# PROGRAM OF RESEARCH

## A SUMMARY OF RESEARCH IN PROGRESS DURING FISCAL YEARS 98

**Gregory R. Wagner, M.D.**
**Acting Associate Director for Mining**

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# INTRODUCTION

The Program of Mine Safety and Health Research described in this document reflects the continuing commitment of the Spokane and Pittsburgh Research Laboratories to focus on the most important areas where research can make a difference in reducing risk and improving safety and health for miners. It is the first program of work conducted since Congress mandated closure of the former U.S. Bureau of Mines (USBM) in the Department of the Interior and supported integration of the health and safety research function of the former USBM into the National Institute for Occupational Safety and Health (NIOSH).

Organizational changes made FY97 a challenging year of transition. Ongoing research was reviewed and revised to reflect the new, more limited, health and safety mandate of the research laboratories. The mining industry, mine worker representatives, and interested government agencies provided broad input to assure that the research performed would focus on the most critical safety and health problems confronting mining today and which are expected to be faced in the future.

The two laboratories worked to evolve coordinated programs of safety and health research, each with a special focus. The work of the Spokane Research Laboratory is directed toward issues of special importance to the Western mining industry, particularly those safety hazards found in metal/nonmetal mining and surface mining. The work of the Pittsburgh Research Laboratory will continue to focus on Eastern mining, particularly underground coal mining. Traditional areas of expertise for understanding and preventing fires and explosions and for controlling the hazards of dust and noise will continue to reside in Pittsburgh.

Each laboratory is developing new capabilities in the analysis of relevant safety and health information to assure that program priority-setting decisions are informed by the best available data. Recognizing the continuing importance of communicating the results of research to all who are capable of improving safety and health conditions in mining, each laboratory has developed an activity for information dissemination and coordination with stakeholders.

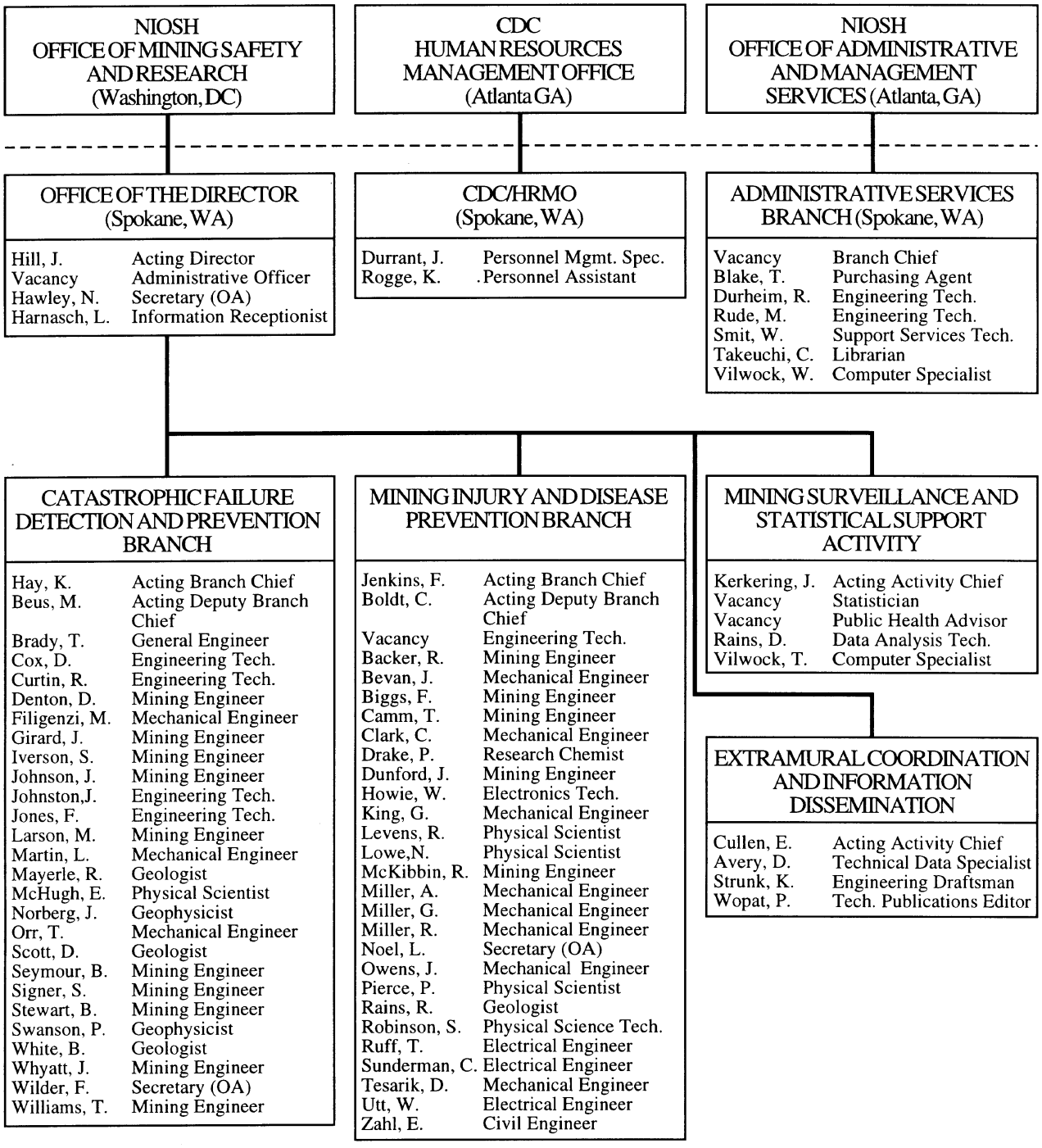
In the midst of organizational self-examination and change, the research staff in Pittsburgh and Spokane have never wavered from their continuing commitment to conduct the highest quality scientific research—solution-oriented scientific work meant to reduce the risk of injury, disease, and death from occupational hazards in mining. The pages that follow give insight into some of the program activities and accomplishments from FY97. I hope you share my pride in the many accomplishments of the NIOSH mine safety and health research program during this year.

This report comes at a time of increasing stability for the mine health and safety research program. The organizational changes in Spokane and Pittsburgh have been concluded, and NIOSH has succeeded in recruiting a new, permanent associate director for mining to lead this critically important national program. Congress has contributed to an optimistic future by providing expanded funding for NIOSH mining-related research for the next fiscal year.

On a personal note, I greatly appreciate the opportunity I have had to serve as the NIOSH Acting Associate Director for Mining during this transitional year. The commitment and intelligence with which the mining research staff pursued their mission was matched by their patience and understanding in moving into a new organizational environment. All of us committed to improved safety and health for this Nation's miners owe them our respect and appreciation.

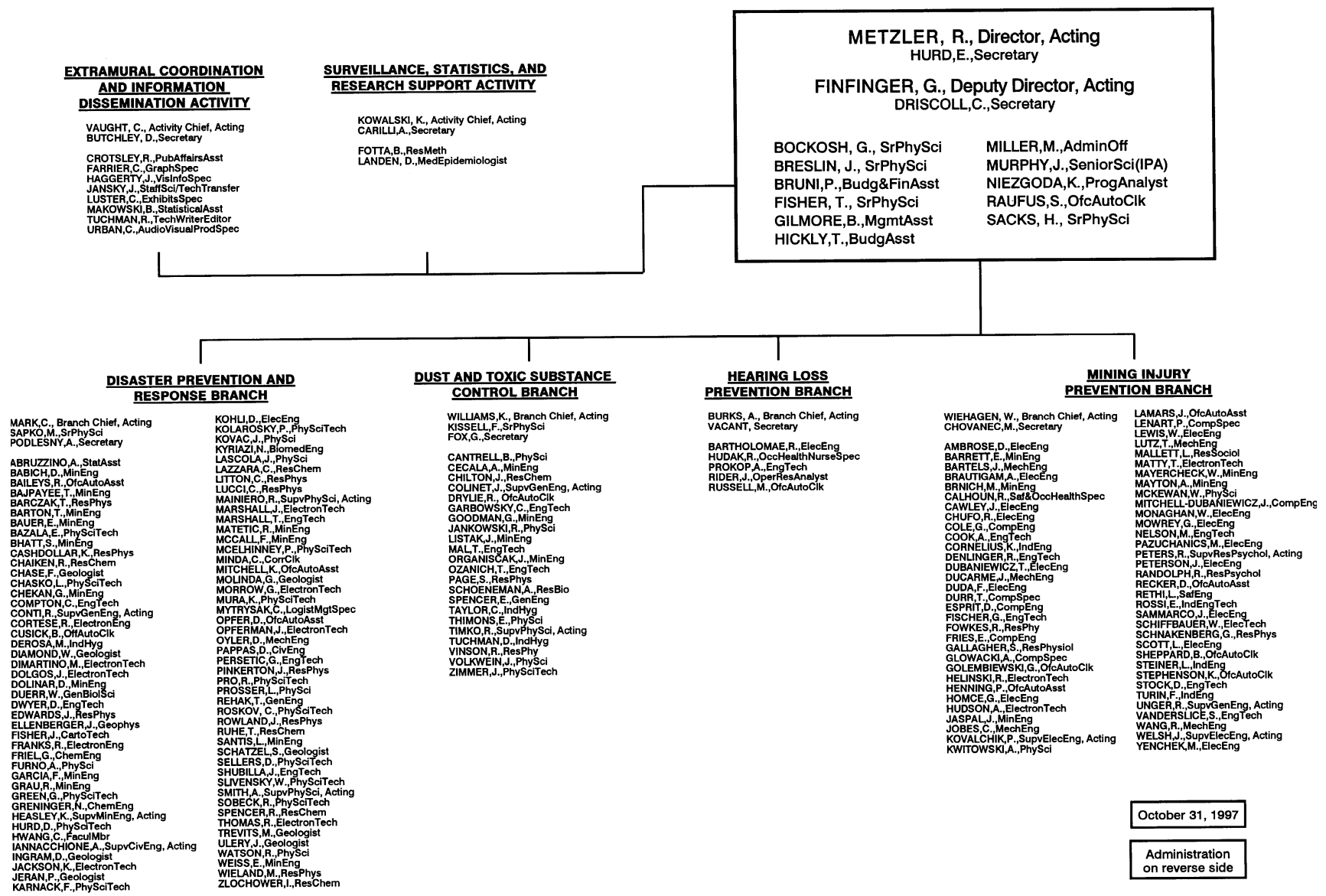
*Gregory R. Wagner, M.D.*
*Acting Associate Director for Mining*
*National Institute for Occupational Safety and Health*

# Spokane Research Laboratory
# Organizational Structure




January 6, 1998

# PITTSBURGH RESEARCH LABORATORY



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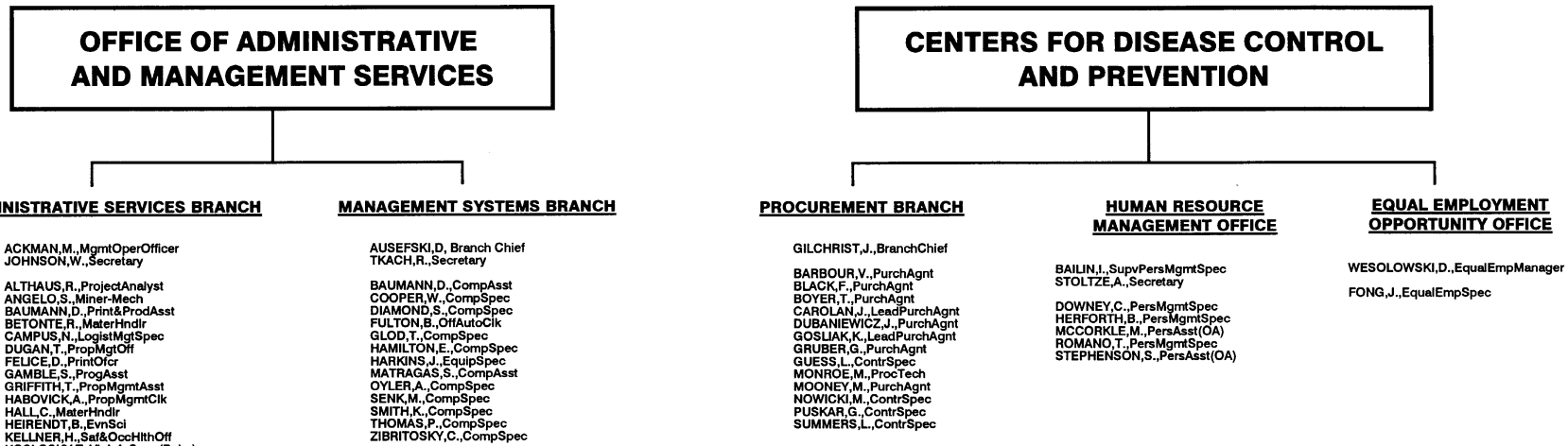


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October 31, 1997

Research on reverse side

# MINING INJURY AND DISEASE PREVENTION BRANCH

## Control Systems for Drilling

*Principal Investigators: Greg G. Miller, Wayne L. Howie, Walter K. Utt, and Carl B. Sunderman*

### RESEARCH OBJECTIVES

The objectives of this project are to (1) develop strata characterization and void detection techniques so that an operator can be alerted to unsafe roof conditions and (2) develop technology to control a roof drill automatically from the rear of a roof bolting machine, which will allow operators to be positioned away from areas where the roof might fall.

### PROBLEM STATEMENT

Roof bolting is the most dangerous operation in underground mining. According to MSHA statistics, during the 10-year period from 1984 to 1994, there were about 1,000 accidents per year associated with roof bolting. The U.S. Dept. of Labor estimates there are 2,500 roof bolting machines currently in use at underground mines in the United States. In 1995, 17.9% of the nonfatal lost-time injuries were associated with roof bolting tasks.

The principal benefit of this research will be the reduction of roof bolting accidents and injuries in both coal mines and metal/nonmetal operations. Customers are mining companies and operators of roof bolters.

### RESULTS TO DATE

#### Roof Strata Characterization

This year, research focused on using neural networks to characterize the rock that the drill is penetrating. Various neural network software packages were evaluated, and two—supervised and unsupervised neural networks—were selected for this study. Existing roof bolter drilling data collected from an instrumented roof bolter were used initially to train and test each neural net.

The feature vectors must be scaled for the supervised neural network learning routine. Consequently, a routine was written in C programming language to convert files of drilling parameter data to a form compatible with the neural network software. The specific energy of drilling is also computed in the routine. As a test case, a neural network was "trained" using existing borehole data files from prior research. The trained network then successfully classified data from another file containing borehole data.

Another software package that requires the feature vectors to be scaled and normalized in a different manner was obtained to evaluate the unsupervised neural network learning routine. This network also successfully classified a data set. A drill hole collaring effect was identified by the unsupervised neural network clustering program, which agreed with observations. Unfortunately, the drilling parameter features for this second neutral net program must be scaled and normalized. This requirement will make it more difficult to reformulate data in a subset for near-real-time operation of the strata characterization neural network. The supervised neural network package is faster and more promising in its ability to provide a warning while drilling is still underway.

An autoregressive integrated moving average routine (ARIMA) has been written in C. This routine will be used to estimate values for a subset of the data, which will be necessary for near-real-time operation.

Research also included evaluation of five alternative neural network techniques. In 1997, a set of six graphics programs were written to evaluate two unsupervised neural network techniques, the learning techniques of Kohonen, and a technique that combines fuzzy cluster means with Kohonen's approach. All of these techniques worked.

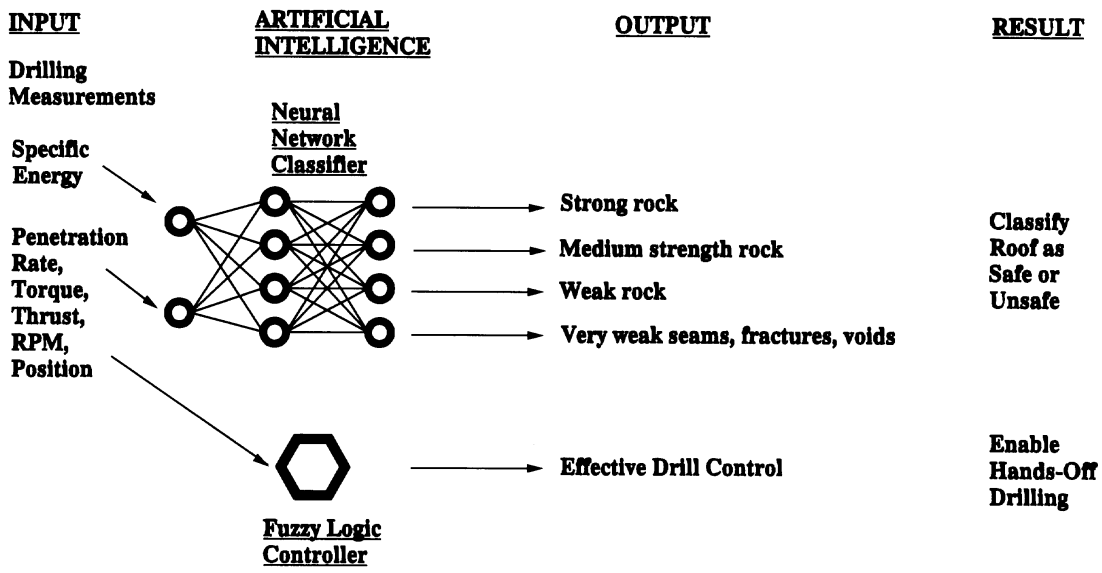
The most promising appears to be a supervised learning technique. It will be evaluated further. Integration and refinement of the data processing system will continue through FY98.

A data acquisition system has been developed for drilling test blocks in the laboratory. Windows-based data acquisition software will be used in conjunction with PC-based data acquisition boards.

A system has been designed for integrating the data acquisition system, the C language preprocessing routines, and the neural network classifier. The system will be used in subsequent testing of a near-real-time processing system.

#### Fuzzy Drill Controller

Fuzzy logic software has been successfully applied to a classic inverted pendulum control problem for fuzzy controllers. The software is now being configured for the drill control system. In addition, analog and encoder interface cards are being installed in the control system computer and tested. The drilling platform is in position. Concrete blocks for the test have been poured. Pressure transducers and optical encoders have been installed. A mineworthy RPM sensor was designed and installed into the drill head. Power supplies and instrument breakout boxes have been assembled and installed on the drill rig. Instruments and interface boards have been installed, data acquisition programming tasks have been completed, and the controller has been tuned.




**Relocating roof bolter operators away from hazards using artificial intelligence.**

## Safety Enhancements for Rock Scaling Personnel

*Principal Investigator: Art Miller*

### RESEARCH OBJECTIVES

To study present methods of scaling and their associated safety risks and develop scaling techniques and/or equipment that will reduce the number of injuries caused by scaling-related accidents.

### PROBLEM STATEMENT

In MSHA accident reports for underground mines, 12% of accidents were classified as 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.

Almost any accident in a mine which involves loose rock could be considered a scaling-related problem because all loose material should be removed by scaling. The problem must therefore be investigated holistically by examining not just the act of scaling, but all accidents involving prying, barring down, and movement of loose rock and ore.

### RESULTS TO DATE

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

#### Phase I. Problem Assessment

- Searches of the MSHA mine accident database were completed using Accident Data Analysis (ADA) and Mine Accident Decision Support System (MADDS) software. More than 300 scaling-related accidents were identified for the years 1992-1996.

- Information acquired from a search of MSHA fatalgrams was augmented by meetings and telephone interviews with MSHA inspectors and technical support staff.

- A search of engineering databases was completed. Although the material available on the topic of scaling safety is limited, several pertinent articles were found describing, most notably, work done at Pennsylvania State University, Laval University in Quebec, and the Pittsburgh Research Laboratory of NIOSH.

- Employees of several mines were contacted and questioned as to scaling methods in current use. A database was set up to hold the information from these interviews, as well as many others to be done in the upcoming months. Using these interviews as a first contact, visits were set up with two mines. Extensive interviews and brainstorming with mine personnel during such visits have resulted in many good ideas about scaling safety issues and how scaling problems might be addressed.

- A meeting was held with members of both the Human Factors and Ground Control groups at the Pittsburgh Research Laboratory to discuss ongoing work in scaling safety practices and to collaborate on individual and mutual goals.

### Phase II. Design Concepts for Safer Methods and Equipment

- The technical feasibility of using a handheld, pneumatic tool for rock scaling was demonstrated. The vertical wall of a fractured basalt formation was scaled using an off-the-shelf pneumatic scraping tool. Although a scaling bar is lighter and more maneuverable, the pneumatic tool penetrated fractures without the need to use the jabbing motion often required to remove rock with the bar.

- A prototype scaler modeled after the pneumatic tool was constructed. The tool was designed to minimize weight, maximize reach, and allow chisel bits to be changed easily.

**Demonstrating the technical feasibility of a pneumatic scaling tool.**

**The obvious hazards of scaling loose rock.**

## Chemical Hazards at Active Metal/Nonmetal Mines

*Principal Investigators: Pamela L. Drake and Russell L. Levens*

### RESEARCH OBJECTIVES

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

### PROBLEM STATEMENT

Exposure to metals and organic chemicals in mining workplaces, in particular, milling and refining facilities, may adversely affect thousands of workers. As one example, mercury is a hazardous metal associated with gold and silver in many ore deposits in the Western United States. Mercury persists during processing and refining because the chemical complexing and adsorption characteristics of mercury, silver, and gold are similar. Silver is another metal to which refinery workers are exposed. The potential for exposure to mercury and silver is expected to depend on mercury and silver concentrations in the ore, the processing steps employed at each mine, and the engineering controls implemented to protect the workers.

### RESULTS TO DATE

Exposure to mercury vapor and silver dust and fumes are the focus of this project. Site surveys have been conducted at two gold and silver mines in Nevada. Air samples from "personal breathing zones" and surrounding work areas were collected in the refineries and Merrill-Crowe processing facilities to detect excessive exposures, if any, and to identify potential sources of mercury and silver. Air velocity measurements were taken on exhaust ventilation systems at the refineries with the purpose of assessing their effectiveness and making recommendations for design changes where needed. The preliminary results from these surveys have been forwarded to the participating mines. Two alternate designs for ventilation hoods for the refinery at one site were completed. The new hood designs were presented to mine personnel as a relatively inexpensive means of reducing worker exposures to silver during the ingot cleaning process. An overview of the Chemical Hazards project was presented to the Health and Safety Committee of the Nevada Mining Association in June 1997 in Winnemucca, NV.

**Project personnel conducting spot checks for mercury vapor during a pour of molten slag.**

## Mobile Roof Support Technology

*Principal Investigators: John K. Owens and Wayne L. Howie*

### RESEARCH OBJECTIVES

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

### PROBLEM STATEMENT

Recent years have seen a resurgence in pillar extraction in underground coal mines where MRSs are being used for support instead of posts. Approximately 40 U.S. coal mines have adopted this emerging new technology. It is estimated by major manufacturers that there will be 150 machines in operation by the end of 1998. With the increase in the number of MRSs, MSHA has received requests to approve roof control plans that involve novel approaches to the use of these machines. 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 MRSs. Topics of concern include optimum setting pressure, critical loading rates that could signify imminent failure of the mine roof, and optimum location of MRSs during specific operations.

Another problem that has arisen with the use of MRSs is the lack of a warning system that would alert miners to dangerous ground conditions. In the past, post and cap noises, displacement, and failure allowed miners to "read" unstable ground, but with the increasing use of MRSs, such an early warning system is no longer available. Thus, during the investigation of a fatality that occurred in a mine section using MRSs, 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 MRSs that would alert miners to unstable ground conditions during pillar removal so that miners and equipment could be removed before a fall occurs.

### RESULTS TO DATE

The most significant result has been the development of a load rate monitoring (warning) system for MRSs. Spokane Research Laboratory studies at room-and-pillar retreat operations have shown that the loading rate on an MRS is critical to the safe use of these machines and can be used as an aid in determining when it is appropriate to remove miners and equipment from an area. The system uses an embedded processor that can monitor either the pressure inside the four hydraulic jacks of the MRS or strain in the hydraulic cylinder walls to determine loading on the MRS. The embedded processor reads changes in cylinder pressure or strain in the cylinder walls through four multiplexed data acquisition channels. It then converts these pressure or strain changes to loading rates, which in turn activates green, amber, or red warning lights mounted on the MRS. Each light represents a

different loading rate on the machine. A strobe light also flashes when the yield pressure of the hydraulic cylinders is reached, and an alarm sounds at high loading rates. A computer program was also developed that allows for easy in-mine adjustment of loading rates based on the geologic and geotechnical conditions present at the mine.

A prototype system was tested on a Fletcher MRS three-stage cylinder at the Pittsburgh Research Laboratory using its mine roof simulator loading frame. The system performed as designed, with rapid response time to changing load rates. The tests showed that the most accurate MRS loading data were obtained by strain gages attached to the wall of the top stage cylinder. Because of the success of the testing at Pittsburgh, a field-ready MSHA-permissible loading rate monitoring system was fabricated. The system will be sent to Triadelphia, WV, early in FY98 for MSHA permissibility tests and approval. Plans are to test the system at mines having the range of conditions typically found where MRSs are used to develop a protocol on how to use the system as a tool for alerting miners about dangerous conditions during pillar removal and to collect the data needed to develop guidelines for the safe use of MRSs.

Project updates have been given periodically to MSHA and members of the West Virginia Board of Coal Mine Health and Safety. MRS manufacturers are actively participating in the research by supplying the machines and multistage hydraulic cylinders to test the system, furnishing blueprints of their machines, assisting in system installation, and locating mine sites at which to test the system.

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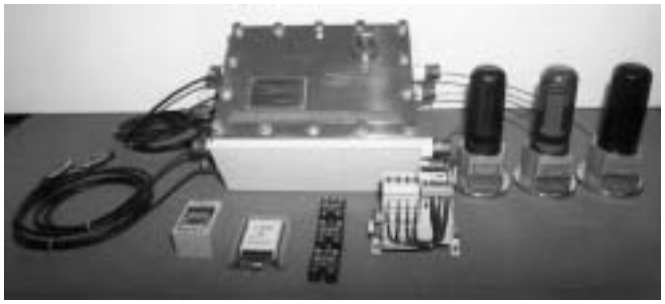


**Components of load rate monitoring system.**

**Mobile roof support in the laboratory.**

## Engineering Controls for Reducing Surface Mining Health Hazards

*Principal Investigators: Fred R. Biggs and Richard Miller*

### RESEARCH OBJECTIVES

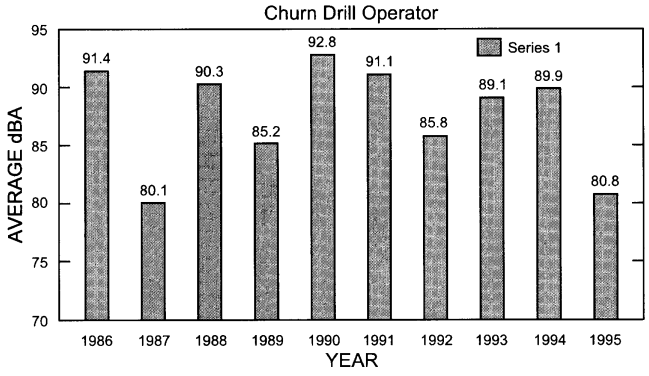
To devise and promote the use of engineering controls in metal/nonmetal surface mines to eliminate or minimize health hazards related to dust, noise, diesel emissions, jarring and jolting, and blasting agents.

### PROBLEM STATEMENT

Engineering control technologies can be applied to metal/nonmetal surface mine environments to eliminate or minimize long-term health hazards. For example, equipment noise in mining environments is pervasive. In the past few years, there have been significant developments in noise attenuation and active noise cancellation technology that could be applied to mining environments. Another example is worker exposure to respirable crystalline silica, which has prompted MSHA to propose a rule regulating miner exposure to this health hazard. A third example is related to back injuries and multiple sprains and strains; between 1986 and 1995, 35% of the lost-time injuries in surface haulage were back injuries caused by jarring and jolting. Spokane Research Laboratory personnel's engineering expertise can be applied to

characterizing jolting and jarring on mining equipment through bench and field testing and isolating those elements that could lessen shock loads to equipment operators.

**MTS IMPACT test machine.**




**Average noise exposure in decibels per year for a churn drill operator. The use of engineering controls is one approach to reducing noise exposure in mines.**

### RESULTS TO DATE

Initial work involved evaluating surface mine health hazards using the Mine Inspection Data Analysis System (MIDAS). This resulted in graphs that showed average noise levels and quartz concentrations by year by job for the period from 1986 through 1995 and pinpointed those mine occupations where exposures to noise and respirable dust were highest. Analysis of the MSHA database in the MIDAS format will continue.

An MTS IMPACT Mark II free-fall shock test machine was acquired from the former USBM Twin Cities Research Center. This machine can simulate the jolting and jarring experienced by heavy equipment operators in a surface mine so that injuries to these operators can be evaluated. Initial machine calibration and bench testing have been completed, and project personnel are now interfacing electronic recording instruments with the machine to record readings during drop tests.

An instrument package that can monitor the shock impacts on operators of various sized trucks under different loading, hauling, and dumping conditions was developed and tested on the IMPACT machine and on several service vehicles at the laboratory. The package is nearing readiness for field testing, and a mine has been found that has agreed in principle to cooperate in this research.

## Skeletal Modeling for Protective Mine Gear

*Principal Investigator: Marc T. Filigenzi*

### RESEARCH OBJECTIVES

To develop numerical modeling techniques for analyzing the effects of excessive forces and acceleration on the human skeletal system during occupational accidents. The results of these analyses will be used to improve the design and construction of personal protective equipment, thereby reducing the severity and incidences of traumatic injuries to mine workers.

### PROBLEM STATEMENT

A NIOSH study of occupational deaths between 1980 and 1989 indicated that the two occupations with the highest annual fatality rates were mining (at 31.9 deaths per 100,000 workers) and construction (at 25.6 deaths 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.

NIOSH's National Occupational Research Agenda (NORA) has identified 21 research priorities aimed at increasing worker safety. One of these priorities is to improve control technology and personal protective equipment. The NORA report states

that "in some cases where it is not otherwise possible to maintain a healthy work environment, personal protective equipment…can be used to isolate workers from the hazard." The report also states that "the need for…personal protective equipment research continues to be crucial." Personal protective clothing and personal protective equipment are the last lines of defense separating a worker from an otherwise hazardous environment. The design and construction of personal protective clothing and personal protective equipment are crucial if the safety and health of workers are to be protected.

### RESULTS TO DATE

This is a new project.

## Accident Reconstruction and Training for Metal/Nonmetal Mines

*Principal Investigators: Marc T. Filigenzi and Timothy J. Orr*

### RESEARCH OBJECTIVES

To 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 deaths 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

This task is to develop simple, cost-effective computer visualization tools 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.

#### Mine Evacuation Training

Cost-effective simulation tools will be developed 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

This is a new project.

## Injury Prevention for Metal/Nonmetal Drilling and Bolting Operations

*Principal Investigators: Robert McKibbin, Greg Miller, Curtis Clark, Carl Sunderman, John Bevan, and Richard Miller*

### RESEARCH OBJECTIVES

To 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 70 fatalities and 35,136 injuries in drilling and bolting operations in metal/nonmetal mines during the most recent 10-year period, accounting for 14% and 25% of all fatalities and injuries, respectively. A significant percentage of these were lower back injuries, which, when coupled with the fatalities, would address two NORA priorities—traumatic injuries and low back disorders.

**Typical dual-boom roof bolting machine.**

### RESULTS TO DATE

The scope of project and performance outcome measures for this new (FY98) project have been determined. The first year of the project will involve problem identification, although the research approach is intended to be dynamic so that either several small problems or a few large problems can be solved. In this regard, the background research and problem-solving phases of the project may be conducted simultaneously. Statistical information will be augmented by discussions with various segments of the mining community, including miners, mine managers, engineers, safety officers, and union representatives. Technology to solve this problem could include a mechanical engineering solution, such as a design modification, a modular component to add to an existing piece of machinery, design recommendations to equipment manufacturers, or procedural changes based on results of human factor evaluations. 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.

Representatives from Carnegie Mellon University and Joy Mining Machinery attended a technology transfer session on the bolting module at the Spokane Research Laboratory. Mechanical, hydraulic, and visualization components of the module were discussed in detail with project personnel.

### BIBLIOGRAPHY

Although this is a new project for FY98, some initial work was performed under the project "Remote-Controlled Roof Bolting Technology," which ended in FY97. There were two presentations resulting from that work.

Spokane project personnel attended an open industry briefing at the Pittsburgh Research Laboratory to demonstrate the reduced exposure mining system (REMS). A video of the bolter filmed and edited by Spokane project staff was presented at this meeting.

## Hazard Reduction in Surface Mining of Sand and Gravel

*Principal Investigator: C. M. K. Boldt*

### RESEARCH OBJECTIVES

To reduce worker fatalities and injuries occurring in surface sand, gravel, and stone operations.

### PROBLEM STATEMENT

The sand, gravel, and stone industries have been underrepresented in mine safety research. A cursory look at MSHA accident data, however, shows that surface sand, gravel, and stone operations had 28 fatalities in 1995 and 34 fatalities in 1996. This is nearly one-third of mining industry fatalities for those years. 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. The average number of employees at each mine was less than six. The NFDL (nonfatal occurrences with days lost) incident rate was 4.05. Stone mills employed 66,196 workers at 703 operations in 1994 (MSHA Metal-Nonmetal Monitor, August 12, 1996). Safety hazards at these operations are expected to be different from hazards at surface metal and coal mines because of the smaller size of the operations, fewer employees at each site, proximity of the quarries to urban areas, and the greater use of mobile equipment.

During the first year, accident data specific to surface sand, gravel, and stone operations will be reviewed, and project personnel will solicit input from these operations so that they can focus their research on problems pertinent to the industry. The second year will be spent developing improved engineering systems to address the most important problems found. On the basis of a preliminary review of the data, we expect that such problems will include improvement of braking systems for haulage trucks, modifications to materials handling equipment such as conveyors and crushers, improvements in maintenance practices, and development of training and safety devices for reducing strains and sprains. The third and fourth years will be used to conduct field demonstrations, evaluate the results, and disseminate the information to the industry.

### RESULTS TO DATE

This is a new project.

## 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.

**Doppler radar backup alarm being tested on 240-ton class mining truck.**

### PROBLEM STATEMENT

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 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 the equipment, 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, or simple tasks. Improvements in sensing technology, such as radio frequency, radar, laser, and infrared devices, offer another opportunity to introduce technological improvements to vehicle operation and/or control.

There is little in the literature quantifying costs associated with various methods of truck dumping procedures (end-dumping materials over a spoil pile versus dumping and bulldozing the materials over a dump edge). 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

The project addresses three issues: hazard recognition, operator safety, and the economics of safety. Project personnel participated on an MSHA-sponsored task force of industry and equipment representatives chartered to improve the safety of large, off-road haulage trucks used in surface mines. Brochures describing the best practices for 11 different problems have been developed as training handouts. In addition, researchers reviewed and provided input on two MSHA training videos dealing with stockpiles and waste piles.

The hazard recognition task included an evaluation of warning devices that could alert a driver to obstacles that could be run into or run over, mirrors and/or Fresnel lenses that could improve operator vision, and video cameras and monitors.

Available proximity warning devices (Doppler radar and radio frequency tags) have operating characteristics that do not quite meet the requirements of mining haulage trucks at surface mines. Only two manufacturers of the Doppler radar devices could be found in the United States, and only one of these devices demonstrated reasonable performance. Radio frequency technology shows promise, but current systems are too expensive and do not have the range or coverage desired for large haulage trucks with their many blind areas. In field tests, the Doppler radar alarms were found to be difficult to mount, adjust, and aim, with a tendency to generate false alarms. Efforts to identify and customize proximity warning systems for surface mine haulage vehicles will continue. It was determined that special mirror-type systems (Fresnel lenses) are no longer available from any source. Video cameras are being installed on some trucks as an accessory to mirrors and backup alarms on large trucks. Problems associated with camera use include in-cab monitors that are difficult to view because they are not clear enough and they do not have enough resolution to distinguish what is being viewed. Also, existing camera lenses are not capable of staying clean under the dirty conditions associated with mining.

Studies of the effects of jarring and jolting on the operators of large haulage trucks were initiated. Work will concentrate on developing instrument packages to evaluate the impacts of such shocks. The instruments were tested on an MTS machine in the laboratory and then installed on several service vehicles. A mine has agreed in principle to cooperate in this research. The next step is to install the instruments on trucks of various sizes so that they can be tested under conditions of loading, hauling, and dumping in operating mines.

Economic studies of various dumping practices (end-dumping versus short-dumping) have been initiated. This work is being coordinated with the Pittsburgh Research Laboratory. End-dumping materials over a spoil pile exposes the driver to greater danger than dumping and bulldozing the materials over a dump edge. Some operators may be reluctant to switch from end-dumping because they feel short-dumping is more costly. Results from this study will define the costs and benefits of modifying current dumping practices.

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# CATASTROPHIC FAILURE DETECTION AND PREVENTION BRANCH

## Slope Stability Hazard Recognition for Metal/ Nonmetal Mines

*Principal Investigators: Jami M. Girard, Russ Levens, Ron Mayerle, Ed McHugh, and Mark Larson*

### RESEARCH OBJECTIVES

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

### PROBLEM STATEMENT

Whether underground or on the surface, unanticipated rock movements create the potential for a mine catastrophe. Through the first three quarters of 1997, separate accidents have claimed the lives of two miners because of falls of highwalls at open-pit mines in the United States. Between 1992 and 1996, nearly 14% of surface mine fatalities were related to slope failures. In addition, a comparative study of fatal and nonfatal accidents over the last 5 years indicated that slope failure accidents in surface mines were 12 to 30 times more likely to result in fatalities than other types of accidents in these mines. With U.S. surface mine production reaching new highs in States such as Nevada and Arizona, the potential for surface-mine-related accidents is likely to increase. This project at NIOSH's Spokane Research Laboratory was initiated early in 1997 with an objective of reducing injury and fatality incidence rates associated with slope failures.

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 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 engineering situations, including the design of roadcuts, railroad beds, canals, refuse disposal sites, and earth dams, as well as landslide control.

### RESULTS TO DATE

Project personnel have visited a number of surface mine operations to observe current slope control practices and solicit input from mine geotechnical engineers. A database of documented slope failures and back-analysis information has been created. Several potential new technologies for slope monitoring and design have been selected for further research.

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**Truck buried in highwall failure that resulted in one fatality and one nonfatal injury.**

## Design Analysis of Ore Passes

*Principal Investigators: Michael J. Beus and Bill Stewart*

### RESEARCH OBJECTIVES

To 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

The ore pass design project seeks to develop safer mine ore passes and ore pass structures. Current work is focused on particle flow computer analyses and the installation of sensors on ore pass chute and control gate assemblies. This work will enable researchers to determine actual static and dynamic loads that cause structural failure.

### RESULTS TO DATE

Safety analyses and surveillance studies are ongoing. Accidents related to ore passes are being identified, and a method to determine the extent of miner exposure to ore pass hazards is being developed. Field surveys have been conducted at five large underground metal mines in four States to assess the scope of existing and potential safety problems around ore passes. These surveys also helped in refining a fault-tree analysis that allowed the project team to focus its research and identify cause-and-effect relationships of which they had previously been unaware.

Construction of a full-scale mockup of an actual ore chute support structure was completed to test a new approach for determining loads on ore pass gates. Strain gages were installed on the support bolts, and hydraulic jacks are being used to apply test loads. Procurement, assembly, and debugging of data acquisition systems to take static and dynamic measurements have also been completed. Closed-form calculations for dynamic forces have been validated by ball-and-beam drop tests. Test problems incorporating a computer program using the particle flow codes $PFC^{2d}$ and $PFC^{3d}$ have been developed.

A one-third-scale ore pass, storage bin, and chute and gate assembly have been designed and are currently under construction. Prototype sensors for the one-third-scale chute and gate assembly have been built, and tests of the design are underway.

A field test was completed on an ore pass chute and gate system at the Lucky Friday Mine in northern Idaho. Thirty-two weldable strain gages were installed on the eight support bolts from which the chute and control gate are suspended. Tensile strains were averaged to obtain a measurement of the total vertical force acting on the structure as material was dumped into the ore pass. Fourteen loads averaging 5,000 to 6,000 lb of material each were dumped from a load-haul-dump (LHD) unit into the ore pass. Preliminary analyses indicate that dynamic loads were reduced significantly by offsetting the chute and control gate support structure from directly below the dump point at the top of the ore pass. This allowed a cushion of material to pile up at the base of the ore pass and absorb the initial impacts from the leading edge of the falling column of material. The data also show that energy losses from collisions among particles and between particles and the walls are considerable, resulting in much lower impact forces than predicted by theory. Static loads were in line with predictions. Tests are continuing at the mine to refine the approach and validate the particle flow computer models.

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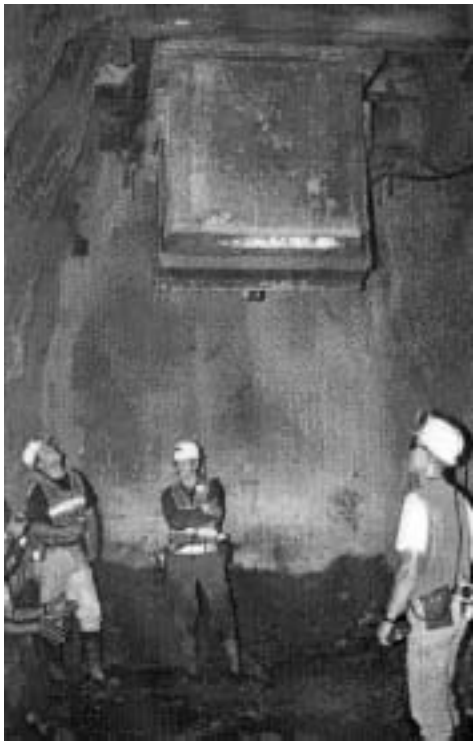


**Conducting field test on ore pass chute and gate assembly.**

## Mine Hoist and Elevator Safety

*Principal Investigator: Michael J. Beus*

## RESEARCH OBJECTIVES

To improve the safety of hoist and elevator operations by using sensor and computer technology to increase the amount of information and efficiency of information flow available 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.

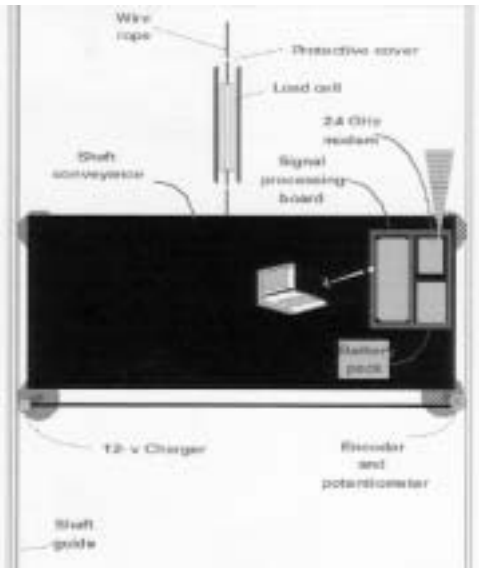
## RESULTS TO DATE

A state-of-the-art hoisting and ore pass research facility has been constructed. This facility will allow 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 will be 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. A "flex-beam" load cell has been developed to measure rope tension and is being patented. 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. This newly developed conveyance load sensor and data transmission scheme will advance hoist and conveyance monitoring.

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 laptop or handheld computers.

Further integration of a customized signal processing board to minimize size and increase transmission speed is underway. In-shaft charging methods and modification of modems to transmit voice and data will be designed and tested. Ways to integrate conveyance monitoring data into the hoist room computer at the test facility are being studied.

Field tests were completed in deep shafts in the Sunshine and Lucky Friday Mines to test wireless transmission methods for monitoring mine shaft conveyances. One shaft is a 5,000-ft-deep escape shaft and has two 5-ft-square hoisting compartments with timber lagging. The other shaft is a concrete-lined, 6,000-ft-deep production shaft. It is 21 ft in diameter with steel sets. Error-free transmission was achieved in both shafts from a depth of approximately 1,900 ft. It is anticipated that distances can be improved by the use of repeaters and better antennas.




**Shaft conveyance monitoring system.**

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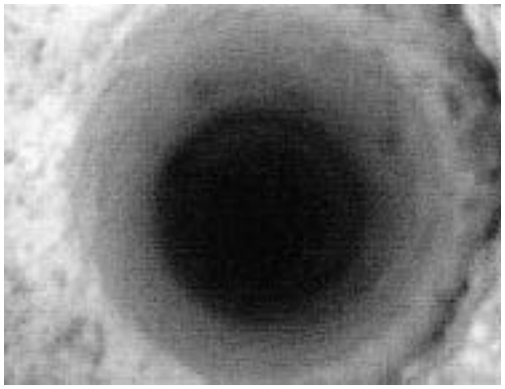
**Skip inside headframe at test facility. See diagram above for location of data acquisition equipment.**

# Mining Under Adverse Geologic Conditions


*Principal Investigators: Jeffrey K. Whyatt, Jami M. Girard, Brian G. White, and Timothy J. Orr*

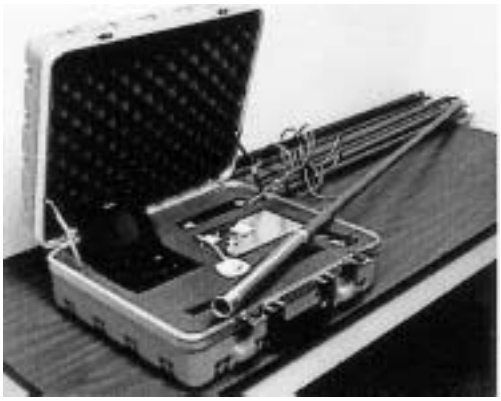
**Breakout of borehole walls indicates high stress and elevated ground control safety hazards.**

## RESEARCH OBJECTIVES

To 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. Although 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 actively mining 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 of 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. Pockets of highly hazardous working environments created by adverse geologic conditions need to be identified so that working conditions can be improved.



**Prototype of video borescope.**

## RESULTS TO DATE

Recent research has shown that geologic conditions exert a strong control on ground control hazards. For instance, an investigation of a recent rock burst fatality found evidence, including disced drill cores, geologic conditions, of unusually high stresses in subunits of hard vitreous quartzite. A similar study of development of two sublevels found that rock bursts and other seismic events were concentrated in an area encompassing less than one-third of the project area. The injury rate for miners in the hazardous one-third of the project area was 30 times higher than the national average for underground mining.

The location of these high-risk sections appears to be controlled by a combination of preexisting geologic conditions and mining-induced stresses. These observations suggest that a program of ground-control-oriented geologic mapping and analysis could support a priori identification of hazardous sites if sufficient information were available.

Exploration boreholes provide an important first look at ground conditions. Sections of boreholes that are heavily fractured or broken out from their nominal circular shape are proving to be good indicators of adverse geologic conditions.

A video borescope is being developed at the Spokane Research Laboratory to gather such information. A prototype was demonstrated to MSHA. A number of mining companies are cooperating in field trials of the borescope, and a Public Health Service employee invention report has been submitted.

Data collected using the borescope, as well as from coring and geologic mapping, will be integrated into the design procedure using visualization and stress analysis software that allows mine engineers to examine the interactions among mining, geology, mining-induced seismicity, stress levels, and ground stability as they plan mining operations.

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## 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, the Republic of 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. Most of the underground gold mines in Nevada are now using cemented backfill as support where ground conditions are weak. Backfill is also being used to reduce the incidence of hazardous rock bursts in deep metal mines and to recover remnant ore pillars in room-and-pillar mines.

However, 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 backfill, and a more comprehensive engineering approach to mine design. The need for further backfill research is exemplified by frequent requests from the industry and from State and Federal agencies for cooperative assistance in solving backfill-related health and safety problems.

**Mining through backfilled cross-panel and entry pillars in the 8-Right longwall panel at the Foidel Creek Mine.**

### RESULTS TO DATE

In cooperation with Cyprus Twentymile Coal Co., an instrumentation plan was developed for the Foidel Creek Mine, an underground coal mine in Colorado. The purpose was to monitor the safety and stability of underground working conditions as a longwall mined through a series of backfilled cross-panel entries. Because the mine's longwall panels are extremely large (approximately 850 ft wide by 18,000 ft long), three parallel entries were driven across the middle of the 8-Right panel to provide additional access and escapeways for underground miners. To maintain the stability of these cross-panel entries during subsequent extraction of the longwall panel, the entries were backfilled with a grout mix consisting of cement, fly ash, and a foaming agent. Instruments installed in the cross-panel entry pillars, backfill, longwall panel, and headgate entries were continuously monitored by a computerized data acquisition system as the longwall approached and mined through the backfilled section of the mine. The information collected from this study is currently being analyzed in greater detail to determine how far stresses extend ahead of the advancing longwall face, the magnitude and direction of principal stresses as mining progressed toward the backfilled entries, in situ properties of the engineered fill, maximum stress on the backfill and support pillars before they yielded, and the applicability of numerical modeling codes to evaluate bedded deposits such as coal. Instrument readings are being used to validate numerical models. All this information (results of numerical modeling, underground observations, and measurements) will provide valuable information about ground behavior, performance of the fill, and safety and stability of the mining method.

A second study is being conducted in cooperation with Hecla Mining Co. to investigate the cause of a recent backfill roof failure in a ramp-stope intersection at the Lucky Friday Mine, a deep silver mine in Idaho. Laboratory tests were run with samples of cemented mill tailings cored from a large slab of the fallen backfill to determine the material properties and quality of the placed fill. Because these backfill roof failures pose serious hazards to miners working in the intersections, preliminary recommendations were given to the mine staff regarding the dimensions of the ramp-stope intersection and the procedures for installing an intersection truss embedded in the fill. In cooperation with the mine staff and its consultant, an instrumentation plan was developed to monitor deformation of the backfill and host rock and loads on the truss in a selected ramp-stope intersection during mining of the undercut stope beneath the intersection. Additional laboratory tests are being conducted with samples of cemented fill collected from the instrumented stope as it was being backfilled. The results of these tests will be analyzed together with the information collected from the underground instruments and numerical modeling to evaluate the stability of the backfilled intersection and the safety of the underhand cut-and-fill mining method.

An instrumentation plan was developed in cooperation with The Doe Run Co. to address safety concerns at the Fletcher Mine, a lead-zinc room-and-pillar mine in Missouri. Instruments are to be installed to monitor the safety of underground working conditions during mining of remnant ore pillars and to document the stability of placed cemented backfill, the mine roof, support pillars, and a boundary pillar separating the Fletcher Mine from the adjacent West Fork Mine operated by ASARCO.

## Warning Systems To Reduce Traumatic Injuries in Underground Mines

*Principal Investigator: Todd Ruff*

### RESEARCH OBJECTIVES

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 mobile equipment.

### RESULTS TO DATE

#### Mine Roof Evaluation Sensor

The object of this task is to decrease the number of injuries and fatalities associated with falls of rock in underground metal/nonmetal mines. The method proposed would provide information on roof conditions to each individual equipment operator as he or she moved through the mine. A new development in radar technology called micropower impulse radar (MIR) showed promise in providing a low-cost, ground-penetrating sensor to evaluate mine roof conditions. However, discussions with personnel at Lawrence Livermore National Laboratory, the inventor of MIR, have revealed that the technology is not ready for the application proposed. As a result, no progress has been made toward purchasing and evaluating an MIR unit, and researchers will have to wait until the technology has been developed further before its

applicability to this problem can be evaluated. Cost-effective alternatives to this technology are few, however, so other solutions will be studied while monitoring the progress of MIR.

### Navigation and Warning Aids for Mobile Equipment

The objective of this task is to eliminate fatalities associated with workers being crushed by collisions with large mobile equipment in underground metal/nonmetal mines. This work is also applicable to haulage trucks used in surface mines. Research on available collision avoidance sensors has shown that existing backup alarms and sensors have excessive limitations and are not being used effectively. The most promising technology for this application uses radio frequency identification (RFID) tags and tag readers to warn equipment operators. Each worker in the mine would wear a small RFID tag. A tag reader would be mounted on each vehicle. If a tag is sensed within the reader's sensing range, the operator of the equipment is warned. This solution eliminates false alarms and the possibility that backup alarms associated with available systems would be ignored.

Two off-the-shelf systems were purchased to evaluate this technology. Tests were conducted in the Silver Strand Experimental Mine to determine the effects of the tunnel, surrounding rock, and steel supports on the two systems. The first system tested transmits around 400 MHz at very low power. Consistent detection of the tag occurred within 30 ft of the reader. Because of its complexity, extensive modifications would be needed on this system before it would be useful as an alarm. It is also very costly. However, this frequency seems to be the least susceptible to errors from different tag orientations or body shielding. The second system transmits at a lower frequency, and the tag was detected within a reading range of 7 ft. However, the reading range would have to be extended to at least 20 ft before the system would be useful in a mine. Missed readings were very frequent if the tag was not correctly oriented with respect to the reader's antenna.

**The collision avoidance sensor is mounted on a front-end loader while the tag is worn on the pedestrian worker's belt.**

Because of the difficulty in modifying existing off-the-shelf systems, a Request for Proposal has been submitted to several companies to develop a low-cost, dependable system for underground use. Evaluation of this new system will be completed by next fiscal year.

### Injured Worker Locator System

The objective of this task is to eliminate fatalities resulting from the failure of medical aid to reach injured workers in a timely manner. 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.

The scope of this task has been limited to one particular problem area 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 has been 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 past year has been spent evaluating the effectiveness of each sensor. The dust sensor has proven to be the most reliable; however, one drawback is that, because 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 was built based on the dust sensor and will be tested during the next fiscal year. Other sensors will also be evaluated.

## Mine Deformation Monitoring for Ground Hazard Assessment

*Principal Investigators: Peter Swanson, Mark Larson, and Doug Scott*

#### RESEARCH OBJECTIVES

To develop effective methods to describe mining-induced fracturing and deformation 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. Although 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

A cooperative effort was initiated with Silver Valley Resources, Inc., to develop seismic monitoring technology to combat rock burst hazards at the Galena Mine (Wallace, ID). Specific goals were to (1) give shift bosses and safety personnel stationed underground information on the location of large mining-induced seismic events and rock bursts so that they could initiate rescue operations in a timely manner and (2) transfer this information automatically to engineering and management personnel on the surface to facilitate both day-to-day operations and longer term planning to reduce rock burst hazards. An automated network-based system that acquires, processes, displays, and archives raw and processed seismicity data was designed and installed on the 4600 level of the mine, where its performance will be evaluated.

To gauge the suitability of this new seismic system in coal mines, a monitoring array was temporarily deployed at Cyprus Twentymile Co.'s Foidel Creek Mine (Oak Creek, CO) during the mine's recent longwall mine-through of backfilled cross-panel entries. The spatial distribution of the intense seismic activity (up to 2,500 events per day) generated a visual indicator of time-varying mine deformation not available with conventional rock mechanics measurements. Spatial and temporal seismicity prior to, during, and after mining through this critical mine structure was remarkably regular, consistent with the absence of ground control problems. The next step is deploying the system in a mine experiencing significant ground control problems so that the system's effectiveness in identifying problems before they pose a hazard can be gauged.

Research is also aimed at preventing mine collapses such as the 5.3-Richter-magnitude event that occurred in 1995 at a southwestern Wyoming trona mine. However, efforts to develop constitutive laws for trona rocks under dynamic loading conditions through a joint study with the St. Petersburg Mining Institute were put on hold when the Russian government withdrew its support of the laboratory.

As part of an effort to determine more realistic constitutive relations for use in developing better rock mass support technology, instruments were installed at the Shoshone Mine (Hanna, WY) to measure deformation during longwall development and retreat. The data document different styles of time-dependent deformation at two locations. A new time-dependent constitutive model for joints has been written in the FISH language for use with the numerical code FLAC. This model will be debugged and tested before simulating the field cases. Direct-shear laboratory tests have been conducted to determine the frictional and time-dependent parameters in the constitutive model. Additional laboratory tests are planned.

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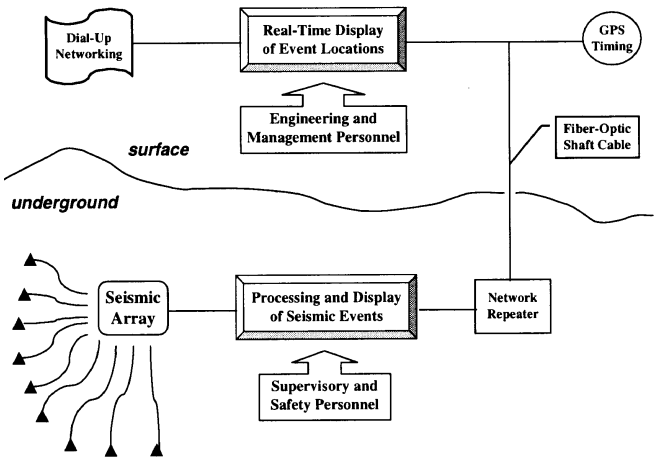


**LAN-based automated seismic monitoring system for rock-burst hazard reduction.**

## Methods for the Prevention of Mine Roof Support Failure

*Principal Investigator: Steve Signer*

### RESEARCH OBJECTIVES

To develop methods for preventing roof support failures that cause roof falls.

### PROBLEM STATEMENT

More than 100 million roof bolts are installed in U.S. coal mines each year. Many of these supports fail, resulting in more than 400 injuries and 10 fatalities per year. However, there are no adequate design criteria for the selection of roof bolts. Roof bolt spacing, diameter, length, and physical properties of the roof bolt itself under different mining conditions (geology of the rock mass, geometry of the mine, and in situ stress fields) are critical to preventing roof support failure and subsequent ground falls. These problems have not been easy to solve because of the difficulty of accurately measuring rock properties and stress fields in a changing underground environment. Recent work by the Spokane Research Laboratory has resulted in a technique for measuring loading along the length of fully grouted bolts that will improve our understanding of the mechanics of interaction between the roof bolts and the rock. Field tests showed load levels exceeding the yield point of the steel. Such load levels result in unstable roof conditions that pose safety hazards for mine workers.

In this project, the approach is to use fully grouted bolts instrumented with strain gages to measure the effects of geology, geometry, and in situ stress fields. This information will be used to develop methods that MSHA can apply when evaluating roof support designs. A large-scale biaxial shear machine will be used in laboratory tests to study the bending mechanics of support-rock interaction. Such information is critical because steel is weakest in shear, and field observations indicate shearing is the primary mechanism of roof bolt failure.

### RESULTS TO DATE

Tests were begun at three mines. Bolt lengths and diameters, spacings between bolts, entry widths, overburden depths, and geological profiles were all varied to study the effects of geology, geometry, and in situ stresses on roof bolt loading.

- Forty instrumented fully grouted roof bolts were installed at five test sites in General Chemical's trona mine in July and August 1997. The mining method is pillar retreat with a low extraction ratio to prevent caving. Results show that bolt loading from entry development is influenced greatly by entry width. Monitoring will continue until the section is retreated sometime this winter. This test is being conducted in cooperation with the Pittsburgh Research Laboratory, which has installed instruments to monitor roof movement.

- Fourteen fully grouted bolts instrumented with strain gages were installed in a longwall recovery room at the Emerald Mine to monitor roof stability. Other instruments were installed by the Pittsburgh Research Laboratory to monitor pillar stresses, rock movement, truss loading, and loads on point-anchored bolts. When the longwall approached the recovery room, an unplanned roof fall occurred. Readings showed that there had been a significant buildup of shear that contributed to failure of the roof support. Processing and analyzing the data are continuing. This work is being done in cooperation with the Pittsburgh Research Laboratory, Cyprus-Emerald, Jennmar Corp., and West Virginia University.

- Eight instrumented bolts and 18 sagmeters were installed at the Aberdeen Mine in a two-entry longwall gate road. The test site is located under approximately 1,600 ft of overburden. The immediate roof is composed of siltstone and sandstone. Results show that bolt loading from entry development is less than the yield point of the steel, which probably reflects the good roof conditions and the large bolt diameter. Monitoring will continue until the longwall passes the test site sometime next spring.

At the Deer Creek Mine, the second longwall panel has passed test sites where 10 instrumented bolts and 18 sagmeters were installed last year. The immediate roof is composed of competent sandstone with several thin coal layers. Shear stresses were measured at several positions on the bolts after the first longwall panel had passed; these measurements indicated bolt loading increased at many bolt locations. Preliminary data analysis shows that use of concrete-filled cans as secondary support had a significant effect on reducing bolt loading as the second panel approached the test sites. Bolts installed in the crosscuts showed higher load levels than bolts installed at mid-pillar. Processing and analyzing the data are continuing.

Project personnel visited the Trail Mountain Mine near Orangeville, UT, to discuss the potential for establishing a test site in the 10th West and 6th West gate road entries. Failure of both primary and secondary supports occurred in other gate roads just after the first longwall panel passed. This would be an excellent site for the roof bolt study.

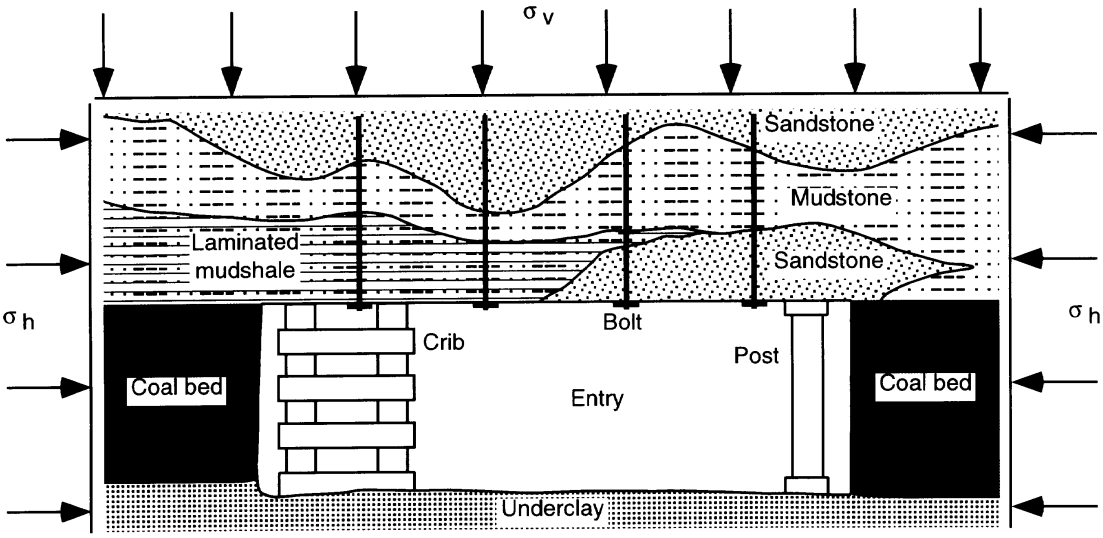


**Diagram of typical entry support. $\sigma_v$ = vertical stress; $\sigma_h$ = horizontal stress.**


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## Total Mine Safety Systems

*Principal Investigators: Tom Brady and Jeff Whyatt*

### RESEARCH OBJECTIVES

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

### PROBLEM STATEMENT

Loss of ground stability, either locally or across large sections of a mine, remains a serious problem in mines. Large- scale rock mass instabilities attract the most attention and have the greatest disaster potential. Recent examples include a chain reaction sequence of instabilities at the Macassa Mine that devastated the bottom half of the mine and a 0.75-square-mile collapse at the Solvay Mine. In both of these events, minor changes in timing could well have killed miners by the crew or even by the shift. Smaller sequences of pillar collapse receive less attention, if any, until miners are injured or killed, but they are quite common and are a concern across the mining industry.

The difficulties of dealing with mine stability issues is reflected in the plateauing of accident and fatality rates at significant levels over the past 15 years. Overall, 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, are computationally intensive, as are the geophysical and geomechanical sources of supporting data. Recent dramatic progress in the cost effectiveness of computational power, however, has brought these analyses into the realm of the personal computer. In fact, these methods are now breaking through to general use in related applications as slope stability of surface mines. This project seeks a similar breakthrough in the treatment of stability in underground mines.

### RESULTS TO DATE

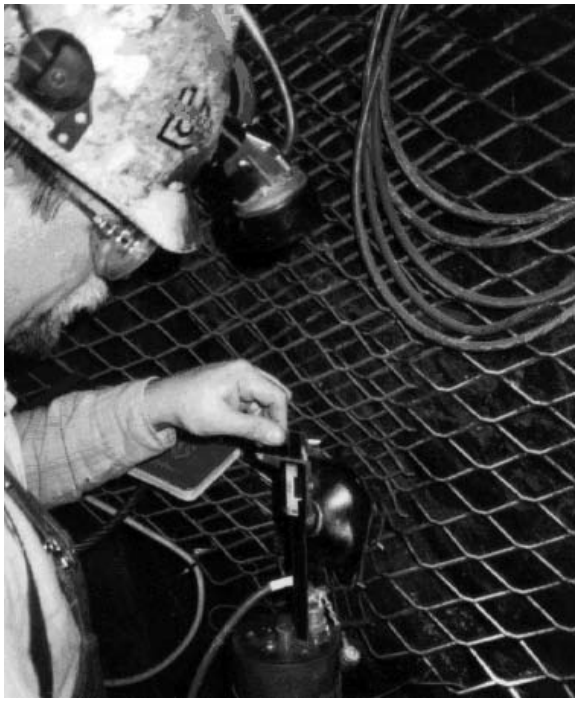
Earlier project work concentrated on the most critical of mine structures—the shaft pillar. Loss of a shaft pillar, like that experienced at the Macassa Mine, can threaten an entire shift of miners with entrapment, injury, and death. Loss of a shaft pillar can also result in closure of major portions of a mine or even the entire mine, resulting in significant economic and social losses. 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. This work was initiated when pillar mining resulted in unexpected shaft deformation, creating considerable concern for miner safety. A monitoring and analysis program was initiated that showed good short-term success. However, continued monitoring of the shaft pillar has shown that 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. Thus, work on a visco-plastic constitutive law has started. Work on supporting laboratory and field monitoring procedures is planned.

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 geophysical investigations of rock mass properties by Montana Tech and a substantial contribution of resources by the mining company.

Progress to date has included in situ stress measurements completed by a Stillwater Mine crew trained by SRL project personnel. The commitment of the mine crew to this effort has greatly reduced costs and marks an important juncture in the transfer of this technology from research to routine site characterization. A related rock property testing program was also completed.

All of these analyses, instruments, and tests have been conducted with an eye to developing tools and training materials that can be transferred from expensive research techniques to commonplace, cost-effective engineering procedures.



**Taking manual extensometer readings of displacement in an underground mine to evaluate pillar stability.**

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## SURVEILLANCE OF MINE SAFETY HAZARDS


*Surveillance Team: Chuck Kerkering, Denise Rains, Eric Zahl, John Norberg, Ted Lowe, Tom Brady, Russell Levens, Carolyn Takeuchi, and Fred Biggs*


### RESEARCH OBJECTIVES

To provide hazard and accident information and the analytical tools necessary to ensure that the Spokane Research Laboratory addresses the most significant health and safety problems in the mining industry.

### PROBLEM STATEMENT

We are currently focusing our efforts on two approaches philosophically defined as the a priori (proactive) approach and the a posteriori (reactive) approach. The reactive approach is concerned with traditional "body counts"; that is, numbers of accidents, types, severity, etc., are recorded for various segments of the mining industry and then analyzed for trends and correlations. At present, MSHA is the prime source of information. There are, however, many other databases,

publications, and contacts, which we are now investigating as possible sources of information.

The proactive approach is concerned with detecting the presence of safety and health hazards and their possible consequences before any adverse consequences occur. This approach uses systematic safety assessment procedures to identify and eliminate hazards before accidents are triggered. Examples of such safety assessment methods include preliminary hazard analysis, fault-tree and event-tree analyses, and consequence analysis. These are excellent tools for research in areas considered dangerous, but where there is not a well-defined accident history (such as catastrophic failures, which are low-frequency but high-consequence events).

## RESULTS TO DATE

Until recently, there was no official surveillance activity at the Spokane Research Laboratory. Consequently, a team composed of personnel from throughout the center was formed to carry out surveillance activities. Six goals were established: (1) to identify and prioritize occupational health and safety problems in the mining industry with a focus on mining issues in the Western States, (2) to ensure that resources are being used to address the most important problems, (3) to track the effectiveness of health and safety research over time (a GPRA requirement), (4) to develop and refine the processes of surveillance and risk assessment, (5) to provide technical surveillance support to principal investigators and management, and (6) to ensure that important surveillance results are communicated to external customers and stakeholders.

Surveillance activities were divided into data analysis and systematic safety analysis.

### Data Analysis

- To date, 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.

- Data have been obtained from the Mine Inspection Data Analysis System (MIDAS), and some preliminary trends have been established for hearing loss and exposure to silica in surface mines.

- A "metadatabase" that lists all of the accident, injury, and health databases has been constructed that might be of help to health and safety researchers. To date, the most important of these databases is the MSHA database of coal and metal/ nonmetal mining accidents.

- A library of surveillance-related material is being computerized for easy access.

- A newsletter describing the surveillance activity was published.

### Systematic Safety Analysis

- A preliminary hazard analysis of the walkout escapeway in a longwall mine was completed.

- A qualitative fault-tree analysis of a malfunctioning ore pass was completed.

- Research has been started on developing a meaningful concept of risk as applied to mining activities. Prioritizing mining activities by risk incurred will help focus health and safety research.

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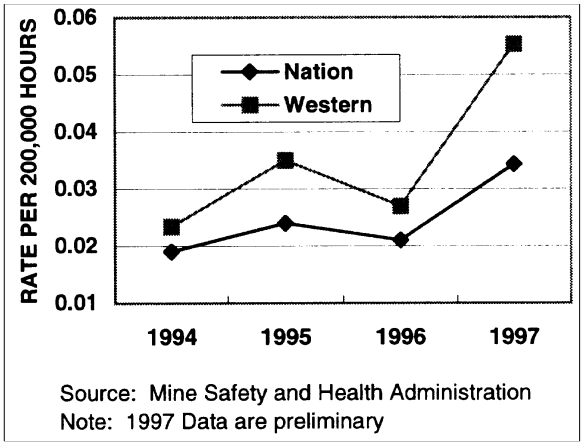


# COMMUNICATIONS AND TECHNOLOGY TRANSFER

*Communications Team: Elaine Cullen, Dale Avery, Ken Strunk, and Priscilla Wopat*

## RESEARCH OBJECTIVES

To consolidate the communications program at the Spokane Research Laboratory, assess its effectiveness, and develop new ways to meet the needs of the customers served by the laboratory.

## PROBLEM STATEMENT

We are focusing on three major areas: (1) technology transfer, which deals with providing technical information to the mining industry and other related industries to increase the level of industry participation in mine health and safety research, (2) public information, which includes the development of activities and forums for the dissemination of broad-based scientific information to the public, and (3) public outreach, which uses educational opportunities to teach the public about the importance of minerals, science, and technology in everyday life. These areas encompass all of SRL's external customers.

## RESULTS TO DATE

Although in the past there has been no official Communications Group at SRL, there has been a strong communications function. Consequently, many of the activities this year are continuations of very effective programs.

### Technology Transfer

SRL/NIOSH was represented by a booth, poster session, or presentation at several conferences, including the Governor's Safety Council conference, Northwest Mining Association convention, Society of Mining and Metallurgical Engineering conference, Montana Mining Association, NMA Communications conference, Western Mining Coalition conference, Mining Safety and Health conference, and National Mining Association convention. Three issues of Technology News were published, and a video on SRL entitled *The Spokane Resource* was completed. This video has been shown at several conferences and to visitors to SRL. Articles about the laboratory were published this year in *News Link*, the Federal Lab Consortium newsletter, and in *The Far West Bulletin*, the FLC western U.S. newsletter. A Web site for SRL is under development, and several patents and inventions are being guided through the system.

### Public Information

SRL was represented on the boards of numerous organizations, including the Northwest Natural Resources Institute, Spokane Area Chamber of Commerce, Spokane School District's Public Affairs Advisory Council, the Federal Executive Association, the New Century Plan, the Northwest Mining Association Education Committee, and the National Minerals Education Coalition. A representative from SRL also participated on the NIOSH Communication Advisory team.

### Public Outreach

More than 1,000 visitors were given tours of the Silver Kid Mine, a demonstration mine in the basement of the SRL facility. A televised tour through the mine was broadcast to more than 700 schools in the Pacific Northwest and Canada as part of the local Educational Service District's "Project Earth" class.

Several employees participated in the week-long Northwest Natural Resources Teachers' Workshop, during which hands-on earth science classes were presented to nearly 70 K-12 teachers. An old-time gold mining camp was set up and staffed, and 1,200 rock and mineral kits were built (with the help of area high school students) for this workshop and others like it.

SRL was an integral part of many regional education organizations, including the PARTNERS of the Greater Spokane Area, Northwest Natural Resources Institute, Chamber Education Council, Health Improvement Partnership, Partnership for Learning, Natural Resources Camp, and Potlatch Natural Resources Festival. Employees provided educational opportunities at "outdoor education days" at Camp Reed and Camp Spaulding, Riverside High School's Career Day, Bear Lake Outdoor Education Day, and Tekoa Natural Resources Camp. More than 3,600 students were reached during these activities.

**Teachers on tour in a deep underground mine in northern Idaho during a session of the Northwest Natural Resources Teacher's Workshop.**

# PITTSBURGH RESEARCH LABORATORY

# HEARING LOSS PREVENTION BRANCH

## Quiet-by-Design Engineering Noise Control

*Principal Investigator: J. Alton Burks*

### RESEARCH OBJECTIVES

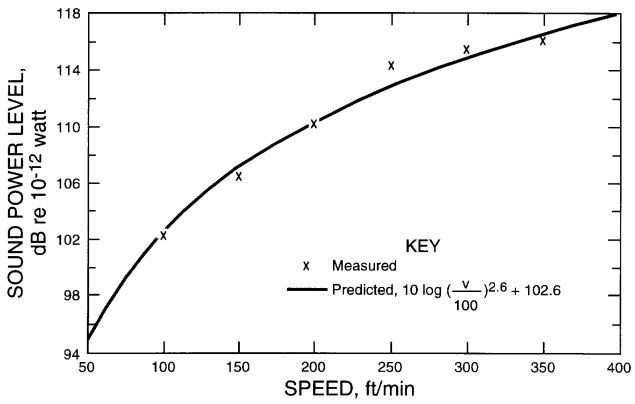
To work collaboratively with mining equipment manufacturers to fill gaps in noise control technology.

### PROBLEM STATEMENT

The quiet-by-design technology development activity is a vital component of an overall effort to prevent noise-induced hearing loss. The primary emphasis of the research is to identify and develop quiet-by-design technology that can be integrated into the design of new mining equipment. Where feasible, cooperative research with equipment manufacturers will be sought to ensure a new generation of quiet mining machines. The most obvious machines and processes that should be addressed at the design stage are conveyors, percussion drills, cutting heads, and mobile diesel equipment.

### RESULTS TO DATE

This is a new project. A sound and vibration laboratory with state-of-the-art measurement and analysis capabilities is needed to support this research. Thus, considerable effort is being devoted to identifying and procuring the hardware and software to upgrade the measurement and analysis capabilities of the present Noise Laboratory. Two researchers of the Hearing Loss Prevention Branch have attended a workshop on noise prediction software. We are also seeking the cooperation of a manufacturer who is interested in pursuing development of the variable-speed conveyor drive concept.

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## Technical Assistance for Hearing Conservation

*Principal Investigator: J. Alton Burks*

### RESEARCH OBJECTIVES

To control the noise exposure of miners by identifying and implementing intervention strategies that use existing technologies and information.

### PROBLEM STATEMENT

Twenty-five percent of the Nation's miners continue to work in an environment where time-weighted average noise levels exceed 90 dBA. A key provision of the new noise regulation proposed by MSHA will require the industry to use all available engineering noise controls, with no credit allowed for the use of personal hearing protection. Thus, providing technical assistance to the industry, especially to small mining opera-tions, to help them with designing and implementing short-term solutions on existing equipment is considered a critical adjunct to long-range research in developing new, quiet equipment. Such assistance will also provide opportunities to explore new applications for existing technologies, investigate "hot spots," and interact directly with those mine personnel who are actually responsible for implementing noise controls.

### RESULTS TO DATE

This is a new project. MSHA has requested assistance in the development of retrofitable noise controls for air-track surface mining drills. This effort will consist of designing operator booths and partial barriers, documenting their acoustical performance, and providing guidelines for their use. Initial work has concentrated on measuring the noise levels produced by a drill at PRL's Lake Lynn Laboratory. Levels

of 110 dBA have been recorded. Discussions are also underway with a silica operation to identify intervention strategies for reducing noise exposures among mill workers. To date, measurements of noise levels and reverberation times have been obtained on pebble mill and screening tower facilities at one plant.

**Conducting an acoustical survey in a silica plant.**

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## Hearing Conservation Communications/ Technology Transfer

*Principal Investigator: J. Alton Burks*

### RESEARCH OBJECTIVES

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

### PROBLEM STATEMENT

Despite progress during the last 2 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 NIHL and the potential solutions currently available are critical components of a strategy to eliminate NIHL 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 is a new project. Preliminary work is underway to plan, organize, and conduct a workshop later this year for all parties having a stake in preventing NIHL. The workshop will be used as a forum to examine why miners are still losing their hearing after 25 years of regulation. A primary goal of the workshop will be to solicit feedback from stakeholders to assist in defining a research agenda that is responsive to their needs.

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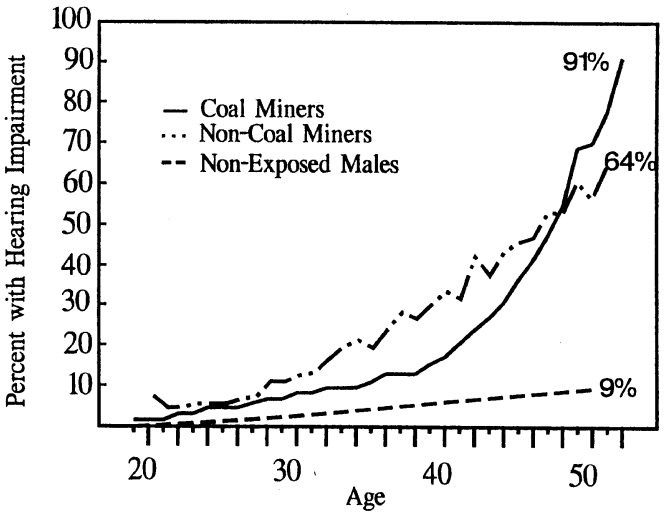


**Males with hearing impairment.**

# MINING INJURY PREVENTION BRANCH

## Coal-Rock Interface Detection Systems

*Principal Investigator: Gary L. Mowrey*

### RESEARCH OBJECTIVES

To develop and evaluate sensor technologies to provide operators of coal extraction machines with enhanced sensory information for identifying the coal-rock interface.

### PROBLEM STATEMENT

Sixteen thousand workers operate face equipment and are at the face for the entire shift in underground coal mines. Jobs exposing workers to the greatest hazards involve the operation of roof bolters and coal cutters. Any people standing near these moving machines are at risk of being exposed to dust and noise or being struck by the machines. Occasionally, the roof and/or rib caves in on the worker. The operation of mining machines requires visual acuity and a trained ear to determine when floor and roof rock are beginning to be cut. At mines where coal must be left in the roof and/or on the floor, maintaining a consistent remnant coal layer, which maintains the competency of the roof and floor, is also difficult to achieve. Better sensors would help operators control machines to reduce the generation of dust and noise and leave the required amount of roof or floor coal to provide strata stability.

### RESULTS TO DATE

A PC-based program was developed to provide information about coal rib thickness in real time. This program is to be used with U.S. patent 5,500,649, "Method and Apparatus for Monitoring the Thickness of a Coal Rib During Rib Formation," which was issued March 19, 1996.

Two prototype systems were developed—an infrared-based coal-rock interface detection (CID) system that consists of a thermal infrared imaging camera, three accelerometers and two inclinometers, and a video-based CID system that consists of a low-light, high-resolution video camera with three accelerometers and two inclinometers. In addition, two prototype MSHA-approvable, roof bolt vibration monitoring systems were developed.

This project was concluded at the end of FY97.

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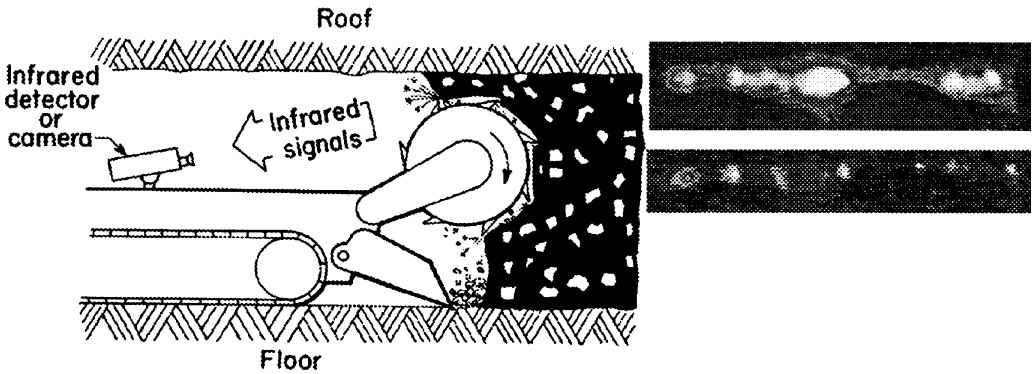


**Schematic of infrared-based, coal-rock interface detection system.**

## Control Circuit Safety Analysis

*Principal Investigator: John J. Sammarco*

### RESEARCH OBJECTIVES

To conduct a safety analysis of processor-based control systems and safety-related devices for mining. The objective is to improve the safety of mining systems and devices by providing guidance for safe application of this emerging technology. The scope includes the approval and certification process, development, testing, and maintenance.

### PROBLEM STATEMENT

Processor-controlled equipment and systems are increasingly being employed in mining. Already, the safe application of this new technology has challenged MSHA concerning accidents involving processor-controlled longwall shields. Currently, only permissibility of electrical equipment is addressed; therefore, the equipment can still be unsafe because the *functional safety* of processor-based control is not addressed. This leaves questions on how to develop, evaluate, and maintain functional safety, as well as how to conduct accident in-vestigations involving processor control effectively.

### RESULTS TO DATE

A panel composed of representatives from the mining industry, equipment manufacturers, an industry trade association, MSHA, NIOSH, and academia was formed to discuss safety issues concerning processor-based mining equipment. The information and ideas that emerged from this panel's meetings were crucial in identifying both the hazards and benefits of the technology. Additional input was received from The Pennsylvania State University and the University of Alabama, which, after mine site visits, had completed an industry study to identify safety issues. Based on this information, unintentional movement or "ghosting" of longwall shields was identified as the most immediate problem. In addition, potential safety problems were categorized as software, hardware, and human factors problems for processor control and served to focus the project.

A study of accident data and prevention techniques in other industries was completed, and more than 200 international standards pertaining to processor safety were reviewed to establish their applicability to mining and their suitability as initial benchmarks. What has resulted is a safety-critical systems approach focusing on *system functional safety*. The first step of this approach is generation of a system safety program plan (SSPP). A draft SSPP for mining is about 70% complete. The SSPP provides guidance on all aspects of processor-based system development, including hardware and software safety, documentation, maintenance, and functional safety evaluation criteria.

Compilation of system and software safety references was completed and has served to accelerate the learning curve for the mining industry and for project members. The list contains more than 200 international standards, exceptional books, confer-ence papers, and safety-related Internet sites. This information has been requested by others in the system safety community such as Underwriter Labs. In addition, a reference collection of international standards, handbooks, guidelines, and textbooks has been established. This collection pertains to topics that include system safety, all phases of software development, hardware, and safety-critical evaluation.

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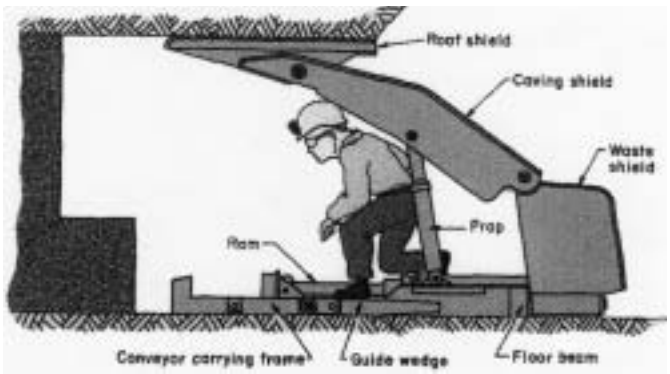

## Control Systems for Mobile Equipment

*Principal Investigators: Chris Jobes, William Monaghan, Tim Lutz, Tim Matty, and William Schiffbauer*

### RESEARCH OBJECTIVES

To develop and evaluate the concepts and practical use of remote control systems for mobile mining equipment so that operating personnel can be moved away from the hazards of the immediate area around the equipment.

### PROBLEM STATEMENT

The jobs that expose workers to the greatest hazards in an underground coal mine are clustered around the area where machinery digs coal from the surrounding rock or involve bolting the roof. Of the 337 deaths and 72,748 severe injuries to workers in underground U.S. mining operations between 1986 and 1995, 113 deaths and 18,704 severe injuries involved this equipment.

With remote control of mining equipment, sensors are necessary to provide the operator with information on the position and orientation of the equipment relative to mine geometry and geographical coordinates, the positions of all operating appendages, and the status of other machine functions. This project addressed all nonnavigational sensors; data acquisition and communication hardware and software; control system design and programming; and the selection, design, and construction of all hardware for the equipment.

### RESULTS TO DATE

A system for remote computer control of a continuous haulage system was designed, built, coded, and installed. The system includes both hardware and software. The control system for haulage was then integrated with a previously designed control system for a mining machine. Both systems were then tested as a single system in the Pittsburgh Research Laboratory's Mining Equipment Test Facility. The control system performed as specified.

Under a CRADA with Joy Technologies, a cable reel system for continuous mining machines for extended-cut mining was designed. Tests of the reels were conducted to determine design ruggedness and ensure that individual components in the system were sized properly. The reels performed as specified and endured the test without failing.

A prototype proximity warning device known as HASARD was designed and demonstrated to MSHA at the agency's request. This device warns personnel when they enter a hazardous area around any mobile machine. In FY98, the system will beinstalled on a mining machine and evaluated in-mine under a cooperative agreement with a mining company and MSHA.

This project was concluded at the end of FY97.

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**Control of a cutter from a remote location.**

## Operator Interfaces for Remote Control

*Principal Investigators: Ed Fries, Chris Jobes, and George Schnakenberg*

### RESEARCH OBJECTIVES

To develop and evaluate the concepts for and practical use of operator interface technology for remote control of mobile mining equipment so that operating personnel can be relocated from the hazards of the immediate area around the equipment.

### PROBLEM STATEMENT

The jobs that expose workers to the greatest hazards in an underground coal mine are concentrated around the area where machinery extracts coal from the surrounding rock or involve bolting the roof. Of the 337 fatalities and 72,748 severe injuries to workers in underground U.S. mining operations between 1986 and 1995, 113 deaths and 18,704 severe injuries involved this equipment.

With remote control of mining equipment, the operator needs both information on the status and performance of the equipment and the controls to operate the machines manually. Operator interface technology was developed and evaluated for automated miners and haulage.

### RESULTS TO DATE

An operator interface for use in a follow-the-leader, straight-ahead mining scenario was developed, coded, tested, and demonstrated. Additions to the operator interface included displays of various types of sensor data. The operator interface performed as specified and provided a more-than-adequate interface with which to operate mining and haulage machines.

A high-resolution, graphical interface was developed that provides control and path-planning algorithms, communication handling, and sensor data processing for automated miners and haulage. The graphical user interface provides the operator with not only a real-time picture of what is happening to the equipment, but also access to equipment control tasks.

This project was concluded at the end of FY97.

**Graphical operator interface for machine control.**

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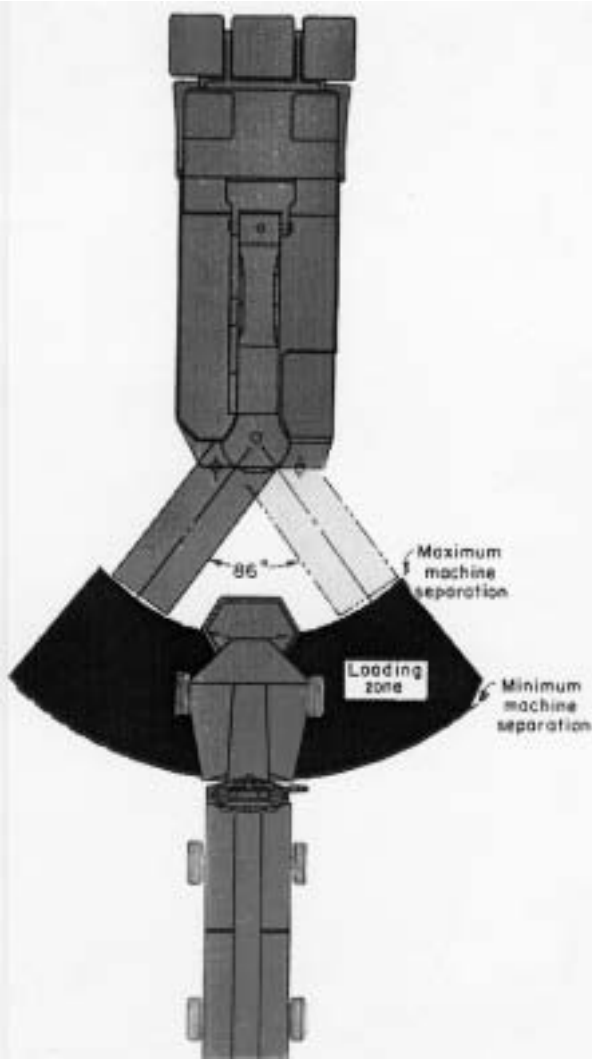
## Navigation and Guidance Systems for Mobile Equipment

*Principal Investigators: Chris Jobes, Tim Matty, John Sammarco, and William Schiffbauer*

### RESEARCH OBJECTIVES

To develop and evaluate the navigational systems for remote control systems for mobile mining equipment so that operating personnel can be relocated away from the hazards of the immediate area around the equipment.




Sensors on continuous mining and haulage system.

### PROBLEM STATEMENT

The jobs that expose workers to the greatest hazards in an underground coal mine are clustered around the area where machinery digs coal from the surrounding rock or involve bolting the roof. Of the 337 deaths and 72,748 severe injuries to workers in underground U.S. mining operations between 1986 and 1995, 113 deaths and 18,704 severe injuries involved this equipment.

With remote control of mining equipment, sensors are necessary to provide the operator with information on the position and orientation of the equipment relative to mine geometry and geographical coordinates, the positions of all operating appendages, and the status of other machine functions. This project addressed all navigational sensors for the equipment being controlled.

### RESULTS TO DATE

An inertial guidance sensor (a ring laser gyroscope called the Honeywell Ore Recovery and Tunneling Aid (HORTA) was modified for use on a continuous mining machine. This sensor monitors azimuth, pitch, roll, and position. Tests were conducted in an open-pit mine to determine the sensor's accuracy in mining situations. These tests proved that the HORTA could provide accurate navigation for continuous mining machines.

A tension inner machine sensor system was developed as a simple solution to follow-the-leader-type guidance for continuous haulage in mining systems controlled by remote computers. The sensor provides information relative to the separation distance of the continuous haulage and continuous miner along with the orientation of each system relative to the other. The necessary information for a continuous haulage system follows a continuous mining machine during mining, regardless of method (highwall, room-and-pillar, underground punch). This system consists of three sensors and a cable reel positioning-and-tensioning system.

Use of the DynaSight sensor was studied to evaluate its suitability for integrating extraction and haulage processes to reduce the potential for miners to get struck or caught by moving machinery. In a series of tests in which the sensor was subjected to machine vibration, shock, dust, and random target obstructions, it continued to provide accurate data and thus was shown to be extremely well suited for this application.

A scanning laser range sensor (Typhoon) was developed. This sensor scans 360° in azimuth and 40° in elevation, accumulating 2,048 range data points per revolution for each of 200 angles of elevation. The sensor is useful for mine mapping, machine guidance, and obstacle detection.

Navigation system software for use in a follow-the-leader highwall mining scenario was developed, coded, tested, and demonstrated. This navigation system used HORTA and the data calculated from the tension machine positioning system

to coordinate the mining machine and continuous haulage. During the demonstration, the system performed as specified.

This project was concluded at the end of FY97.

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**PATENT APPLICATION FILED:** CDC EIR: I-019-97/0; Patent Novelty Search Evaluation completed.

## Equipment Safety Analysis Using Computer Simulation

*Principal Investigator: Dean Ambrose*

### RESEARCH OBJECTIVES

To 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 fatalities and injuries. 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.

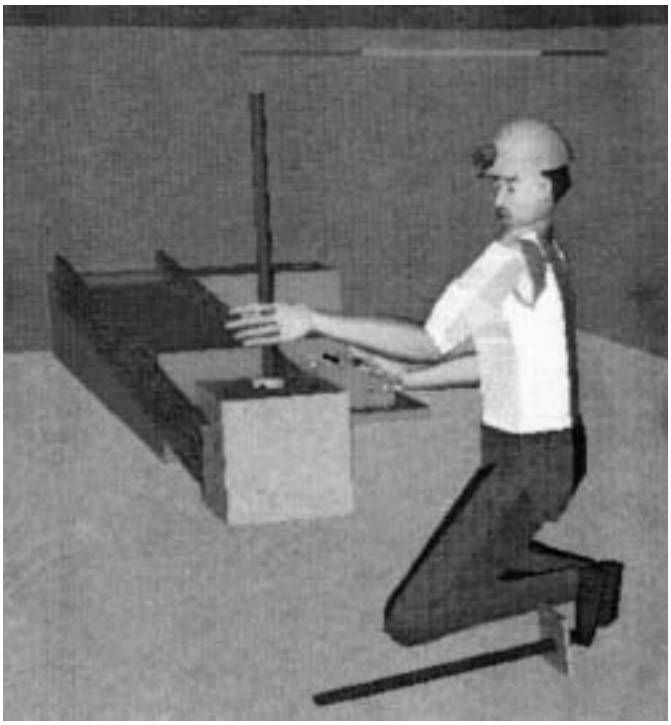
There is a need to view underground and surface mining incidents as a gradually developing sequence of multiple events, rather than in terms of an immediate, last factor in an emergency situation. The intent of this research is to re-create and analyze mine incidents involving mining equipment using 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 continue on determination of a safe, practical drill boom speed for roof bolters. Initial experiments with human motion data were completed and integrated with a roof bolter model using JACK, a human modeling and simulation software. The results provided valuable modeling experience in preparation for additional experiments that will reflect human-operator anthropometric scaling, physical changes in a mine environment, and variable speeds on the boom of the roof bolter.

A study continues to assist MSHA in understanding problems associated with a mine hoist incident. A previously developed mine hoist model was modified to show some of the

detail of the safety brake device to give MSHA additional information into operation of the hoist's brake system. Results showed further simulation detail is needed. The hoist model is being modified to show the safety latch mechanism.



**Human-motion data integrated with roof bolter model using JACK, a human modeling and simulation software program.**

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## Human Factors of Extended-Cut Mining and Other Underground Coal Extraction Methods

*Principal Investigator: Lisa J. Steiner*

### RESEARCH OBJECTIVES

To determine safe positioning and work procedures for continuous miner operators using industrial engineering methods to evaluate the interactions of mining sequence, equipment, job procedures, and mine environment.

### RESULTS TO DATE

A fatality scenario has been developed and is being field tested as an interviewing tool for continuous miner operators. The scenario allows us to study and better understand miners' decision-making processes when turning a crosscut.

Observational data on continuous miner operators and the face crew have been collected at several mines to determine the interactions among methods, crosscut angles, equipment, and mining sequences.

Investigations and development of a warning device for unsupported roof are underway.

Data collected at West Virginia deep-cut mines in collaboration with the West Virginia State Miner's Health and Safety Office are being analyzed. Operator positioning studies along with the West Virginia State data are leading to a better understanding of the demands placed on operators and the methods used by mine operators to increase safety among crew members.

Ergonomic analyses of an extendable methane probe for 20-min gas checks are continuing as designs are developed.

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## Human Factors Design for Machinery Safety

*Principal Investigator: August J. Kwitowski*

### RESEARCH OBJECTIVES

To 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 mining. Much of the research conducted to date has attempted to redesign the equipment or develop experimental remote control technologies in an attempt to relocate workers from the hazards. The application of human factors design principles has been underutilized and needs to be considered alone or in combination with simple engineering controls as a means of decreasing machinery accidents in underground mines.

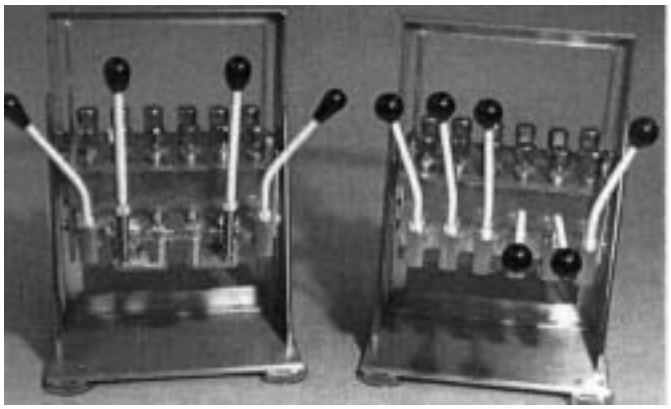
### RESULTS TO DATE

A broad range of ongoing tasks from past and existing projects are being completed or continued as a unified effort. FY97 highlights include the following:

- Working models of mining machinery controls were designed and fabricated to demonstrate good and bad ergonomic features. Concepts exhibited included activation forces, control spacing, control orientation, and utilization of joystick controls in lieu of single-control levers. The first use of these models will be at a short design seminar to be held at the MSHA Academy for mine trainers.

- J. H. Fletcher and Co., a major roof bolter manufacturer, was given details on the advantages and means of implementing a less abrupt, "soft" start on its drill motors to prevent operators' hands from being injured while beginning the drilling or bolting cycle. This option was first presented in a NIOSH report requested by the manufacturer that evaluated the relative ergonomic effectiveness of its control designs. Several designs for the soft start of the drill motors were discussed with the manufacturer's design engineering manager; incorporation of the feature on future roof bolter machines is being seriously considered.

- A surveillance effort identified areas that should be included in a successful machinery injury reduction program, including improved operator protection from ground falls, increased operator visibility and machine maneuverability, and improved tools for materials handling and maintenance. Additionally, the significantly higher frequency of injuries for roof bolter operators should be addressed by selective redesign of machine components and bolting procedures. The project will address these areas to the extent that available resources allow. An effort will also be made to consolidate results from past research on machinery into a comprehensive document.



**Working models of mining machinery controls to demonstrate good and bad ergonomic features.**

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## Systems Approach To Reduce Manual Task Injuries

*Principal Investigator: Sean Gallagher*

### RESEARCH OBJECTIVES

To reduce the incidence and prevalence of injuries resulting from physically demanding manual tasks.

### PROBLEM STATEMENT

Evidence shows that work-related musculoskeletal disorders affect mine workers to a greater degree than these disorders affect workers in other industries. This project consists of two initiatives directed at reducing work-related musculoskeletal disorders in mining. The first is to conduct an analysis of hazards involved with manual tasks in mines using a broad range of mining methods. The second is to evaluate the effectiveness of the participatory ergonomics approach in the mining industry.

### RESULTS TO DATE

The job analysis portion is in the surveillance stage. A literature review and an accident analysis of the MSHA database have been intitiated. A breakout session on participatory ergonomics in mining was arranged and held at the conference on "Ergonomics: Effective Workplace Practices." Proceedings of the session have been placed on the NIOSH Web page and have been used to promote awareness of the successful application of ergonomics in mining. Two potential cooperators have expressed an interest in initiating an ergonomics process that would be evaluated by NIOSH. A draft CRADA has been sent to one of these cooperators. Other accomplishments include publication of a case study on injuries associated with roof bolter tasks. Researchers on this project have been working with the newly formed MSHA Ergonomics Team in its efforts to promote the use of ergonomics in the mining industry.

**Awkward postures adopted in the performance of mining tasks may lead to increased risk of musculoskeletal injury.**

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## Intrinsic Safety

*Principal Investigators: James Cawley and Thomas Dubaniewicz*

### RESEARCH OBJECTIVES

To improve the safety of underground coal mine workers by determining (1) the ignition characteristics of oxygen-enriched, methane-air atmospheres for intrinsic safety tests and (2) the safe application of laser technology in methane-air atmospheres containing dust.

### PROBLEM STATEMENT

MSHA requested that the Pittsburgh Research Laboratory conduct research to characterize whether oxygen-enriched methane-air atmospheres could be used as a testing medium for MSHA's intrinsic safety approvals testing. Intrinsic safety devices are increasingly voltage-sensitive and do not lend themselves to traditional testing methods in which voltage and/or current are increased to provide a safety factor. Experience and existing intrinsic safety testing facilities are ideally suited to this highly specialized research.

Laser technology has been proposed as a way to measure methane concentrations at the faces of underground coal mines. However, laser beams have been shown to ignite dust particles suspended in methane-air atmospheres at relatively low beam power levels. MSHA intrinsic safety evaluation criteria do not address this emerging technology. Before use of laser technology becomes widespread, ignition characteristics must be examined and safe operating procedures in methane-air atmospheres proposed.

### RESULTS TO DATE

#### Task 1

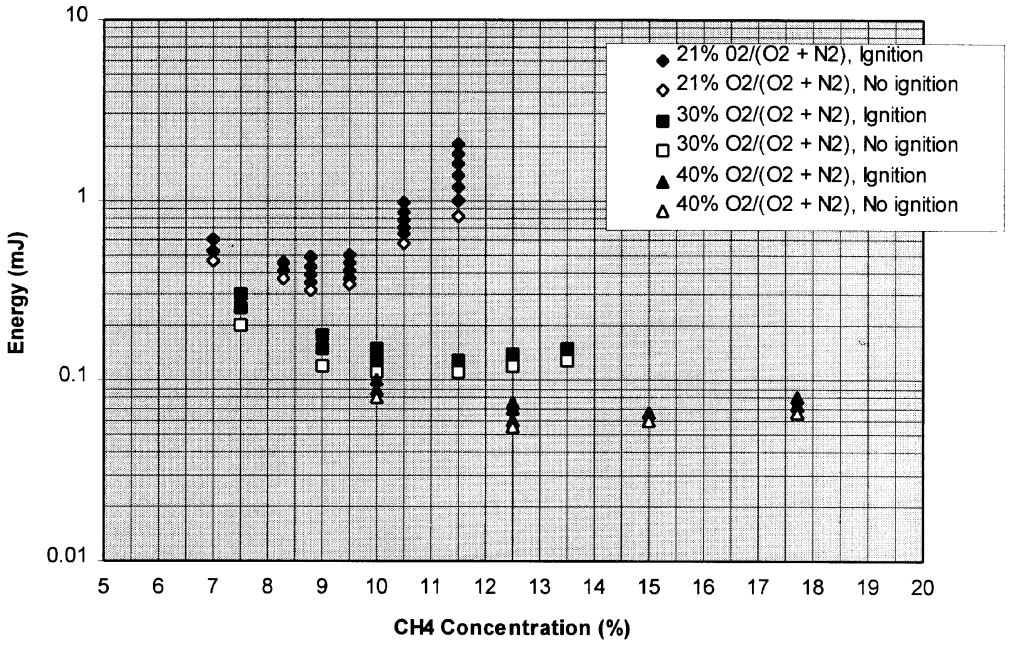
- The minimum ignition energy (MIE) for 1.57-mH inductor circuits in the standard test apparatus using 21% $O_2/(O_2 + N_2)$ is approximately 0.33 mJ, *not* 0.45 mJ as published in the literature.

- The MIE for 1.57-mH inductor and 104-$\mu$F capacitor circuits in the standard test apparatus occurs with an 8.8% $CH_4$-21% $O_2/(O_2 + N_2)$ mixture, *not* an 8.3% $CH_4$-21% $O_2/(O_2 + N_2)$ mixture.

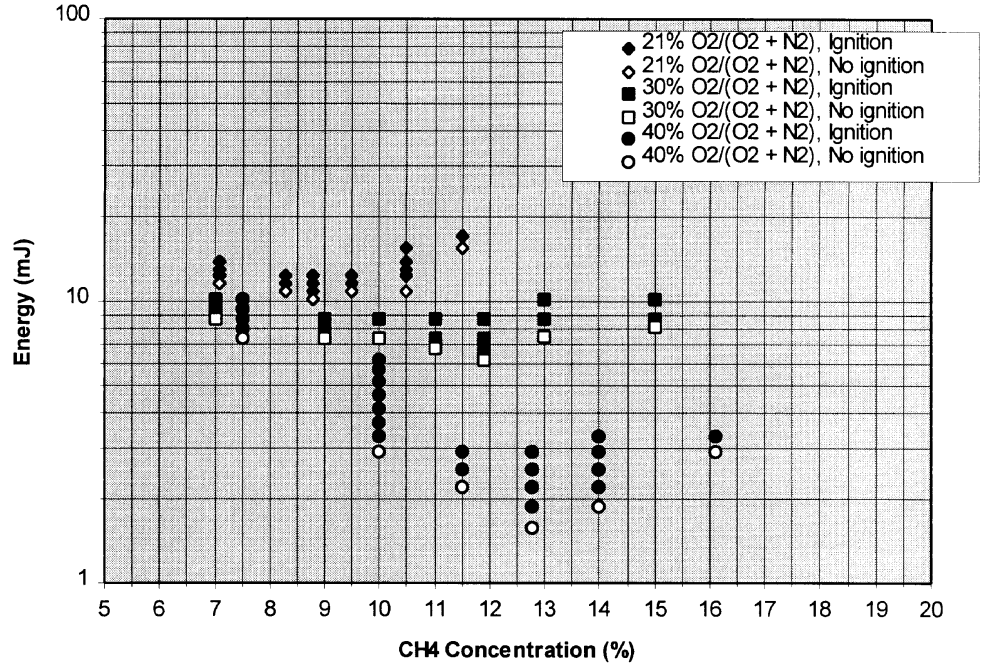
- The MIE for 1.57-mH inductor circuits in the standard test apparatus with a 10.5-11.0% $CH_4$-30% $O_2/(O_2 + N_2)$ mixture is 0.115 mJ.

- The MIE for 1.57-mH inductor circuits in the standard test apparatus with a 12.5% $CH_4$-40% $O_2/(O_2 + N_2)$ mixture is 0.057 mJ.

**Minimum Ignition Energy vs. Methane Concentration, 1.57 mH Inductor**




**Minimum Ignition Energy vs. Methane Concentration, 100 uF Capacitor**



- The MIE for 104-$\mu$F capacitor circuits in the standard test apparatus with an 8.8% $CH_4$-21% $O_2/(O_2 + N_2)$ mixture is 10.5 mJ. This agrees roughly with UL 913's estimate of 12.8 mJ, but is greater than the 0.45 mJ from published MIE curves. The variance may be attributable to the difference in the spark ignition mechanisms.

- In general, UL 913's empirical curves are a better estimate of capacitor MIE than the published curves.

### Task 2

- Minimum igniting powers for target areas of 0.031, 0.126, and 0.5 $mm^2$ were 0.6, 1.1, and 2.2 W, respectively, indicating that methane-air ignitability is proportional to the square root of target area over the areas studied.

- Optical absorptivity played a more significant role than ignitability of coal dust particles in igniting methane-air mixtures over the target areas studied.

- Minimum igniting powers were relatively independent of methane gas concentrations from somewhat less than stoichiometric to 8% methane in air. This is in contrast to MIE phenomena, which show a much stronger dependence on gas concentration.

## Geological Hazard Detection

*Principal Investigator: Robert L. Chufo*

### RESEARCH OBJECTIVES

To develop one-, two-, and three-dimensional imaging systems to "see" into and through unmined roof, floor, and rib in mines; detect and visualize concealed safety hazards; and accurately measure distance to the hazard and thickness of multilayered deposits.

### PROBLEM STATEMENT

Fundamental problems exist with imaging hidden anomalies in surface and underground mines. Conventional time-domain radar techniques do not measure electrical properties of the material and are unable to deal with the nonlinear nature of the media and the antenna. This is called dispersion. A unique frequency-domain technique was developed and field tested to overcome the drawbacks of other methods.

### RESULTS TO DATE

The one-dimensional system, called the radar coal thickness sensor, received the R&D 100 Award from "R&D Magazine." This system measures (1) coal, rock, and concrete thickness from zero to over 10 ft with an accuracy of 1 in, (2) individual layers in multilayered deposits, (3) electrical parameters of the material, and (4) locations of roof fractures.

The two-dimensional version measurements distance and azimuth and determines the location of multiple targets. Progress has been made in the development of three-dimensional software and the accompanying field hardware, but the research is not complete. Field hardware was designed to replace laboratory instruments now used to demonstrate the technology. New antennas were developed specifically to use in through-the-earth imaging, and dielectric materials were developed for encasing the antenna so that it could effectively couple energy to the target media without contacting the target media. Field tests were conducted at several highwalls at surface mines, several underground coal mines, and the Lake Lynn mine. To show that the system could be configured to detect roof hazards, limited tests were conducted in the Bruceton and Lake Lynn mines. Known roof faults were detected at the Bruceton mine. Because of the limited time available at the Lake Lynn mine, long-term measurements of roof movement collected from a stable platform could not be properly run.

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**Detecting roof faults in the Bruceton mine.**

## Fire-Fighting Skills and Communications

*Principal Investigator: Michael J. Brnich, Jr.*

### RESEARCH OBJECTIVES

To determine the state of the coal industry's fire-fighting preparedness in underground operations.

### PROBLEM STATEMENT

Fires have been one of the leading causes of coal mine disasters since the beginning of mining in the United States. Between 1984 and 1994, MSHA investigated 115 reportable underground mine fires, or an average of 10 fires per year. These fires resulted in 28 fatalities and 30 injuries, as well as production losses totaling hundreds of millions of dollars.

The success of safely controlling and extinguishing an incipient mine fire depends on several factors, including awareness of fire hazards, early detection of a fire, the availability of effective fire-fighting equipment, and response time. This project addresses two tasks that focus on the human element in mine fire-fighting and preparedness.

Task 1 includes (1) an assessment of workers' readiness to fight incipient fires underground, (2) definition of the training and technology infrastructure necessary to respond to underground mine fires, (3) development of methods to investigate variabilities in responses to fires within and across mine sites, (4) exploration of innovative methods to enhance industry's awareness of the dangers of underground mine fires, and (5) development of fire-fighting training protocols for new hires and experienced miners.

Task 2 involves in-depth interviews with 29 mine rescue veterans regarding their experiences in managing mine emergencies, including mine fires.

### RESULTS TO DATE

Under a CRADA with a cooperating western U.S. coal mine, field tests of both fire response and fire prevention preparedness checklists (begun in late FY96) have been completed. Initial field tests of both fire hazard identification and fire risk assessment instruments were completed, and an instructor's guide was written. Following a meeting at the cooperator's mine, work began on developing fire-fighting training protocols for both inexperienced and experienced miners.

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## Effective Emergency Warning, Escape, and Evacuation

*Principal Investigators: Launa G. Mallett and Audrey F. Glowacki*

### RESEARCH OBJECTIVES

(1) To improve communications during mine emergencies by developing an emergency communication protocol and training package with a memory aid and (2) develop a stochastic computer simulation for training command center personnel who are responsible for managing mine rescue operations.

### PROBLEM STATEMENT

As the number of major mine disasters decreases, the number of individuals having first-hand experience with major mine emergencies is also decreasing. A gap is being created that could have serious consequences in future mine disasters. One concern is that of the effective evacuation of endangered miners. Workers often neglect to give or ask for important information about the situation. This lack of communication can place escaping miners at unnecessary risk and reduce the efficiency of the emergency response. A second concern is inadequate training of first-line command center leaders who would direct rescue operations if an emergency should occur at their mines. Although MSHA and some larger mines periodically stage mock drills, these events are time-consuming to develop, set up, and present. Furthermore, preparedness training is not currently mandated for these workers.

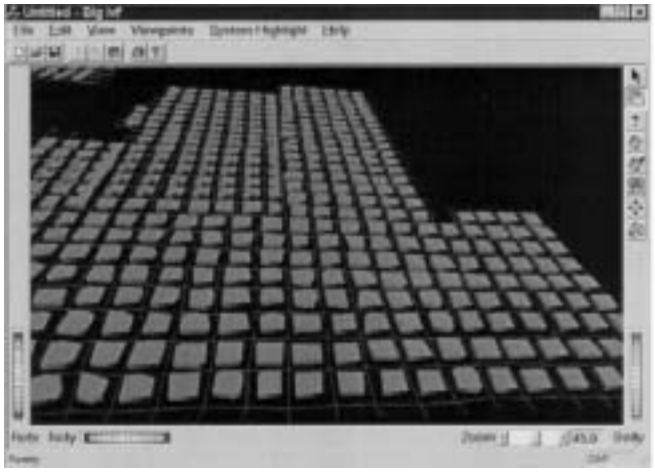
Since 1984, the Pittsburgh Research Laboratory has investigated many aspects of disasters, including evacuation, rescue, fire-fighting, and emergency management. This research will be used to develop and test an effective emergency communications protocol. It will also be used to develop the Mine Emergency Response Interactive Training Simulation (MERITS) software to be transmitted to users via the Internet.

### RESULTS TO DATE

An emergency communications training package, the Emergency Communications Protocol, was drafted. Authentication of the package was conducted with a number of safety professionals. The materials were then tested during a field

experiment at a cooperating mine. Initial analyses showed improvements in each of the six designated categories of information given and received during the simulated emergencies. More detailed analyses and further testing are planned for FY98.

Information required for developing a realistic simulation of a mine was outlined, and a draft emergency scenario was started. A map of a prototype mine was designed with the assistance of MSHA Tech Support and then scanned. A workforce with designated skills and responsibilities was developed for this mine. A thinning algorithm was written to identify mine pathways using scanned mine maps. Prototype client software for displaying mine maps in two and three dimensions was written using Open Inventor. This map-viewing software provides pan and zoom capabilities and can hide or display specific mine systems (e.g., ventilation, haulage, communication lines) and objects (e.g., pillars, paths, miners). A timer-based utility to update client map information periodically and communicate with the host was developed using Active Server Pages, Dynamic HTML, and Visual Basic Script. A Windows NT Web server was set up for software development and testing. Conversion of the MFIRE mine ventilation model to C language for future integration into MERITS is nearly complete.



**Three-dimensional views of MERITS mine map (experimental version).**

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## Preventing Falls in Mining and Related Industries: A Systems Approach

*Principal Investigator: Charles Vaught*

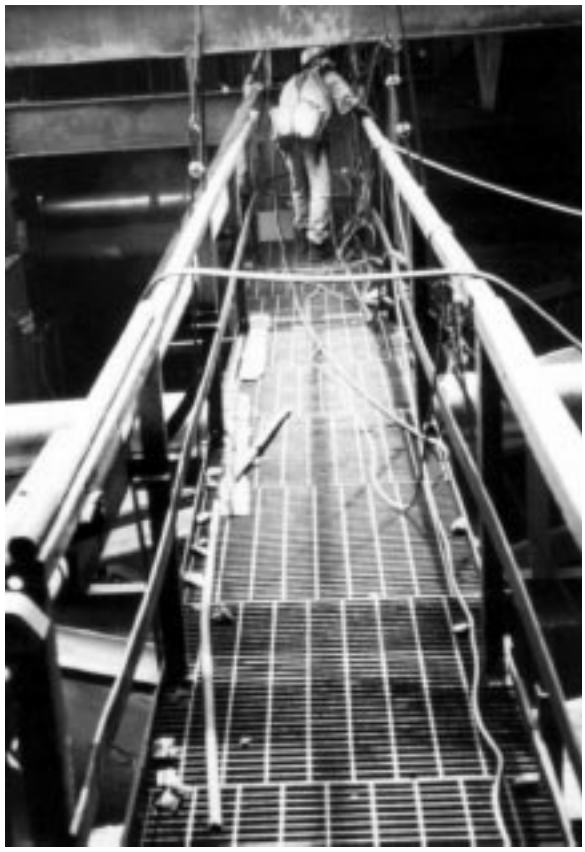
### RESEARCH OBJECTIVES

To protect miners and others who work under highly variable environmental conditions from injuries related to slips, trips, and falls by (1) developing a systems-oriented prevention program that considers all factors in the traditional hierarchy of controls, (2) testing this module at selected worksites in both the Eastern and Western United States, and (3) on the basis of field test results, design and distribute an intervention program to industry.

### PROBLEM STATEMENT

The National Council on Compensation Insurance puts the average cost of a fall- or slip-related claim at $13,000. 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. The fall prevention programs that 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 7,007 falls resulting from slips and trips made this one of the largest categories of lost-time injuries for the period 1992-94, 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, typical interventions might have limited application in a mining environment. Research leading to more robust intervention addresses (1) intervention effectiveness and (2) organization of work.



**Types of tripping hazards encountered during maintenance at a coal preparation plant.**

### RESULTS TO DATE

Researchers have compiled MSHA accident narratives in which slips, trips, and falls were implicated for the 5-year period from 1990 to 1994. A questionnaire has been designed to assess workers' attitudes toward injuries resulting from these types of incidents. A tabletop simulation that deals with how to investigate a fall-related injury, developed independently of this project, has been identified and is being assessed for its efficacy as a possible intervention tool. A risk assessment instrument has been identified for use with focus groups. A literature search has been completed.

Oral agreements have been made with officials at three research sites: an underground bituminous coal mine in the Eastern United States, a surface mine in Pennsylvania's anthracite region, and the Nation's largest rebuilder of heavy truck parts. Top management at all three companies has pledged support and, where a union is involved, the local union has been equally supportive. The underground bituminous mine and the surface anthracite mine already have self-reporting protocols in place to record noninjury falls resulting from slips and trips. Company personnel have shared these data with researchers, and such information is being used to construct a database that can be applied at all three sites.

## Hazard Reduction for Surface Mining Powered Haulage Equipment

*Principal Investigators: Jesse Jaspal, Fred Turin, and William Wiehagen*

### RESEARCH OBJECTIVES

To develop an economic model of end-dumping procedures used by haulage truck operators in which the social and economic costs of end-dumping over an edge are compared to dumping short of the edge and using bulldozers to move and level the material.

### PROBLEM STATEMENT

Injury data suggest that the current practice of using haulage trucks to dump material directly over an edge carries a certain amount of risk to haulage truck operators. This work seeks to balance these perceptions with an in-depth analysis of injury data identified for bulldozer operators working near an edge and haulage trucks dumping material directly over an edge.

### RESULTS TO DATE

A subset of injury data was identified for coal and metal/nonmetal mines that (1) use haulage trucks to dump material over an edge and (2) bulldozer operators working near an edge for the period from 1988 to 1995. The set included 320 lost-time injuries (degree of injury rated 1 through 4). Narratives were analyzed for each injury, and a coding scheme was developed that included the activity, result, factors contributing to the injury, and factors contributing to the severity of the injury.

The project team collected a set of operating procedures and safety training materials that relate to haulage trucks and bulldozers working at dump sites. These materials were gathered from MSHA, domestic mining firms, and the Canadian government. Work is in progress to better organize these materials.

Project team members visited a surface coal mine in August 1997. This visit was the first step in obtaining cooperation from a mine to serve as the location for a case study in which alternatives to dumping directly over an edge would be explored. Much information was obtained during this visit, including inventories of haulage equipment, safe working procedures, cycling times of haulage trucks when plug dumping, and instructional material for haulage truck operators. Future site visits will offer an opportunity to collect more detailed information relating to cycling times and equipment operator perceptions of the safety risks involved while dumping over an edge.

A case study approach will be used in FY98 to determine the merits of a safety and economics model to use in comparing differences among dumping procedures. Goals are to (1) design data collection forms and procedures for the field study, (2) work with a mine to conduct a time study and safety assessment (observations and operator interviews) of the two procedures, and (3) review and analyze injury data comparing end-dumping to dumping short and bulldozing material over an edge.

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## Elevator Ascending Overspeed Protection

*Principal Investigator: Peter Kovalchik*

### RESEARCH OBJECTIVES

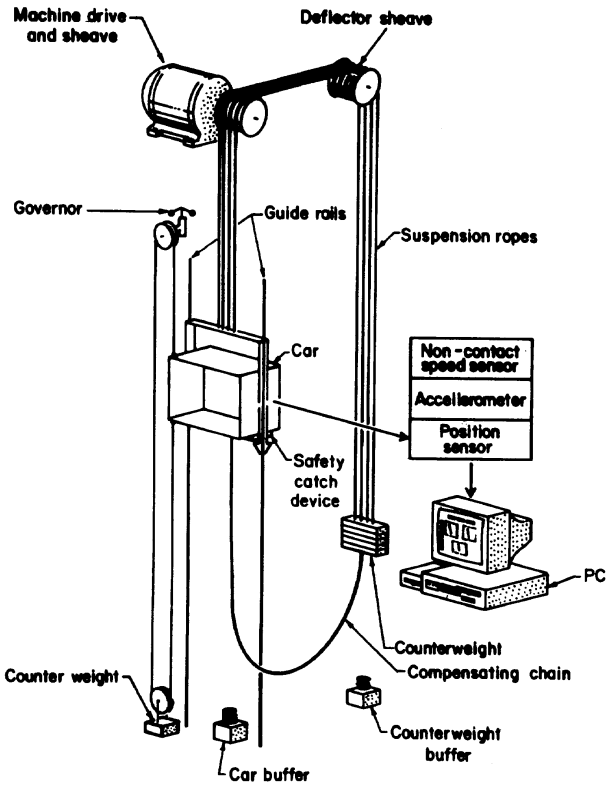
To address specific MSHA concerns regarding the improvement of equipment, methods, and procedures for inspecting mine hoists and elevators.

### PROBLEM STATEMENT

Despite MSHA's required periodic testing, documented mine hoist and elevator accidents resulting from electrical, mechanical, and structural failures occur. For example, shaft

accidents associated with the hoisting cycle may happen when the conveyance is empty or lightly loaded. Survey data showed that the car is empty or lightly loaded during 90% of the hoisting cycles. This creates a situation where the counterweight is heavier than the car. If the brake fails, the car will accelerate upward and crash into the headframe, a condition termed "overspeed" and "overwind." Since this project was initiated, at least four incidents resulting in injuries have occurred in the United States that fit the above situation.

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 economic manner without 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 hazardous hoisting environments. Thus, research is crucial to improve and increase information flow about hoist operating status and/or to relocate personnel from hazardous locations near the hoist.




### RESULTS TO DATE

- A model elevator has been built for training MSHA hoist and elevator inspectors.

- An exhaustive survey of sensing techniques to monitor cage position and velocity was conducted. Results showed that a dc tachometer, accelerometer, and microwave device proved reliable and accurate.

- A computerized data acquisition system (DAQS) was built to monitor and digitally record pertinent electrical signals from a hoist and elevator sensor. The information collected includes hoist cage acceleration, cage velocity, hoist motor armature voltage, armature current, and field current. Mine site evaluations of the system showed that it performed flawlessly and was fieldworthy and reliable.

- Twice during the past year, MSHA visited the Pittsburgh Research Laboratoy to connect an LMA-75/125 wire rope tester with the DAQS. Several tests were successfully conducted on the elevator in building 23 at the Bruceton site. As a result of these meetings and tests, MSHA suggested additional work to incorporate this type of data collection into our research.

## Wire Rope Hoisting Safety

*Principal Investigator: William K. McKewan*

### RESEARCH OBJECTIVES

To provide an understanding of rope deterioration that will enable the development of effective and reliable retirement criteria for wire ropes.

### RESULTS TO DATE

MSHA requested that the Pittsburgh Research Laboratory examine a rope used on a slope hoist that broke in service in a Pennsylvania mine. When the rope broke, three loaded cars rolled back down the slope to crash at the bottom; although there was considerable damage, there were no injuries. A physical examination showed that the rope was badly corroded and no oil was present near the break. Four samples of the rope were tested on the tensile machine. Three other samples from the area near the break showed about a 50% strength loss compared to a dead wrap sample. The MSHA retirement criterion for a man hoist is 10%. Reports on the tests were furnished to MSHA and to the Pennsylvania Dept. of Deep Mine Safety. Samples were given to MSHA personnel to illustrate corrosion and wear of wire ropes during training of inspectors.

At the request of the Pittsburgh OSHA, a company that processes an iron powder was inspected. The company uses a hoist system to lift barrels of iron fines into a separator. A

fatal incident occurred when a barrel of the fines was lifted too high and the contents spilled, creating a dust cloud of fine iron powder that ignited, causing a dust explosion. A report was made to OSHA with recommendations for revamping the equipment to prevent any future incidents of this type.

A meeting organized by the Pittsburgh Research Laboratory and MSHA was held at PRL's Wire Rope Research Laboratory to discuss wire rope retirement criteria and to test nondestructive test instruments. In attendance were representatives from MSHA offices in Morgantown, Pittsburgh, and Denver; Bridon American; the Wire Rope Technical Board from Washington, DC; CANMET; the Noranda Technology Centre; Rotesco; and NDT Technologies. Wires were removed from a 70-ft-long, 1.5-in test rope and tested by three types of NDT instruments brought to the meeting by manufacturers. All instruments performed favorably. The same instruments were also tested using a rope from the fatigue test machine that was ready for retirement; after the tests, the samples were analyzed. Results from the tests of the two ropes will be compared and a report written.

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## Maintenance Safety for Electric Motors

*Principal Investigator: Gerald T. Homce*

### RESEARCH OBJECTIVES

To develop a method of predictive maintenance for induction electric motors that will overcome limitations of currently available methods.

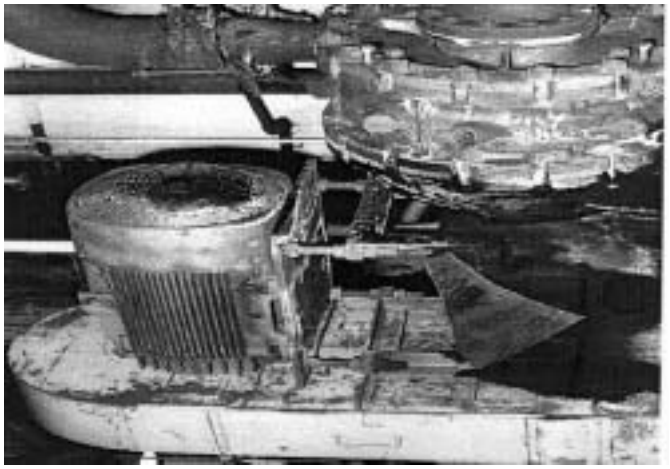
### PROBLEM STATEMENT

Equipment maintenance in mining and mineral processing operations is often a hazardous activity. Maintenance safety can be improved, however, by the use of predictive maintenance techniques that allow repair work to be scheduled rather than being done on an emergency basis. Cage-rotor induction electric motors are one of the most common components found in mining and mineral processing equipment. The approach under investigation is based on continuous monitoring of motors during normal operation to detect subtle changes in terminal information that may indicate deterioration.

### RESULTS TO DATE

A Memorandum of Agreement has been put in place with a large southwestern Pennsylvania coal mine allowing the Pittsburgh Research Laboratory to install an experimental motor-condition monitoring system in its preparation plant. Using this system, motor terminal voltage and current measurements are being stored and analyzed to determine if on-line monitoring can, under actual field conditions, recognize deterioration signatures on motor input power prior to failure.

Analysis of data collected thus far strongly suggests that a significant percentage of cage-rotor induction-motor failures are indeed preceded by measureable changes in specific electrical parameters. Work in FY97 focused on completing comprehensive analyses of all motor data collected through June 30, 1997, as well as a thorough review of plant maintenance records to annotate these data. This information will ultimately be used to create a practical, automated, on-line motor monitoring system. Work this year also included a major upgrade to the data collection computer system used at the plant. The changes will reduce the system from three networked computers to a single PC and will allow data analysis as well as system control and modifications to be done remotely from the Pittsburgh Research Laboratory.



**Large pump motor at a coal preparation plant, 1 of 60 motors monitored in the field tests.**

## Electric Shock Prevention

*Principal Investigators: Gerald Homce and Peter Kovalchik*

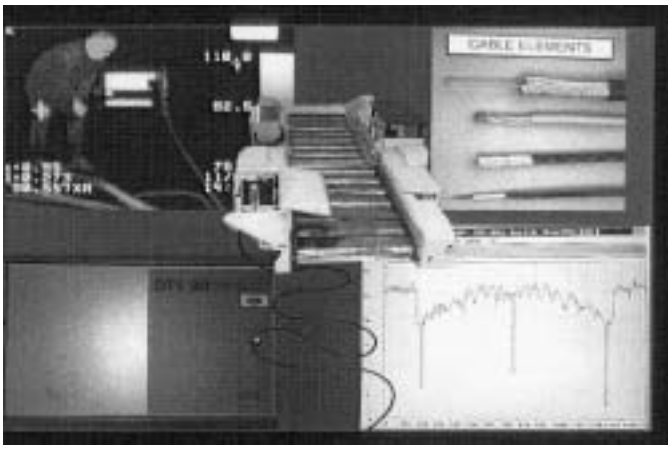
### RESEARCH OBJECTIVES

To provide scientifically valid recommendations for protecting mine workers from electrocution.

### PROBLEM STATEMENT

Electrocution causes approximately 10% of all mining fatalities each year. Approximately 162,000 workers at surface mines are exposed to overhead powerline hazards. Between 1980 and 1996, 47 fatalities were caused by overhead powerlines. Operators of trucks, drill rigs, and cranes, and workers carrying metallic objects were most often victims of overhead line electrocution.

More than 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.



### RESULTS TO DATE

Work on overhead line hazards this year has included data collection and preliminary data analysis. Detailed accident investigation reports have been obtained for 75 overhead line contacts that occurred at mining operations between 1980 and 1996. Initial analysis has shown that about two-thirds of these contacts occurred in noncoal mines. Direct worker contact was the most common factor, followed by crane operation.

Four separate dynamic tests using an optical time domain reflectometer were conducted to measure the temperature of electrical conductors in a mine trailing cable.

## Circuit Protection—Underground Mining

*Principal Investigator: Michael R. Yenchek*

### RESEARCH OBJECTIVES

To evaluate ground fault protection as to its suitability for use on anthracite mine power systems.

### PROBLEM STATEMENT

The power systems of anthracite mines in northeastern Pennsylvania are typically powered at 480 volts, three-phase. They supply light electrical loads, such as pumps up to 75 hp. The power sources are traditionally ungrounded and lack direct or derived neutrals and grounding resistance to limit fault current. In addition, many circuit breakers do not feature protection against ground faults as specified in Title 30 of the Code of Federal Regulations. To bring these systems in compliance with current Federal safety standards, the Mine Electrical Systems Division of MSHA's Pittsburgh Safety and Health Technology Center requested that the Pittsburgh Research Laboratory conduct an investigation to identify suitable ground fault protection.

### RESULTS TO DATE

The commerical relays evaluated were provided by MSHA and consisted of three current-sensing models and one voltage-sensing model. The units were first examined to determine if their construction was acceptable for a mine environment. The voltage relay had exposed line voltage terminals and was not housed in an insulated or grounded enclosure. All current-sensing models used fine-gauge wire to interconnect components, which could result in premature failure should the relays be exposed to significant amounts of vibration. The sensitivity and response time of each relay were inversely related; that is, the greater the sensed current, the faster the relay activated. The units were subjected to voltage surges typically expected on industrial power systems. No relay was adversely affected by these high-magnitude, short-duration impulses. All current-sensing units performed normally in environmental tests ranging from -40 to 60 °C. The electromechanical voltage relays dropped out at higher-than-rated voltages at temperatures above 20 °C.

Life-cycle tests were conducted on the voltage relay. After 100,000 operations, the dropout voltage was unchanged. The devices were then tested in the Mine Electrical Laboratory on both grounded and undergrounded, three-phase power circuits with a 5- or 50-hp motor serving as a load. Ground fault relay operation was also confirmed while installed on a circuit featuring a single- to three-phase convertor, an arrangement common in remote locations of the anthracite region. Differences in ground fault sensitivity were observed between the two existing phases and a third manufactured phase. Finally, a grounded power system featuring a wye-delta grounding transformer was modeled using commerical power system analysis software. This model will enable fault evaluations to be conducted at various points throughout the system. Calculations of ground fault currents will ensure that the grounding transformer and resistor are appropriately rated. Laboratory observations were documented and test results summarized in a letter report to MSHA.

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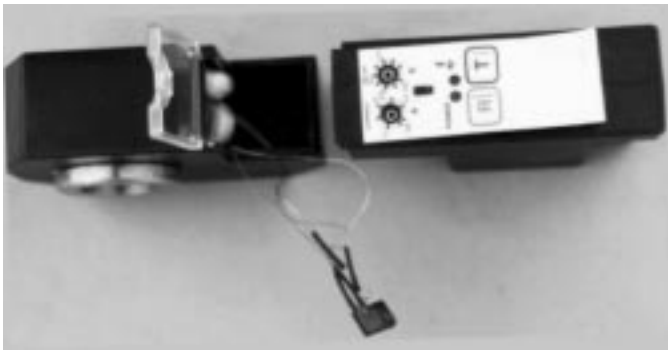

**Interconnection of ground fault relay and current sensor.**

## Improved Safety for Small Mines

*Principal Investigator: Robert F. Randolph*

### RESEARCH OBJECTIVES

To define the disproportionate risk of workers employed at small mining operations and determine ways to reduce this risk.

### PROBLEM STATEMENT

Workers who are employed at small mining operations (i.e., fewer than 50 employees) are at greater risk of serious injury or death on the job than those who work at larger mines. This project focuses on better defining the disproportionate risk of those jobs and determining means to reduce the risk. Ways to make improved technologies, safety information, and training materials available to employees at small mines are also being evaluated.

### RESULTS TO DATE

Analysis of the hypothesis that low underground working heights may be responsible for some of the safety performance of small mines has been completed. Results indicate that risk varies by seam height, but the relationship differs depending on the type of accident. For instance, lower seams correlated with higher risks for some types of machinery-related accidents; higher seams correlated with slipping and falling, falling rock, and certain other types of machinery accidents. Additional studies will investigate causal factors in addition to working height. Resource availability, job switching, and regional variations have been investigated through analyses of data on workforce training and job functions.

Researchers are coordinating efforts with MSHA, the Holmes Safety Association, and other organizations addressing safety issues in small mines. This work includes active participation and anlytical support to the Pennsylvania State Committee for Small Mines Health and Safety. Researchers helped to organize the first New England Mining Health and Safety Conference in April 1997 and the Mid-States Mining Safety Conference in September 1997. These conferences were well attended in areas where small mining operations predominate.

A search of the scientific literature on successful methods of transferring safety information and training to small organizations has identified a general lack of research in this area. A review of this literature will build upon a feasibility study completed by the University of Kentucky. Existing training materials for small mines have been collected from MSHA collaborators and USBM archives and will be summarized in an evaluative review.

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## Worker Safety for Independent Contractors

*Principal Investigators: Edward A. Barrett and Lynn L. Rethi*

### RESEARCH OBJECTIVES

To investigate safety issues and develop effective interventions for reducing injuries to independent contractors working on mine property in all segments of the mining industry.

### PROBLEM STATEMENT

From 1991 to 1995, independent contractors accounted for 25.5% of all fatalities in coal mining (47 of 184) and 37.1% of the fatalities in noncoal mining (56 of 151). These numbers far exceed the proportion of independent contractor employees to the entire mining workforce (an average of 17% in 1995). With the continued growth of this segment of the mining industry, these injury trends may continue or perhaps worsen. To diminish this possibility, effective interventions need to be identified, investigated, and implemented for managing the safety of independent contractors.

### RESULTS TO DATE

Investigations to date have focused on two areas: (1) collection and analysis of injury data (surveillance) and (2) identification of potential intervention measures.

In the area of surveillance, 10-year employment and injury trends for independent contractors in all segments of the mining industry were tracked. These data were used to identify specific problem areas by examining changes in the rates and types of accidents, as well as locations of accidents, in which independent contractor employees were involved. The data have also been used as resource material in training sessions by many Part 48 instructors throughout the mining industry. Additionally, exploratory investigations were conducted of 169 independent contractor employees who worked at various types of coal and metal/nonmetal mines. The objective was to develop a profile of these workers to better define this subset of the mining population. The subjects completed questionnaires that asked for information on employee demographics, work experiences, training, safety awareness, and safety experiences with a mining company. Preliminary data suggest that administrative interventions, such as improved site-specific hazard training and behavioral interventions designed to influence the attitudes of workers and employers may be useful. A draft report was completed during FY97.

In the second problem area, two types of interventions were investigated. MSHA mandates "that the safety of independent contractor workers on mine property is the ultimate responsibility of the production operators at the mine." However, independent contractors are also cited by MSHA for violations committed by them or their employees. Clearly, the issues of company responsibility and accountability are concerns of both mining industry operators and independent contractors. Similar concerns were addressed recently in the petrochemical and construction industries as comprehensive safety programs were developed and implemented for all persons in the workplace.

The strategy was to set responsibilities for every employee, including those working for independent contractors. This approach has produced positive results with regard to improved safety performance. It was therefore posited that certain elements of these comprehensive safety programs, if applied to the mining industry, could also affect independent contractor safety. To this end, two papers were published in which operator and independent contractor safety responsibilities were developed and discussed as to how they could be applied to mining. These responsibilities were based on eight of the most common elements found after completing a literature search and reviewing several comprehensive safety programs from general industry. To date, at least four mining companies have initiated partnerships with MSHA. The working agreements established include many of the elements noted above.

Thirty-three factors contributing to injuries among independent contractors during a 6-year period were identified and categorized during FY97. Frequencies and the relationship of these factors to employee accidents and job classifications were studied, and trends and patterns were noted. A draft report has been completed that provides a database of information on factors that may have contributed to the 122 fatalities among independent contractors from 1990 to 1995.

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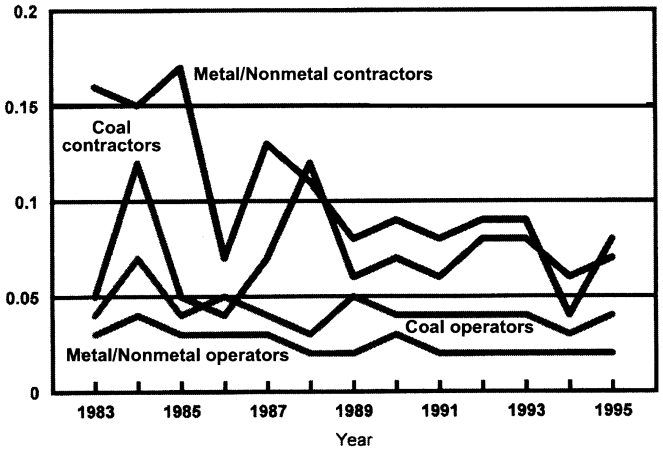


**Fatality incident rate, 1983-95.**

## Hazard Recognition

*Principal Investigators: Lynn Rethi, Edward A. Barrett, Kathleen M. Kowalski, Roberta Calhoun, and Richard S. Fowkes*

### RESEARCH OBJECTIVES

To improve the hazard recognition skills of miners, thus increasing safe intervention behaviors and reducing injury in the mining industry.

### PROBLEM STATEMENT

The safety of the worker is, in part, dependent upon his or her ability to perceive hazards in the workplace. If a hazard is not recognized, the hazard cannot be avoided. Descriptive accident report data have shown that "failure to perceive" the hazard consistently appears as a contributing factor leading to the injury or fatality. Thus, the inability of miners to recognize hazards is an ongoing problem. To this end, new training methods for improving hazard recognition skills need to be investigated, developed, and evaluated.

### RESULTS TO DATE

The former U.S. Bureau of Mines (USBM) began this effort by conducting a major review of the literature available on the topics in psychology, military target identification, pilot and gunnery officer training, transportation safety, and automobile operator behavior, as well as research into sensory function and visual information processing. The purpose of the search was to identify relevant concepts that could be applied in the training of miners to enhance their ability to recognize hazards. The results were published in USBM Information Circular 9422, entitled *Hazard Recognition in Mining: A Psychological Perspective*.

What do fighter pilots and miners have in common? They are learning to recognize hazards using the "degraded image" technique. Research has shown that the pilots were able to identify targets better when trained with less-than-ideal (degraded) pictures of the targets. *Degraded image* refers to pictures in which cloud cover, rain, poor weather conditions, natural barriers, buildings, or other obstructions partially hide the object—conditions that pilots would likely encounter in real life. The opposite approach, highlighed training, focuses attention on the target.

In 1993, a project was initiated in which the goal was to design a training program to determine if this theory of degraded image could be applied to hazard recognition training in the mining industry. To compare the effectiveness of highlighted versus degraded hazard recognition training, researchers developed several experimental and control training modules. Miners trained with the degraded training module scored significantly higher on tests than those trained in the more traditional highlighted manner. Researchers conducted two additional field studies involving more than 2,600 miners in underground coal mines in the South and Midwest. Incidence rates at these mines dropped more than 25%, which management and researchers attributed in part to the degraded image hazard recognition program.

In 1996, the degraded image hazard recognition method of training was incorporated into a training video with the collaboration of the Illinois Dept. of Natural Resources and Illinois Eastern Community College. The video is accompanied by an instructor's guide and slides to form a training module. This module was developed for both surface and underground mining operations and depicts scenes from both locations to introduce the degraded-image method of hazard recognition training.

In addition, a hazard recognition program for underground limestone mines was developed and tested in the field. This program incorporates both the highlighted- and degraded-image methods to explore the visual cues necessary in identifying roof and rib hazards found in an underground limestone mine. This module incorporates the degraded-image method and combines the use of three-dimensional visuals to teach participants hazard recognition skills. The module has been well accepted within the mining industry and is now available from MSHA's National Mine Safety and Health Academy. A third training module using three- dimensional visuals is in progress.

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# DISASTER PREVENTION AND RESPONSE BRANCH

## Lightning Strike Hazard Reduction

*Principal Investigator: Lon Santis*

### RESEARCH OBJECTIVES

To develop a risk-based lightning warning algorithm and to study underground coal mine explosions caused by lightning.

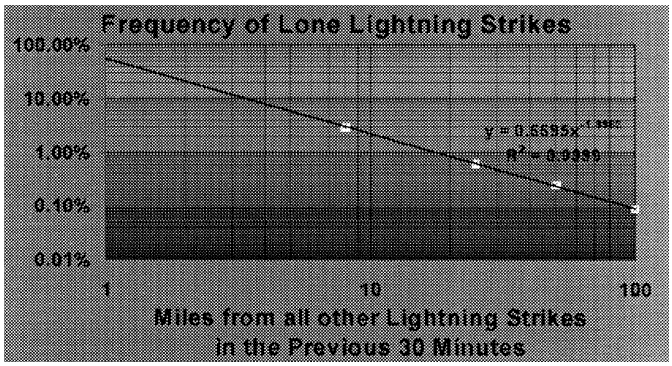
### PROBLEM STATEMENT

Lightning is the leading cause of unplanned detonations in mining. It was responsible for 40 such incidents reported to MSHA between 1978 and 1993. Lightning is thought to have been responsible for seven underground coal mine explosions in the last 3-1/2 years. Little is known about the penetration of lightning energy deep into the Earth. Why explosions are occurring in supposedly nonexplosive gob areas is also a problem. Developing a risk-based lightning warning algorithm would both increase and improve the use of lightning warning systems.

### RESULTS TO DATE

About 40 million lightning strikes have been recorded. In addition, atmospheric electric field measurements in excess of normal levels are being recorded. So far, about 4 million lightning strikes have been examined to identify those that are spatially separate from other lightning strikes. Trends that fit power functions very well have been identified. These trends are affected by geography.

In support of MSHA, a multifunctional team of researchers has been formed. This team has met to discuss the situation and decided that there is reasonable probability that lightning energy can ignite methane gas in deep coal mines. Presently, the group is reviewing existing literature on the subject.




**Frequency of lone lightning strikes fits a power function extremely well.**

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## Analysis of the Impact of Extended-Cut Mining on Ground Control

*Principal Investigators: Eric R. Bauer and Roy H. Grau III*

### RESEARCH OBJECTIVES

To investigate the effects of extended-cut mining on the coal industry in terms of accidents, roof falls, and worker safety, and to develop and implement control strategies that will enhance the safety of mine workers during the extraction of extended cuts.

### PROBLEM STATEMENT

Past practice in the U.S. coal industry when using continuous mining machines has been to advance the face 20 ft at a time, then support the exposed mine roof. This sequence of mining and roof supporting limits the areal extent of unsupported mine roof and minimizes the time between exposure and support of the roof. Today, in contrast, by using remotely controlled operations, mine operators are increasing the depth of cut to as much as 65 ft. In 1995, 436 mines in the United States had received a variance to mine cuts deeper than 20 ft.

However, little is known about the ground control and roof stability of extended cutting and whether this system of extraction exposes mine workers to greater risks of injury from unplanned roof falls. Obviously, the potential for roof falls increases as both the area and the time that the roof is unsupported increase. Between 1988 and 1995, over 28% of the roof fall fatalities occurred during the mining of extended cuts. Also, nearly 7,500 documented roof falls were reported in mines approved to extract extended cuts, resulting in more than 1,600 injuries. As cut depths approach and surpass 40 ft, prediction of safe depths of cut becomes more critical. Failure to determine safe depths of cut accurately will likely result in an increase in unplanned roof falls and associated worker injuries and fatalities.

### RESULTS TO DATE

Mines were visited to investigate worker health and safety during extended-cut mining at the Pattiki Mine, IL, Dotiki

Mine, KY, Big Mt. 16 Mine, KY, and Foidel Creek Mine, CO. Two-dimensional modeling of strata deflection and stress concentrations accompanying the mining of extended cuts was completed. The use of roof-span calculations for estimating safe depths of cut was investigated and determined not to be a suitable technique. A more reliable method of determining safe extended-cut depths was developed using the Coal Mine Roof Rating. Roof fall fatalities for 1996 were reviewed and added to the Fatality Database. Several investigations were conducted for MSHA and the State of West Virginia that addressed the safety of extended-cut mining sequences. An analysis comparing accident incidence rates during continuous mining for extended-cut and nonextended-cut mines indicated that mine workers in the face area of extended-cut mines were nearly 1.5 times more likely to be injured than those in non-extended cut mines. Finally, the data from the underground study at RoxCoal's Diamond TB Mine were reanalyzed to compare the long-term roof stability of extended-cut areas to that of standard-cut areas.

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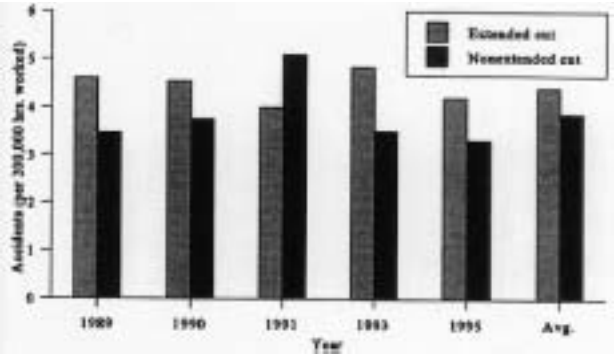


**All incidents in face area of continuous miner sections for extended- and nonextended-cut mines.**

## Evaluation of Highwall Stability Problems

*Principal Investigator: Deno M. Pappas*

### RESEARCH OBJECTIVES

To evaluate and identify geotechnical factors causing highwall rock falls and embankment failures at coal mine portal sites and at surface operations.

### PROBLEM STATEMENT

The highwall is the exposed overburden on the uphill side of a strip mine or the entry location for a drift mine. Most coal mines possess some type of highwall face that is subjected to many factors that often cause failure of the overburden. Since 1990, 7 miners have been fatally injured and 115 were injured because of highwall failures.

### RESULTS TO DATE

Researchers in this fact-finding study conducted an in-depth accident and exposure investigation, conducted a literature review, collaborated with other offices and agencies (i.e., SRL, MSHA, PaDER), conducted a survey of mine operators, and visited several field sites. The types of highwalls were broken into three categories (drift, surface, and auger sites), and specific criteria were listed to minimize highwall stability problems. These criteria and results are detailed in a project summary report. It appears that highwall stability at coal mine sites is not a growing problem; however, certain aspects of highwalls may require additional research, such as modeling auger mining scenarios to determine the appropriate web width between auger holes, designing canopies to minimize canopy collapses during massive rock falls, and studying the use of chemical coatings on highwalls to reduce weathering effects.

**A near-vertical highwall at an Appalachian drift coal mine that poses a serious hazard to workers.**

## Design of Mine Roof Support Systems

*Principal Investigator: Dennis Dolinar*

### RESEARCH OBJECTIVES

To develop a support system methodology that ensures the installation of a support system engineered to minimize or prevent roof falls in underground operations based on local mine conditions.

### PROBLEM STATEMENT

Over the past 5 years, 30 of the 53 fatalities caused by ground falls in U.S. underground coal mines occurred under supported roof. These fatalities highlight the inadequacy of the design of support systems installed to prevent roof falls and to maintain a safe working environment. In general, roof support systems are not designed or engineered; instead, installations are based on past and personal experience, trial and error, or the choices made by a neighboring mine. A roof support vendor's persuasiveness and wares are also a factor in the selection of roof supports. This situation is due to a lack of proven, generally accepted support design procedures and methods.

**A large percentage of the more than 2,500 roof falls reported each year involved supported roof.**

### RESULTS TO DATE

Both experimental and historical data on roof behavior, support performance, and roof fall occurrences have been obtained from a number of mines. These data show a correlation between roof behavior and support performance. Statistical data based on more than 2,500 accidental roof falls in underground coal mines have been analyzed. Although the quality of the reports is variable, at least 31% of the reported falls occurred under supported roof. The data also show strong evidence that support length is a major factor in reducing roof falls and that most falls occur in intersections.

Field work has been conducted at two sites to examine support performance (1) in a cribless recovery room and (2) in nonsystematic patterns. At the first field site, a cribless recovery room for a longwall operation was instrumented and monitored to determine if such a support system could provide adequate roof reinforcement as the longwall was being recovered. The data from this experiment are currently being analyzed. At the second field site, the limitations of spot bolting in maintaining a safe work area were identified. Results demonstrated the importance of using a full bolting plan in areas where roof problems are expected.

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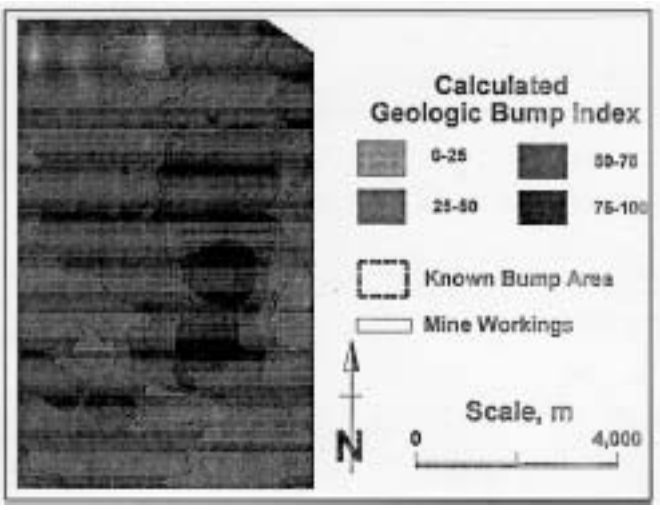
## Innovative Geologic and Engineering Techniques to Reduce the Incidence of Mountain Bumps

*Principal Investigator: Keith Heasley*

### RESEARCH OBJECTIVES

To reduce the incidence of bumps through (1) new design concepts for engineering control of bump-prone geologic and stress conditions, (2) improved techniques for assessing bump-prone geologic environments and stress conditions, and (3) dissemination of bump control information and technologies to the mining industry.




**Bump assessment map for a Virginia coal mine.**

### PROBLEM STATEMENT

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

### RESULTS TO DATE

In this project, a laminated numerical model, LAMODEL, that determines stresses, displacements, and energy release levels within seams was developed to minimize bump potential during mining operations. This fiscal year, an intuitive user interface was created that greatly simplifies modeling and analyzing the new stress analysis program. On the topic of assessing bump environments, preliminary research was completed on using the geologic and stress classifications techniques CMRR, ARMPS, and ALPS for quantitative assessment of bump potential. In addition to numerous presentations on bump research, the database on coal bumps is being organized as a Web site.

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## Ground Control for Pillar Extraction

*Principal Investigators: Christopher Mark and Frank Chase*

### RESEARCH OBJECTIVES

To improve the safety of underground coal miners working on retreat mining sections by developing engineering tools for better mine design.

### PROBLEM STATEMENT

Between 1989 and 1996, 25% of the roof and rib fall fatalities occurred on retreat mining sections. This is a disproportionately high number of fatalities in that less than 10% of all U.S. underground coal production comes from retreat mining sections.

### RESULTS TO DATE

Highlighting this year's accomplishments was a series of technology transfer seminars and open industry briefings. More than 30 technical presentations were given during FY97.

- More than 350 mining industry personnel attended seminars on retreat mining that were held in Indiana, Kentucky, Pennsylvania, Virginia, and West Virginia. In addition to the technical presentations, participants received hands-on training with the Analysis of Retreat Mining Pillar Stability (ARMPS) and the Laminated Boundary-Element Model (LAMODEL) computer programs.

- Two seminars were conducted at the National Mine Health and Safety Academy at the request of MSHA. These seminars included training for roof control specialists and roof control supervisors.

- Two-day short courses on coal mine ground control were also given at the request of A. T. Massey Coal Co. and Peabody Coal Co. Approximately 90 engineers and operational managers attended these meetings.

A Windows version of the ARMPS program was prepared under contract with Southern Illinois University. This program has been well received by industry, and more than 400 copies have been requested. All fatalities that occurred during retreat mining between 1989 and 1996 were analyzed to determine contributing factors and probable causes. Conclusions have been published and presented.

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## Mitigating Ground Fall Hazards in the Stone Industry


*Principal Investigators: L.J. Prosser and Anthony T. Iannacchione*


### RESEARCH OBJECTIVES

To prevent injuries and fatalities to workers employed in the underground stone industry.

### PROBLEM STATEMENT

The fatality incidence rates for underground stone miners are higher than for workers in other underground mining industries.

### RESULTS TO DATE

A December 1996 safety seminar provided information on roof and rib control to 180 stone industry employees. A new remote monitoring safety system has been developed, and preliminary field tests were conducted.

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## Innovative Support Technologies for Gate Road and Bleeder Entries

*Principal Investigators: Thomas Barczak and Gregory J. Molinda*

### RESEARCH OBJECTIVES

To promote improved mine safety by developing new support technologies that reduce the risk of escapeway blockage and materials handling injuries and to develop guidelines to ensure the appropriate use of these new roof support technologies.

### PROBLEM STATEMENT

New support systems are being developed in record numbers for economic as well as ground control reasons. It is essential that these new support technologies be properly evaluated to ensure their safe design and application. Investigators are using PRL's unique mine roof simulator load frame to promote development and safe use of these new supports. Field studies are needed to develop guidelines for various mine conditions.

### RESULTS TO DATE

Laboratory tests of 10 prototype support systems have been completed; 5 of these systems have been satisfactorily developed for mine use. These systems include (1) the Hercules crib support, (2) the Link-N-Lock crib support, (3) the Propsetter support, (4) the Can support, and (5) the 3-C. Assessments have been completed of three innovative support systems in western U.S. mines, and a field evaluation of three innovative support systems has been completed in an eastern coal mine. Plans are being finalized for a technology transfer effort in FY98.

The project was terminated at the end of the second year.

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## Remote Methane Measurements

*Principal Investigator: C.D. Litton*

### RESEARCH OBJECTIVES

To develop techniques to measure methane concentrations at working coal faces from a remote location for the purpose of satisfying current regulatory requirements for periodic methane checks and preventing worker exposure to unsupported roof.

### PROBLEM STATEMENT

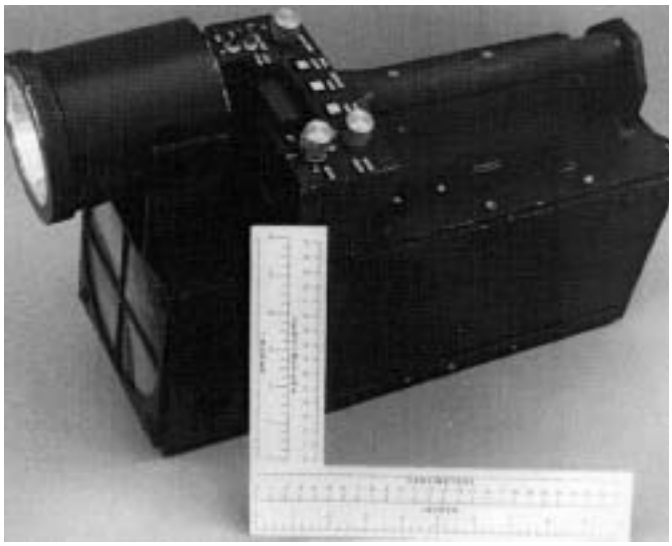
30 CFR 75.362 requires that methane be measured periodically at the working face to vertify that levels of methane are maintained well below the lower explosive limit. Such measurements must be made from under permanently supported roof using extendable probes or other acceptable means. As the practice of extended-cut mining increases, such measurements must be taken from distances of 40 to 50 ft and become much more difficult and time-consuming.

### RESULTS TO DATE

During this fiscal year, we were successful in developing a number of short-term solutions to the problem. These included

a dropoff, large-display methanometer that could be placed near the face by a continuous miner and activated remotely, a flexible hollow tube that could be "snaked" to the face so that a sample of gas could be drawn through the tubing to a conventional methanometer, and a large-display methanometer that could be pushed to the face on a bicyclelike chariot. A modified remote optical device was evaluated in 15 experiments in a specially constructed tunnel and found to be effective at distances up to 28 ft and at average methane concentrations less than 0.125%. This particular device does not provide any information about the spatial distribution of methane within the immediate face area, nor will it easily be made permissible for flammable atmospheres.

Numerous discussions relating to this problem were held with mine operators, MSHA, and the UMWA. The general conclusions were that cost, permissibility, and the need to resolve spatial methane concentrations represent the major constraints for future development of optical devices. With these constraints in mind, additional discussions and meetings were held with other researchers in the field of remote gas detection and measurement to identify approaches that appear to be most feasible and capable of satisfying these constraints. Directions for the research to be conducted in the next fiscal year were then developed, with a major focus placed on the development of an optical device that used diode laser technology.



**Remote optical methanometer evaluated at the Pittsburgh Research Laboratory.**

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## Characterization and Mitigation of Mine Gas Emissions


*Principal Investigators: W.P. Diamond and Steven J. Schatzel*


### RESEARCH OBJECTIVES

To characterize the geotechnical and engineering factors influencing the release and migration of hazardous concentrations of methane and other gases into the underground workplace.

### PROBLEM STATEMENT

Increased methane emission levels resulting from the unpredictable interactions between geology and mining practices may lead to an underground mine explosion. The trend in the coal industry to increase the size of longwall panels is an important factor that has led to elevated methane emissions in underground coal mines and is the focus of this research effort.

### RESULTS TO DATE

Eight sulfur hexafluoride ($SF_6$) tracer gas tests have been conducted at a longwall mine operating in the Pittsburgh Coalbed. The objectives of the tests is to characterize the movement of methane in inaccessible underground locations and evaluate the effectiveness of existing methane control systems. Test results from the seven underground releases and one venthole injection indicate a high degree of ventilation airflow and gas movement segregation between the former bleeder entries and the interior regions of the caved gob.

Evaluation of the COALGAS coalbed methane reservoir numerical model and gas production-emission simulator was completed. The model was successfully used in a history-matching exercise to test its capabilities in simulating the release of gas from strata associated with an active longwall and the subsequent migration of the gas through the gob to the ventholes.

Two rock samples were collected for a preliminary reconnaissance characterization study of hazardous gas associated with trona mining in Wyoming. Currently, the oil shale sample from the mine floor has desorbed only a trace amount ($<0.01$ $cm^3/g$) of methane and higher hydrocarbons, and the run-of-mine trona has released no hydrocarbon gas.

### R&D 100 Award

F. Garcia and S.J. Schatzel were recipients of "R&D Magazine's" R&D 100 Award for the portable modified direct method testing apparatus, September 1997.

**Installation of an automated gas sampler in an instrument housing at a bleeder fan site. Tracer gas ($SF_6$) released during a field study migrates through inaccessible workings and is monitored at all potential migratory pathways by the sampler unit.**

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**Patent Pending**: Portable modified direct method testing apparatus, F. Garcia and S.J. Schatzel.


## Toxic Fumes From Explosives and Blasting Agents

*Principal Investigator: Richard J. Mainiero*

#### RESEARCH OBJECTIVES

To determine the quantity of toxic fumes produced by detonating blasting agents, determine the effect of explosive composition, water content, and confinement on fumes production, and develop and validate a computational method based on Chapman-Jouguet theory to predict toxic fumes production.

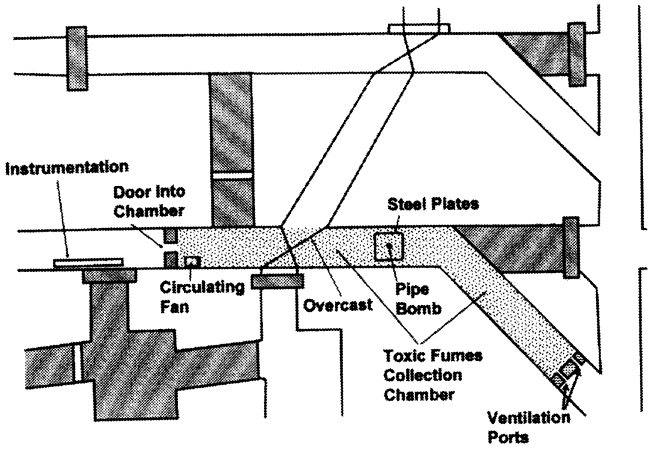
#### PROBLEM STATEMENT

Traditional techniques for the experimental determination of toxic fumes produced by the detonation of high explosives are not applicable to blasting agents. To detonate properly, blasting agents require confinement, a significant booster, a charge diameter of 3 in or greater, and charge lengths greater than two times the charge diameter. Without these conditions, blasting agents will not detonate at full order, leading to a misrepresentation of the gaseous products. This project addresses these issues through the development of a large-scale facility for measuring the toxic fumes from blasting agents. The results will enable explosives manufacturers and blasters to formulate, test, and detonate explosives and to develop blasting patterns leading to elimination of the potential for exposure to toxic fumes, particularly in large (multitonnage) blasting operations.

### RESULTS TO DATE

Toxic fumes have been measured for nine ammonium nitrate/fuel oil (ANFO) formulations, three commercial blasting agents, and five commercial high explosives in a test chamber constructed in PRL's Experimental Mine. For ANFO, the results for carbon monoxide (CO) and nitrogen oxides ($NO_x$) production are following expected trends based on results of earlier studies. CO production increases with increasing fuel oil content, while $NO_x$ production is at a minimum for 6% fuel oil and increases with decreasing fuel oil content. Analytic efforts are underway to replace lengthy wet chemical procedures currently used for gas analysis with instruments that measure in real time.

Evaluations of available computer detonation codes for calculating toxic fume production are proceeding. A relatively new code (CHEETAH) from Lawrence Livermore National Laboratory is currently being employed to examine various equations-of-state (EOS) to describe the chemical equilibrium at thousands of degrees Kelvin and tens of thousands of atmospheric pressures. Toxic fumes of nonideal explosives are also being determined using a work principle from thermo-dynamics with a novel zero-net-interaction constraint.




**Test chamber constructed in PRL's Experimental Mine for measuring toxic fumes from blasting agents.**

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## Seals for Explosion Control

*Principal Investigator: Eric S. Weiss*

### RESEARCH OBJECTIVES

To evaluate the strength characteristics and resistance to air leakage of existing and proposed new explosion-resistant seals for underground coal mines.

### PROBLEM STATEMENT

New seals are being designed for use in underground coal mines to provide increased production against ignitions that originate within the gob or other mined-out areas. It is necessary to evaluate the strength and air leakage resistance of these designs before they are used. It is expected that these new seal designs will reduce materials handling, thereby reducing personnel injuries, and shorten overall seal installation times, which would reduce the amount of time that miners are exposed to hazardous conditions. The new seals should also perform better in terms of strength, air leakage resistance, and durability. Full-scale tests are being conducted at the Experimental Mine at the Lake Lynn Laboratory.

### RESULTS TO DATE

The strength characteristics and air leakage resistance of six reinforced cementitious seal and stopping designs were evaluated under overpressures ranging from 20 to 455 kPa. Size-scaling relationships (seal design to mine roadway dimensions) and the ability of a seal design to withstand the required explosion overpressure within 24 hr of explosion completion were also studied. The program is based on the idea that a seal's resistance to horizontal overpressures can be predicted on the basis of time-related measurements of displacement, static pressure, and acceleration. The successful completion of this evaluation program resulted in seal designs that can withstand overpressures up to 455 kPa while minimizing air leakages. The program will aid in developing a model that can relate roadway conditions and pressure ratings to a particular seal design requirement.

**Full-scale, reinforced cementitious seal instrumented with transducers and accelerometers to measure displacement of the seal during an explosion.**

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## Safety of Waste Oil in Explosives

*Principal Investigators: Thomas Ruhe and T.S. Bajpayee*

### RESEARCH OBJECTIVES

To develop a practical method to evaluate temperature stability of ANFO in the range of 20 to 80 °C, obtain data on the stability of ANFO made with reprocessed oil at such high temperatures, and determine if reprocessed oil can be safely used in ANFO blasting agents stored at these temperatures.

### PROBLEM STATEMENT

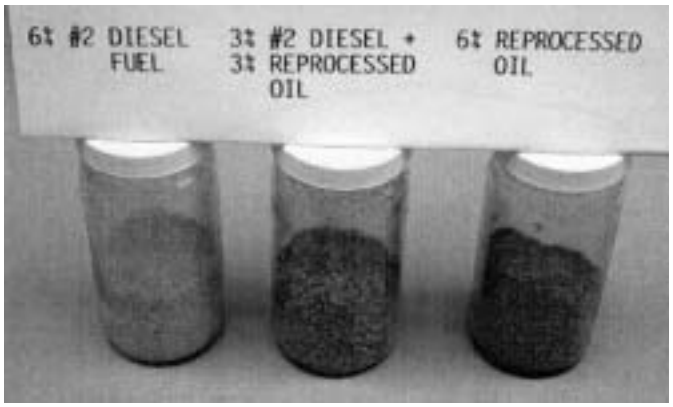
Mines have instituted a practice of disposing of used lubricating oil by reprocessing it and using it as a substitute for fuel oil in ammonium nitrate/fuel oil (ANFO) blasting agents. MSHA allows reprocessed oil to be substituted for up to one-half of the fuel oil in ANFO, but does not allow the use of stored ANFO made with reprocessed oil if its temperature is above 57 °C because of reactivity heating. The agency has requested data on the safe use of reprocessed oil at high ambient temperatures. This information will be used as a basis for more relevant regulations.

### RESULTS TO DATE

A practical method using isothermal ovens and sample containers made of various metals was developed to evaluate the temperature stability of ANFO in the range of 20 to 80 °C. Thermal stability tests involved 12 ANFO samples tested at 60 and 80 °C, four sample holder metal combinations, and heating periods of 1 or 3 days. The samples consisted of ANFO containing 6% each of 12 different oil mixtures: diesel fuel (sample 1); 3% diesel fuel plus 3% high-viscosity oils (from a mine site, new motor oils manufactured from reprocessed oil stock, and one new synthetic motor oil) (samples 2 through 6); 5% diesel fuel plus 1% graphite (sample 7); and 6% each of the higher viscosity oils (samples 8 through 12).

All samples except sample 7 reacted at 80 °C in a steel pipe with zinc caps. Sample 1 was most reactive, samples 2 through 6 were moderately reactive, and samples 8 through 12 were least reactive.

All samples were heated to 60 °C, but were nonreactive at that temperature. All ANFO samples were found not to be cap-sensitive. The viscosity of the oil samples was also measured.




**ANFO samples used in thermal stability tests.**

## Malfunction of Explosives in Delay Blasting

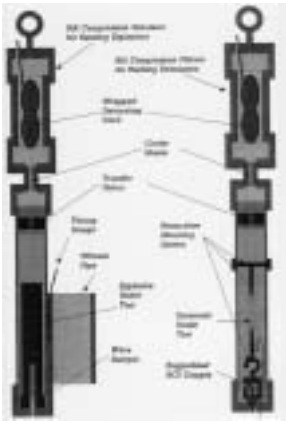
*Principal Investigator: Michael S. Wieland*

### RESEARCH OBJECTIVES

To develop technologies that measure the wave-impact damage resistance of commercial delay-period detonators and cap-sensitive explosives and to model how much charge malfunctions would be reduced if more rugged components were used under those same delay-blast conditions.

### PROBLEM STATEMENT

Certain natural mechanisms cause malfunctions in delay detonators and cap-sensitive explosives during blasting of underground coal, which raises the prospect of increases in toxic fumes or misfiring incidents.



**Rift compression fixtures for ranking ruggedness of explosives and detonators.**

### RESULTS TO DATE

There have been no changes in published representative interactions for shock waves and rift compressions, although the four different laboratory simulators used to rank the damage resistance of charge components (quasi-static, rift compression, regular shock wave, and ultraslapper) have been refined and calibrated. The last three types require dynamic calibration, which was completed this year, thereby allowing researchers to interpret resistance-to-damage statistics for the four different cap-sensitive explosives tested. Reduced mass detonator studies were conducted to understand the detonator malfunction mechanism and fixture response to reduced detonator output. Termination of the project precludes ranking the ruggedness of commercial detonators, although the calibrated fixtures will be useful if incident investigations require such determinations. The statistical information acquired can be utilized in con-junction with the refined malfunction probability model to generate specific explosive malfunction trends for a wide range of compressions, including cross-hole interactions.

Research results include a representative description of cross-hole wave interactions, laboratory simulators for imposing compression impact, ranking techniques for establishing damage resistance of charge components, and ruggedness trends for charge components as deduced from a refined malfunction probability model.

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## Detonator Transport Containers

*Principal Investigator: Lon Santis*

### RESEARCH OBJECTIVES

To establish guidelines for evaluating the safety of detonator container boxes on mining vehicles.

### PROBLEM STATEMENT

Over 4 billion lb of explosives are transported over U.S. public highways (often in quantities in tens of thousands of pounds) to mines and construction sites each year. A separate container is needed when detonators and explosives are transported on the same vehicle to prevent the inadvertent initiation of a detonator so that it does not set off the entire explosive load. However, nine mixed-load fire incidents resulted in four mass detonations on public highways since 1977. The mining laws on this situation are inconsistent and poorly defined and were developed without tests or consideration of fire hazards. Researchers on this project seek to quantify how much protection the mining standards for hardwood offer. They will also examine other barrier materials, including composite materials. MSHA will use the results of this study to clarify and possibly revise its ambiguous legal mandate. The Institute of Makers of Explosives is also considering revising its standard for public highways after NIOSH suggested safety improvements based on test observations.

### RESULTS TO DATE

Sixteen detonator boxes were tested in bonfires. Eight thermocouples were used to monitor each test, and each test was recorded on video. Barrier tests on various laminated and hardwood partitions have been completed and will be reported in FY98.

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**A detonator is sent skyward and a 25-ft-tall fireball erupts during a test.**

## Explosion Prevention and Suppression

*Principal Investigator: Kenneth L. Cashdollar*

### RESEARCH OBJECTIVES

To improve worker safety through research on the prevention and suppression of mine explosions, with particular emphasis on the problem of frictional ignition of methane in mines; to obtain basic data on the explosibility and ignitability of dusts, gases, and vapors from mining and other industries; to develop instruments and procedures for characterizing explosion hazards; and to assist in the forensic investigation of explosions.

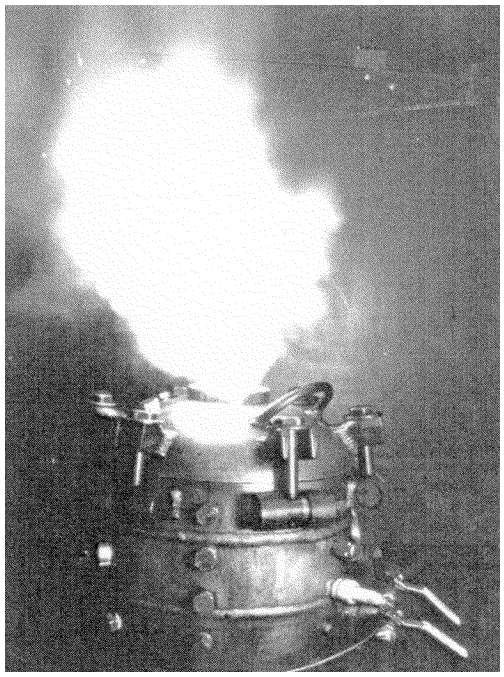
### PROBLEM STATEMENT

Explosions in underground coal mines are caused by accumulations of coal dust and/or methane. Explosions can be prevented by minimizing methane concentrations through ventilation, by adding sufficient rock dust to make the coal dust inert, by eliminating ignition sources, and by the use of barriers and seals to mitigate explosions. Since 1980, there have been 88 fatalities resulting from explosions in U.S. coal mines, including 10 in 1989 and 12 in 1992. The potential for a major disaster involving multiple fatalities is a primary concern. Research on the mechanisms of gas and dust explosions and their mitigation is needed as a basis to develop techniques and strategies for preventing explosions and suppressing them in underground mines and aboveground processing plants.

### RESULTS TO DATE

An Open Industry Forum on Frictional Ignitions was held in November 1997 at the Pittsburgh Research Laboratory. The forum covered the problems of frictional ignitions and suggested solutions, such as the wet-head continuous mining machine. Explosion research, primarily in the 20-liter laboratory chamber, has focused on the effects of coal dust and rock dust particle size. Confirmation of laboratory data through full-scale tests has started in the Lake Lynn Experimental Mine. Development of standard test methods for flammability, explosibility, and ignitability is being coordinated with OSHA, ASTM, and the National Fire Protection Association. Cooperative and in-house efforts have continued on the development of rock dust meters to evaluate the sufficiency of rock dusting in coal mines. Currently, prototype units are in use by MSHA's Mt. Hope Laboratory and by the Kentucky Dept. of Mines and Minerals. The coal dust explosibility meter, a variation of the rock dust meter, shows promise for measuring the explosibility of coal mine dust samples without being calibrated for the specific size of coal dust. Mine dust samples supplied by MSHA are also being used to determine particle-size distributions of coal mine dust. A joint NIOSH-Polish proposal to hold an international conference on mine seals and barriers has been approved.

Other NIOSH centers and government agencies have been given assistance with their explosion investigations. For example, an ongoing NIOSH investigation has shown that flammable hydrogen gas is being generated inside the sealed frames of two farm plows that were involved in explosions. In addition, a study of the flammability of mixtures of volatile organic compounds and hydrogen has been completed for Lockheed Martin Idaho Technologies Co., the operator of the U.S. Dept. of Energy's Idaho National Engineering Laboratories.



**Dust explosion in PRL's 20-liter laboratory chamber.**

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## Mine Fire Detection Strategies and Technology

*Principal Investigator: J. C. Edwards*

### RESEARCH OBJECTIVES

To investigate the level of mine fire detection and alarm capability currently possible using state-of-the-art technology.

## PROBLEM STATEMENT

This project develops strategies for mine fire detection using state-of-the-art mine fire detection technologies to prevent mine fire injuries and fatalities. Strategies are based upon in-mine fire experiments and application of mathematical models for analysis.

## RESULTS TO DATE

Analyses were completed of mine fire detection under zero airflow conditions. It was shown that, based upon in-mine diesel fuel fires, (1) thermal detectors are inadequate 30 m from a 300-kW fire, (2) a diffusion-mode smoke sensor can be as effective in detecting mine fires as a diffusion-mode carbon monoxide (CO) sensor, and (3) using CO buoyancy-induced spreading rates along a mine roof, recommendations can be made for sensor spacings in a mine entry. Additional in-mine fire experiments with diesel fuel were conducted to determine how dilution caused by turbulent mixing, leakage around a brattice, and a junction with a fresh air splint affected CO sensor deployment under normal mine airflow conditions. It was determined that (1) CO concentrations 2 ppm above background are compatible with smoke sensor alarm times, (2) a uniform products-of-combustion distribution can be expected 30 hydraulic diameters downwind of the fresh air junction, and (3) an ionization diffusion-mode smoke sensor and an optical path sampling smoke sensor were set off earlier than the 2-ppm CO alert. A prototype optical diesel-discriminating 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 $m^{-1}$, no optical scattering was measured for diesel smoke, while relatively intense scattered signals were measured for smoldering coal smoke.

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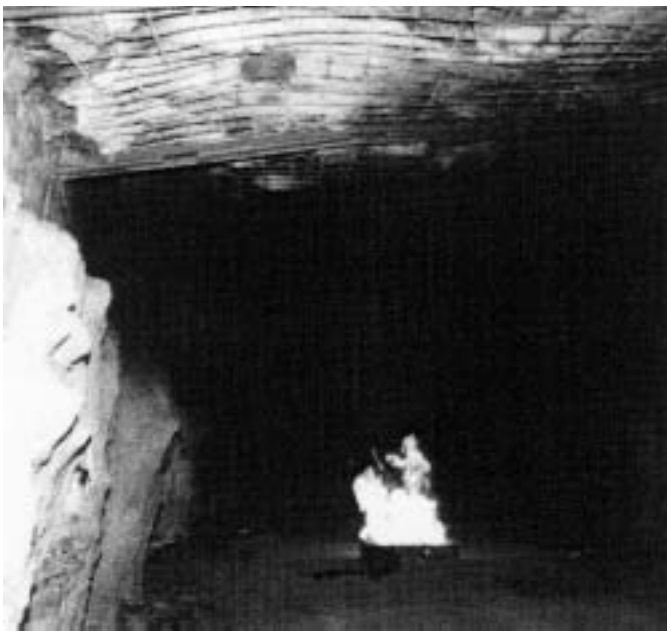

**In-mine diesel fuel fire.**

## Mine Fire Preparedness

*Principal Investigator: Ronald Conti*

### RESEARCH OBJECTIVES

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

### PROBLEM STATEMENT

Underground mine fires are a continuing threat to the life and safety of miners. The state of fire preparedness for underground mines can be enhanced by employing large-scale tests and evaluating current technology. Improved training protocols for miners and mine rescue teams need to be developed and evaluated.

### RESULTS TO DATE

Experiments in the Lake Lynn underground mine continued with 6,000- and 3,000-$ft^3$/min, diesel-powered, high-expansion foam generators connected to the inflatable feed-tube partition. The 6,000-$ft^3$/min, high-expansion foam generator with a constant driving force used 42% less foam concentrate to fill an entry in less than one-half the time of the 3,000-$ft^3$/min foam generator. Experiments also showed that the partition can be successfully deployed in an entry with a 240-$ft^3$/min airflow by using a nylon net secured to the roof and ribs. Under an MOA with Cyprus Amax Twentymile Mine, a mine emergency response training simulation was conducted. Field tests of an underground coal mine fire preparedness checklist continued. Under a CRADA with TeleMagnetic Signaling Systems, wireless receivers were constructed and connected to devices such as strobe lights to map an escape route for evacuating underground personnel. A high-temperature, superconducting, low-frequency receiver developed by Los Alamos National Laboratory was evaluated in PRL's Lake Lynn Laboratory. Under working agreements with the Pennsylvania Dept. of Deep Mine Safety and CONSOL, simulations of mine rescues were developed and conducted. Two open industry briefings on mine fire preparedness and one briefing on the Carins Iris helmet-mounted thermal-imaging camera were held.

**Mine rescue team member wearing the Carins Iris thermal-imaging camera.**

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## Prevention and Extinguishment of Mine Fires

*Principal Investigator: Alex C. Smith*

### RESEARCH OBJECTIVES

To evaluate the effectiveness of water-mist fire suppression systems for extinguishing fires in diesel fuel storage areas.

### PROBLEM STATEMENT

MSHA has identified mobile diesel-powered equipment as the largest source 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. Researchers from the Pittsburgh Research Laboratory and others have shown that water-mist technology may be applicable for fighting diesel fuel fires, and MSHA has requested that NIOSH investigate this technology. The effectiveness of water mist in the underground mining environment is affected by several factors, such as the type of storage container and configuration of the storage area, and will depend upon interaction between water droplets and ventilation, temperature, and corrosive atmospheres.

Large-scale experiments will be used to determine the relationship between the extinguishing effectiveness of water mist and mist properties, fire type and geometry, and fire detection and system activation times. The results will be used to provide engineering guidelines for the design, installation, maintenance, and inspection of water-mist fire suppression systems in underground diesel fuel storage areas. The results will also be used to determine if water-mist technology is applicable for the suppression of other types of mine fires.

### RESULTS TO DATE

A large-scale fire suppression system facility was constructed at PRL's Lake Lynn Laboratory to simulate an underground diesel fuel storage area. The facility's fire test area is configured as a 78-ft-long main entry with a 40-ft-long crosscut located at the center of the entry. The entry and crosscut are 18 ft wide and 7 ft high. The entire test area was fireproofed and equipped with thermocouples and gas instruments for monitoring temperatures and CO, $CO_2$, and $O_2$ concentrations. The facility is equipped with a water pump capable of delivering water at pressures up to 200 psi, the pressure required to generate water mists, and an oil-water separator and liquid storage system to recycle all water and diesel fuel. Experiments were conducted to evaluate how droplet size, pressure, flow rate, and nozzle type affected the ability of water-mist suppression systems to extinguish diesel fuel fires in restricted areas. To evaluate these factors, various nozzle types and spacing configurations were also used to extinguish 0.5- and 2-MW fires. The fires were located either in the center of the crosscut, against one wall in the crosscut, or in the corner of the crosscut against a permanent stopping. Results thus far indicate that extinguishing effectiveness is dependent on droplet size, nozzle pressure, and flow rate, as well as fire size and location.

**Fire suppression facility at Lake Lynn Laboratory.**

## Effect of Airflow on Fighting Mine Fires

*Principal Investigator: C.D. Litton*

### RESEARCH OBJECTIVES

To develop guidelines for assessing the impact of changing ventilation airflow to facilitate fighting mine fires and minimizing worker exposure to fire hazards.

### PROBLEM STATEMENT

When fighting a fire in an underground mine, the question of whether to change ventilation airflow often arises, and information relevant to the consequences of such changes is needed to make a decision that will have a positive impact on the fire-fighting operation and minimize worker exposure to fire hazards.

### RESULTS TO DATE

Both large- and small-scale tests have been conducted at PRL's Lake Lynn Laboratory to assess changes in fire hazards that occur when ventilation air velocity is changed. In one series of large-scale tests, air velocity was changed during stages of flame spread along horizontal lengths of styrene-butadiene rubber conveyor belt. Most tests were conducted using a single strand of belting with a length of 15.2 m. These tests indicated that, where the major hazards were an increase in the rate of flame spreading, CO concentrations, and depleted $O_2$ concentrations, a reduction in air velocity generally resulted in an increase in the fire hazard regardless of the initial air velocity. On the other hand, increases in air velocity had no positive effect unless the air velocity was increased by a factor of 2 or more. Intermediate increases in air velocity, for example from 1.5 to 2 m/sec, neither increased nor decreased the resultant fire hazards.

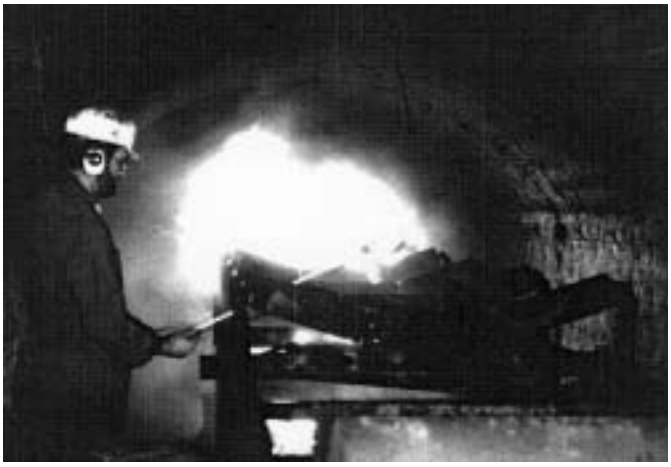
In another series of large-scale tests, the minimum air velocities necessary to prevent backflow of combustion products were determined for two tray fires of No. 2 liquid diesel fuel, corresponding to heat release rates of 235 kW and 2,600 kW. For the smaller fire, the minimum air velocity to prevent backflow was 1.3 m/sec; for the larger fire, the minimum air velocity was 1.78 m/sec.

In the small-scale tests, it was found that when the conveyor belt surface was close to the roof of the tunnel, faster flame- spreading rates and higher CO concentrations were produced using both high and low air velocities, although these effects were more pronounced at higher air velocities. In addition, the $CO_2$:CO ratio was substantially lower for belts near the roof, indicating more fuel-rich combustion. In this situation, increasing the air velocity resulted in more intense fires and higher rates of CO production; for tests in which the conveyor belt was farther from the roof, increases in air velocity produced more intense fires, but lower rates of production of CO. In addition, when the conveyor belt was farther from the roof, the $CO_2$:CO ratios did not indicate any transition to fuel-rich combustion. The major conclusions were that:

- Reducing air velocity should be avoided because fire hazards tend to increase when air velocity is low.

- Increases in air velocity to values greater than the critical velocity to prevent backflow can be beneficial for gaining access to the fire.

- Any increase in air velocity should consider the closeness of the belt surface to the entry roof as an important factor.



**Checking ventilation air velocity during a large-scale fire test at the surface fire gallery at PRL's Lake Lynn Laboratory.**

## Life Support: Survival and Mine Rescue

*Principal Investigator: John Kovac*

## RESEARCH OBJECTIVES

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

## PROBLEM STATEMENT

The underground environment is not benign for any type of equipment, including self-contained self-rescuers (SCSRs). The former U.S. Bureau of Mines was engaged in testing SCSRs in underground coal mines since 1981 to ensure their viability. Many design flaws were identified during this time, resulting in manufacturer recalls and design changes. In addition, this program aided in determining the service life of SCSRs, that is, when the apparatus should be retired and when it was safe to continue using it. The program for evaluating SCSRs has been continued under NIOSH.

## RESULTS TO DATE

In the program's sixth phase, several Mine Safety Appliances Co. (MSA) Portal-Pack SCSRs were found that had potassium oxide dust in the breathing circuit that would cause severe coughing if inhaled. MSA has ceased production of the Portal-Pack and has replaced it with the Life-Saver 60. Tests of the Life-Safer 60 found that, after approximately 50 min of use at a moderately high work rate, the breathing bag seal to the chemical canister melted and opened to ambient air. The manufacturer has voluntarily stopped sale of the apparatus and is working to remedy the problem.

Escaping from a mine (the only circumstance when a miner should don an SCSR) means that a miner must go on foot and under oxygen from the deepest point of the mine to the surface. An important concern expressed by miners, mine operators, and manufacturers is: how many SCSRs does a miner need to make such an escape? The answer is that the number depends on many factors, such as the miner's body weight, escape distance and grade, condition and height of the escapeway, how much usable oxygen an SCSR stores, SCSR readiness, and ex-pectations. 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.

Much life support research revolves around using a breathing and metabolic simulator (BMS) to test closed-circuit breathing apparatus (CCBAs). Before the development of the simulator, it was not possible to evaluate the performance of CCBAs objectively because tests on human subjects do not provide a sufficiently quantitative or repeatable metabolic load on the apparatus. Several years ago, MSA built three BMSs to test CCBAs in both the development stage and on a production line. This year, Ocenco, Inc., an SCSR manufacturer, built and delivered BMSs for NIOSH's Morgantown Laboratory and the Navy Coastal Systems Center, Panama City, FL. Cooperation among these organizations in efforts to refine and standardize BMS design will be led by the Pittsburgh Research Laboratory.

The BMS is being used in a performance comparison of 14 mine rescue breathing apparatus that are now, or have been, commerically available, with the goal of providing users and manufacturers with a back-to-back comparison of various apparatus types. During the past year, the Siebe Gorman Aerorlox, a liquid-oxygen apparatus, and the new Litton Litpak II, a mixed-gas system, were tested. Prototype apparatus are also being tested with the BMS at the request of both manufacturers and other Government agencies.

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**Inspecting SCSRs for long-term performance in the field.**

## Lake Lynn Laboratory

*Principal Investigator: Eric Weiss*

### RESEARCH OBJECTIVES

Lake Lynn Laboratory, near Fairchance, Fayette County, PA, is a unique multipurpose research laboratory design to provide a full-scale realistic environment for research in mining health and safety technology. The laboratory plays a crucial role in conducting full-scale operational research by providing continued development, maintenance, and operational support to the numerous specialized underground and surface test facilities.

### PROBLEM STATEMENT

Lake Lynn Laboratory provides an isolated surface facility and a full-scale underground mine for conducting research in mine disaster prevention and response, as well as numerous other health and safety problems in both underground and surface mines. Specific research includes the development and evaluation of fire suppression systems and early warning technologies; development and evaluation of ventilation seals, stoppings, and bulkheads; evaluation of prototype mining equipment and sensors; ventilation studies; roof support technologies; evaluation of explosive incendivity; determination of explosion limits for combustible dusts and ignitability of mists and vapors; and respirable dust deposition and diesel particulate studies. The information generated as a result of this research is vital to agencies such as MSHA in the development of regulations to protect mining personnel from the many hazards associated with their jobs.

### RESULTS TO DATE

Lake Lynn Laboratory continues to support and coordinate the numberous research efforts for the Pittsburgh Research Laboratory, other NIOSH laboratories, MSHA, other governmental and industrial organizations, and colleges and universities. Through the use of in-house contractors and an outside contractor, a new fire suppression facility has been constructed. West Virginia University's Dept. of Mining Engineering continues to use the facility as a field location for its mine surveying class. Two open industry briefings on mine fire preparedness were conducted at the laboratory, and throughout the year, mine rescue exercises were conducted with Pennsylvania State teams and other rescue teams from the mining industry.

## Multiple-Seam Technology Transfer

*Principal Investigator: Gregory J. Chekan*

### RESEARCH OBJECTIVES

To disseminate information obtained from analyses of multiple-seam mining case studies to customers through technology transfer workshops.

### PROBLEM STATEMENT

Recent response from MSHA regarding priority health and safety issues has indicated that ground control problems associated with multiple-seam mining are common in many mining districts. MSHA realizes that information is available

and recommends that a program be developed to transfer research concerning multiple-seam design and planning to interested customers. In the past, dissemination of this information has been through traditional channels, such as conferences, symposia, peer-reviewed journals, and Government pub-lications. A focused means to transfer this technology to the industry has never been organized. To meet the needs of our customers, a more concentrated effort to distribute this information is required.

## RESULTS TO DATE

Predicting multiple-seam interactions in advance of mining can become a very complex problem because of numerous mining scenarios and different geologic conditions between two or more seams. A significant amount of research has been conducted in the past decade by both Government and university researchers in which case studies were analyzed and mine design and geologic factors were correlated using a systems design approach. This research has led to the development of expert systems and numerical models that can be used as a predictive tool for assessing interaction potential among mines. The objective of the project is to disseminate this information to customers through technology transfer workshops.

The information will come from three major sources:

- Case study analyses of multiple-seam mining problems have led to mine design and planning recommendations. This information is readily available in various Government and university publications and was combined into a single publication for distribution.

- Virginia Polytechnic Institute and State University, through the Generic Minerals Institutes, developed a Windows-based expert system (the Multiple-Seam Analysis Package (MSAP)) that analyzes interaction potential for different seam sequences and mining scenarios.

- LAMODEL is a displacement-discontinuity program developed by the Pittsburgh Research Laboratory and is a state-of-the-art research tool to predict stress in multiple-seam operations.

Technology transfer workshops were attended by 199 participants. More than 200 copies of the proceedings and both the MSAP and LAMODEL programs were distributed. Attendees included MSHA ground control inspectors, consultants, and respresentatives from the mining industry, as well as researchers from the Pittsburgh Research Laboratory.

# DUST AND TOXIC SUBSTANCE CONTROL BRANCH

## Influence of Coal Seam Properties on Dust Generation

*Principal Investigators: John A. Organiscak and Jeff Listak*

### RESEARCH OBJECTIVES

To determine the effects of coal seam composition on airborne respirable dust generation and to evaluate the rock matrix petrographically to determine the effects of grain size and shape, degree of cementation, and mineral composition on the generation of airborne respirable silica dust.

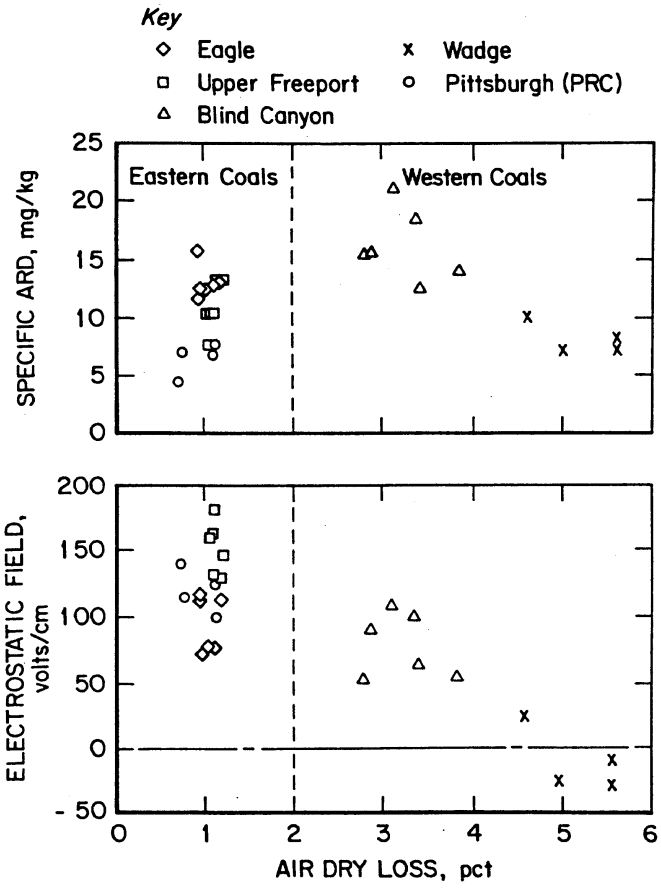
### PROBLEM STATEMENT

About 120,000 miners are employed in the U.S. coal mining industry and are potentially exposed to airborne respirable coal dust. NIOSH's Coal Worker's X-Ray Surveillance program showed that at the current coal mine dust standard of 2.0 mg/m$^3$, the prevalence of pneumoconiosis among coal workers at the category 2 level or greater was 10% for workers with 30 years of exposure. A NIOSH criteria document recommended that the dust standard be reduced to 1 mg/m$^3$. Prior research shows that underground airborne dust generation is correlated to coal seam type. Understanding the effects of coal seam and rock composition on respirable dust generation could identify new avenues for suppressing coal mine dust.

### RESULTS TO DATE

In laboratory experiments, five ranks of bituminous coals were crushed to study the various factors influencing airborne respirable coal dust generation. The results of these experiments indicate that a combination of several factors is associated with the generation of airborne respirable dust (ARD). The most likely factors are (1) the coal rank, which affects the amount of coal dust particles in the product, and (2) the effect of air dry loss moisture in the coal seam on the electrostatic charge in the dust cloud. The resultant effect of these factors is that different percentages of coal particles <10 µm are dispersed as airborne respirable dust. The higher ranked bituminous coals from the eastern regions of the United States produced more dust particles, greater electrostatic fields in the dust cloud, and lower percentages of airborne respirable dust per amount of <10-µm particles in the fines than the lower ranked coals of western regions. Future research should focus on determining if coal dust charging properties can be exploited by using surfactants to improve water spray dust suppression and if pneumoconiosis is in part influenced by the greater dust-charging properties of higher ranked coals.

Five different shale samples and one sandstone sample were also crushed during laboratory experiments to study the various factors influencing airborne silica dust generation. The results from these experiments show that the proportion of silica in the rock material is not indicative of the proportion of silica present in the dust generated. The amount of silica dust generated in the laboratory seemed to be more related to the compressive strength of the rock. Notable inconsistencies in the amount and size distribution of silica dust generated by the roll-crushing apparatus and continuous mining machines in the field indicate differences in the rock-breaking mechanisms of these two machines. Extracting rock with a continuous mining machine is postulated to involve more grinding than the roll crusher apparatus.




**Effect of dry air loss moisture in coal on both dust cloud electrostatic field and airborne respirable dust.**

## Controlling Respirable Silica Dust During Underground Mining

*Principal Investigator: Gerrit V.R. Goodman*

### RESEARCH OBJECTIVES

To develop methodologies for controlling respirable silica dust exposures during underground coal mining.

### PROBLEM STATEMENT

The Federal Coal Mine Health and Safety Act of 1969 limits the amount of respirable coal mine dust to a permissible exposure limit (PEL) of 2.0 mg/m$^3$ for a working shift. If the dust sample contains more than 5% silica by weight, the dust standard is reduced. This is equivalent to a PEL for silica of 0.1 mg/m$^3$. In a recent NIOSH criteria document, it was suggested that the recommended exposure limit (REL) for respirable coal dust be reduced to 1 mg/m$^3$. The current REL for respirable silica is 0.05 mg/m$^3$. According to recent MSHA statistics, approximately 40% of the samples collected from operators and helpers on continuous miners exceeded 5% silica. Furthermore, roughly 25% of the samples from underground workers in the remaining (nonbolting) occupations had silica percentages in excess of 5%. Such levels represent an unacceptable health risk to U.S. coal miners and suggest that available methods are unable to control silica dust exposures during underground coal mining. Research must therefore focus on development of new control technologies or improvements in older ones.

### RESULTS TO DATE

Work during this fiscal year examined the effectiveness of water sprays in confining the dust under the cutting boom of a continuous mining machine. With the help of a cooperating mine, two water sprays were mounted on the left and right sides of a continuous miner near the scrubber inlets. These sprays induced additional airflow along the sides of the miner to improve confinement of the dust cloud. The results of this study showed that the sprays reduced the dust flowing back over the continuous mining machine to the remote operator location.

A second task emphasized the importance of proper positioning of the operator of the remote mining machine during deep cutting. Dust rolling back over the machine to the remote operator was measured. At one operation using an intake curtain, the exposure of the operator was nearly four times the intake dust level. This was attributed to the operator's leaving the fresher airflow behind the curtain and walking into higher dust levels that flowed over the mining machine. To reduce personal dust exposures, it is recommended that this worker stay within the mouth of the blowing curtain. At a second operation where an exhaust curtain was used, exposure of the mining machine operator was nearly five times the intake dust level. This also was attributed to the miner operator's entering the high dust levels rolling back over the continuous mining machine. To reduce personal dust exposure, the operator should be positioned away from the rollback and outby the mouth of the exhaust curtain.

A final task addressed the control of dust exposures on a miner-bolter. Unlike regular continuous miners, a miner-bolter often operates with an independent mobile loading machine. In a typical operation, coal is cut, dumped on the mine floor, and then transferred into shuttle cars by the loading machine. Dumping and loading both generate additional dust that flows back over the miner and bolter operators. A study at a miner-bolter operation showed that dust levels were affected more during the loading phase of the mining cycle. Exposures were greatest for the bolter operator on the exhaust tube side of the continuous miner.

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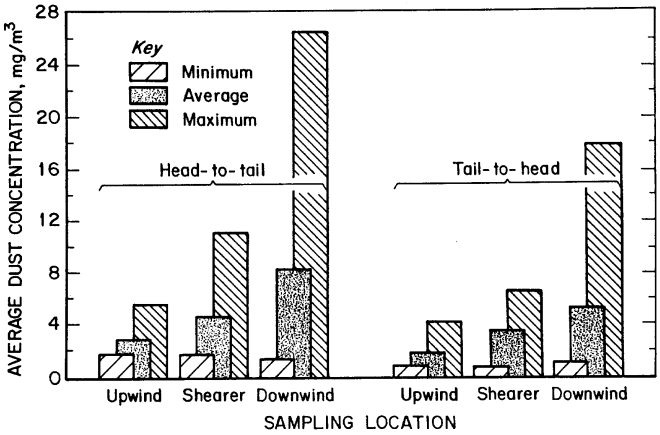
**Proper positioning of the operator can control exposure to respirable silica dust.**




**Summary of respirable dust levels measured during cutting passes at 13 longwalls.**

## Improving Dust Control Technology for Longwall Mining

*Principal Investigator: Jay F. Colinet*

### RESEARCH OBJECTIVES

To determine the state of the art of longwall dust control technology in the United States, identify particularly effective dust control practices, investigate application of new control technology to reduce worker exposure, and disseminate this information to the mining industry.

### PROBLEM STATEMENT

Over the last 15 years, longwall production has increased fourfold, and recent compliance sampling indicates that over 27% of shearer operator samples exceed the 2.0 mg/m$^3$ standard. The potential for increased dust generation and the proximity of mine workers to multiple dust sources exacerbates the problem of dust exposure in longwall mining operations. Past advances in longwall dust control technology have been tempered by significant production gains. Improvements in longwall dust control technology must be developed to reduce the exposure of longwall workers to respirable dust.

### RESULTS TO DATE

Data obtained from surveys at 13 longwall operations were analyzed to determine the state of the art of longwall dust control technology. These data indicate that the effectiveness of control technology varies widely throughout the industry, but in general, ventilating air and spray water are being applied now at higher levels than ever before on longwalls. Studies also show that "basic" control technology has not been universally applied throughout longwall operations and that technology transfer efforts need to be more effective in disseminating control technology information.

The application of two-phase (water and compressed air) spray nozzles for an external spray system on longwall shearers was evaluated at PRL's full-scale longwall gallery. Results of these tests indicate that dust reductions with the two-phase spray system were similar to those obtained with conventional sprays. However, the two-phase spray system reduced water consumption by over 30%.

Two-phase spray nozzles were also evaluated on a simulated longwall face at the Pittsburgh Research Laboratory's Experimental Mine. Two-phase spray manifolds were positioned at 25-ft intervals along the simulated longwall face in an attempt to maintain a "clean" air split in the worker walkway. Dust was sampled to determine their effectiveness. Preliminary results indicate that the manifolds would need to be placed closer together to improve air splitting down the length of the face. Closer spacing of the manifolds would require a greater number of manifolds and higher quantities of spray water and compressed air, making the system less feasible at operating faces.

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## Control of Respirable Dust in Noncoal Mines and Mills

*Principal Investigators: Andrew B. Cecala and Robert J. Timko*

### RESEARCH OBJECTIVES

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

### PROBLEM STATEMENT

This research program adddresses one of the priority research areas specified in the National Occupational Research Agenda (NORA): to provide the basis for reducing chronic obstructive pulmonary disease. Dust such as crystalline silica is harmful because it causes progressive deterioration of the lungs once it has become embedded in tissue. Within the last year, the International Agency for Research on Cancer has classified crystalline silica as a human carcinogen. MSHA's records have shown that since 1974, more than 82,000 of the 134,000 full-shift air samples collected by inspectors in the metal/nonmetal mining industry have contained at least 1% quartz. The occupations with the highest exposures in the entire surface metal/nonmetal mining industry were bagging and packing, and cleanup.

**Instruments sampling respirable dust concentrations near pebble mill in portland cement plant.**

### RESULTS TO DATE

In February 1997, a dust survey was completed at a wet-processing portland cement operation in western Pennsylvania. The objective was to determine respirable dust concentrations at various locations throughout the plant. Thirteen sampling locations were monitored continuously for 70 hr. This work was a followup study to an identical evaluation performed in July 1996. This work allows a comparison of dust levels during the two extreme weather conditions. A similar analysis was performed at a dry-processing plant during the previous year. The results are being finalized, and all information will be compiled into a report.

Work began on a new project to determine the impact of structural design on respirable dust concentrations inside mill buildings. U.S. Silica's plant in Berkeley Springs, WV, was surveyed in September 1997. This plant is one of the largest silica sand operations in the country. Numerous locations in the screening tower and pebble mill buildings were sampled to monitor dust levels during 72 hr of operation. The screening tower is constructed of block and the pebble mill of brick. Results of the monitoring will enable researchers to evaluate whether the design has an effect on dust levels.

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## Control of Silica Dust in Underground Metal/Nonmetal Mines


*Principal Investigators: Andrew B. Cecala and Robert J. Timko*


### RESEARCH OBJECTIVES

To develop control technology to provide a healthier work environment for underground metal/nonmetal miners.

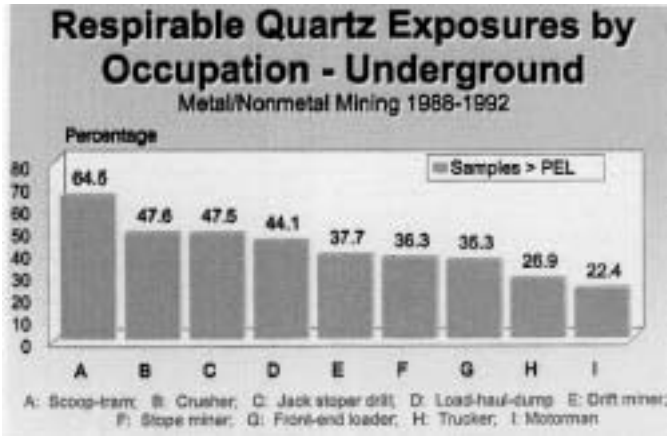
### PROBLEM STATEMENT

All respirable dust (particles having an aerodynamic diameter of 10 $\mu$m or less) is harmful to workers because of its ability to get into the alveolar regions of the lungs. Some dust, like crystalline silica, is even more harmful because it causes progressive deterioration of the lungs once it becomes embedded in the tissue. The goal of this research is to determine

effective control technology to reduce worker exposure to silica and other harmful dusts in underground metal/nonmetal mines.

### RESULTS TO DATE

This project began in the spring of 1997. An extensive literature search was completed to identify previous work in this area. Discussions were held with other NIOSH laboratories to see if any additional information could be obtained on related work. In addition, we have had meetings with MSHA, the National Mining Association, and a number of labor unions to discuss this new program area. Our goal is to determine the most critical areas of worker exposure to silica and other harmful dust in underground metal/nonmetal mines. A substantial amount of communication among the various partners is needed to establish a plan of action for this research. We anticipate visiting a number of operations to observe problems in the underground environment and determine high-exposure job functions, as well as key factors in or sources of these high exposures. Abatement control research will be initiated in the most critical areas found during this preliminary investigation.




**MSHA's compliance dust records showing underground metal/nonmetal occupations with the highest percentage of samples exceeding the permissible exposure limit.**

## Surface Mine Dust Control

*Principal Investigators: Steven J. Page and John A. Organiscak*

### RESEARCH OBJECTIVES

To provide a broad-based approach toward the eradication of silicosis in surface mining operations through evaluation of current control technologies and sources of occupational dust, representative sampling, and testing of new control technology.

### PROBLEM STATEMENT

From 1988 to 1992, the average concentration of respirable crystalline silica in samples collected by MSHA inspectors and mine operators was greater than the permissible exposure limit (PEL) established by MSHA at 0.1 mg/m$^3$ for all surface occupations combined. Exposures of drillers and drill helpers to respirable crystalline silica are of particular concern. Average concentrations ranged from 0.15 to 0.51 mg/m$^3$, up to 70% of all samples exceeded MSHA's PEL, and up to 82% exceeded NIOSH's recommended exposure limit. In 1992, NIOSH reported 23 cases of silicosis in rock drillers ranging from 25 to 60 years of age who had between 3 and 20 years of drilling experience. Most of these cases involved operators in their 30's and 40's, indicating that high silica exposure levels were associated with their occupation. A recent study of 91 surface coal mine drillers found an additional 7 cases of silicosis. Further examination of surface miners has shown that the incidence of lung abnormalities is not limited to drillers.

### RESULTS TO DATE

To address these problems, the project is divided into two phases. The first phase will assess silica dust sources and current control technology at surface mines. Dust source surveys will be conducted at mines having both poor and good dust compliance sampling histories; these mines will be selected with the assistance of MSHA health specialists at district offices. The sampling focus will be on sources associated with occupations historically identified by NIOSH as having a high incidence of silicosis and/or identified by MSHA as having a high risk of exposure to quartz. These sources are likely to include drills, dozers, pans, and trucks. During the surveys, dust control methods and their operating parameters will be documented. The effectiveness of dust control methods used at the various operations will be analyzed.

The second phase of the project will investigate those areas where dust control technology is deficient. Because rock drills are expected to be the most significant source of silica, the focus is likely to be on reducing the amount of silica dust generated by the drilling operation.

On June 18-19, 1997, a deck shroud on a surface coal mine drill at the Sky Haven Mine, Clearfield, PA, was evaluated. The shroud is unique in that it is circular in design, has no open seams, and is capable of being hydraulically raised and lowered to make contact with the ground. Tests consisted of comparing the shroud in full contact with the ground to the shroud partially

raised to simulate a leak. Respirable dust concentrations were less than 0.5 mg/m$^3$ and 52 mg/m$^3$ for the two conditions, respectively, yielding dust reduction efficiencies greater than 99%.

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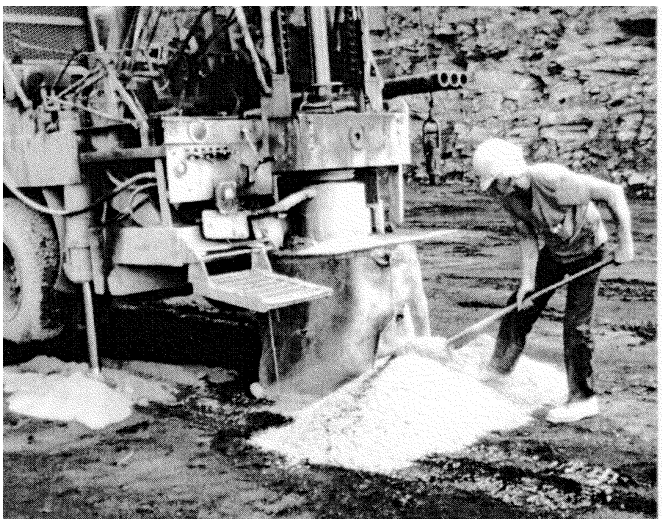

**Circular drill shroud was more than 99% efficient in reducing airborne respirable dust.**

## Improved Application and Monitoring of Dust Control Parameters

*Principal Investigator: Jay F. Colinet*

### RESEARCH OBJECTIVES

To evaluate the interactions and effectiveness of ventilating air and spray water for longwall dust control and to quantify the impact of recent changes in flooded-bed scrubber operations on dust collection capability.

### PROBLEM STATEMENT

The most recent results of the X-Ray Surveillance program for underground coal mine workers indicate that approximately 8% of those workers with 20 to 24 years of experience contract coal worker's pneumoconiosis. Prevention of worker exposure to excessive levels of respirable dust remains a primary concern for the coal mining industry. MSHA sampling results indicate that at any given time, 25% of operating longwalls are out of compliance with the applicable dust standard. Water spray systems and delivery of suitable quantities of ventilating air are the primary means used by operators to limit worker exposure to respirable mine dust. Water and air systems must be improved to reduce dust generation and afford adequate protection to mine workers under a variety of operating conditions.

### RESULTS TO DATE

An experimental test program and sampling protocol were developed to evaluate the effects of changes in face ventilation levels, water quantities, and water pressures on respirable dust levels for shearer drum and external spray systems, spray systems design, mining height, and cutting direction in longwall operations. In phase 1 of the project, 90 tests were completed in PRL's longwall test gallery, which had been configured to represent a 7-ft mining height and the shearer cutting in a head-to-tail direction. The gallery has been configured to simulate tail-to-head cutting, and tests will resume as soon as modifications to the gallery ventilation system are completed.

It is suspected that panels in which density has been reduced by as much as 75% are allowing greater quantities of respirable coal and silica dust to pass through the scrubber, increasing exposures of mine workers. Laboratory tests were conducted with six different filter panels to quantify silica collection efficiency. Results indicate that the least dense panel can allow over 40% of respirable silica to pass through the scrubber. In contrast, the most dense filters remove over 90% of silica, and these panels are recommended for improved silica dust collection.

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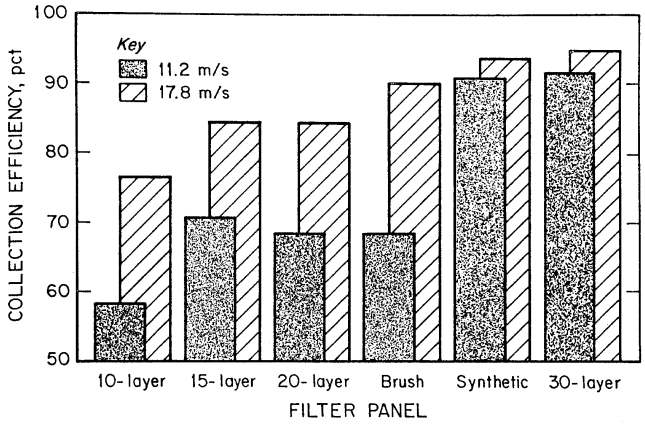



**Efficiency of filter panels in collecting respirable silica.**

## Personal Dust Dosimeter

*Principal Investigators: Jon C. Volkwein and Steven J. Page*

### RESEARCH OBJECTIVES

To develop an inexpensive personal dust monitor based on the correlation of increasing differential pressure across a filter with increased mass loading of the filter.

### PROBLEM STATEMENT

Assessing respirable dust levels in mining workplaces is currently time-consuming and expensive. An inexpensive personal dosimeter would permit more frequent sampling with results immediately available to the worker. More timely dust exposure information may improve the chances that dust levels will be reduced promptly to avoid repeated dust overexposure.

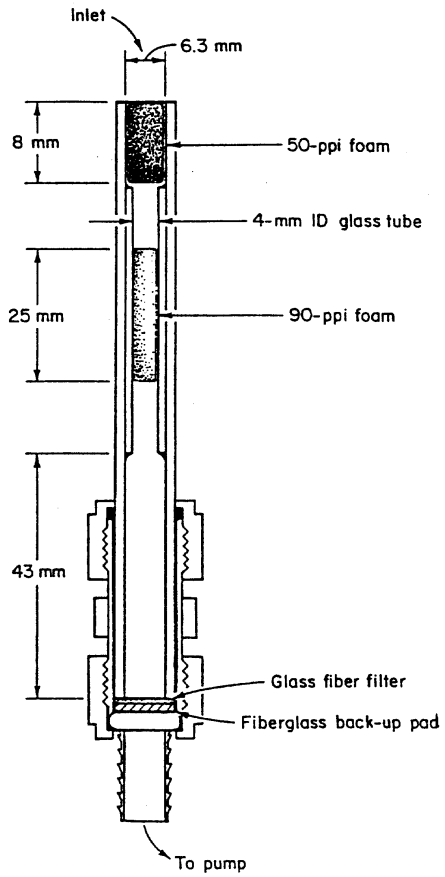
### RESULTS TO DATE

A personal dust dosimeter has been fabricated based on the correlation of increasing differential pressure across a filter with increased dust mass loading. The device uses a section of porous foam to collect the nonrespirable fraction of the dust and passes the respirable dust to the filter across which pressure is measured. The foam preclassification device was evaluated at NIOSH's Hamilton Laboratory using the aerodynamic particle sizer to match foam penetration characteristics with those of a 10-mm nylon cyclone. It was determined that the best approximations of cyclone performance was a 4-mm-diam, 25-mm-long section of foam operating at a face velocity of 35 cm/sec.

Tests of the dosimeter in parallel with conventional personal dust sampling filters have been completed. Six different coal dusts were aerosolized in a laboratory dust chamber, and 118 triplicate observations were obtained. For individual coal types, the correlation coefficients were between 0.90 and 0.97. The precision of the two methods was similar; the personal samplers had a coefficient of variation of 11.83%, and the new detector had a coefficient of variation of 13.96%. For all coal types tested, the data were best described by a power function where $y=1.43x^{0.85}$ with a correlation coefficient of 0.73. The method became more accurate at higher dust loadings, so that all laboratory data with mass loadings greater than an equivalent concentration of 2 $mg/m^3$ fell within ±25% of the power function. Assessment of the method under field conditions has begun with the results from two underground mines agreeing well with the laboratory data. A patent application has been filed on the invention.

#### Provisional Patent Application

Dust Detector Tube, Jon C. Volkwein, Steven J. Page, and Harry Dobroski, Jr. Filed July 3, 1997, CDC Ref. No. I-004-9710.




**Dust detector tube to be used with a low-flow-rate pump that displays differential pressure continuously.**

## Methane Assessment in Auger Highwall Mining

*Principal Investigator: Jon C. Volkwein*

### RESEARCH OBJECTIVES

To develop a method to assess methane concentrations in augered mining holes where the rotating auger's drill string prevents the use of conventional methane monitors and hard-wired communication with the operator.

### PROBLEM STATEMENT

Auger highwall mining machines are increasingly encountering exposive quantities of methane gas. Use of conventional monitoring technology is impossible because extending the electrical cable that carries the monitoring signal through the auger's drill string is not practical.

### RESULTS TO DATE

Tests in PRL's Safety Research Coal Mine have demonstrated that data can be transmitted using a multiple-frequency radio signal through a 6-in-diam, 100-ft-long hole that contains an auger drill string. This system uses an inexpensive radio transmitter and receiver to send the signal, which includes data on gas concentrations. A mineworthy transmitter has been purchased and coupled with the methane monitor.

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**Measuring explosive gas concentrations in augered mining holes using a wireless transmitter.**

## Extended-Cut Air Delivery Systems

*Principal Investigator: Charles D. Taylor*

### RESEARCH OBJECTIVES

To develop improved face ventilation techniques that will increase airflow distribution at the face and to improve monitoring of methane levels.

### PROBLEM STATEMENT

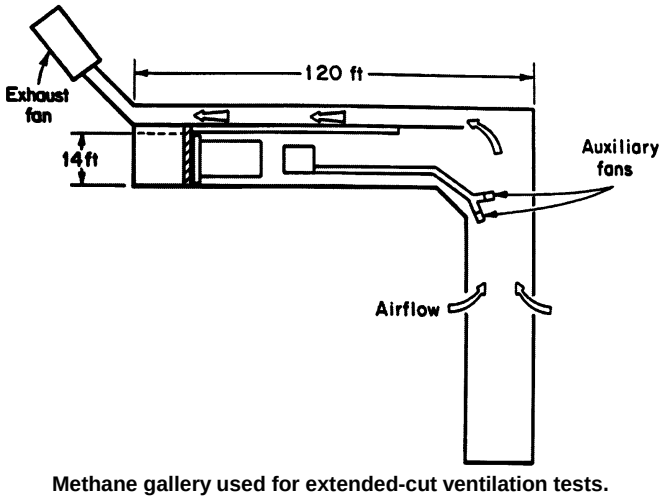
All mining personnel who work underground in face areas are exposed to particulates and gases that are produced as a result of the mining operation. Accumulations of methane near the face present a significant safety hazard. Methane concentrations greater than 5% can be ignited by frictional heating that occurs when metal mining bits strike the rock. Providing adequate face airflow to dilute and remove methane as it is liberated at the face is the primary means for preventing frictional ignitions.

The deeper a mining machine cuts, the more difficult it becomes to maintain adequate airflow at the face. More efficient face ventilation systems for methane control and improved sampling strategies for monitoring the performance of these controls must be developed.

### RESULTS TO DATE

Studies were conducted at the Pittsburgh Research Laboratory's ventilation test gallery to evaluate face ventilation and monitoring of methane concentrations during the mining and bolting of extended-cut faces. Two of the studies examined alternative sampling strategies for taking gas measurements every 20 min at the face. Full-scale roof bolting and mining operations were simulated. A series of tests was conducted using a range of operating conditions (intake flow, curtain and tubing setback distance, equipment configurations). The results provide data for comparing peak and average methane readings at the face to concentrations measured at other locations.

The quantity of air reaching the end of 40- and 20-ft empty box cuts during an extended cut was evaluated. These box cuts were simulated with the model mining machine positioned at the beginning of the slab cut. Methane concentrations were measured at the face. The results show the effects of various curtain setbacks and intake flows on face airflow.




**Methane gallery used for extended-cut ventilation tests.**

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## Effects of Airflow on Escaping Mine Fires

*Principal Investigator: Robert J. Timko*

### RESEARCH OBJECTIVES

To reduce the likelihood that an underground fire goes undetected by developing a hazard evaluation program for operating coal mines, and to expand the level of fire detection at hazardous locations by improving fire detection methods or increasing the quantity of fire detection devices in those areas.

### PROBLEM STATEMENT

An underground fire is perhaps the most hazardous emergency confronting miners because it can generate tremendous quantities of both gaseous and solid contaminants in a very short time. Typically, ignitions that occur without witnesses become more fully developed before they are positively identified and therefore are more difficult to extinguish. Because it is impossible to eliminate all fires, it is important to identify and catalog potential fire sources, as well as the detection methods that are already in place. Many hazards are normally unsupervised, including power centers, rectifiers, conveyor belts, belt drive mechanisms, and air compressors. Locating these sources and describing techniques for reducing their potential as fire hazards, either by adding redundant detection devices or improving alarm response time, will reduce the likelihood of fires at these sources becoming well developed before they are detected.

### RESULTS TO DATE

An examination of historical mine fire data found that fires occurring in belt entries were the most likely to cause injuries, while those in main haulageways were responsible for the highest number of fatalities. Fires in main haulageways were also the most likely to require that the immediate area be sealed before the fire could be extinguished. A study that looked more closely at fire detection at various underground locations found that redundant detection methods existed, but that these varied from place to place within a mine. Face, near-face, and belt

locations had the highest levels of redundant safety devices because (1) more time was spent in designing methods that could continuously monitor and rapidly extinguish an ignition in these areas and (2) miners spent a larger portion of their workday in these areas, which tended to make an ignition more likely to be witnessed and more quickly and safely extinguished. Conversely, haulageways had the lowest level of redundancy because miners are present less often and the types of equipment located in haulageways are so varied that it is more difficult to design detection strategies for specific pieces.

In FY97, efforts were concentrated on identifying the locations for potential fire in haulage entries. Because of the wide variation in haulage entries in different mines, this has been a more complex problem than originally thought. It now appears that corporate philosophy relative to mine engineering has a lot to do with mine haulage design. In other words, if a power center is vented to the return in a specific way in one mine owned by a specific company, it is likely that other mines owned by the same company will have similar designs. If this proves to be the case, hazardous locations may be able to be modified through general management decrees rather than mine by mine.

This project was terminated at the end of FY97.

## Diesel Engine Emission Measurement and Analysis

*Principal Investigators: Bruce Cantrell and Emery Chilton*

### RESEARCH OBJECTIVES

To reduce worker exposure to diesel emissions in underground mines.

### PROBLEM STATEMENT

NIOSH's Current Intelligence Bulletin 50 published in 1988 recommended that "whole diesel exhaust be regarded as a 'potential occupational carcinogen,' as defined in the Cancer Policy of the Occupational Safety and Health Administration." NIOSH further stated that "though the excess risk of cancer in diesel-exhaust-exposed workers has not been quantitatively estimated, it is logical to assume that reduction in exposure to diesel exhaust in the workplace would reduce the excess risk." The International Agency for Research on Cancer also classified diesel exhaust as "probably carcinogenic to humans." In addition, MSHA received a recommendation from an advisory committee to establish a diesel exhaust aerosol standard and to establish regulations to minimize exposure to all diesel pollutants in underground coal mines.

Measuring worker exposure to toxic agents is the first step in determining the exposure-dose response relationship and quantifying the associated risk. Exhaust components, such as diesel particulate matter (exhaust aerosol) and nitrogen dioxide ($NO_2$), are considered of prime importance. This work and development of diesel controls through directed contact work have contributed to MSHA's current efforts to develop a diesel particulate standard.

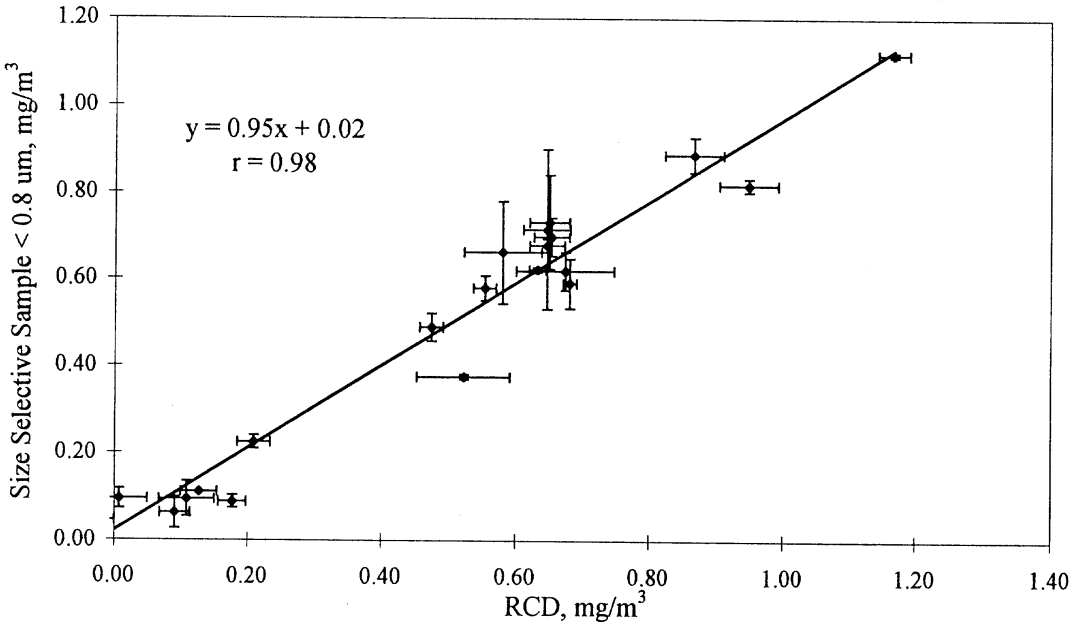
### RESULTS TO DATE

This work addresses both measurement and control of diesel emissions. Comparisons of sampling and analytical methods for diesel particulate were conducted in an underground survey in a Canadian nickel mine and in an ongoing cooperative effort with MSHA. Analytical methods investigated included a size-selective sampling method, a respirable combustible dust (RCD) method, and NIOSH Method 5040, for elemental carbon and total carbon. Results from 81 comparison samples in the Canadian mine survey show that each measurement technique is appropriate for diesel exhaust aerosol. Size-selective sampling and RCD gave identical results for diesel particulate concentrations, and both elemental carbon and total carbon correlated highly with these measurements. At this mine, elemental carbon accounted for 50% of the measured total carbon.

Method development for diesel exhaust aerosol was advanced by issuance of a contract to produce a commerical version of a NIOSH-developed size-selective sampler. Evaluation of the commerical prototypes will be conducted in FY98. In addition, a round-robin test of diesel aerosol particulate analysis using both the NIOSH 5040 and the European elemental carbon test protocols was completed. This test included laboratories in the United States, the United Kingdom, and Europe. Results show that total carbon measured by these methods agree very well, but that elemental carbon is method-dependent.

Passive samplers for measuring $NO_2$ exposure, developed in a cooperative program with MSHA, were used in six mine surveys. These samplers included Palmes-type tube samplers and a sampler using dust-type cassettes developed by the Pittsburgh Research Laboratory. Twenty sampler pairs were used in each mine. The mean comparison ratio is $1.16 \pm 0.38$. The large variance is suspected to result from sampler handling errors in the field. These tests and work with electrochemical, solid-state sensors, and chemiluminescence detectors are continuing.

Under contract, the University of Minnesota Center for Diesel Research (CDR) defined maintenance procedures for underground diesels using emissions measurements. MSHA has distributed these procedures in a report on an emissions-assisted maintenance procedure for diesel-powered equipment. This procedure uses measured exhaust CO and $CO_2$ to determine the state of a diesel engine and whether or not it needs repair. Other work on diesel control technique characteristics includes the use of aftertreatment devices, alternate fuels, and modern engine technology in modifying diesel engine




**Size-selective submicrometer fraction compared to RCD analysis for diesel aerosol.**

exhaust to reduce worker exposure. Currently, the CDR and NIOSH are conducting a study in a Canadian nickel mine to investigate the effect of a 50% soy-methyl-ester, low-sulfur diesel fuel mixture on particulate and gas emissions from a diesel load-haul-dump vehicle.

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## Respirable Dust Measurement and Analysis (Instrumentation)

*Principal Investigator: Kenneth Williams*

### RESEARCH OBJECTIVES

To reduce worker exposure to hazardous respirable aerosols in the mining workplace through improved measurement and control technology.

### PROBLEM STATEMENT

Prolonged inhalation of respirable coal mine dust can cause coal worker's pneumoconiosis (CWP). Between 1968 and 1990, CWP caused the deaths of 55,467 U.S. coal miners. Accurate measurement of respirable dust is crucial to reducing dust exposures and eliminating this disease. Real-time dust monitoring is the most effective way to locate areas where dust controls are needed and, subsequently, to determine how well these controls are working. Silicosis, which is caused by quartz in mine dust, is another genuine concern for the U.S. mining workforce. The National Coal Workers Autopsy Study records that 12% of miners have silicosis lesions. Other studies show that >5% of surface mine workers have silicosis. Better ways to measure quartz will enable the health and enforcement community to pursue improved epidemiology, describe dose-response relationships in detail, and verify the effectiveness of

control technology. This project directly addresses the NORA priority research area of "exposure assessment methods" by developing technology to measure respirable dust.

## RESULTS TO DATE

A dust monitor that measures respirable dust continuously was developed. This sensor uses the inertial behavior of a specially tapered, vibrating tube to measure the mass in a sample of dust. By drawing air through the tube, the sensor collects dust from the mine air on a filter. The more dust on the filter, the greater the mass, which decreases the frequency of oscillation of the tube. By measuring changes in frequency, the amount of dust can be determined. Phase 2 evaluations of prototypes have been completed in two mines. Laboratory and in-mine tests have shown that a properly designed sensor based on this technology can operate successfully in the underground coal mine environment and provide accurate, continuous measurements of respirable dust concentrations. A field test protocol for 10 monitors was written and presented to participating mines. The production monitors will be evaluated first in laboratory tests and then in underground coal mines as they become available.

Another technology for measuring the mass of sampled respirable dust is the resonant filter membrane mass monitor (RFM3). In this approach, a filter membrane is stretched taut and made to vibrate. As the filter collects dust, resonant frequencies of vibration decrease. Those changes in frequency can be related to the mass of dust collected. NIOSH sponsored early research on the device and is now cooperating with the developer by evaluating prototypes at the Pittsburgh Research Laboratory. The monitor's dust sampling capabilities and the effects of humidity on the instrument's output were tested; although the RFM3 agreed with gravimetric measurements to within ±25% for mass loadings above 0.5 mg, it was shown that humidity affects the glass fiber filters currently used. When sampling dust-free air at 23°C and 60% relative humidity, the monitor indicated a mass gain of more than 50 mg.

NIOSH has developed a method for analyzing the quartz content of coal mine dust samples directly on the collection filter using Fourier transform infrared spectroscopy. Twenty-five field samples of coal dust on 37-mm PVC filters were analyzed first by the on-filter method and subsequently by the established P-7 method. The correlation between the two methods is extremely high; however, the on-filter method consistently reports quartz mass values about one-third higher than the P-7 method. Different ways of calculating spectroscopic results or preparing analytical standards may be causing this systematic variation. Further research is expected to resolve this question. Under contract, Spectros Associates wrote specialized software to automate on-filter quartz analysis. Once perfected, the software will allow refinements of the analytical method to proceed more rapidly by reducing the need to manipulate the samples by hand.

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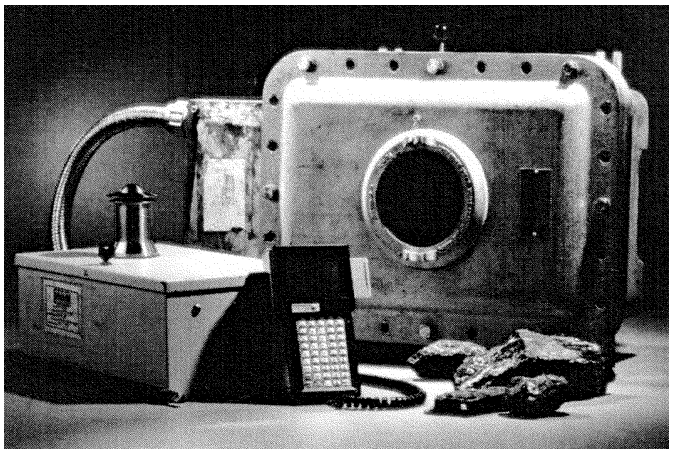


**Prototype dust monitor.**

# SURVEILLANCE, STATISTICS, AND RESEARCH SUPPORT ACTIVITY

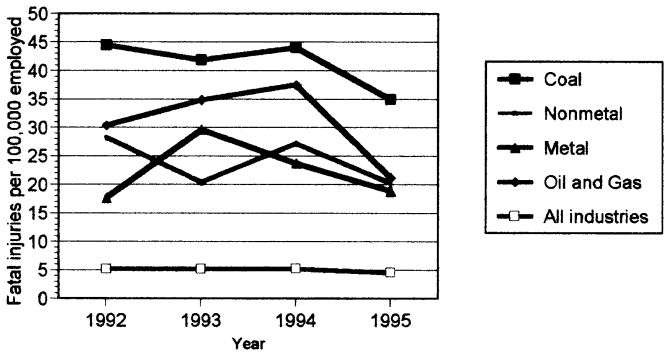
*Principal Investigator: Deborah Landen*

### RESEARCH OBJECTIVES

To produce a surveillance report describing trends in injury and illness incidence and hazard exposures in the U.S. mining industry during 1986-1995.

### PROBLEM STATEMENT

This project will enumerate and describe the diseases, injuries and hazards related to work in the mining industry using many data sources. Trends in existing data will be described, and needs for additional data sources for future surveillance will be assessed. Results of the project will be a key factor in defining NIOSH mining health and safety research priorities.




Data source: Bureau of Labor Statistics Census of Fatal Occupational Injuries

**Fatal injuries per 100,000 workers for mining commodities and all industries by year.**

# EXTRAMURAL COORDINATION AND INFORMATION DISSEMINATION ACTIVITY (ECIDA)

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### RESEARCH OBJECTIVES

To clearly and effectively transfer the results of scientific and engineering research to the mining workplace, helping make it safer and more healthful.

### PROBLEM STATEMENT

The Extramural Coordination and Information Dissemination Activity (ECIDA) at the Pittsburgh Research Laboratory (PRL) is a critical technology transfer link between scientific/ engineering research at PRL and the end user. Through its collaboration with other branches, activities, and teams within the Office for Mine Safety and Health Research, ECIDA helps convey research products to stakeholders, thus contributing to our mission of making workplaces safer and more healthful for all miners.

The ECIDA group accomplishes its mission by engaging in three general activities: (1) coordinating research agreements with outside entities in such a way that the Laboratory receives a high return on its resource outlay, (2) facilitating the transfer of ideas and R&D to a market setting in which PRL products will significantly impact safety and health in the American workplace, and (3) designing, implementing, and assessing the delivery of scientific and technical information to target audiences using expertise in marketing, education and training, communication, and the social sciences.

### RESULTS TO DATE

PRL coordinated a stakeholder meeting, which was held in conjunction with the Mine Safety and Health Administration's (MSHA) annual State Grants Meeting at the National Mine Health and Safety Academy, Beckley, WV, in February 1998. We also hosted the annual meeting of the Mid-Atlantic Section of the Federal Laboratory Consortium (FLC) during March 1998. The FLC helps form the bridge between federally developed technology and the private sector.

During 1997-98, PRL published the following in-house NIOSH publications: 5 Reports of Investigations (Ris), 2 Information Circulars (ICs), 10 Technology News flyers, 2 Mining Health and Safety Update newsletters, and 1 Hazard ID. During the same period, PRL personnel also published 83 outside papers, 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, including 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. Technology News and Mining Health and Safety Updates were

disseminated on a mailing list to more than 5,000 customers worldwide. The results of our research are also often reported and/or reprinted in the mining literature, e.g., MSHA's Holmes Safety Association Bulletin, "Sensors" magazine, and the Mine Regulation Reporter.

We collaborated with the Spokane Research Laboratory and the Management Systems Branch at Pittsburgh to design a home page for the Internet. This site will give the world access to research conducted by the Office for Mine Safety and Health Research.

PRL/NIOSH was represented by exhibits at a number of conferences and events, including the International Methane Conference and Exhibit (Morgantown, WV); Society for Mining, Metallurgy, and Exploration, Inc., (SME) annual meetings (Denver, CO, and Orlando, FL); National Conference To Eliminate Silicosis (Washington, DC); and the NAACP Convention's Job Diversity Fair (Pittsburgh, PA). The NAACP exhibit was costaffed by personnel from PRL and the Health Effects Laboratory Division (HELD), Morgantown, WV.

We have reviewed eight Reports of Invention and Patent Applications submitted by PRL researchers since October 1, 1997. We also processed 10 Memorandums of Agreement, 2 CRADAs, 9 Evaluation Agreement extensions, and 1 Military Interdepartmental Purchase Request. Seven of these agreements have cleared the system and are in place.

The ECIDA group arranged and conducted laboratory tours for seven schools, 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, and a total of 43 visiting scientists and engineers. ECIDA staff also assisted the Administrative Services Branch with tours for students participating in the ASSET program.

**NIOSH exhibit at the NAACP Convention's Diversity Job Fair in Pittsburgh, PA, staffed by PRL and HELD (July 1997).**

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