY

PRINCIPAL INVESTIGATOR: Larry Layne

RESEARCH OBJECTIVE

Develop an injury surveillance database to identify the magnitude and severity of injuries to miners performing construction, maintenance, and repair activities.

PROBLEM STATEMENT

Stakeholders in the mining industry have contacted both the NIOSH mining program and MSHA seeking safety and health information about miners who perform work activities related to construction, maintenance, and repair. A very good injury surveillance system for the mining industry is maintained by MSHA, but these data are not coded in the manner necessary for extracting

these cases for further study. The MSHA injury data do, however, contain a narrative description of the injury incident and circumstances of its occurrence. These descriptions provide a mechanism for identifying positive injury cases involving construction, maintenance, and repair activities. (Note: the word "positive" means that a case was coded "yes" as to whether it involved construction, repair, or maintenance activities.) The tasks of this project include (1) selecting a probability sample of injury cases among mine operators and contractors and (2) reviewing the narrative descriptions and coding cases identified as positive. Because these data are from a probability sample, NIOSH will be able to estimate the magnitude and severity of these types of injuries for the entire mining industry, advise stakeholders of the significance of this injury problem, and plan appropriate intervention and prevention strategies.

RESULTS TO DATE

The ability to identify injuries to miners that were related to construction, maintenance, and repair activities (using the narrative descriptions of injury incidents) required that a concise definition of these activities be developed. Researchers from the NIOSH mining program worked in conjunction with several stakeholders, including MSHA personnel and mining industry safety representatives, to develop this definition. Slightly more than 600 injury cases from the MSHA database were studied by these researchers. Results showed that approximately two-thirds of all injuries in this data subset involved work activities related to construction, maintenance, and repair. Because these work activities accounted for a large proportion of all injuries, a contract was established with Battelle Laboratories to have a sample of the narrative injury descriptions for the period 1993 through 1997 reviewed and coded according to whether the injury case was positive for these activities. A sample of more than 20,000 cases was selected for this study.

KEYWORDS: Construction, maintenance, repair, injury, mining industry

WATER WELL DRILLING: CAUSES OF INJURIES AND FATALITIES

PRINCIPAL INVESTIGATOR: R. J. Matetic

RESEARCH OBJECTIVE

Provide a strategic plan for determining the causative factors related to injuries and fatalities in the water-well-drilling industry and determine ways to create a more healthy and safe working environment.

PROBLEM STATEMENT

The National Ground Water Association (NGWA) has determined that 53% of the U.S. population depends on ground water for its drinking water supply, be it from a public source or private well. There are approximately 300,000 public supply wells in the United States and 800,000 boreholes being drilled in the country annually. From 1990 through 1996, 62 fatalities have been attributed to water-well drilling. The causes of these fatalities were electrocution (approximately 50%), being struck by objects (parts and materials), and working in confined spaces.

According to the Bureau of Labor Statistics (BLS), incidence rates (representing the number of injuries and illnesses per 100 full-time workers) among water-well drillers are *higher* than in the overall construction industry. The overall incidence rate in the construction industry is 4.86, whereas the rate for water-well drillers is 5.16.

RESULTS TO DATE

A cooperative agreement has been established between NIOSH and NGWA. Comprehensive literature searches have been conducted in BLS, OSHA, and CNA Insurance Co. databases.

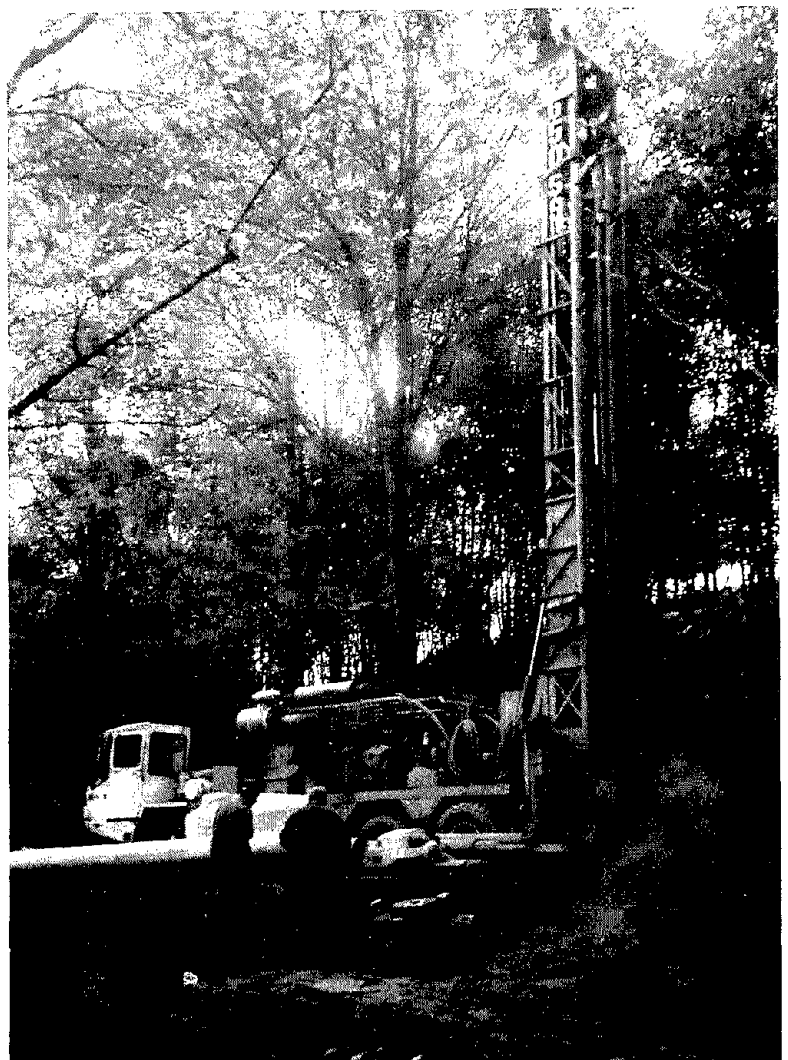
- The BLS data included lost workdays, length of service of worker, age of worker, sources of injury or illness, nature of injury or illness, parts of body affected by injury or illness, events or exposures leading to injury or illness, and fatality information associated with the well-drilling process.

- The OSHA data incorporated an overview of OSHA and state regulations regarding water well

drilling, identification of Federal and/or state jurisdiction on operation and safety regulations, and a summary of the most common violations per inspection with suggestions as to how to decrease these violations.

- CNA provided information on workers compensation loss trends by type, general liability loss trends by type, and commercial automobile loss trends by type.

Numerous well sites in Pennsylvania and West Virginia were visited to identify what factors might cause injuries and how these factors are associated with specific tasks or stages of the well-drilling process (e.g., equipment and tools, workplace environment, procedures, etc). In addition, a trip was made to Southwest Mississippi Community College to observe the training and education students receive to obtain a 2-year Associate's degree in well drilling.



A crew drilling a water well in southwestern Pennsylvania.

EDUCATION FOR EFFECTIVE MINE EMERGENCY RESPONSE

PRINCIPAL INVESTIGATORS:

Launa G. Mallett and Audrey F. Glowacki

RESEARCH OBJECTIVES

Reduce the risks associated with infrequent, but potentially catastrophic, incidents by improving training for miners, responders, and incident commanders.

PROBLEM STATEMENT

As mines become safer and disasters fewer, the number of individuals that have hands-on experience with mine emergencies is decreasing. A gap in expertise is being created that could have serious consequences during future major emergencies. Currently, a limited amount of training is available for these individuals, and much of that training is cost and resource intensive. Furthermore, it is not easily accessible to many smaller mining operations.

RESULTS TO DATE

A multidisciplinary research team is focusing on improving mine emergency response training. New training programs are being developed and evaluated with the assistance of outside industry professionals through formal (establishment of CRADA's) and informal means. In FY99, the primary effort will be development of the Mine Emergency Response Interactive Training Simulation (MERITS). This product will provide Internet-based training for emergency command center personnel. A second effort will be to develop training to reduce fire hazards by increasing employee awareness and involvement.

MERITS

A simulation of a mine was developed that includes geographical information about the mine structures and environment, as well as staffing and resources information. Computer graphics were used to represent the mine and its various systems (electrical, hydraulic, etc.). An emergency response plan was also developed and represented graphically. Various behaviors were programmed for simulated underground miners, including evacuation and "milling

about." Development of a draft emergency scenario is underway. The feasibility of providing this training via the Internet was demonstrated. The demonstration included the creation of methods for passing data between host and client computers and showing the capability for command center trainees to issue "orders" to the host simulation.

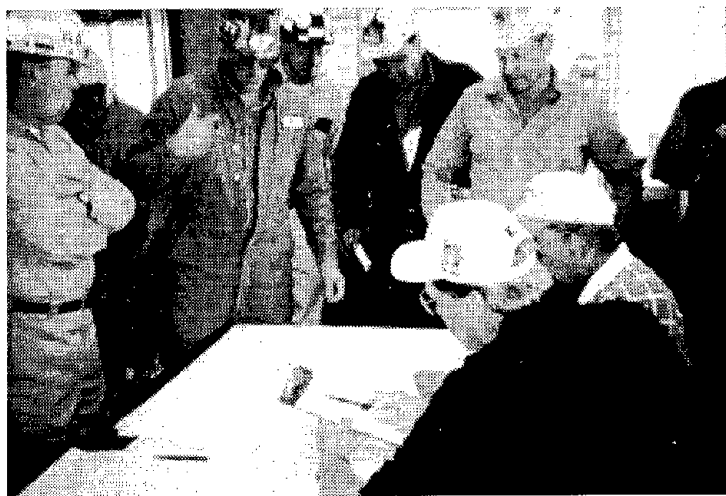
Fire Prevention and Response Training

Four training packages have been produced with an industry cooperator on the topics of fire prevention and basic first response. A field test of the materials is being conducted at a cooperating mine. Four additional modules are being developed.

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KEYWORDS: Emergency response, fire prevention, simulation, training, Internet



Emergency command center personnel at mock mine disaster



NIOSH researchers conducting a class in the improved "degraded" method of hazard recognition. Three-dimensional slides are one of the effective techniques for improving the realism of training.

EVALUATION OF INTERACTIVE MINE SAFETY & HEALTH TRAINING METHODS

PRINCIPAL INVESTIGATOR:

Robert F. Randolph

RESEARCH OBJECTIVE

Evaluate the effectiveness of new interactive training methods, including multimedia computerized modules, realistic multimedia, and interactive group techniques, to improve safety and health in the mining workplace.

PROBLEM STATEMENT

Annual Refresher Training – Oh, No! Not Again!

This title of a popular mine safety workshop expresses an important problem with current training—It's seen as a tiresome chore by both the instructors and students. There's little argument about the importance of training—mining is too dynamic and hazardous to engage in without gaining special skills and knowledge. However, the format of mine safety and health instruction is too often dry and uninvolving.

To solve this problem, new training formats are arriving that do what the best teachers do. That is, they involve the student in his or her own instruction through the use of interesting, interactive materials. For instance, groups of students solve a roof support problem by working through a simulated scenario. After each decision, the students get feedback about whether their answer was right or wrong. If the answer is wrong, the students are given the reasons *why* it's wrong and *how* a different decision-making approach could produce the right answer.

New computerized technologies have made it possible to make materials even more interactive, entertaining, and flexible. In this project, computerized prototypes of several training modules will be created and their effectiveness tested. The ultimate goal will be to give trainers new and valuable sets of training tools that will make training a task they and their students look forward to, as well as result in higher levels of safety and health skills.

RESULTS TO DATE

This new project incorporates an earlier project on hazard recognition and avoidance. Some of the work accomplished to date includes—

- Completion of a comparison test of the traditional "highlighted" versus the new "degraded" method of hazard recognition training. The test showed that miners trained with the degraded training module scored significantly higher on a hazard recognition test than those trained in the more traditional, highlighted manner. The degraded presentation of hazards is more realistic than the traditional highlighted method and improves the ability of trainees to detect and avoid hazards. The degraded training method was implemented at two sites in the South and Midwest; both sites experienced more than a 25% drop in incident rates. Site managers and researchers attributed this improvement in part to the degraded hazard recognition program.
- Production of a training video demonstrating the degraded method. This video was done in collaboration with the Illinois Dept. of Natural Resources and Illinois Eastern Community College.
- Development and field tests of a hazard recognition program for underground limestone. This program incorporates both the highlighted and degraded methods of hazard recognition to explore the visual cues necessary for identifying roof and rib hazards found in an underground limestone mine.
- Creation of a prototype computer screen saver showing steps in the "3+3" self-rescuer donning method.
- Conversion of existing paper and pencil training materials developed at PRL to a format that can be downloaded over the Internet.
- Training project team members in the use of multimedia authoring software.
- Pilot testing of an interactive group training module on construction, maintenance, and repair.

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KEYWORDS: Training, evaluation, computer, hazard, recognition



A video showing the safe placement of explosives is one of several safe practices videos being produced for deep mines.

INTERACTIVE TRAINING AND EDUCATIONAL DEVELOPMENT

PRINCIPAL INVESTIGATORS:

Elaine T. Cullen, Marc T. Filigenzi, and Timothy J. Orr

RESEARCH OBJECTIVE

Develop mine safety training tools (1) by generating computerized multimedia mine safety programs and (2) producing mine safety training videos.

PROBLEM STATEMENT

Multimedia Mine Safety Training Program

The objective of this task is to develop, evaluate, and refine a multimedia computer program that will be used by the mining industry to train miners in hazard recognition, mine evacuation

procedures, accident avoidance, equipment use, and general mine safety. This multimedia program will enhance current training techniques by providing a real-time, visually appealing interactive training environment for mine workers. In addition, this program will provide network capabilities, which will allow trainees stationed at different computers to work as a team in mine hazard recognition and evacuation exercises. This program will also be used to record trainee scores and evaluate the effectiveness of the training techniques. The inherent flexibility of this type of program will allow easy and rapid updating and modification of training material.

Mine Safety Training Video

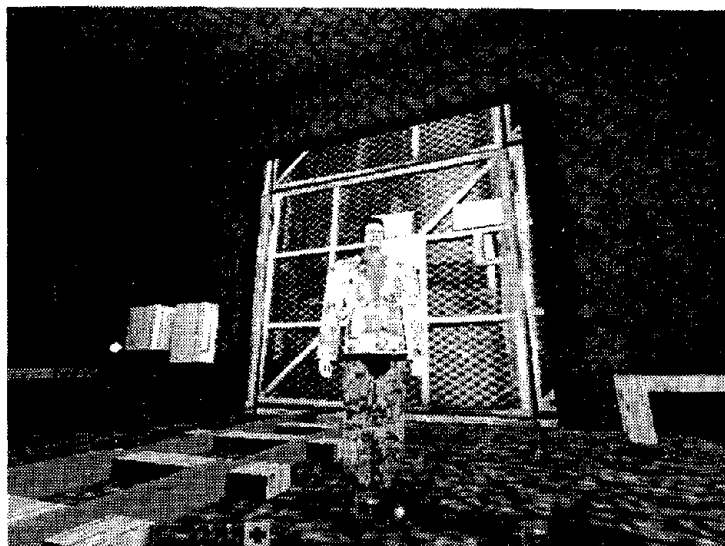
This task focuses on development of safety training videos to be used both in annual refresher training and in new miner training classes. An advisory group made up of safety directors from several operating underground hard-rock mines, as well as members from MSHA's State Grants program and the Central Mine Rescue organization, has been put together. This group is assisting in defining those areas where training materials are either nonexistent or outdated. The primary area of interest to date has been underground noncoal mines. This task will evaluate the need for new safety training materials, work with the safety advisory group to develop videos to fill the gaps, and evaluate the new materials for effectiveness.

RESULTS TO DATE

This project was a new initiative that began late in FY98. Multimedia development software has been investigated, and a product has been selected. The basic multimedia training interface has been designed. Multimedia content has been collected and created for several training modules, including fire safety, personal protective equipment, and ground control. Barrick Mining Co. of Nevada has agreed to help guide the development and testing of the initial modules.

A video on handling explosives in underground, noncoal environments is nearing completion. Footage has been shot at three separate deep mines and will be incorporated into the new video. Other footage on topics such as hazard recognition, mine rescue, and equipment safety is also being gathered for use in future products.

KEYWORDS: Training, multimedia, simulation, mining, explosives



ACCIDENT RECONSTRUCTION AND TRAINING FOR METAL/NONMETAL MINES

PRINCIPAL INVESTIGATORS:
Marc T. Filigenzi and Timothy J. Orr

RESEARCH OBJECTIVE

Develop computer programs for educating mine workers on the hazards of mining and training them in evacuation routes and procedures.

PROBLEM STATEMENT

A NIOSH study on occupational deaths between 1980 and 1989 indicated that the mining industry had the highest average annual fatality rate (31.9 per 100,000 workers). Mining is also the highest risk industry in 23 states and accounts for the largest number of occupational deaths in three states. Researchers believe that the use of computer visualization techniques for accident reconstruction and employee training will help to reduce these injury and fatality numbers.

Accident Reconstruction

Simple, cost-effective computer visualization tools can be used to reconstruct accidents at mine sites. These reconstructions can then be used to train miners about the hazards associated with their jobs, as well as to show practical ways to avoid these hazards. Work will begin with a literature search to determine the state of the art in computer-generated animation used in accident reconstruction. Researchers will also contact the Human Interface Technology (HIT) lab at the University of Washington and other local universities to learn about current trends in computer software development. Work will continue with a survey of computer resources available at SRL. Finally, researchers will work with software developers, industry, and other research centers to develop computer visualization programs and techniques that can be used for accident reconstruction. These techniques will be tested by re-creating a surface haulage accident.



Computer simulations of hazardous situations in mining. The top image shows a scene from a multiuser mine evacuation and hazard recognition training simulator. The bottom image shows a reconstructed haulage accident that resulted in a fatality at a surface mine. The accident occurred when a worker stepped behind one dump truck to direct a second dump truck. The first truck then backed over the worker. By viewing these types of reconstruction, mine workers will be more keenly aware of the hazards at their site and more likely to avoid such hazardous situations.

Mine Evacuation Training

Cost-effective simulation tools are being used to train underground mine workers and rescue personnel in evacuation procedures and route evaluation. The individual being trained would be able to practice escapes in a three-dimensional, immersive computer simulation of a mine in a disaster situation, complete with smoke, fire, and other hazards. The simulation could be practiced numerous times, allowing the trainee to become familiar with procedures and evacuation routes particular to a mine. Three-dimensional simulation technology presently exists and can be run on any multimedia computer. The technologies that need to be developed and tested include (1) a method of translating CAD files of the mine to the simulator program, (2) a unique operator interface for the simulation program to convey a miner's "virtual health," and (3) input and output devices to make the experience as realistic as possible for the trainee. Finally, a method of measuring the effectiveness of this training should be developed. This method will then be compared to other methods of training that include videos and drills.

RESULTS TO DATE

Researchers at SRL have created one mine fatality reconstruction based upon an MSHA fatality report. Researchers have also created three-dimensional computer models of several pieces of heavy mine equipment. These models will be used for future accident reconstructions.

Several different generic mine evacuation and hazard recognition training modules have been completed. These modules provide a basic mine evacuation scenario along with several hazards that must be identified and avoided by the trainee. These hazards include falling hazards, electrical hazards, bad air hazards, and a roof fall hazard.

A generic three-dimensional graphics engine has been selected. Researchers have created an evacuation simulation by importing mine map data from an actual mine. Extensive programming has been completed incorporating collision detection, lighting, and equipment interaction.

The accident reconstruction and the mine evacuation and hazard recognition training modules have been demonstrated to several mining professionals. Preliminary surveys indicate that the mining industry is

supportive of the use of this type of technology as a training tool. However, further objective tests are being planned to assess the effectiveness of computer-based training materials for the mining industry.

KEYWORDS: Training, computer visualization, modeling, mining

COMMUNICATIONS AND TECHNOLOGY TRANSFER ACTIVITY

RESEARCH OBJECTIVES

Communicate the results of mining health and safety research to the mining industry, state and Federal agencies, and the general public, as well as inform the public about the importance of mining and minerals industries.

PROBLEM STATEMENT

Research without communication of results is research that is uncompleted. There are three important ways to accomplish this goal of communication.

- Technology transfer, which deals with providing technical information to the mining and related industries so that the level of industry participation in mine health and safety research can be increased.
- Public information, which includes the development of activities and forums for the dissemination of broad-based scientific information to the public.
- Public outreach, which targets schools, Boy and Girl Scouts, community groups, and business and environmental organizations to educate them on the importance of minerals, science, and technology in every day life.

RESULTS TO DATE—JOINT ACTIVITIES

- Exhibits, displays, and materials showing SRL and PRL research projects were put up at several conventions, including Northwest Mining, SME, National Mining Association, Western Mining Show, Critical Issues in Mine Safety Conference, Control of Workplace Hazards Conference, National Minerals Education Conference, and the Idaho Governor's Safety Conference.
- A Web site was created to coincide with the NIOSH and Office for Mine Safety and Health Research sites. This site provides detailed information on projects and tasks.

SPOKANE RESEARCH LABORATORY

ACTIVITY TEAM: Elaine Cullen, Dale Avery, Ken Strunk, Priscilla Wopat, and Lisa Pitts

Technology Transfer

- Six employee invention reports have been submitted to the Tech Transfer office in Atlanta, GA. A standard operating procedure for inventions has been developed and approved by the agency.
- A new memorandum of agreement has been signed with Phelps-Dodge-Morenci. In addition, informal work agreements have been set up with numerous mines.

- Stakeholder input plays an important role in the formation of NIOSH's mining research program. Three stakeholders' meetings were held during the year in the western United States: Wallace, ID, Grand Junction, CO, and Colorado Springs, CO. These meetings were designed to gather information from mine safety representatives, engineering professionals, and mine union representatives about what they thought were the most important safety and health issues in mining and how NIOSH could address these issues. The information from these meetings was analyzed using social science software to better define issues and the hidden assumptions behind the issues, and discover similarities and dissimilarities among the views of the participants.

- Researchers presented 10 papers at seven conferences this past year, including the Northwest Mining Association conference in December, 17th International Conference on Ground Control in Mining, annual meeting of SME, 3rd International Conference on Mechanics of Jointed and Faulted Rock, 3rd N. American Rock Mechanics Symposium, IEEE Industry Applications Conference, and the 100th annual meeting of the Canadian Institute of Mining, Metallurgy, and Petroleum. Eight papers were published in five journals as well.

Public Information:

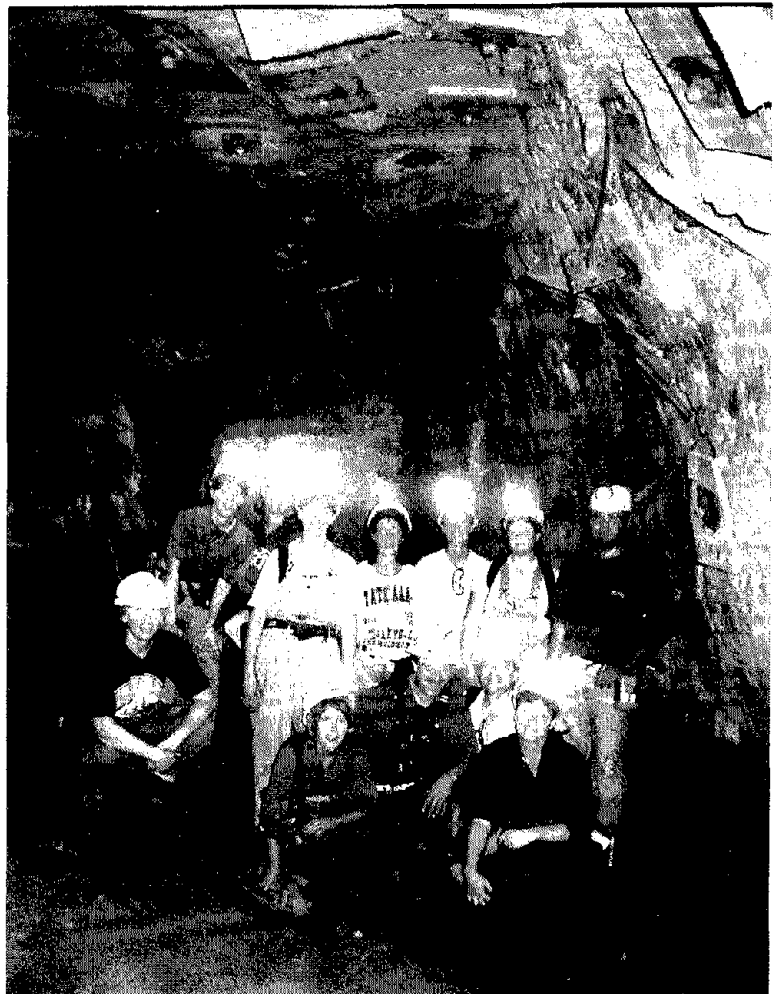
- An 11-minute video entitled *The Spokane Resource* was produced. This video has been shown to numerous groups and at many conferences. It provides information on the work of the mining safety and health program of NIOSH and the Spokane Research Lab.
- A trifold brochure on SRL was developed for use by regional customers.
- A "virtual library" of presentation-quality photos was put together. The idea is to make high-quality graphics materials available to SRL researchers to use when preparing slide talks.

Public Outreach:

- The Silver Kid Mine remains a very popular destination for area schools and organizations. The Silver Kid is currently undergoing expansion to include a shaft station, dry room, and tag-in room.
- Four sessions on minerals and mining were taught at the week-long Northwest Natural Resources Institute workshop for teachers. One-hundred-eleven teachers from grades K-12 participated, and 25 were allowed to take an all-day tour to an underground silver mine at the end of the week.
- A major effort this year was the organization of the Minerals Coalition booth and workshops at the National Science Teachers Convention in Seattle. Ten months of planning went into this event, which included gathering over 30 tons of minerals (20 different samples), 3 tons of literature, posters, videos, coloring books, etc., and 50 volunteers to hand out samples. SRL employees were the primary organizers of this event, with over half of the Lead Team

members from the Lab. An estimated 1,500 K-12 teachers were served by this work.

- Several educational and instructional activities were held for area schools. These activities included hands-on investigations of the rock cycle, the nature of specific gravity (gold panning), minerals identification, and careers. Outside partners included PARTNERS of the Greater Spokane Area, Northwest Natural Resources Institute, Partnerships for Learning, Health Improvement Partnership, Potlatch Natural Resources Festival, Northwest Mining Association, National Minerals Education Coalition, Minerals Education Network, Spokane School District 81's Superintendent's Public Affairs Advisory Council, and the GEM committees of the Society for Mining and Metallurgical Engineering.



Teacher participants visiting a mine during the Northwest Natural Resources Institute.

PITTSBURGH RESEARCH LABORATORY

ACTIVITY TEAM: Dana L. Butchle, Rose Ann Crotsley, Cynthia I. Farrier, John J. Haggerty, Jacqueline H. Jansky, Kevin Luster, Barbara D. Makowski, Robert J. Tuchman, and Charles W. Urban

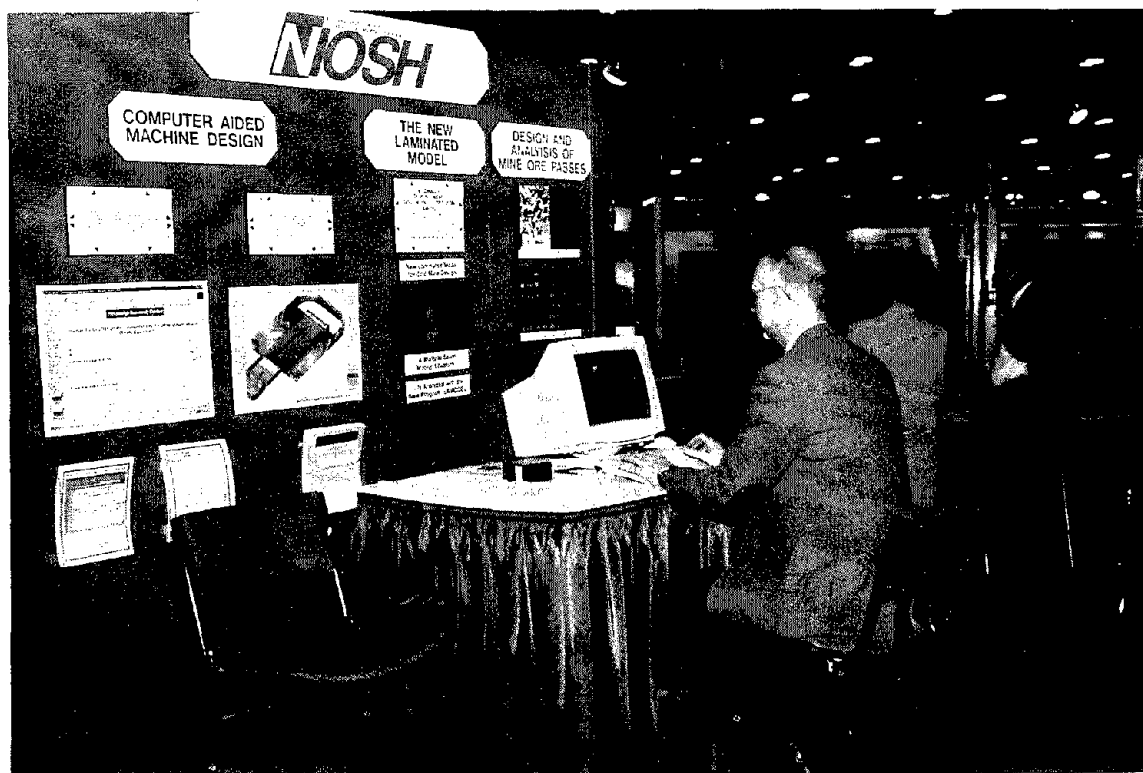
Technology Transfer

- Eight employee invention reports have been submitted to the Tech Transfer office in Atlanta, GA.
- An R&D 100 Award was received for the PRL-developed Portable Modified Direct Method Apparatus, which measures the gas contents of coal and other rock samples in field or laboratory settings. The device is easy to use, rugged, compact, lightweight, reliable, and relatively inexpensive, yet provides more accurate gas content data than current instruments. Through these advances, the invention can reduce the risk of mine explosions, thereby improving safety for underground mine workers. The R&D 100 Award recognizes the 100 most technologically significant new products of the year as judged by *R&D Magazine*.

- One new CRADA was executed and three were extended during fiscal year 1998. In addition, 11 memoranda of agreement, four memoranda of understanding, and three military interdepartmental purchase requests were executed during the year.

- Stakeholder meetings were conducted during the year at Beckley, WV, Arlington, VA, and Lexington, KY. PRL also hosted the annual meeting of the Mid-Atlantic Section of the Federal Laboratory Consortium (FLC) in March 1998. FLC helps form the bridge between Federally developed technology and the private sector.

- Researchers presented 91 formal papers at 33 conferences and workshops during fiscal year 1998. These included the 17th International Conference on Ground Control in Mining, National Mining Association convention, The International Emergency Management Society (TIEMS) conference, SME annual meeting and exhibit, American Industrial Hygiene Conference and Exposition, IEEE Industrial Applications Society annual meeting, and the North American Coalbed Methane Forum. PRL organized semin-



NIOSH exhibit at SME annual meeting

ars and open industry briefings on Safety in Underground Stone Mines (Evansville, IN), Improving Safety During Extended-Cut Mining (Charleston, WV, and Evansville, IN), and Mine Fire Preparedness (Lake Lynn Laboratory, Fairchance, PA).

Publications

During 1997-1998, PRL published the following in-house NIOSH documents: nine Reports of Investigations (RIs), two Information Circulars (ICs), 15 Technology News flyers, three Mining Health and Safety Update newsletters, and two Hazard ID's. During the same period, PRL personnel also published 164 outside publications, which included peer-reviewed journals and papers in conference proceedings. Topics covered a wide range of high-priority mining safety and health research areas, including dust control and measurement, silica, and diesel exhaust; human factors; haulage; equipment design; noncoal mining; new and emerging practices and technologies; fires and explosions; life support, and ground control. The results of our research are also often reported and/or reprinted in the mining literature, e.g., *Coal Age* and *Sensors* magazines and MSHA's *Holmes Safety Association Bulletin*.

Flyers on PRL and the Experimental Mine/Safety Research Coal Mine were published for use by visitors and other customers.

Visitors

- Tours of the laboratory tours were conducted for seven grade schools, as well as area high school students participating in the Engineering Apprenticeship Program sponsored by the Allegheny Intermediate Unit and the Pittsburgh Chapter of the Pennsylvania Society of Professional Engineers. PRL was also visited by a number of scientists and engineers from foreign countries, including Canada, the United Kingdom, Germany, Sweden, Russia, Poland, the Czech Republic, the Republic of South Africa, Japan, Australia, Brazil, and the People's Republic of China.

Exhibits

- Exhibits describing NIOSH mining research were designed and displayed at a number of conferences and events. These included the Northwest Mining Association Conference and Exhibit (Spokane, WA), SME Annual Meeting (Orlando, FL), Western Mining Conference (Colorado Springs, CO), Longwall U.S.A. (Pittsburgh, PA), Third Health and Safety Seminar for Small Mines (Somerset, PA), and Coal Ops '98 Operators' Forum (Lexington, KY).

SURVEILLANCE ACTIVITY

RESEARCH OBJECTIVES

Gather and analyze information on mine workplace safety and health hazards, fatalities, injuries, and illnesses, and develop the appropriate tools for such analyses.

PROBLEM STATEMENT

The on-going systematic collection and analysis of mining health and injury data provides the basis for defining and prioritizing safety and health research for the mining industry in the United States.

RESULTS TO DATE-JOINT ACTIVITIES

The Surveillance, Statistics, and Research Support Activity (Surveillance activity) is a relatively new activity (as of October 1997) that was established following the integration of the safety and health functions of the former U.S. Bureau of Mines into NIOSH. The Pittsburgh Research Laboratory and the Spokane Research Laboratory have cooperated to develop the surveillance function within the Office for Mine Safety and Health Research. The on-going, systematic collection and analysis of mining health, injury, and fatality numbers, rates, and severity will allow industry trends and other key information to be used as a basis for defining and prioritizing mining research.

Strategic Planning

Members of the SRL and PRL Surveillance activity groups were intensely involved in all phases of the strategic planning process. Phase 1 involved gathering and integrating accident statistics (frequency and severity) and stakeholder information into a risk matrix. This matrix indicated high-risk mining areas and thus helped planners prioritize research projects. Phase 2 involved formulation and prioritization of research goals by commodity and location for each of the major mining topics (e.g., underground coal, surface coal) based on the information collected during Phase 1 and current research program focuses. Phase 3 was a comparison of Phase 2 research goals to the current research program, a determination of where research gaps occurred, and recommendations for appropriate projects to fill these gaps.

PITTSBURGH RESEARCH LABORATORY

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The Surveillance activity group has been in place at PRL for 1 year. During that time, we have established a mission, focused on building databases, and integrated the work of the team into that of NIOSH. One of the results of the strategic planning process last year indicated that there is a limited amount of data on the health of American miners, and so the Surveillance activity group plans to expand miner health databases. Stakeholder input will be an important part of prioritizing research needs in the future, and a project is being developed regarding stress among mine workers.

Projects

Three in-house projects have been established and are reported upon more fully in the body of the Program of Research. These are

- Risk-Related Characteristics of the Mining Workforce
- Analysis of Risk to Face Workers Using Mining Machinery
- Economic Cost Models for Traumatic Mining Injuries.

In addition, contracts have been established with a private organization for three other projects: Surveillance of Injuries Related to Construction, Maintenance, and Repair Activities in the Mining Industry; Audiometric and Noise Survey in the Sand and Gravel Industry; and Analysis of Mine Safety and Health Administration Accident/Injury/Illness Database.

Status of Miner's Health

The results of the analysis completed last year as part of the strategic planning process indicated that there is a limited amount of data on American miners. Therefore, the Surveillance group plans to expand the databases on miner health and produce the first *Status of Miner's Health: An Annual Report*. This work will be done in conjunction with the work in other branches. A more complete overview of this work can be found in the description of projects.

SPOKANE RESEARCH LABORATORY

ACTIVITY TEAM:

Chuck Kerkerling, John Norberg, Ted Lowe, Terri Vilwock, Carolyn Takeuchi, Eric Zahl, Tom Brady, and Fred Biggs

The SRL Surveillance team has established six goals: (1) Identify and prioritize occupational health and safety problems in the mining industry with a focus on mining issues in the Western states, (2) ensure that resources are being used to address the most important problems, (3) track the effectiveness of health and safety research over time (a GPRA requirement), (4) develop and refine the processes of surveillance and risk assessment, (5) provide technical surveillance support to principal investigators and management, and (6) ensure that important surveillance results are communicated to external customers and stakeholders. To achieve these goals, the surveillance team has grouped its activities into data acquisition and analysis, systematic safety analysis, and CDC/NIOSH support activities.

Data Acquisition and Analysis

Mine Inspection Data Analysis System (MIDAS)

Data have been obtained from MIDAS and some preliminary trends have been established for hearing loss and exposure to silica in surface mines.

Metadatabase

A metadatabase that lists all the accident, injury, and health databases has been constructed. To date, the most important of these databases is the MSHA database of coal and metal/nonmetal mining accidents.

MSHA Data Acquisition and Analysis

SRL researchers completed a 3-day course on the structure of the MSHA database, the types of variables it contains, and how to download data into preferred statistical analysis program, such as SPSS, EXCEL, and the Mine Accident Data (MADSS) program from PRL. This course was taught by Barbara Fotta from PRL. Ready access to up-to-date MSHA accident data allows SRL researchers to track accident trends themselves.

Geographical Information Systems

The team has put together a geographical information system (GIS) and used it to plot distribution of mines and mining accidents throughout the United States. The purpose is to investigate possible relationships between mine density and type and accident frequency and accident type. If there is some relationship, then this may help in formulating effective engineering interventions.

Systematic Safety Analysis

Efforts continued in applying systematic safety analysis tools to mining situations. A new version of fault tree analysis software (Faultrease) was acquired and used to update the fault tree analysis of a malfunctioning ore chute. Work also continued on completing a preliminary hazard analysis of the walkout escapeway in a longwall mine. Negotiations were started with the Idaho National Engineering Laboratory to acquire its sophisticated fault tree-event tree software program, Sapphire, and evaluate its use for mine safety issues. Decision-making procedures

under conditions of uncertainty were evaluated to determine practical ways to maintain safe and reliable mine operating systems.

CDC/NIOSH Support Activities

The Surveillance Activity chief is serving on the Strategic Coordinating Committee for NIOSH. The purpose of the committee is to acquaint members with the surveillance activities within NIOSH, offer help to those divisions requesting it, and support NIOSH-wide surveillance activities. The committee is currently developing a plan for a nationwide occupational safety, health, and hazard system for the next decade. Such a plan is mandated as one of NIOSH's four GPRA objectives.

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KEYWORDS: Mine accidents, safety analysis, accident statistics

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ORGANIZATIONAL STRUCTURE

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SPOKANE RESEARCH LABORATORY**

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CENTERS FOR DISEASE CONTROL
AND PREVENTION

OFFICE OF ADMINISTRATIVE
AND MANAGEMENT SERVICES

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PROCUREMENT BRANCH

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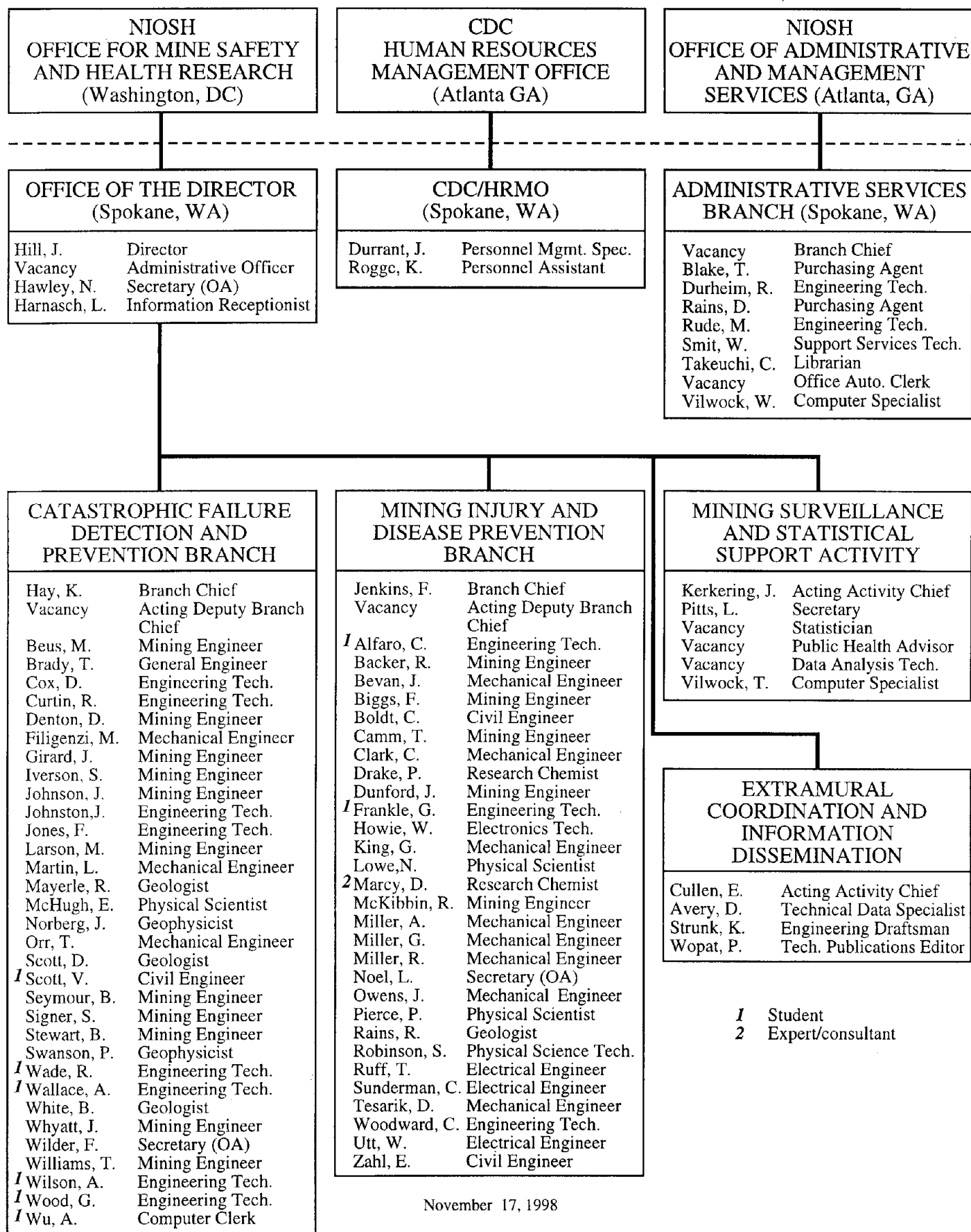
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October 1, 1998

Research
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Spokane Research Laboratory Organizational Structure



November 17, 1998

