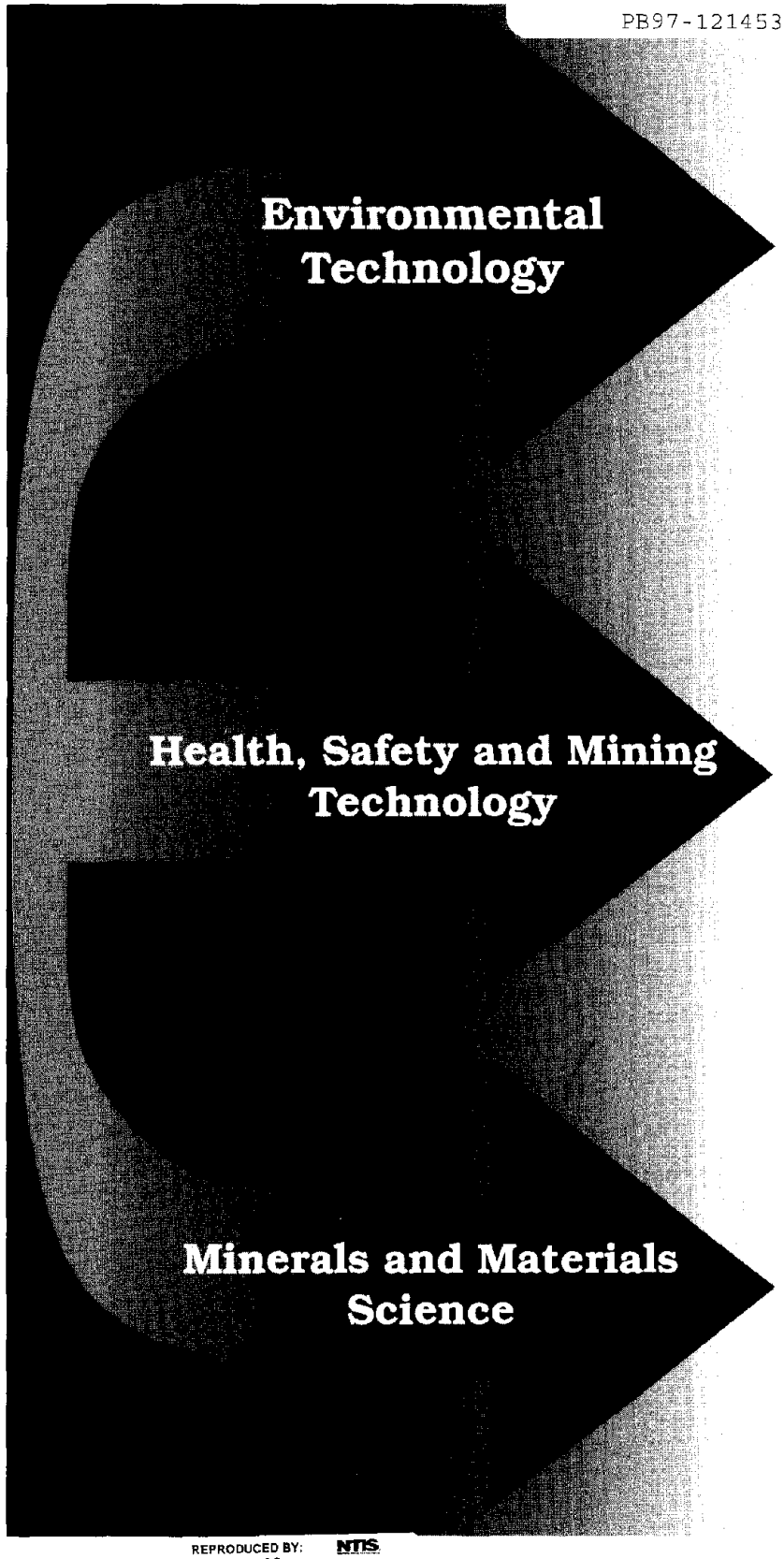
SP 11-94

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
FY 1993 Annual Research Report



BIBLIOGRAPHIC INFORMATION

PB97-121453

Report Nos: BUMINES-SP-11-94

Title: Bureau of Mines FY 1993 Annual Research Report.

Date: 1994

Performing Organization: Bureau of Mines, Washington, DC.

NTIS Field/Group Codes: 48A (Mineral Industries), 68 (Environmental Pollution & Control)

Price: PC A05/MF A01

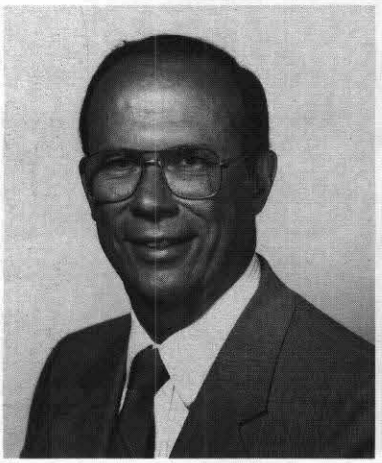
Availability: Available from the National Technical Information Service, Springfield, VA. 22161

Number of Pages: 64p

Keywords: *Annual reports, *Mining, *Research management, Occupational health, Safety, Environment management, Environmental protection, Minerals, Materials, Technology transfer, Pollution, Land reclamation, *US Bureau of Mines.

Abstract: Contents: Environmental Technology; Health-Safety and Mining Technology; Minerals and Materials Science; Research Support Programs; and Research Projects.

FROM THE ASSOCIATE DIRECTOR—RESEARCH



David R. Forshey
Associate Director-Research

I have the honor to present the fiscal year (FY) 1993 Annual Report for the Research Directorate of the U.S. Bureau of Mines (USBM). In FY 1993, the USBM research program realized many significant research accomplishments in support of its research mission of protecting the environment during raw materials processing, conserving natural resources, recycling, and protecting workers from health and safety risks.

Our research program is continuing to increase its focus on environmental research. The Environmental Technology (ET) program budget has been increased by 25 percent from its FY 1990 level. As a result, the ET program has produced several significant accomplishments. For example, the USBM's R&D-100 Award winning acid leach-electrowinning system, which electrochemically extracts metals from solutions, was successfully demonstrated on a range of lead-contaminated materials including urban, paint-contaminated soils, sediments, and site debris.

In the area of health and safety, a wireless, mine messenger communication system, called the Canary, was developed that allows mine personnel on the surface to send individual messages directly to miners deep within a mine regardless of their location or work activity. This can be a life-saving device in the event of an underground emergency. For this achievement, the USBM was awarded another prestigious R&D-100 Award to its impressive list of R&D-100 Awards. The USBM has won 33 of these awards to date and ranks number 14 among the "Top 20 Winners" for the past 30 years of award competition.

We have been taking steps in increasing research program emphasis towards more formal government-industry cooperation. The Federal Technology Transfer Act (FTTA) provides the legislation that encourages the pooling of resources to benefit U.S. industries. In light of the FTTA enabling legislation, the USBM, as a matter of policy, reviews research and development project plans for possible cooperative involvement by industry and actively seeks cooperators at every stage of research and development. In 1993, we had 283 cooperative agreements with various cooperators in the mining, minerals processing, and environmental industries. Twenty-nine of these agreements were Cooperative Research and Development Agreements, which play a key role in our overall research strategy.

In addition to agreements with industrial cooperators, the USBM had 71 interagency agreements with other Federal agencies. Many agencies are utilizing USBM technical expertise to assist in solving some of their more complex problems. For example, under an Interagency Agreement with the Environmental Protection Agency (EPA), the USBM applied its flotation technology to reduce residual lead levels in the reprocessed tails to below the EPA's target level for commercial sites from the Sharon Steel Superfund Site in Utah.

We look forward to continuing to play a stronger, more effective role in Department of the Interior and Administration efforts to solve the most important minerals-related problems in the coming years.

The U.S. Bureau of Mines (USBM) headquarters building is located at 810 Seventh St. NW, Washington, DC 20241. The USBM occupies 120,000 square feet of space in the 260,000-square foot structure. Close to major Government components, the headquarters building is only a short distance from the White House and Capitol Hill. The building is next door to the District of Columbia Convention Center. The Gallery Place-Chinatown station of the Metro subway system (on the red, yellow, and green lines) is one-half block to the south.

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As a Nation, we cannot live and prosper without minerals. The mining and mineral processing industries supply the raw materials, metals, and minerals supporting the Nation's economy and standard of living. The U.S. Bureau of Mines (USBM) research program develops technology to help meet the Nation's mineral and material needs and mitigate associated economic, human, and environmental costs. The program seeks improvements for most aspects of the materials production cycle—from removing minerals from the earth to enhancing the performance of materials—and beyond to waste management, recovering spent mineral values, and resource conservation. The health and safety of workers in the Nation's mines and mineral processing plants and the environmental impact of mining and mineral processing are major USBM concerns. The strategic objectives of the program are to—

✔ *Provide cost-effective technology for the cleanup of past environmental problems associated with mineral production and use, especially on Department of the Interior lands.*

✔ *Provide environmentally compatible materials and processes that conserve our natural resources, and that enhance U.S. product innovation, industrial productivity, and economic growth.*

✔ *Provide the scientific basis for the necessary extraction, worker health and safety, and waste management technologies to meet the Nation's materials requirements.*

The research program is structured into three major research areas: Environmental Technology (ET); Health, Safety and Mining Technology (HSMT); and Minerals and Materials Science (MMS).

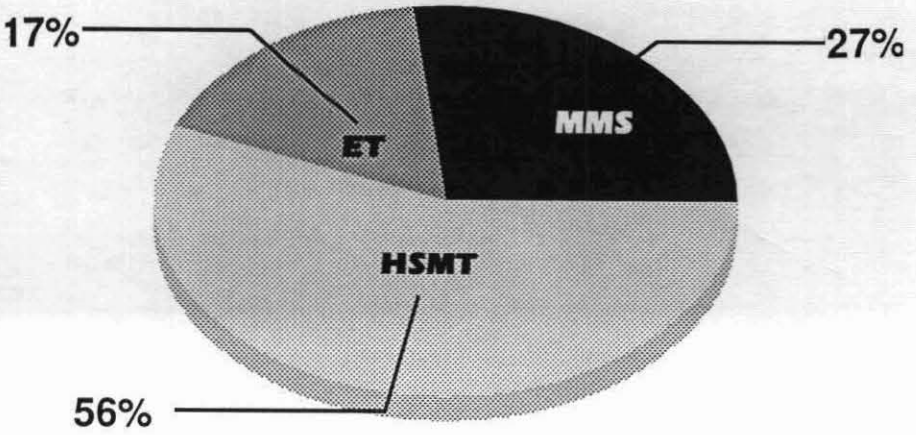
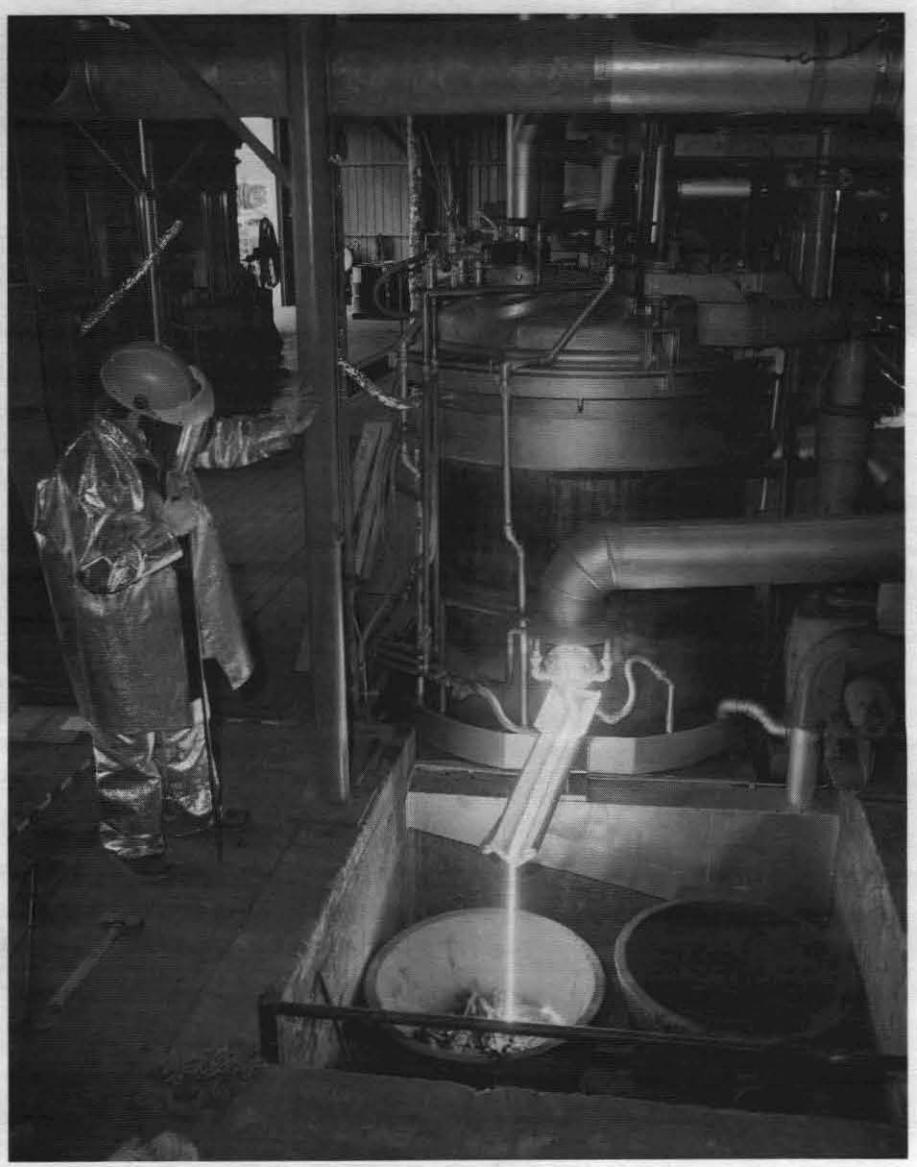


Chart showing the percentage of fiscal year (FY) 1993 research funding for the three major areas.

The electric arc furnance installed at the USBM Albany Research Center resulted from a cooperative vitrification study conducted with the American Society of Mechanical Engineers and 38 corporate and government sponsors. Initial tests involved melting over 54,000 pounds of residues from municipal combustion facilities during 100 hours of continuous furnace operation. Current tests are evaluating the sealed furnace for use in thermal treatment of mixed transuranic contaminated wastes and soils from the Idaho National Engineering Laboratory.



ENVIRONMENTAL TECHNOLOGY

Throughout the United States, and indeed the world, there is a growing awareness of how human activities affect the environment. With this awareness comes a stronger commitment to reconciling economic needs with environmental protection. The Department of the Interior, other Federal agencies, the mining industry, and the American people face a common concern—the environmental threat from past, present, and future use of minerals. Large quantities of waste materials are produced during mining, beneficiation, processing, and recycling. These wastes account for nearly 40 percent of all solid waste generated in the United States annually. The ET program conducts research to provide the science base for technologies to reduce the volume and toxicity of liquid and solid wastes generated through minerals-related activities; remedy hazardous waste sites contaminated with heavy metals throughout the country, especially those on Federal lands; and mitigate the environmental effects of coal mining on active and abandoned coal mine lands.

The ET program is divided into five research areas: Control of Mine Drainage and Liquid Wastes, Solid Waste Management and Subsidence, Hazardous Waste Treatment Technology, Abandoned Mined Land Reclamation Research, and the National Mine Land Reclamation Center.

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CONTROL OF MINE DRAINAGE AND LIQUID WASTES

Thrusts

The goal of the Control of Mine Drainage and Liquid Wastes program is to prevent, mitigate, and control contamination of the Nation's waters from the results of mining and mineral processing. A major source of polluted water is acid mine drainage (AMD) resulting from the weathering of minerals containing iron sulfide. Since most coal and metal mines contain iron sulfide minerals, the problem of AMD affects most mining sites in the United States, especially the Appalachian and other coal regions in the East and the historic mining regions of the West. Other sources of pollution include mineral processing facilities. The objectives of the Control of Mine Drainage and Liquid Wastes program are to—

✔ *Determine the scientific basis for cost-effective treatment of waste water and liquid processing wastes from active mines and bringing these wastes into compliance with environmental regulations.*

✔ *Develop and demonstrate low-cost, low-maintenance water treatment systems based on physicochemical and biological processes for abandoned and inactive mines with contaminated-drainage problems.*

✔ *Develop and demonstrate processes for decontamination of liquid wastes and recovery of useful products.*

✔ *Investigate methodologies and techniques for predicting the occurrence and severity of contaminated mine drainage based on short-term tests.*

Recent Program Accomplishments

Arsenic Remediation: Process technology developed by the USBM has been successful in cleaning up arsenic-contaminated waters. Sulfate-reducing bacteria are used to produce sulfides, these sulfides then precipitate arsenic as an insoluble arsenic and sulfide complex that can be collected by conventional filtration technology. A second technology developed by the USBM, porous polysulfone beads containing other materials that bind metal ions, shows promise as a polishing step to remove any remaining arsenic.

Systems Approach for Control of Mine Drainage: Several USBM technologies (liquid membrane, immobilized extractants, ion elutriation, and biogenic sulfide reduction) were tested on waters from several mines. The systems approach provided a good basis for solving complex environmental contamination problems.

Hydrologic Assessment of Wellhead Protection in Mining Regions: The USBM is identifying and assessing various hydrogeologic and mining variables important in delineating wellhead protection zones around public supply wells in mining regions. USBM researchers monitored hydrologic conditions between an active underground coal mine and municipal wells in southwestern Pennsylvania. Results

were used to assess the relative importance of hydrologic variables, such as mine proximity to the municipal wells, well pumpage, and groundwater flow rate into the mine, on delineating groundwater capture zones for public wells and mine workings. From these capture zones, wellhead protection zones were proposed to better manage development of coal and groundwater resources in the area.

Hydrologic Data Base for Coal Mine Drainage: A data base was constructed relating postmining water quality to premining geochemical parameters for reclaimed surface and underground coal mines. The data base can be used in the prediction and interpretation of AMD problems and in the design of in situ treatment systems.

Biological Extractants for Anion Contaminants: Biological extractants were identified and tested at industrial locations for the removal of anion contaminants, including arsenic, phosphates, and selenium.

Hydrogeologic Studies of Mine Tailings: Groundwater flow through mine tailings was studied to assess the relationships among the mineralogy and chemistry of the ore and tailings, the levels of solution of certain metals of environmental concern, and the attenuation rate of those levels downgradient.

Future Research

The development of predictive models and control and/or treatment technologies for mitigation and decontamination of wastes from mineral processing will be continued. Bench-scale tests of these technologies will be carried out and promising ones will be demonstrated at field sites of cooperators. Successful techniques will be transmitted to public land managers (U.S. Forest Service [USFS], Bureau of Land Management [BLM], and other Federal agencies) and regulators through workshops, software distribution, and training programs.

Researcher collecting water samples from contaminated stream.

SOLID WASTE MANAGEMENT AND SUBSIDENCE

Thrusts

The goal of the Solid Waste Management and Subsidence program is to develop cost-effective technology for the disposal of mining and mineral processing wastes from current operations and to remedy environmental damage resulting from past mining and waste disposal activities. This program includes research in other mining-related areas such as developing innovative technology for reclaiming and closing mines and waste disposal sites, preventing or mitigating damage caused by surface subsidence (collapse) from underground mining, and providing techniques for evaluating the potential for damage to homes resulting from low-frequency blast vibrations. These efforts are directed toward correcting existing environmental problems and preventing future problems. The objectives of this program are to—

✔ *Remove and recover residual toxic metal contents from industrial mining and mineral processing wastes, and render them benign.*

✔ *Immobilize toxic constituents of solid wastes.*

✔ *Predict and control ground surface movements, hydrologic effects, and mining-induced movements on surface structures above active mining operations.*

✔ *Ensure that technologies used by mines and mineral processing operations do not result in wastes that cause environmental degradation when the facilities are closed.*

Recent Program Accomplishments

Reducing the Effects of Subsidence on Residential Foundations: Analysis of data from 12 linear test foundations constructed over an advancing longwall coal mine panel in southern Illinois shows that curvature of the foundations of the structures is the major damaging mechanism to structures during a subsidence event.

Effects of Subsidence on Escarpment Stability: A numerical modeling strategy for simulating subsidence of overburden strata near a plateau escarpment has been developed by incorporating factors such as nonlinear deformation, gob area, horizontal slippage along bedding planes, and the effects of geologic structural discontinuities.

Revegetation of Barren Mine Wastes: Mine land stabilization through revegetation research has shown a steady increase (from 0 to 80 percent cover) over the last four growing seasons on coarse tailing material from past taconite iron ore mining. Similar results occurred in an abandoned lead and zinc chat tailings site in southwestern Kansas.

Metal-Mine Rock Dump Characteristics for Stability: An assessment of USFS and USBM research needs in the area of metal-mine rock dump stability was initiated under the USBM-USFS Mem-

orandum of Understanding (MOU). A report, analyzing work applicable to metal-mine rock dump problems on USFS lands, identifies future research objectives of both the USFS and the USBM.

Environmentally Safe Disposal of Coal Combustion Residues: A comprehensive investigation of the disposal of coal combustion residuals in or on mined lands will consider existing regulatory practices at the State level, evaluate leachate testing, review State permit and monitoring data, and will initiate long-term monitoring at selected sites.

Waste Vitrification: About 24 tons of soils containing five different mixtures of simulated contaminants were vitrified in the USBM's electric arc furnace (EAF) facility to determine the suitability of using EAF technology for vitrifying radioactive waste materials. Data necessary to design full-scale applications were obtained.

Cooperative Industrial Testing of USBM Process for Treating Steelmaking Dusts: A major U.S. steel company is assisting the USBM in testing agglomeration methods for a mixture of steelmaking dust and ore fines, optimizing conditions for a rotary kiln process, and final testing of recycling processed wastes to a blast furnace.

Future Research

Future research will focus on verification of the benefits of subaqueous disposal of mining and mineral processing wastes, full-scale mine closure for surface waste disposal sites, environmentally effective metal-mine rock dump stability, stabilization of combinations of heavy metals contained in industrial solid wastes, effects of subsidence on the soil structure and pipeline interface, and development of criteria for the environmentally sound disposal of coal combustion residuals.

Metal-mine rock dump, Cyprus's Thompson Creek Mine (molybdenum), Challis National Forest, Challis, ID.

HAZARDOUS WASTE TREATMENT TECHNOLOGY

Thrusts

The goal of the Hazardous Waste Treatment Technology program is to develop more efficient and cost-effective technology for the remediation of hazardous waste sites and to find better methods to characterize these sites. This program applies the skills in extractive metallurgy that the USBM has acquired over its 80 years to help other Federal, State, and private organizations in developing technology for the treatment of hazardous wastes. USBM experience has shown that the basic problem—the type and extent of contamination and determination of the applicable treatment options—is fundamentally similar to the problem of mineral exploration and recovery. In recent years, through various agreements such as its MOU with the EPA Superfund program, the USBM has shown that adaptations of mining and mineral processing technologies have wide application to the remediation of hazardous wastes. The objectives of the Hazardous Waste Treatment Technology program are to—

✔ *Develop improved, generic site characterization protocols for complex metal-contaminated sites.*

✔ *Develop new, innovative technology to allow permanent, cost-effective cleanup of metal-contaminated sites.*

✔ *Adapt methods of processing and extracting minerals to remedy contaminated sites.*

✔ *Promote recovery technology as a permanent solution to metal contamination through demonstration and increased technical assistance to other organizations.*

Recent Program Accomplishments

Application of Mineral Beneficiation Processes for Lead Removal: Laboratory tests on soils from contaminated berms at small-arms firing ranges were tested in the laboratory to determine if metallurgical processes could be applied to extract lead and lead bullet fragments. A 1,500-pound-per-hour pilot plant was then designed and an initial on-site test was successfully performed at Camp Pendleton, Oceanside, CA. The test determined further design criteria for the operation of the plant. This technology has potential application to approximately 300 Navy and Marine Corps sites.

Advanced Flotation Technology: The USBM's modified, air-sparged hydrocyclone and column flotation cell technologies were combined in a prototype hybrid flotation cell that combines high throughput and better froth separation with fine particle wastes. These flotation technologies, and conventional cells with nonstandard flotation reagent schemes, were applied to lead tailings samples from the Sharon Steel Superfund Site in Utah under an Interagency Agreement with the EPA. The USBM was able to reduce residual lead levels in the reprocessed tails to below EPA's 1,000 parts per million

target level for commercial sites and, in some cases, to below 350 parts per million. These compact, low capital cost technologies can be used to minimize lead levels in process waste streams as well as to recover metal values from existing tailings.

Future Research

Future research in the Hazardous Waste Treatment Technology program will focus on extractive metallurgical technologies for innovative treatment of metal-contaminated soil and groundwater, mixed organic and inorganic wastes, and processing feed material for treatment.

Demonstration of USBM-developed technology at Camp Pendleton, CA. USBM and Navy personnel are operating the gravity circuit of a process plant for removal of lead bullet fragments and lead in soil at small-arms firing range.

ABANDONED MINED LAND RECLAMATION RESEARCH

Thrusts

The goal of the Abandoned Mined Land (AML) Reclamation Research program is to find solutions to the environmental problems associated with reclaiming abandoned coal mines. This program supports the Nationwide AML program carried out by Primacy States and the Office of Surface Mining (OSM) under Public Law 95-87. Problem areas targeted for research include AMD, subsidence, abandoned shafts and adits, mine fires, and slope stability of mining wastes. The objectives of the AML Research program are to—

✔ *Develop new and improved coal mine reclamation technology responsive to the needs of State, Federal, and other agencies responsible for AML reclamation.*

✔ *Develop a coordinated research effort through involvement with the Association of Abandoned Mine Land Programs and OSM.*

✔ *Promote transfer of the resulting technology through field implementation of the AML research projects.*

Recent Program Accomplishments

Cross-Borehole Acoustic Logging System: In cooperation with State highway officials, a cross-borehole acoustic logging system to map underground voids and associated collapsed structures was demonstrated at a highway construction site in Bullhead City, AZ.

An Experimental Wetland Treatment System: A design for an experimental wetland treatment system was developed to compare surface and subsurface flow systems for treating AMD waters. Subsurface flow design proved to be more effective in improving levels of pH, iron, and aluminum.

Innovative Concrete Placement Device: A concrete placement device was developed to effectively stow concrete in a cylindrical fashion for remote placement in underground mine openings. Through an 8-inch borehole, an 8-foot cylindrical pillar can be constructed from floor to roof of the mine opening.

Evaluation of Chemical Treatment Methodologies to Remove Ions From Acid Mine Drainage: A combined calcium phosphate and sodium hydroxide treatment method was tested and successfully removed metals from AMD.

Abatement of Manganese in Coal Mine Drainages: Aerobic and anaerobic constructed wetlands were evaluated for manganese removal. Manganese-oxidizing microbes were examined for optimal growth conditions and maximum manganese removal efficiency.

Future Research

Future research will focus on demonstrating encapsulation technology for pyritic materials that cause AMD, the effectiveness of the cryogenic extinguishment technique for a waste-bank fire in Ohio, the cross-borehole acoustic logging system at a field site on BLM lands, and the effectiveness of sealing shafts using inflatable forms coupled with lightweight foam concrete. In addition, grouted-point support systems for use in flooded coal mine voids will be evaluated.

Field tests of a cross well acoustic tomography system to locate abandoned underground mines and subsidence failure.

NATIONAL MINE LAND RECLAMATION CENTER

Thrusts

The National Mine Land Reclamation Center (NMLRC) program provides support for university-based research on the surface effects of mining on coal-mined lands and the amelioration of those effects. Research thrusts include AMD, prime farmland restoration, soil reconstitution and revegetation, groundwater salinization, subsidence prediction and control, erosion and sediment control, and waste disposal. The NMLRC is organized to address issues on a regional basis with eastern, midwestern, and western components, each with a separate Regional Council for providing direction.

Recent Program Accomplishments

Evaluation of Amendments for Prevention of Acid Mine Drainage: Kiln dust, slag, alkaline coal ash, and limestone have been shown to have the capacity to prevent AMD when incorporated with rock having acid-producing potential. Studies at a large coal mine in West Virginia have shown that adding kiln dust to the refuse conveyer effectively neutralizes acidic components, producing a neutral water suitable for discharge without further treatment. Long-term performance is under study.

Soil Decompaction Techniques: A device for measuring soil compaction has been developed that is now used by Illinois regulatory staff. Studies are evaluating various soil decompaction techniques with the objective of increasing plant-usable soil volume.

Chemical Evolution of Subsurface Water at Abandoned Mine Land Sites: Topographic control of groundwater recharge, and the effect of spoil geochemistry and water movement in abandoned mine sites have led to improved understanding of recharge at mined and adjacent unmined areas, and their effect on the water table and the root zone.

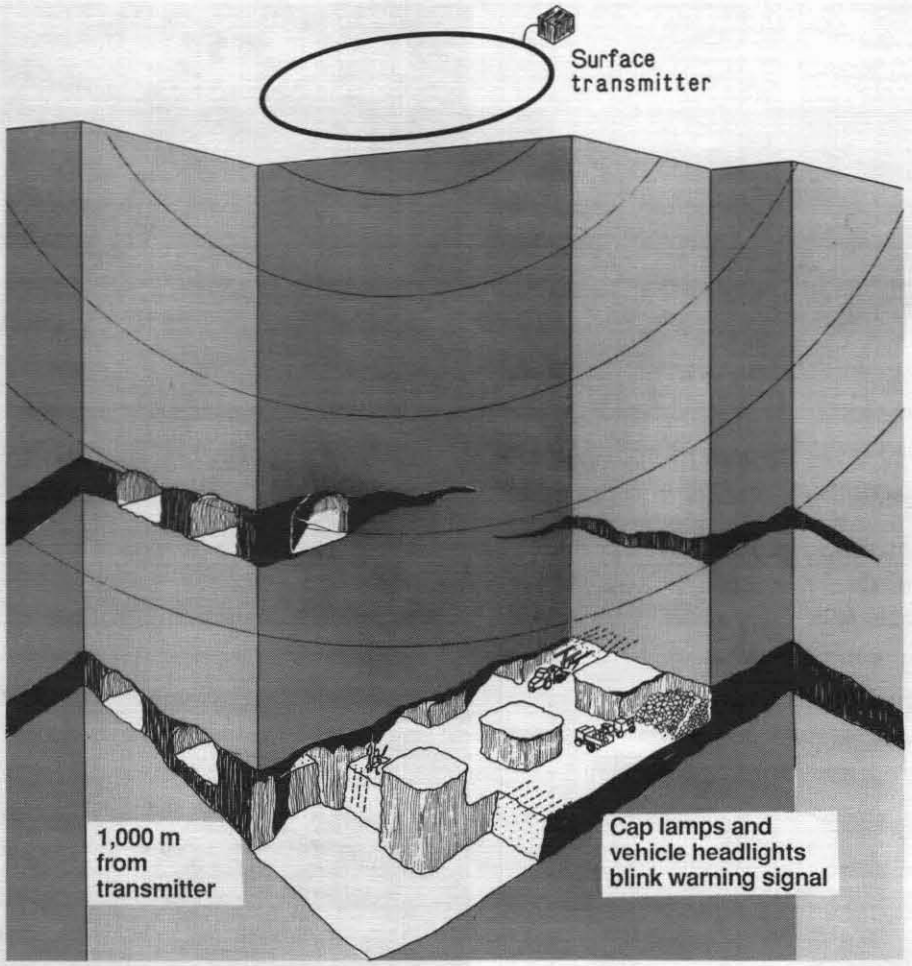
Future Research

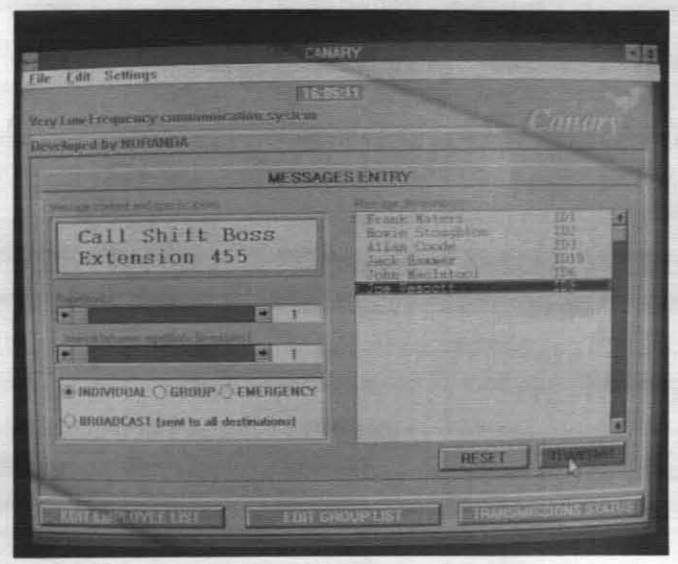
Effective in 1993, this university-related program was transferred to become part of the Mineral Institute program. Research will continue on the surface effects of mining on active and abandoned coal mines based on the priorities established in the National and Regional Research Councils for the NMLRC program.

West Virginia University researchers test mine drainage water quality under a variety of weather conditions. Here a researcher takes a sample in the snow.

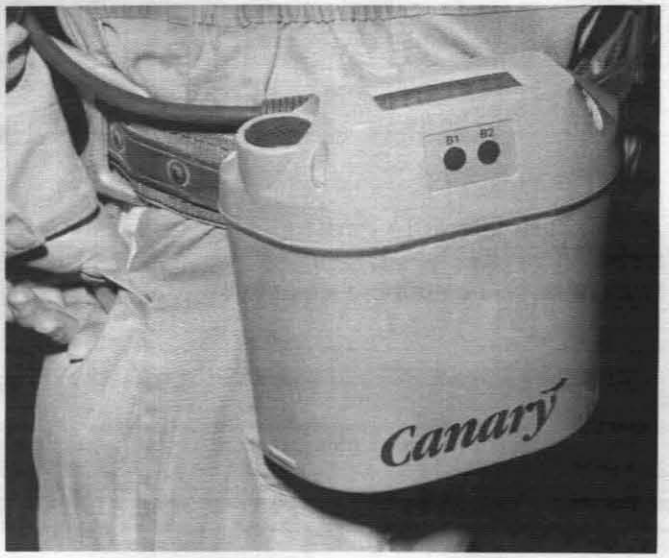
Southern Illinois University researchers monitor soil conditions at a reclaimed mine site.

Overall view of the Canary system, a wireless, mine messenger communications system. This system allows mine personnel on the surface to send individual messages directly to individual miners deep within an underground mine despite their location or work activity. The transmitting antenna is normally on the surface (about a 1,000-meter-diameter loop, usually buried); however, it can be placed underground if the mine operator does not own or have access to the surface over the mine.





This shows a typical message on a CRT screen of a standard PC computer located at the surface transmitting site.



The cap lamp battery case is fastened to the miner's belt. When the message is received, the miner's cap lamp blinks. The message is then read from a 32-character dot matrix screen. Vehicle dashboard-mounted units are also available for equipment operators.

HEALTH, SAFETY AND MINING TECHNOLOGY

The HSMT program pursues fundamental scientific and engineering research in order to provide new technology to protect the Nation's miners, who are employed in one of the most hazardous of all occupations. Injuries and occupational diseases to workers are costly to the Nation in terms of compensation costs to current and future generations, economic growth in the raw materials sector of the economy, and the Nation's industrial competitiveness.

The research program focuses on solutions to the health and safety hazards that confront miners and other workers in the mineral sector of the economy: exposure to dust, falls of roof, proximity to large equipment in confined space, and the potential for fires and explosions. This program also concentrates on long-range activities to devise new mining concepts that will safeguard miners with mechanisms that rapidly warn of, or suppress, hazards in advance of mining, thus enhancing productivity. Implicit in this program is the conservation of natural resources and environmental protection. In order to develop the advanced materials that will enable future technological revolution, economic growth, and improved quality of life, minerals in the ground must be mined safely and productively. The HSMT program is divided into seven research areas: Occupational Health, Ground Control, Human Factors, Mine Safety Systems, Mine Disaster Prevention, Experimental Facilities, and Advanced Mining Systems.

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OCCUPATIONAL HEALTH

Thrusts

The Occupational Health program is providing the technology for a healthy environment for workers in our Nation's mines and mineral processing plants. The program's goal is to reduce worker illness and disease in the minerals industry through environmental control technology for harmful airborne contaminants in the workplace. Reduction of harmful contaminants will not only prevent the pain and suffering associated with occupational diseases, but will also reduce health care and Federal compensation costs. This research supports the Federal Government's responsibilities for the establishment, promulgation, and enforcement of health regulations in mines. In addition, research control technologies are essential to ensure future regulations are based on scientific knowledge, thus preventing undue regulatory costs. The objectives of the Occupational Health program are to—

✔ *Reduce worker exposure to respirable dusts through more effective monitoring techniques and design of dust control technology.*

✔ *Reduce worker exposure to harmful diesel engine exhaust contaminants and noise levels.*

✔ *Identify toxic substances and carcinogens in the minerals industry and provide for their monitoring and control.*

Recent Program Accomplishments

Continuous Monitoring of Respirable Coal Mine Dust: A major focus of the health program is on developing a continuous-reading dust instrument capable of monitoring dust during the actual coal extraction process. This real-time monitoring will more accurately assess worker exposure, and will enable operators to adjust daily mining operations to produce less dust. No commercial instrument had existed for this purpose, but in 1993 this research progressed to the stage where underground testing of the technology was warranted. Investigations to date have confirmed the feasibility of a dust sensor approach that correlates the mass of dust deposited on a collection filter with the oscillating frequency of the filter support element. This approach is known as the Tapered-Element Oscillating Microbalance, or TEOM.

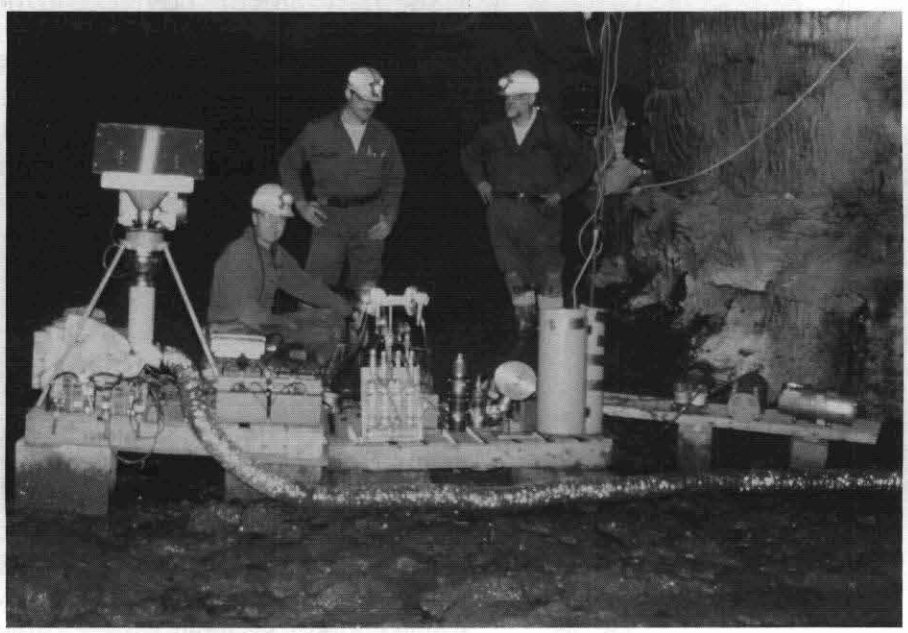
Dust Reduction in Longwall Mining Operations: Successful dust control methods for longwall coal mining have focused on water sprays, ventilation techniques, and modified cutting procedures to reduce dust from the largest source, the cutting action of the shearer drum as it extracts the coal. The success of these techniques has refocused the program on the control of other dust sources. Another effective control technique reduces dust from the interaction of the longwall shield support and the mine roof it supports. Application of a water-soluble foam layer between the shield support and the mine roof has resulted in a 25 percent reduction in respirable dust.

Reducing Worker Exposure to Crystalline Silica: Worker exposure to crystalline silica dust in the respirable size range is such a serious health hazard that the Federal dust standard for mining is based on the amount of silica dust contained in the workplace atmosphere. The standard becomes more stringent with higher concentrations of airborne silica dust. This is a particular problem in plants that process and package silica and other fine particulate minerals in bags. To reduce worker exposure in mineral processing plants, the USBM developed a system to clean the product bags of residual dust using a combination of adjustable brushes and air jets. Evaluation of the system at a silica sand and clay processing plant resulted in a 78- to 90-percent reduction in the amount of product contaminating the outside of the bag. This reduces worker exposure to the dust, and further prevents the dusty bags from contributing to the exposure of others who transport and use the product.

Personal Diesel Engine Exhaust Sampler: A USBM-designed, personal diesel-particulate soot sampler has been developed, and is available for commercial manufacturing and sale. This development has made it possible to evaluate diesel soot exposures in underground mines. This technical information will be provided to the Mine Health and Safety Administration (MSHA) to measure worker exposure to diesel soot and to enforce proposed Federal standards.

Future Research

Future research in the Occupational Health program will focus on defining the worker risk associated with gaseous toxic substances, including carcinogens in mines and mineral processing plants, and the monitoring and control of these substances. The Occupational Safety and Health Administration (OSHA), MSHA, the minerals industry, and organized labor all have reported increased concerns and complaints related to the use of chemical agents that contaminate the environment of mines and processing plants.



Air-quality sampling equipment for underground mines, necessary for conducting health research, is becoming more sophisticated.

GROUND CONTROL

Thrusts

The goal of the Ground Control program is to produce technology to forecast impending catastrophic failure, maintain structurally sound and stable mine openings, and reduce injuries and fatalities caused by ground failure. The objectives of the Ground Control program include—

✔ *Determining the critical geological and geophysical criteria to be used to identify potentially unstable and hazardous zones in mines.*

✔ *Developing and demonstrating monitoring systems to collect and analyze critical geomechanical and geophysical parameters in real time.*

✔ *Developing support technology to enhance stability of the mine roof.*

Enhanced efficiency in achieving Ground Control goals has occurred by consolidating technologies from two subprograms—geosensing and gcocontrol. Products from geosensing will be integrated into operating systems to detect imminent ground failures during mining and delineate characteristics for implementing effective controls. Geocontrol will focus on providing solutions to mitigate or eliminate ground hazards.

Recent Program Accomplishments

Coal Mine Roof Rating: Mines are different from other structures because they are built of heterogeneous rock formations. The properties of those formations are affected by cracks, small faults, and layering that make the roof-rock mass hazardous unless stabilized. The USBM's Coal Mine Roof Rating (CMRR) replaces geologic description of roof-rock mass with engineering characterization of the structures. Properties factored into the CMRR include rock strength, bedding plane resistance, fracture spacing, cohesion, and gcometry. Information to determine the CMRR can easily be collected underground using only simple field tests and observations. The CMRR has been used in the design of longwall gateroad entries systems, and investigations are finding new applications in roof support selection, extended cut mining, and yield pillar design.

Analysis of Retreat Mining Pillar Stability: In the last 4 years, one-third of roof-fall fatalities occurred during pillar extraction. USBM research has documented additional safety hazards resulting from many pillar squeezes, floor heaves, roof falls, and bumps. The USBM is developing a methodology called the Analysis of Retreat Mining Pillar Stability, or ARMPS. The goal of ARMPS is to maintain stability under the severe loading conditions that can occur as the pillars are extracted and the roof caves. The ARMPS method, developed from extensive studies in room-and-pillar and longwall mines, has been verified by back analysis of more than 60 case histories. Five mine operators have used ARMPS in the design of pillar extraction panels, and considerable use of it has been made by MSHA.

Cable-Roof Support Systems for Longwalls: This investigation examined cable-support systems to minimize the hazards associated with the placement and maintenance of secondary artificial support structures. Cable-support systems with a capacity of 58,000 pounds have been

installed to provide stability in gateroad entries. This research involved installing cable supports in the roof rock with resin cartridges, a task never attempted before in this application. Cable-support systems have been tested successfully in four underground mines, and the number of users is increasing rapidly.

Integrated Monitoring and Analysis Techniques for Ground Failures: This research developed a real-time monitoring and analysis technique that detects failures in an underground longwall coal mine. This continuous, remote monitoring and analysis system was demonstrated in the mining of six longwall panels. A computerized master controller unit at the mine is programmed to control and monitor roof shield support functions automatically along the longwall face. The system has also been used to evaluate the design and stability of various gateroad pillar designs, resulting in an alternate gateroad system for subsequent longwall panels.

Future Research

Research in Ground Control will focus on reducing accidents and fatalities through display and analysis techniques to detect and delineate anomalous strata and ground conditions, and to forecast their effects.

Scientist locating and identifying geologic structures in a coal mine roof. Proper identification of geologic structure allows a mine operator to determine the best artificial support to maintain roof stability, helping to eliminate roof falls. Features such as stratigraphy, bedding planes contacts, faults, joint surfaces, and slip planes all contribute to mine opening instability.

HUMAN FACTORS

Thrusts

Studies have shown that human error contributes to over 80 percent of all mining injuries. Factors such as inappropriate worker behavior, poor ergonomic design, inadequate training, or failure to recognize hazards contribute to a decreased level of safety in mines. Human Factors research investigates the mine workers' interaction with mining systems and the mining environment and provides technologies to reduce injury to those workers. This research focuses on providing a safer work environment that incorporates the needs and limitations of the human worker to optimize performance in the total mining system. The objectives of the Human Factors program are—

✔ *Maximize human resources through a better understanding of human behavior and worker reactions.*

✔ *Enhance worker health and safety through advanced training technologies and methods to meet the needs of a changing workplace.*

✔ *Apply sound human engineering principles and ergonomic ideas to reduce injuries by improving the workplace.*

Recent Program Accomplishments

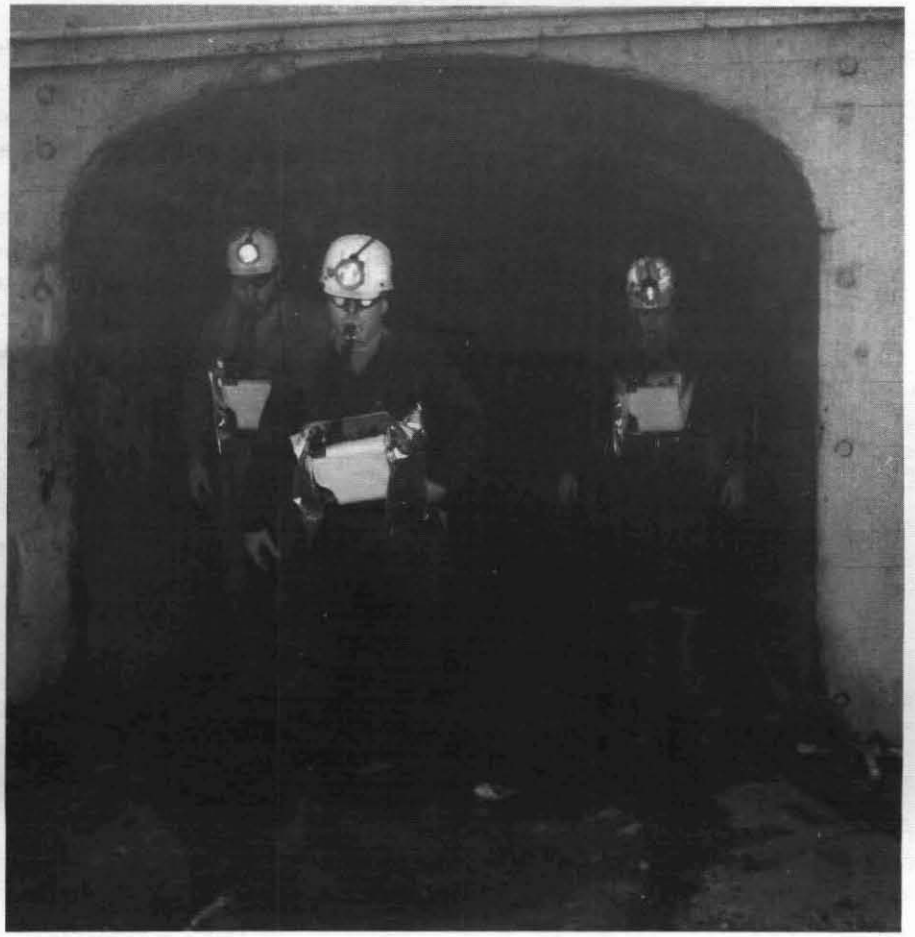
New Training Materials Increase Miners' Chance of Survival: When a mine fire or explosion occurs, miners must wear a breathing apparatus called a Self-Contained Self-Rescuer (SCSR). Research has shown that miners have problems donning these SCSRs in an emergency. Also, miners who have escaped through smoke from an underground mine fire also have had trouble using their SCSRs properly. The USBM has developed a training simulation that teaches workers what to expect when they must don and use an SCSR in smoke. Participants in field tests report reinforced skills and better understanding of what to expect of the SCSR performance in a real escape situation. This instructional tool is available to the mine worker through the Mine Safety and Health Academy in Beckley, WV.

Ergonomic Job Design Reduces Back Injury Risk: Back injuries are the leading cause of lost work days in the mining industry and account for 30 to 40 percent of the industry's worker compensation payments. Recently, under cooperative efforts with the industry, the USBM has shown injury risk can be reduced through improved job design. Changes in the methods used to handle materials in mines can eliminate unnecessary lifting, increase the use of mechanical lifting aids, and improve the design of materials so that they are easier for the miner to handle. Mines employing this idea have discovered that the redesigned jobs are safer and that the miners are more productive.

Future Research

Future research will emphasize a reduction in injury through refinement of the workplace to match the needs of the worker. Emphasis will be placed on recognizing the contributions, needs, and limitations of the mine worker, creating a safer and more healthful

workplace. Efforts will concentrate on maximizing the human resource, improving the ergonomics, and identifying worker training needs. Industry segments, such as small mines and independent contractors, having a high incidence rate for worker fatality are recognized as a high priority by MSHA. These areas will be investigated to learn the causes and possible solutions to the unacceptable, elevated fatality rates. The program will examine new technologies and changing mining practices that modify the mine workplace and that may create new hazards. One such technology, extended cut mining, is a growing method of room-and-pillar mining that has been identified by USBM customers as posing unique hazards to underground miners. This mining method will be studied to maximize safety for the mine workers.



Proper training is essential for mine workers to escape underground fires.

MINE SAFETY SYSTEMS

Thrusts

The Mine Safety Systems program addresses the hazards to mine workers created by the operation and design of the physical systems that make up a modern mining operation. Mining is a very complex operation with large excavation equipment, fast-moving haulage vehicles, conveyor and hoist systems, high-voltage machinery, complex ventilation schemes, and sophisticated control and monitoring systems. Despite all of this mechanization, the mine worker is still the essential component in any mining operation. When these workers operate and interact with the mining machines in the harsh environments of underground or surface mines they are exposed to many hazards. These hazards historically are a factor in 55 percent of all mining fatalities and 25 percent of all mining injuries. To solve this problem, new technologies will be developed and applications of existing technologies will be pursued to remove or mitigate the safety hazard. The objectives of the Mine Safety Systems program are to—

✔ *Reduce injuries resulting from mobile powered-haulage and transport equipment through modification of existing systems and the design of inherently safer systems.*

✔ *Improve safety in the use of high-voltage power systems.*

✔ *Reduce the injuries associated with the use and maintenance of the mechanical systems used in mines.*

Recent Program Accomplishments

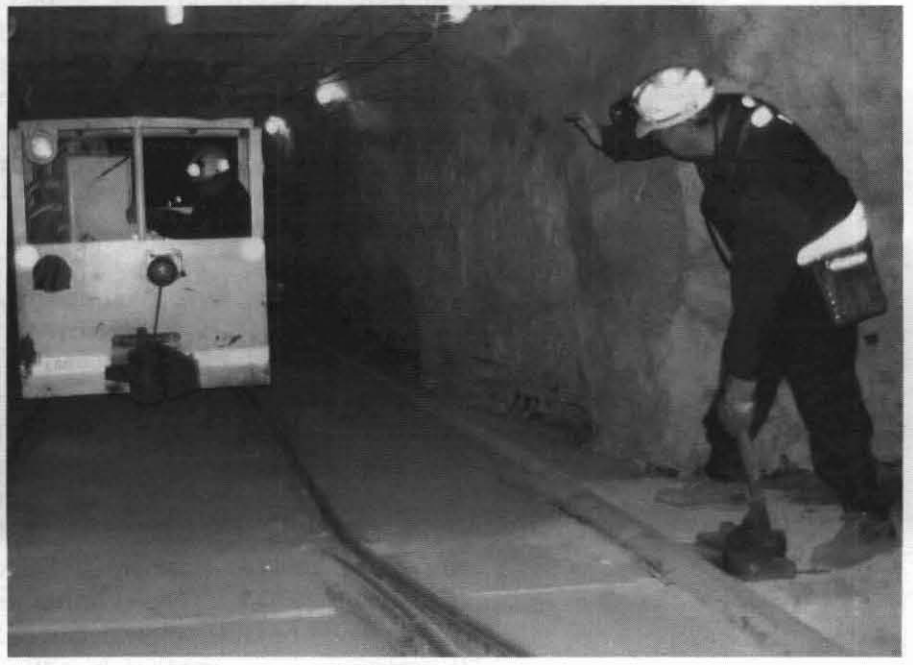
Positive Track Switch Position Indicator for Rail Haulage Safety: Many accidents occur while moving workers in and around the mine on rail-based haulage systems. Often a rail track switch is either thrown in the wrong direction or fails to close. This situation leads to derailment of the vehicles and injury to workers. The USBM has developed a system to address this problem. This system will electronically identify the hazardous conditions of incorrect switch direction and failure to close. An interface panel will alert workers to a hazardous condition and allow sufficient time to avoid an accident. The system, by design, can easily be retrofitted into existing haulage systems. Prototypes have been fabricated and tested with excellent results. The system will increase haulage safety when incorporated into underground rail haulage systems.

Safer High-Voltage Enclosures for Underground Mines: With the introduction of more powerful equipment into mines, higher voltage electricity is also needed. Research has been conducted on the safety of high-voltage and high-power electrical enclosures necessary for new longwall mining systems. At the request of MSHA, studies have been conducted to find out if existing enclosure construction is suitable at these high voltages to prevent explosions should an

electrical malfunction occur in the presence of methane gas. Results are being provided to MSHA for use in their approval and certification process.

Future Research

Research will focus on areas that pose the greatest risk of death or injury to the American mine worker. Haulage, the leading cause of mining fatalities, will continue to be investigated to learn the causes and to develop solutions to reduce the rate of injury. Research on safer, new, and innovative haulage systems that can economically replace existing conveyor haulage is ongoing. Powered haulage and transportation of personnel, on the surface and in underground mines, remains a serious safety hazard. Machinery, another major source of worker injury, will also continue as a focus of the program. Electrical safety remains a concern, especially as larger, more productive equipment that demands higher voltages is being introduced into mines. As with most USBM research, this area will continue to support MSHA's need for knowledge and technical information in the development of mining safety regulations. Mine Safety Systems research will be closely coordinated with the Human Factors research to properly and adequately address the human-machine interaction.



Innovative track switch position indicator.

MINE DISASTER PREVENTION

Thrusts

In mining, no other accidents can have broader consequences than those involving fires, explosions, or outbursts of methane gas. Research under the Mine Disaster Prevention program strives to develop technologies and strategies that will either prevent the occurrence of these mine emergencies or enable miners to survive them. The program focuses on the avoidance or elimination of fires and explosions through early detection, containment, and suppression; the prediction, measurement, and removal of dangerous methane accumulations; the development of protective breathing equipment and efficient escape tactics; and the safe and optimal use of explosives. The objectives of the Mine Disaster Prevention program are to—

✔ *Diminish mine worker exposure and vulnerability to the hazardous circumstances associated with fires and explosions.*

✔ *Design reliable life-support apparatus and escape strategies for safe, expedient evacuation from mine emergencies.*

✔ *Control hazardous methane accumulations in all phases of underground mining.*

✔ *Further the generation of safe and effective blasting practices and products for mining.*

Recent Program Accomplishments

New Emergency Communications System Wins R&D-100 Award: The USBM has developed the Canary, a wireless, mine messenger communications system. This system allows mine personnel on the surface to send individual messages directly to individual miners deep within an underground mine despite their location or work activity. The messages are sent to tiny receivers built into the cap lamp batteries carried by miners. Upon receiving a signal, the Canary causes the miners' cap lamps to blink, thus quickly alerting them to an emergency situation. The Canary will help make the underground mining environment a safer place to work. The system offers applications to the tunneling and construction industries as well. The USBM received the prestigious R&D-100 Award for this system.

Computer Models to Predict Fire Behavior: Two computer programs developed by the USBM can be used to alleviate fire emergencies. The first program, MFIRE, is a computer code that predicts fire behavior and the effects of a fire on mine ventilation. In experiments to validate this program, predicted temperatures agreed well with observed readings and were within a few degrees of each other. The second program is an expert system on the self-heating of coal. Self-heating is more commonly known as spontaneous combustion. In coal mining, the self-heating of coal usually occurs in worked out areas and is not easily detected. This model determines a coal's tendency to self-heat, based on the coal's physical characteristics. The information from this program can help mine engineers devise controls in the original mine plans to reduce the occurrence of self-heating events.

Communications System for Breathing Apparatus: In case of a mine fire or explosion, miners require a breathing apparatus to isolate their lungs from the smoky, toxic mine atmosphere. Breathing units, SCSRs, provide miners with a one-hour supply of oxygen. To enhance escape efforts, underground tests were performed on four prototype SCSR communication apparatuses. The units featured radio links, a dual microphone input system, and an enhanced mouthpiece design to improve communications capability among miners wearing SCSRs during a mine emergency. The tests were successful and proved the viability of the concept.

New Probe to Monitor Malfunctions of Explosives: Various malfunctions of explosives, such as strong detonations, deflagrations, and misfires, can lead to mine fires or explosions. The USBM has developed a rugged, high-resistance probe for continuously monitoring the detonation rates of explosive charges to pinpoint abnormal reactions. This technology was successfully proven in the laboratory and will be evaluated in an underground coal mine.

Future Research

Mine disasters occur less frequently today than they did 50 years ago; however, the potential for their occurrence persists in the Nation's mines. To eradicate disasters from the mining industry, future studies will examine low-cost, cement-like seals to control fires and explosions. Efforts will continue on improved fire detection strategies, predictive models for methane emissions, enhanced survival and escape tactics, and disposal of waste oil in explosives.

A SCSR modified with communications equipment. A miniature microphone is built into the mouthpiece to enhance speech. The earphone allows this miner to hear his own voice as well as those of coworkers.

EXPERIMENTAL FACILITIES

Thrusts

The successful completion of many USBM research projects requires specialized facilities to conduct full-scale tests and to validate results. The USBM operates and maintains two full-scale experimental mines at Bruceton, PA, and the Lake Lynn Laboratory at Fairchance, PA. The Lake Lynn Laboratory has surface and underground facilities. Detailed, time-consuming experiments that often cannot be performed in cooperating mines because of safety, production, and legal restrictions can be conducted safely in the USBM's specialized facilities. Because similar installations do not exist in other Federal agencies or in the private sector, the USBM's facilities are essential to the research program. The objective of the Experimental Facilities program is to—

✔ *Provide, operate, and maintain specialized underground and surface test facilities to perform full-scale experiments and to evaluate technological advances, equipment, and procedures.*

Recent Program Accomplishments

Full-Scale Mine Experiments: Various full-scale mine experiments were staged at the Bruceton experimental mines and the Lake Lynn Laboratory in support of many ongoing projects in the USBM research program. These tests included carbon monoxide and ventilation monitoring studies, mine water treatment investigations, trials of heat-triggered and shock-triggered barriers for explosion suppression, conveyor belt burn tests, roof bolt evaluations, and explosive sensitivity determinations.

Demonstrations and Briefings: Mine fire preparedness briefings were held at the Lake Lynn Laboratory for representatives from industry, the United Mine Workers of America, and other government agencies. Included in these briefings were demonstrations of full-scale conveyor belt fires, fire-fighting hoses and nozzles, mine-wide monitoring systems, and various types of fire detectors. The Bruceton and Lake Lynn facilities were used for other full-scale demonstrations of foam generating systems, fire barriers, ventilation seals, and performance characteristics of explosives. These dynamic demonstrations were observed by many visitors from various government agencies, schools and universities, private industry, and foreign countries.

Future Research

The USBM facilities will continue to house full-scale mine experiments. These tests will be performed in conjunction with the research to assess results and to ensure progress. Additionally, the USBM will continue to open its doors to visitors to keep the public informed of significant accomplishments.

Fire-fighting techniques are demonstrated during an open industry briefing at the Lake Lynn Laboratory.

ADVANCED MINING SYSTEMS

Thrusts

The Advanced Mining Systems program focuses on ensuring that future mining technology will provide a healthy and safe environment for the worker. Researchers give a high priority to concepts that protect the health and safety of workers and preserve the environment. New concepts not constrained by current mining methods can provide technologies capable of harvesting mineral deposits at a lower cost without degrading the environment. Many of the more advanced new concepts will not be in general use until the 21st century; however, incremental accomplishments will improve present technology. The objectives of the Advanced Mining Systems program are to—

✔ *Adapt computer control technologies to equipment to increase the safety and efficiency of recovering coal and minerals.*

✔ *Conceive innovative mining concepts for low-grade deposits and the basic technologies necessary to mine them economically in the 21st century.*

✔ *Provide mining engineers with space-age design methods that employ advanced computer modeling to optimize mine safety, layout, and operation for conventional and future systems.*

✔ *Investigate safe and environmentally compatible mining methods that can recover minerals in regions with sensitive ecosystems.*

Recent Program Accomplishments

In Situ Mining: On August 23, 1993, the Santa Cruz Joint Venture received official notice from the Arizona Department of Environmental Quality of their preliminary and conditional intent to issue an aquifer protection permit for the In Situ Copper Mining Project. Issuance of the permit will trigger the construction of the pilot-scale solvent extraction electrowinning (SXEW) surface plant and subsequent testing of in situ leaching technology at the Santa Cruz field site near Casa Grande, AZ. The project is designed to test the commercial feasibility of leaching copper from a fracture-hosted oxide deposit reached only by surface wells. This technology has the potential to remove metals from ore deposits with little or no adverse environmental impact.

Fragmentation Technology: Several continuous, nonexplosive fragmentation technologies developed by the USBM are being transferred to the mining industry. Aqua-Dyne of Houston, TX, was granted a license to manufacture and sell the USBM-patented abrasive jet rock drill. Three companies have applied for rights to license the concave bit, another USBM-patented technology. In addition, a cooperative effort was begun with the State of Minnesota and iron mining companies to develop a microwave-powered oversize rock breaker.

Gold Recovery: USBM research demonstrated that water-based solutions containing polysulfide and bisulfide can mobilize high concentrations of gold at elevated temperatures. Because these solutions are nontoxic, are made of low-cost components, and have

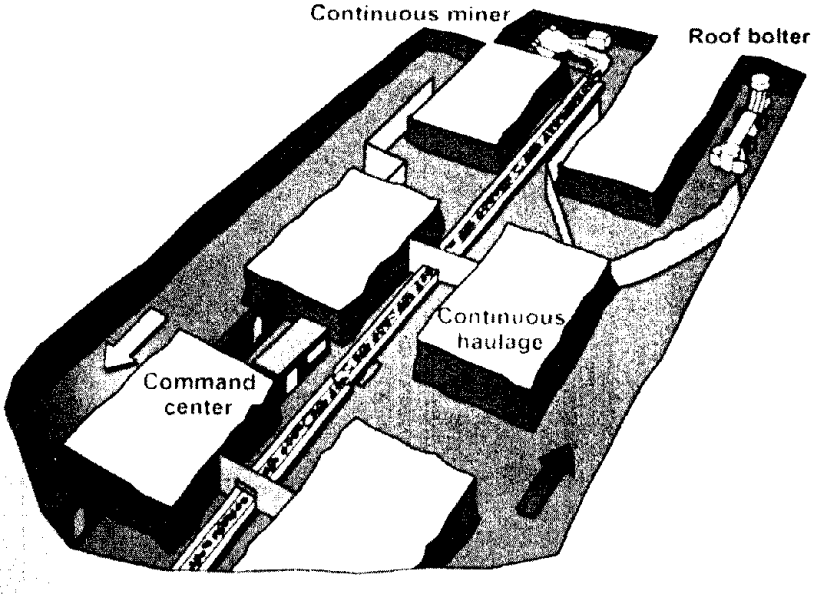
high selectivity for gold, an application has been submitted to patent this process for use in in situ gold-leaching systems.

Computer-Assisted Mining: The USBM's research program on computer-assisted mining involves technology that will allow computer-assisted operation of all mechanized equipment normally used for room-and-pillar coal mining, while locating workers away from hazardous area. As a result, injuries and deaths, and health problems due to noise and dust, can be reduced. Technologies required for computer-assisted mining include navigation, machine condition, coal interface detection, and computer systems. The USBM has developed a computer control architecture based on guidelines developed by the National Institute of Standards and Technology for robots used by the National Aeronautics and Space Administration (NASA).

Proximity Warning System: Joy Technologies, Inc. and the USBM teamed under a Cooperative Research and Development Agreement (CRADA) to develop a proximity warning system that detects the presence of a worker in hazardous areas around mobile mining equipment. The system has a transmitter with tuned-loop antennas on the mining machine, and a small receiver with an indicator on the worker. The receiver provides visual and audible alarms to a worker entering a hazardous area. The receiver can also be connected to the operator control panel to automatically shutdown the machine. This safety device is now commercially available from Joy.

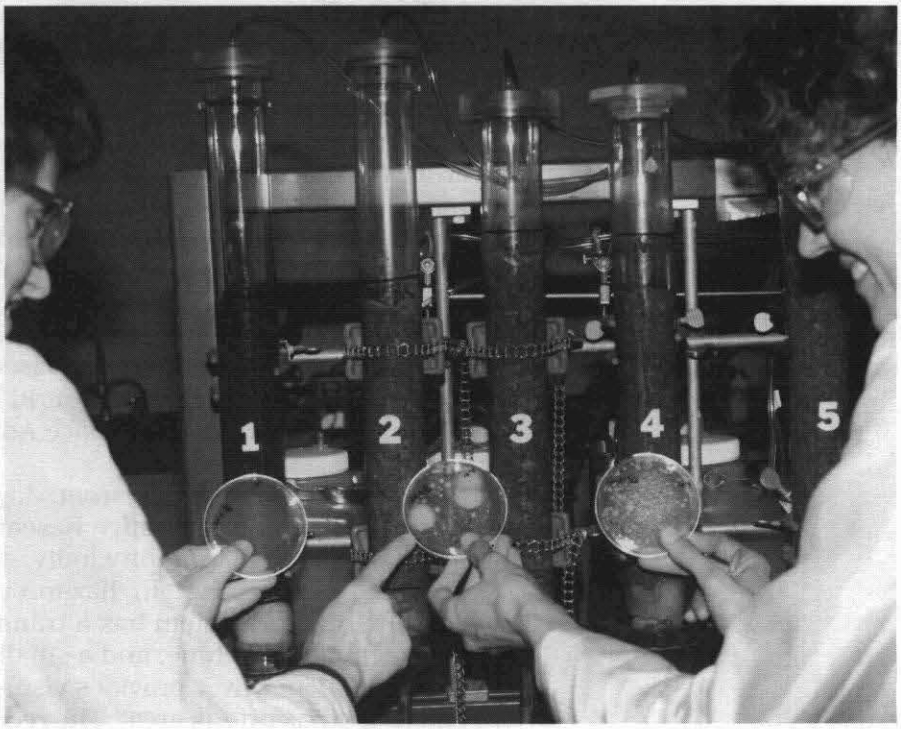
Future Research

Future Advanced Mining Systems program research will stress recovery of minerals while maximizing the health and safety of mine workers and reducing the environmental impacts of mining. Research will be directed specifically to investigations of environmentally compatible mining methods that can recover minerals in regions with sensitive ecosystems.



Computer-Assisted Mining System. Computer technology can allow workers to control mining equipment from a safe location, reducing their exposure to the many safety and health hazards of the working face area.

Advances in biotechnology promise new, low-cost, and environmentally safe processes for extracting metals from ores, effluents, and waste sites. Here, USBM scientists are identifying the conditions in which the bacteria are most productive. For example, the petri dish on the right demonstrates conditions under which the bacteria population is productive and thus can extract metal values from the effluent. In contrast, the dish on the left contains an unhealthy or nonproductive bacteria population that can not extract metal values.



MINERALS AND MATERIALS SCIENCE

The MMS program addresses technology needs in the conservation and extraction of mineral resources. The research accelerates the realization of national priorities such as natural resource and environmental preservation, especially in economic sectors made up of small, independent, and widely scattered operations.

Conservation research provides environmentally sound raw materials processing and recycling technologies, which directly maximizes the recovery of valuable minerals from each ton of ore mined and reduces loss of materials from disposal and degradation (e.g., wear, and corrosion), thereby decreasing land disturbance.

Extraction and separation research is focused on pollution prevention and control. Research emphasizes innovative technology leading to new materials, processes, and/or facilities to prevent environmental problems. This focus contrasts with research conducted by the ET program, which develops technology to remedy environmental degradation from past mining and raw materials production. However, the cutting edge of the USBM's environmental remediation technology is based on its 80 years of experience in extractive science.

A small part of the MMS program is focused on economic growth in response to an overwhelming need for new technology to stimulate and expand the raw materials manufacturing sector. This research is planned and carried out in cost-shared partnerships with the potential users of the technology, the private sector, and other Federal agencies. Precompetitive generic research having clear commercial applications and a commitment for use by cooperators is emphasized.

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MINERALS RESEARCH

Thrusts

The goal of the Minerals Research program is to ensure that the Nation has an adequate technology base to address the long-term problems of materials supply into the 21st century. This base is essential if a domestic raw materials industry is to compete in a global economy while addressing environmental compatibility, land disturbance minimization, and resource conservation. The objectives of the Minerals Research program are to—

✔ *Provide generic breakthrough technologies for extracting and processing raw materials with an emphasis on pollution prevention.*

✔ *Transfer new technology to improve the competitiveness of the domestic raw materials industry.*

✔ *Develop and transfer waste-minimization and recycling technology to industry to minimize the environmental impact of an industrialized society and to conserve natural resources.*

Recent Program Accomplishments

Upgrading the U.S. Cobalt Stockpile: The national defense stockpile contains 23.8 million kilograms of cobalt, with approximately 19.2 million kilograms failing to meet chemical specification for defense applications. The USBM has developed a process that uses a double-membrane electrolytic cell to upgrade the impure cobalt. An independent chemical analysis of the cobalt cathode using this technology showed that the product was over 99.9 percent cobalt and exceeded the most stringent Department of Defense specification, P13-R6, grade A, for all 30 impurity elements.

Standard-Quality Titanium Powder Produced in a Continuous Process: Titanium could be the material of choice for tonnage applications in the chemical, transportation, and construction industries, if not for the high cost. Conventional titanium production uses a batch reduction process, followed by multiple energy-intensive melting operations for purification, followed by atomization to powder. USBM scientists have produced titanium powder using a continuous vapor-phase process for reduction, purification, and atomization, eliminating the need for the costly multiple stages currently used.

Characterization and Improved Utilization of Scrap Commodities: Household appliances are either recycled or disposed of in landfills, depending on local issues such as regulations and economics. The current recycling process is economical for appliances with high metal content. However, the increasing use of nonmetallics and the presence of deleterious materials will require the investigation of alternative, economic recycling technology. The USBM has successfully dismantled refrigerators and is in the process of characterizing materials and/or assemblies in order to identify potential sources of contaminants.

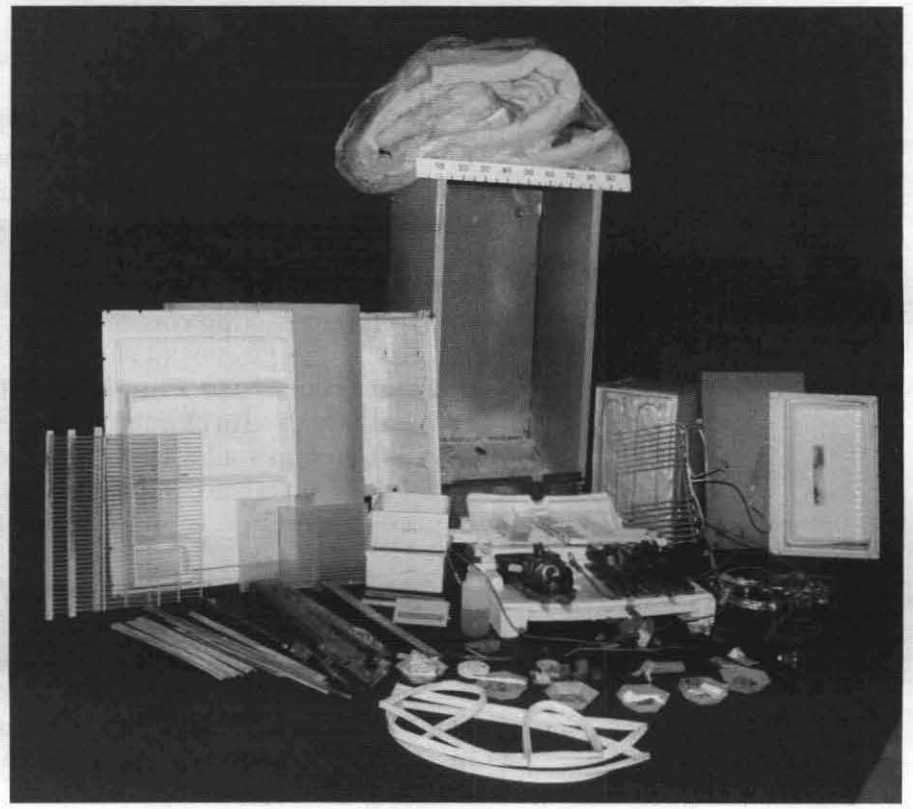
The Recovery of Platinum-Group Metal (PGM) From Used Automobile Catalytic Converters: The United States depends on foreign sources for

more than 80 percent of its PGM needs. An underutilized source of PGM is spent automobile catalytic converters. Current estimates are that 50 percent of the used catalysts are collected and only 30 percent are processed domestically. The USBM has developed a novel high-temperature process that uses cyanide to recover up to 80 percent of the PGM from catalytic converters. The high-temperature process has several advantages, including elimination of furnacing operations and total destruction of the cyanide.

Advanced Computing Techniques Make Automated Control of Complex, Unpredictable Mineral-Separation Processes Feasible: Automated control of a unit process can reduce feed consumption, waste production, and improve product quality at a lower cost. By combining advanced mathematical techniques, control systems can display excellent performance in adapting to unpredictable and changing conditions. A fuzzy-logic control system for a column flotation unit has been developed and will be tested. The technology has broad potential application beyond the minerals industry. A control system for a pilotless Blackhawk helicopter has been developed in conjunction with the U.S. Army and NASA.

Future Research

Future research in Minerals Research will emphasize minimizing the environmental impact of mineral production and utilization. Research will include new processes that are inherently cleaner than current processes, as well as modifications to current process flow sheets to minimize the production of wastes. Other research will be conducted on recycling or treating wastes, and on new processes for producing materials, such as titanium, which are needed by other industries to reduce the environmental impact of their products.



A disassembled refrigerator showing the variety of components and materials found in these appliances. The USBM has worked with both appliance manufactures and recyclers so that more material from these appliances will be recycled instead of discarded.

MATERIALS RESEARCH

Thrusts

The goal of the Materials Research program is to protect the environment and infrastructure, to conserve domestic resources and reduce energy requirements through increased service life, and to provide new technology for the development of value-added engineered materials. As such, it is in support of the Department of the Interior's priorities of environmental protection, and resource conservation. The objectives of the Materials Research program are to—

✔ *Create substitute materials or processing routes for those that are hazardous or cause environmental problems.*

✔ *Conserve domestic resources and reduce energy requirements by reducing losses due to wear, corrosion, and fracture.*

✔ *Develop high-value-added advanced materials from inexpensive, domestically available precursors using cost-effective processing.*

Recent Program Accomplishments

Development of Computer Models to Predict Performance and Degradation Resistance of Structural Materials: Basic research in degradation strongly emphasized analytic and numerical modeling of degradation processes. A model was developed to predict the deformation characteristics of ceramic materials. Finite element modeling of the micromechanics of heterogeneous materials correlated with laboratory fracture experiments. Modeling is especially important in wear, fracture, and corrosion research because short-term experimental data must often be used to predict long-term failure.

Nondestructive Evaluation (NDE) Research: Using lasers to interact with a material under study, USBM NDE technology can obtain material property data without physically touching the material. Research showed that the technique could measure the depth of a molten pool of metal and follow changes as the metal solidified. Through this research, the USBM is participating in a multi-agency and industry casting consortium.

Lead-Free Brass Plumbing Fittings: To eliminate lead from copper alloys used in plumbing fixtures, USBM scientists have produced a lead-free copper alloy to achieve the machinability formerly provided by the addition of lead. Machinability of the new alloy is superior to that of pure copper, and is approaching that of leaded brass.

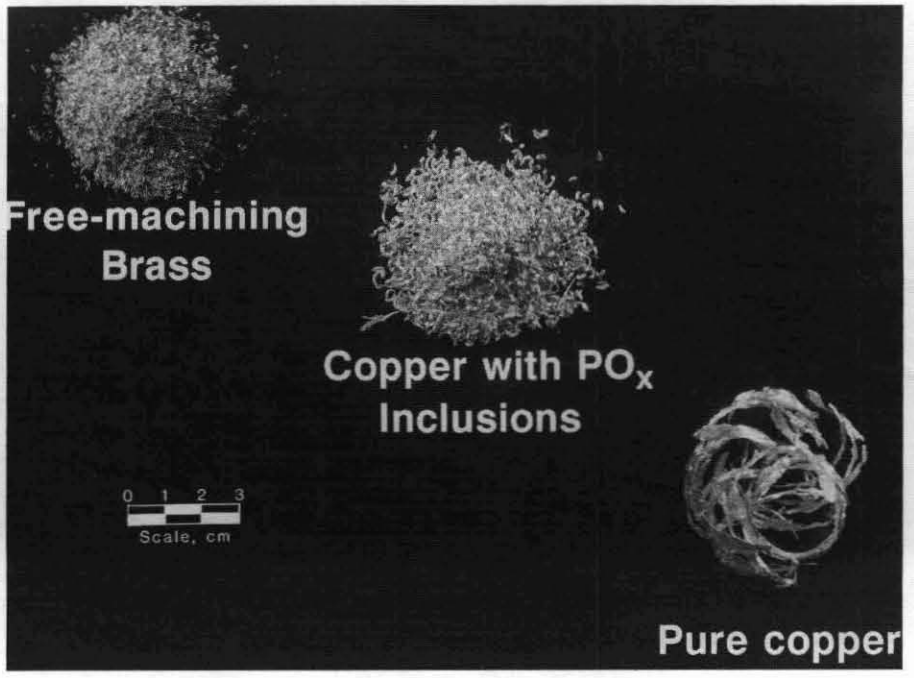
"Smart" Steels Able to Warn of Impending Structure Failure: Known as TRIP (transformation induced plasticity) steels, these smart materials become magnetized when strained and can be used in stress monitoring systems. In cooperation with an industrial partner, steel compositions that change from nonmagnetic to magnetic under applied stress were identified and incorporated into monitors for use on bridges.

New Layered Titanium Composite Material: Many-layered material structures, containing titanium, were developed as part of the low-cost titanium research. The new layered structures are expected to have high impact resistance with potential application to automotive engine components, aerospace structural components, and military armor. This work will enable wider use of high-strength, lightweight, and corrosion-resistant titanium-based materials with the potential to reduce environmental problems.

Characterization of High-Nitrogen Steels: USBM research in high-pressure melting has produced steel alloys with nitrogen contents much higher than the solubility limit, leading to a marked improvement in the mechanical properties of chemically resistant steel. Nitrogen steels that are two to three times stronger than conventional steels, but with the same ductility, have been produced. Current research is investigating a broad range of techniques to incorporate nitrogen into iron-based alloys. Similar infusions of very high nitrogen levels have been demonstrated by gas atomization of powders in nitrogen, by high-pressure diffusion of nitrogen into powders, and by mechanical alloying.

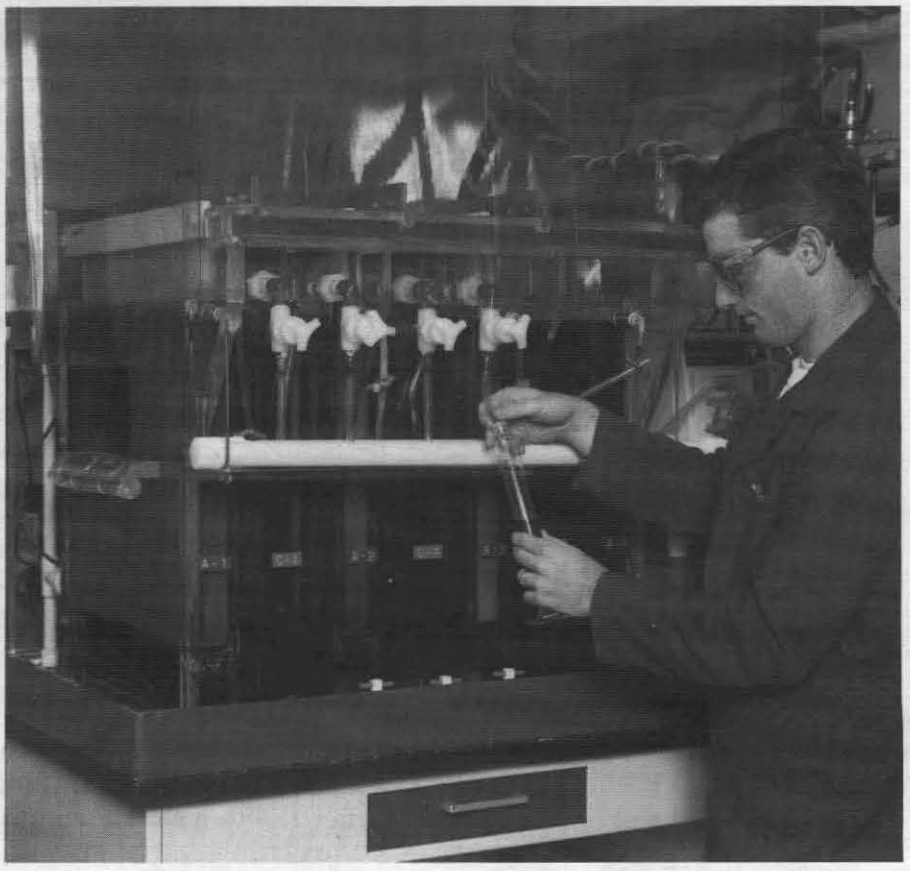
Future Research

Future research in cost-effective, low-waste materials processing will continue in collaboration with industry and outside organizations. Research in support of pollution prevention, infrastructure protection, and worker safety will also continue. Degradation of bridges and concrete structures will be investigated in collaboration with outside organizations and State agencies. Work to improve wire hoist ropes used in mines will include nondestructive evaluation techniques to monitor ropes for failure, and failure detection sensors for incorporation into the rope.



Turnings from commercially available, free-machining brass (containing lead); copper with phosphorus oxide inclusions; and pure copper. Adding phosphorus to the copper allows the desirable, smaller, discontinuous chips to form during machining without the addition of toxic lead.

The demonstration-scale double-membrane electrolytic cell, a novel electrorefining cell, recycles cobalt and nickel from superalloy scrap. The Technology Transfer program negotiated CRADA agreements with companies interested in participating in the further development of this process.



RESEARCH SUPPORT PROGRAMS

The Research Directorate includes several Research Support programs, in addition to the three research areas of Health, Safety and Mining Technology; Minerals and Materials Science; and Environmental Technology. These Research Support programs consist of Technology Transfer, Process Evaluation, and Mineral Institutes. Each of these programs performs functions for all three of the major research areas. Some of these functions include identifying and packaging USBM-developed information and technology and ensuring that this expertise is made available to those who can benefit from using them, and giving the private sector an assessment of the economic potential of USBM-developed metallurgical processes and mining technology. In addition, research conducted by the Mineral Institutes program complements the research conducted in-house by the USBM. These programs are described in the following sections.

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TECHNOLOGY TRANSFER

Thrusts

The Technology Transfer program encourages USBM customers in private industry, academia, and other government agencies to adopt and use USBM products, information, and technology.

Recent Program Accomplishments

Cooperative Research and Partnerships: The USBM conducts research in close partnership with its customers through formal Memoranda of Agreements (MOAs) and CRADAs. Through cooperative agreements, the USBM is allowed access to actual operating mines to conduct in-mine investigations and to operating plant facilities to conduct in-plant investigations. At the same time that the USBM is testing its technology in industrial facilities, it is also demonstrating its technology to the industrial sector, thereby providing cooperators a greater opportunity to commercialize USBM-developed technology. Through CRADAs, the USBM and industry pool their resources to engage in cooperative research ventures. In FY 1993, the USBM had 254 MOAs and 29 CRADAs with industry, academia, and professional organizations.

In addition, USBM research is conducted in close partnership with other Federal agencies such as the EPA, Department of Defense, BLM, NASA, MSHA, and OSHA. In 1993, the USBM had 71 agreements with other Federal agencies. Many of these agreements involve the use of USBM expertise to solve complex problems such as helping in the cleanup of public lands and Superfund sites.

Technology Transfer Projects: Another effective means of accelerating the successful transfer of USBM-developed technology and research results has been the Technology Transfer Projects program. In FY 1993, the USBM identified 21 promising, mature research developments and designed marketing plans tailored for each to help encourage their commercialization. The program is showing marked success. For example—

✔ *A major producer of tantalum and a major manufacturing company are working with the USBM to commercialize a process for recovering scandium from tantalum residues. A CRADA is being negotiated to perform a pilot-scale demonstration of the technology.*

✔ *The USBM is working with Hecla Mining and BHP Minerals Companies to demonstrate the application of a double-membrane electrolytic cell on a commercial scale. The cell offers many different applications and could beneficially impact the recovery of high-purity metals such as cobalt and PGM.*

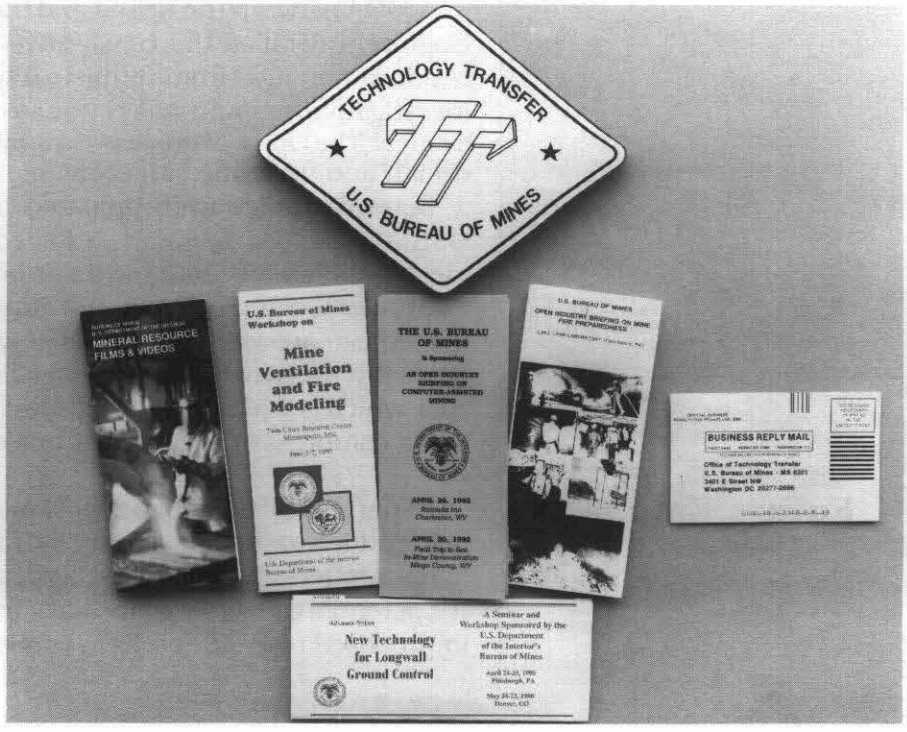
✔ *Three companies are negotiating for an exclusive license to commercialize the USBM's novel concave cutting bit. Another company is working with the USBM to test the bit on its trenching machines, thus expanding the possible market for this innovative technology into the construction and tunneling industries.*

Intellectual Property: The success of technology transfer depends, to a certain degree, upon incentives provided to companies through intellectual property such as patents and patent licenses. In FY 1993, three patents were received, and two licenses to patented technology were granted to companies interested in commercializing and marketing USBM research. The USBM also collected approximately $40,000 in royalties, on licensed patents, that were distributed to USBM inventors.

Exhibits, Meetings, Workshops, and Publications: During the fiscal year, 65 exhibits, seminars, and briefings were sponsored by the USBM to highlight significant accomplishments. In addition, 17 **Technology News** were published and mailed to a list of over 27,000 subscribers. The USBM also published 76 series reports during the year consisting of Reports of Investigations, Information Circulars, and Mineral Institute Reports. The USBM also published 185 outside journal articles.

Future Emphasis

The USBM's Technology Transfer program will focus on the identification of research-product customers and of cooperative research opportunities to help build additional industry partnerships. Emphasis will be placed on obtaining input and guidance from industry, and on providing the format for increased collaborative research between the government and private industry. In addition, the program will continue to develop marketing plans designed to accelerate the commercialization and use of specific, mature research products. The timely integration of research project-specific economic evaluations and market data into the technology transfer process will also be explored.



The USBM uses a variety of tools to move information about its research accomplishments into practical use. Meetings, videos, and newsletters are just a few of the mechanisms used to keep USBM customers informed.

PROCESS EVALUATION

Thrusts

The goal of the Process Evaluation program is to perform technical and economic feasibility studies to provide management, the researcher, and industry with a basis for assessing the potential value of the USBM's research developments. Through these economic studies and technical assessments, management is provided another means for assessing the potential value of the research venture, the researcher is provided with a basis for selecting various research possibilities to improve potential high-cost areas, and industry is provided with the economic commercial value of USBM-developed processes and techniques.

Recent Program Accomplishments

Process Evaluation Studies: A major effort was directed toward a series of evaluation studies on techniques being developed for treating AMD. As the first step, preliminary studies were prepared to address the weaknesses of each technique to provide information to the researchers so that improvements could be made to each process. These studies have been completed and the researchers have modified their processes to reduce costs. Currently, new studies are being made on these improved processes to determine which ones should be used on a pilot-plant scale at the Midnite Mine.

Another completed evaluation included a process to recover scandium oxide from tantalum processing waste, which showed a very good interest rate of return. Preliminary evaluation of a technology to remove lithium scrap indicated an interest rate of return exceeding 15 percent. This study pointed out additional data needs to improve the cost estimate and to scale up to a pilot plant.

A MOA between the USBM and the American Society of Mechanical Engineers detailed the cooperative study for the vitrification of the residues obtained from municipal waste combustion facilities. This investigative program was conducted at the USBM's Albany Research Center. The Office of Process Evaluation developed a conceptual plant design and performed an economic evaluation.

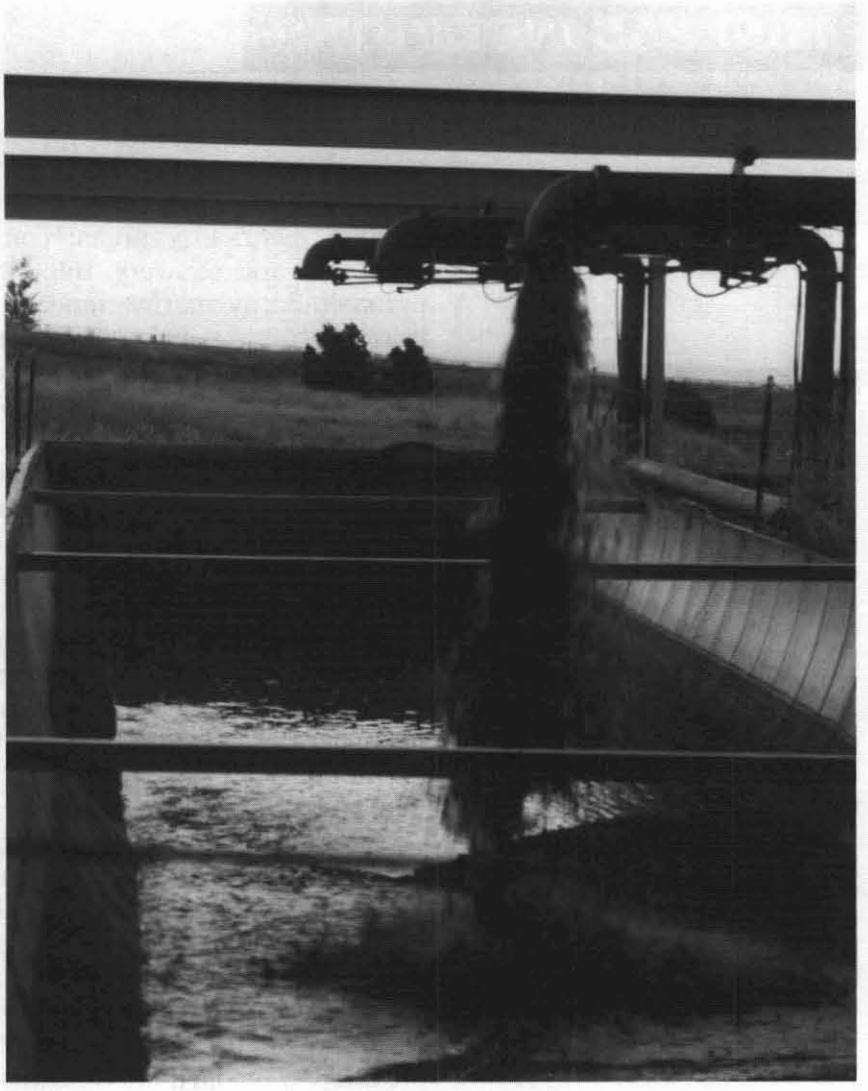
Several studies were prepared to show the economic benefit of USBM-developed technology for coal mining. These technologies included a remote methane detector, and a thrust bolting technique.

Studies on removing coal from mines showed that a technique known as an air-lift hydrohoist would have economic potential. Basically, the hydrohoist is a water-filled, "U-tube" pipe that transports coal, which is injected vertically into the pipe near the bottom of the "U," using compressed air as the lifting agent.

Future Emphasis

Expanded analysis of possible modifications to ongoing research is being added to the preliminary evaluations to better provide guidance to researchers. An expanded effort will be directed toward analysis of the potential economic gains that would occur if the research described in proposed research projects is successful.

Coal slurry being discharged into a 114-cubic-meter-capacity settling basin after it is transported up a 50-meter-high, air-lift hydrohoist and returned to ground level.



MINERAL INSTITUTES

Thrusts

The Mineral Institute program is a university-based research program sponsored by the USBM in technical areas of significance to the mineral economy. Research grants are concentrated in six generic mineral technology areas: comminution, mineral-industry waste treatment and recovery, mine systems design and ground control, pyrometallurgy, marine mineral technology, and respirable dust. One lead institution coordinates research activities, provides for an annual seminar, and operates a reference center that disseminates results relating to its particular area of expertise.

Recent Program Accomplishments

Recycling of Aluminum Scrap: Remelting secondary aluminum scrap, such as that from beverage cans, requires only 5 percent of the energy needed to produce aluminum ingot from bauxite, conserves resources, and enhances waste disposal. However, thin oxide films on aluminum scrap hinder the coalescence of the molten scrap droplets leading to melting losses as high as 10 percent. A study of the interfacial phenomena of aluminum in molten salts, and its relationship to salt composition, and the time required for the kinetics of the chemical attack required to strip impeding oxide layers has resulted in information that will improve recovery and reduce processing time.

Predicting Ball-Mill Performance From Single-Impact Tests: Industrial comminution machines rely on the impact fracture of individual particles in large numbers. An ultrafast load cell has been used to study the elementary breakage process of single particles and these studies have been extended to particle beds. Once breakage fracture is statistically understood, breakage and selection functions can be predicted and combined with the collision energy spectrum provided by media motion simulations to provide estimates of ball-mill performance. Since the technique does not rely on any empirical parameters determined in small-scale ball mills, this technique offers significant potential for scale up, control, and process design.

Cable Bolting for Pillar Recovery at the Magmont Mine: A cooperative effort by COMINCO METALS, the USBM's Spokane Research Center, and the University of Utah is underway to use cable bolting to reinforce roof spans of 30 meters during removal of support pillars. The objective is to extend the profitable life of the mine and conserve resources. Three-dimensional, super computer modeling is used to understand cable bolt action and improve design methodology.

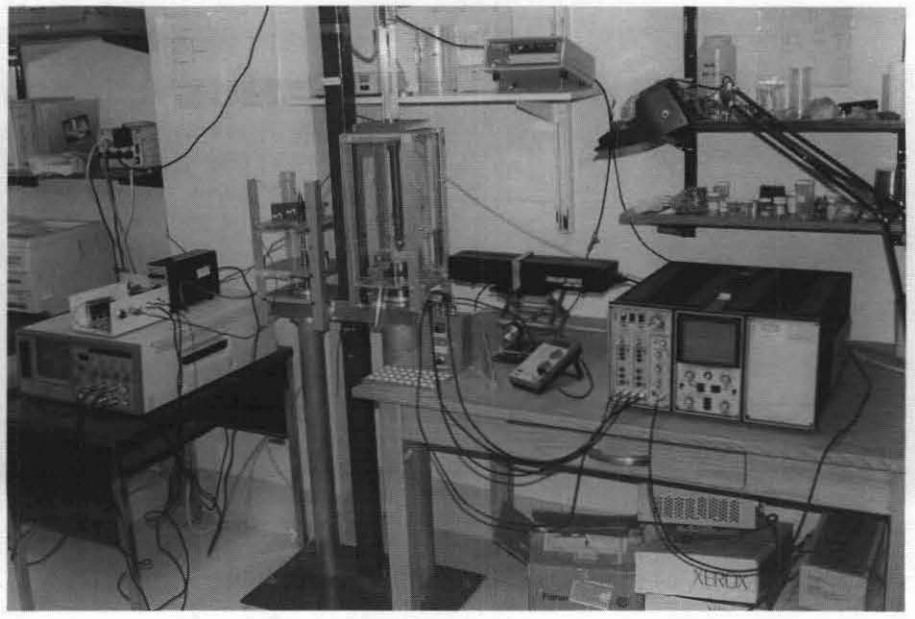
Enhancement of the Oxidative and Photochemical Decomposition of Cyanide Species in Precious Metals Treatment Wastes: Titanium dioxide is an effective catalyst for the photochemical oxidation of cyanide. Cyanide is the most effective leaching agent for the recovery of microscopic gold; however, cyanide may remain in leach heaps and in surface water and groundwater as a potential threat to humans and wildlife. Cyanide is oxidized slowly by the oxygen in the

air, but an accelerated procedure for decontamination is desirable. A suite of candidate catalysts for cyanide oxidation has been investigated, but none approach the capabilities of titanium dioxide.

Geochemical Characterization of the Ocean Minerals Company Manganese Nodules From the Clarion-Clipperton Zone of the Pacific: The data base of more than 4,600 nodule samples representing an area of 3.5 million square kilometers obtained between 1978 and 1984 by the Ocean Minerals Company has undergone detailed statistical analysis. The data show that compositional differences can be accounted for by three factors; the incorporation of elements into the nodules from fluids generated by suboxic diagenesis of the underlying sediments, oxic diagenesis of the underlying sediments, and precipitation and scavenging of elements from seawater.

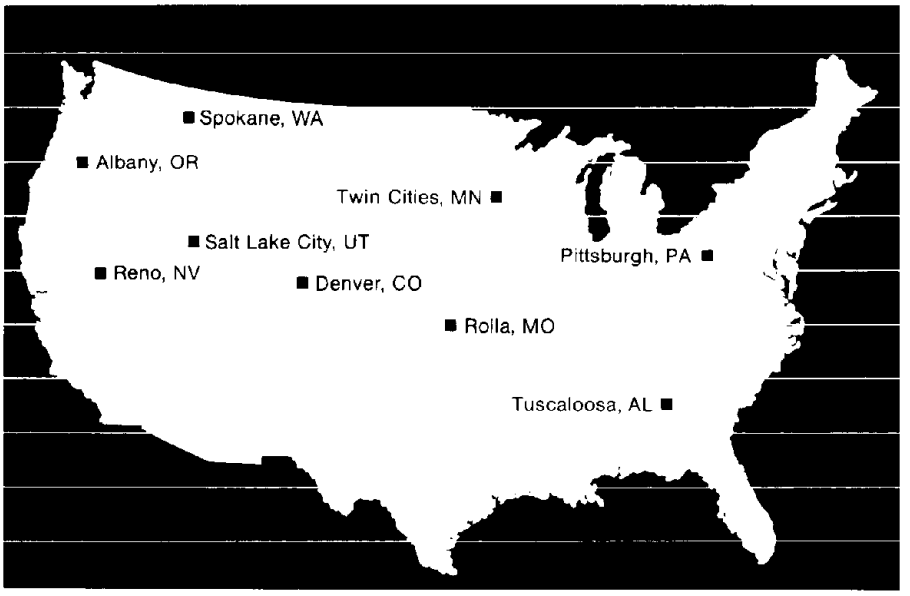
Future Research

Advice on the direction and administration of the Mineral Institutes program is provided by the Interior Secretary's Committee on Mining and Mineral Resources Research. The Committee also prepares an annual update to the National Plan for Research in Mining and Mineral Resources. The Committee has recommended the addition of research in hydrometallurgy and advanced mining systems.



Upper ends of the dual-impact (left) and ultrafast (right) load cells with associated instrumentation for predicting ball-mill performance from single-impact tests. These devices allow precise and reproducible monitoring of the force and strain experienced by single particles during very rapid impacts, which may or may not result in fracture.

Nine centers form the foundation for USBM research.



RESEARCH PROJECTS

Research is conducted mainly at nine USBM research centers located across the country. The geographic proximity of the research centers to the mineral extraction and processing industries has enabled a continuous transfer of USBM technology and information to the public and private sector. Also, research is conducted, by grants, at the 30 university-affiliated Mineral Institutes throughout the United States. Most of the research centers are located close to either a Mineral Institute or other major university, thereby facilitating the close exchange of information, personnel, and equipment between the USBM and the academic community. Additional research is performed by contract at the Idaho National Engineering Laboratory in Idaho Falls, ID.

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ENVIRONMENTAL TECHNOLOGY

Control of Mine Drainage and Liquid Wastes

Albany Research Center	Water Treatment Systems—Liquid Emulsion Membranes
Pittsburgh Research Center	Biological Treatment of Metal-Mine Waste Water Mechanisms of Acid Mine Drainage Formation and Mitigation Hydrology and Geochemistry of Acid Mine Drainage Systems Biological Treatment of Coal Mine Drainage Solid Coal Waste Leaching Systems
Reno Research Center	Alternate Agents and Recycling Cyanide Chemical Treatment of Waste Water Detoxification of Lime Sludge Natural Minerals for Waste Water Treatment Systems Effective Closure Methods for Metallurgical Operations
Salt Lake City Research Center	Biohydrometallurgical Decontamination of Mining and Milling Wastes Immobilized Extractant Technology for Waste Water Water Treatment Systems—Biotechnology Predictive Chemical Models for Acid Mine Drainage
Spokane Research Center	Hydrologic Control of Mine Tailings Drainage Mine Waste Management—Dissolution Mechanisms Mine Waste Management—Hydrologic Phenomena Mine Waste Management—Contaminant Fate Hydrologic Factors in Mine Waste
Tuscaloosa Research Center	Treatment of Phosphate Wastes Carolina Gold Wastes Water Treatment System—Physical Minerals Processing Waste Water Treatment

Solid Waste Management and Subsidence

Denver Research Center	Western Subsidence Studies Correlation of Surface Subsidence With Mine Level and Overburden Movements Effects of Subsidence on Escarpment Stability
Pittsburgh Research Center	Effects of Coal Mine Subsidence Fundamental Mechanisms of Coal Mine Subsidence Abatement of Subsidence Areas in North Arlington, New Jersey Delineation of Subsidence Areas in Mine Hill, New Jersey
Reno Research Center	Extractive Metallurgy of Wastes
Rolla Research Center	Treatment of Hazardous Residues Carbon-Based Wastes
Salt Lake City Research Center	Treatment of Copper Industry Wastes

Spokane Research Center	Environmental Impacts of Backfill in a Metal Mine Subaqueous Disposal of Mining Wastes
Twin Cities Research Center	Western Arctic Coal Reclamation Characterization and Reduction of Illinois Subsidence Alleviating Structural Damage From Subsidence Hydraulic Analysis of Shallow Water Loss Surface Management at Minerals Operations Low-Frequency Vibrations Study Fly Ash Research
Tuscaloosa Research Center	Stabilization of Mineral Wastes Elimination of Soil Contamination at Mining and Mineral Processing Sites
Contract	Arkansas Revegetation Environmental Assessments

Hazardous Waste Treatment Technology

Denver Research Center	Geophysics for Hazardous Waste Detection
Rolla Research Center	Treatment of Lead-Bearing Wastes Electrolytic Decontamination of Groundwater and Surface Water Treatment of Lead Tailings
Salt Lake City Research Center	Microbial and Chemical Removal of Arsenic From Wastes Bioremediation of Uranium at Midnite Mine Treatment of Chicago River Sediment
Spokane Research Center	Midnite Mine Remediation
Twin Cities Research Center	Chicago River Sediment Quantity and Depth Profile
Contract	Midnite Mine Remediation

Abandoned Mined Land Reclamation Research

Denver Research Center	Mapping Underground Coal Mine Fires Remotely Plugging Mine Shafts—Foamed Concrete
Pittsburgh Research Center	Measurement of Magnetic Susceptibility for Fire Detection in Abandoned Mines Effectiveness of Remining as Abandoned Mined Land Alternative Evaluation of Grout Columns in Flooded Environments Pneumatic Stowing Laboratory Full-Scale Investigation of Grout Columns
Twin Cities Research Center	Utilization of Natural Magnetotellurics to Locate Underground Mine Fires

National Mine Land Reclamation Center

Grants

Comparative Evaluation of Methods of Selenium Analysis for Determining Potential Environmental Hazard
Physical and Geochemical Modeling of Waste Migration From Mining-Contaminated Floodplains, Phase I: Process Analysis
Modeling Soil Water Status of Mine Land Profiles
Wetland Hydrology of Mine Lands
Diagenesis and Leach Characteristics of Aged Coal-Conversion Solid Residues From Mine Disposal Environment
Establishment of Native Hardwoods on Mined Lands Revegetated Under Current Regulations
Temperature and Oxygen Modeling for Determining Acid Mine Drainage Reaction
Development of New Reagents for Reduction of Acid Mine Drainage at the Source
Control of Nucleation and Crystal Growth Rates to Produce High-Density Sludges From Acid Mine Drainage and Coal Pile Runoff
Simulated and Constructed Wetlands Designed to Treat Acid Mine Drainage: Performance Over Long Term
Long-Term Impacts of Underground Mining on Groundwater Quality
Manual for Revegetation of Mine Land in Eastern United States Using Municipal Biosolids
Advanced Management for Revegetation With Trees
Evaluation of the Feasibility of Using Mixtures of Fluidized-Bed Combustion Waste and Coal Refuse in Mine Reclamation
Mitigation of Coal Pyrite Dissolution Due to Humic Acid Treatments
Improvement of Plant Diversity in Coal Slurry Ponds Reclaimed as Wetlands Through Treatment of the Seed Bank During Drawdown
An Interagency Demonstration of the Use of Utility Waste in Reclamation of Abandoned Surface Mines
Validation and Use of Modified Pyrite Oxidation Technique for Reclamation of Abandoned Mine Lands
Subsidence Due to Flooding and Dewatering of Abandoned Mine Workings
Influence of Soil Properties on Row Crop Yields of Reclaimed Soils under Similar Management Systems
Direct Seeding of Late Successional Tree Species on Reclaimed Mine Soils
Crop Production Management Strategies for Reclaimed Surface Mine Soils
Evaluation and Preparation of Reclamation Technologies
Impact of Ash Disposal on Water Quality
Fly Ash to Control Acid Mine Drainage
Coatings for Underground-Mine Acid Mine Drainage Control
Hydrological Modeling for Watershed Restoration
Large-Scale Disposal of Fly Ash on Abandoned Mine Lands
Control of Acid Mine Drainage Production from Coal Refuse
Relation of Acid-Base Accounting to Accelerated Oxidation Testing
Ultrasonic Method for Pyrite Oxidation Testing
Prediction of Acid Mine Drainage Quality and Quantity
Potential of Fluidized Bed Combustion Ash and Kiln Dust as Acid Mine Drainage
Chemical and Fluid Mass Balance Evolution in Acid-Generating Coal Refuse Piles
Manganese Oxide Coated Media for Removal of Soluble Manganese in Mine Drainage
Fluidized-Bed Desulfurization and Fluidized-Gas Desulfurization Residues for Use in Anoxic Limestone Drains
Remining to Reduce and/or Prevent Acid Mine Drainage

HEALTH, SAFETY AND MINING TECHNOLOGY

Occupational Health

Denver Research Center	Radiation Calibration Laboratory
Pittsburgh Research Center	Auxiliary Fan Noise Cancellation Atmospheric Monitoring Systems Mine Acoustical Modeling Implementation of Dust Monitoring Multiplexing and Remotely Powering Fiber-Optic Gas Sensors Coal Mining—Chemical Agents Expert System for Dust Control in Coal Mines Reducing Exposure to Silica Advanced Longwall Dust Control Technology Innovative Silica Control Monitors for Dust Mass Measurement
Twin Cities Research Center	Dust Formation Linear Cutter Feasibility Evaluation of Reusable Filters Empirical Cutting Model Continuous Dust Monitor Development Mining Environment—Chemical Agents Laboratory Investigations of Diesel Emission Technology Diesel Emission Monitors In-Mine Evaluation of Diesel Emission Control
Contracts	Continuous Real-Time Dust Monitoring Linear Cutter Feasibility

Ground Control

Denver Research Center	Numerical Modeling in Mine Structure Design Stress Control Methods Rock Bursts and Failures Gateroad Entry Design Reduction of Stresses by Transmission to Gob Innovative Support Systems for Advanced High-Production Longwalls Pillar Reinforcement Techniques Yield Pillar Design Mine Design For Full Extraction Stress Distribution With Advanced Geophysical Instrumentation Real-Time Hazard Mapping Coal Bump Forecast—Longwall Mining Integrated Monitoring and Analysis Advanced Sensor Technology for Ground Control Applications
Pittsburgh Research Center	Stability Evaluation for Underground Coal Mines Geologic and Engineering Techniques to Reduce Mountain Bumps Control of Horizontal Stress Fiber-Optic Stress Sensor Development Shield Loading Algorithms for Ground Warning Systems Coal Mine Roof Classification System

Spokane Research Center	Fundamental Studies of Support Techniques Innovative Rock Burst Control Rock Burst Hazard Assessment Noninvasive Sensing Techniques for Geologic Hazards Application of Fractal Analysis and Sterology to Rock Mass Characterization Mechanics of Roof Presupport Mine-Wide Monitoring Expert Systems for Ground Control in Coal Mines Rock Burst Mechanics and Control
Twin Cities Research Center	Damage and Fracture Detection Geosensing of Hazards in Advance of Mining Induced Caving to Enhance Longwall Coal Mining Control of Rock Fall Hazards in Surface Mines

Occupational Safety

Albany Research Center	Laboratory Analysis of Wire Rope
Denver Research Center	Coal Air-lift Hydrohoist Innovative Haulage System
Pittsburgh Research Center	Environmental Effects on Intrinsic Safety Monitoring and Control for Mine Hoists: Task 1 Protective Canopy for Extended Cuts Remote Reset for Continuous Miner Wire Rope Hoisting Safety Investigation of Kevlar Hoist Rope Personnel Transport Safety—Coal Circuit Protection for High-Voltage Longwall Research for Small Mine Training Lackawanna Mine Display Human Factors Issues in Extended Cut Fire-Fighting Technology and Skills: Task 2 Human Resource Development—Teaching and Measurement Skills Applied Research in Risk Assessment and Performance Engineering Mine Emergency Management and Data Analysis Detection of Downed Trolley Lines Thermal Profiles of Damaged Cables High-Voltage Enclosure Faults Human Factors Research to Prevent Groundfall Accidents Biomechanical and Work Physiology in Mining Human Factors of Mining Automation Ergonomic Work Design
Spokane Research Center	Control System for Expert Drill Nondestructive Wire Rope Evaluation Monitoring and Control System for Mine Hoists: Task 2
Twin Cites Research Center	Managing Technological Change in Mining Risk Reduction for Cumulative Trauma Hazard Management for Small Mines Cohesion of Granular Materials Analysis of Mine Maintenance Safety Adaptive Seat Mountings Surface Mine Haulage Hazard Reduction Haulage Safety in Underground Metal-Nonmetal Mines
Contracts	Vibration and Shock Isolation

Mine Disaster Prevention

Pittsburgh Research Center

Optimization of Longwall Gob Gas Holes
Survivability (Gateroad) Study
Seals for Explosion Control
Influence of Mine Design on Methane Emissions
Microbial Conversion of Methane
Toxic Fumes Research
Effects of Aging on Permissible Explosives
Pyrolysis and Microscopic Structure Study
Disposal of Waste Oil in Explosives
Permissible Explosives Evaluation
Hazards of Dusts, Gases, and Vapors
Malfunction of Explosives in Delay Blasting
Shock-Induced Damage to Detonators
Breathing Apparatus for Underground Fire Fighting
Mine Fire Detection Strategies
Hazard Detection and Instrumentation
Fire-Fighting Technology and Skills: Task 1
Diesel-Discriminating Fire Sensors
Fires in Mine Passageways
Flammability of Mine Materials
Prevention and Suppression of Full-Scale Explosions
Spontaneous Combustion Fires
Control and Extinguishment of Mine Fires
Improved Ventilation Methods
Safer Blasting Agents—Noncoal
Life Support—Survival and Rescue
Effect of Air Flow on Mine Fires

Twin Cities Research Center

Safer Blasting Design
Fire Hazards of Electrical Installations
Pacification of Sulfide Oxidation
Mine Environmental Effects on Fire Detection
Analysis and Evaluation of Mine Fire Suppression Systems
Preventive Model for Fires

Experimental Facilities

Pittsburgh Research Center

Operation of the Safety and Research Mines
Operation of the Lake Lynn Laboratory
Mine Roof Simulator

Advanced Mining Systems

Denver Research Center

Innovative Mine Design for Automated, Mechanical Excavation
Stope Leaching

Pittsburgh Research Center

Fundamental Investigation of Robotics
Advanced Sensor and Control Technology
Haulage Systems for Automated Mining
Advanced Strata Recognition System (Multiple Coal Interface Detector)
Advanced Ventilation Techniques
Advanced Intelligent Planning System

	Coal Interface Detector
	Mountaintop Coal
	Investigate Geomechanics in Multiple Coal Seams
	Microbial Conversion of Coal
	Biological In Situ Mining of Sulfides
	Biological Coal Desulfurization
	Navigation and Guidance for Bolters
	Advanced Diagnostics Systems
	Highwall Guidance System
	Control Systems for Mobile Machines
	Automation Technology Evaluation and Forecasting—Metal-Nonmetal Mining
	Selective Borehole Slurry Mining
Reno Research Center	Frozen Tailings as Backfill
	Heap, Stope, and In Situ Leaching Lixiviants
Spokane Research Center	Automation of Mining Equipment for Metal-Nonmetal Mines
	Improved Fill Placement Methods
	Mine Design for Optimum Resource Recovery
	Control Systems for Remote Roof Support
	In Situ Mining of Deep Veins
	Autonomous Roof Support Subsystems
	Metal Recovery—Borehole Slurry
	Mine Development and Analysis for Critical and Strategic Mineral Recovery in Alaska
	New Methods for Mining Shallow Deposits—Stillwater Complex
	Advanced Concepts for Mining Deep Ore Bodies
	Underground Mining for Alaska Deep Placers
	Conical Caving
	Spiral Slot and Fill
Twin Cities Research Center	Blasting to Enhance Permeability
	Novel Permeability Enhancement
	Geomechanical and Geophysical Technology for Evaluating Rock Masses for In Situ Mining
	Empirical Cutting Model
	In Situ Reduction of Iron Ore
	Seabed Sampling and Mining Technology
	In Situ Copper Mining Experiment
	Lixiviant Flow Modeling and Containment
	Borehole Mining in Placers
	Assessment of Space Resource Utilization Technology
	Characterization of Rock for In Situ Leaching
	Tailoring Blast Designs for Improved Fragmentation
	Remote Selective Hard-Rock Mining
	Development of Novel Hydrologic and Geochemical Systems for In Situ Mining
	Fragmentation of Hard Rock
	Thermal Fragmentation Concepts
Contracts	Automation Studies
	Selective Mining Study—University of Minnesota
	In Situ Experiment—Copper
	Robotics Research—Carnegie Mellon University
	Control Architecture—National Institute of Science and Technology
	Flexible Automation—West Virginia University

MINERALS AND MATERIALS SCIENCE

Minerals Research

Albany Research Center

Characterization of Fine Particle Values by Image Analysis
Identification, Characterization, and Recycling of Advanced Materials and Alloys
Improved Arc Stability in Electric Arc Furnace Steelmaking
Continuous Production of Titanium Powder
Production of Powder by Vapor-Phase Reduction
Titanium Alloys from Secondary Resources
Metal Extraction from Dilute Solutions with Emulsion Membranes
Parameters Affecting Selective Leaching of Copper
Predictive Control of Nonlinear Processes
Process Mineralogy of Domestic Resources
Removal of Copper and Tin from Ferrous Scrap
Solvent Extraction Fundamentals
Submerged, Gravity-Pressurized Reactor

Reno Research Center

Anode Reactions That Decrease Energy Consumption
Fundamental and Applied Aspects of Mineral Bioprocesses
Hyperaccumulator Mining
In Place Leaching Chemistry
In Situ Leaching—Solvent Investigations
New Solvent Systems to Recycle Advanced Materials
Rapid Rate Reduction
Recovery of Ancillary Metals from Mill Tailings
Recovery of Platinum-Group Metal From Spent Automobile Catalytic Converters
Removal of Magnesium, Zinc, and Hydrogen From Aluminum Scrap by Vacuum Distillation
Thiosulfate as an Alternative to Cyanide

Rolla Research Center

USBM-Department Of Energy Cooperative Research—Design for Recycle
Conservation of Mineral Values in Metal Annealing and Pickling Processes
Lead-Free Brass Separation and Recycling
Rare-Earth Metals from Missouri Iron Mines
Shear Treatment of Molten Matte to Enhance Selective Metal Extraction
Sorting and Recycling of Consumer Products

Salt Lake City Research Center

Advanced Solvent Extraction Stripping Technology
Advancing Autoclave Technology Through Automation and Control
Appraisal of Critical Minerals From Northwest and Alaskan Resources
Beneficiation and Processing of Ocean Floor Minerals
Flotation Demonstration
Nonconventional Fracture in Comminution
Concentration and Recovery of Heavy Rare-Earth Elements
Critical Metals Recovery from Advanced Materials Scrap
Liquid, Liquid-Solid, and Induced-Force Separations of Fine Particles
Lixiviants for In Situ Leaching of Copper Sulfides—Ammoniacal

	National Defense Stockpile—Upgrade Pre-1980 Cobalt
	Optical Monitors for Metallurgical Processes
	Rapid Analysis and Control of Process Streams
	Rare-Earths Recovery from Secondary Sources
	Steel Plant Sludge Dewatering
	Surface Chemistry of Oxidized Mineral Flotation
	Synthetic Rutile from Hard-Rock Ilmenite
	Systems Approach to In Situ Mining Leach Solutions
Tuscaloosa Research Center	Flotation Demonstration
	Development of Improved Stirred Media Mills
	Improved Conditioning and Flotation of Coarse Phosphate
	Mineral Recovery From Very Fine Slurries
	Process Simulation for Improved Minerals Recovery
	Salt-Enhanced Shear Flocculation
	Sensors for Process Control
	Steel Plant Sludge Dewatering
Twin Cities Research Center	Abatement of Nitrogen Oxide During Iron Oxide Pellet Induration
	Double Vortex System for Comminution
	Enhanced Iron Ore Pellet Properties
Idaho National Engineering Laboratory	Biologically Assisted Minerals Processing
	Intelligent Control of Nonlinear Processes
	Metal-Gas Reactions in Thermal Plasmas
	Novel Solvent Extractants for Cobalt and Nickel
	Synthesis and Binding Studies of Selective Crown Ether Extractants

Materials Research

Albany Research Center	Advanced Alloying Technology Using Inert Gases
	Smart Materials—Monitor and/or Alarm Systems for Structural Members in Mines
	Lightweight Titanium-Ceramic Composites
	Structure and Properties of Advanced Intermetallics
	Wear-Corrosion Mechanisms in Minerals Processing
	Mechanisms of Passivity of Pseudostainless Steels
	Micromechanics of Compressive Fracture in Heterogeneous Materials
	Protection Strategies in Corrosion Science
	Fundamentals of Wear and Machining
Pittsburgh Research Center	Sensor Development
Reno Research Center	Transition Substrates for Diamond Coatings
Rolla Research Center	Net Shape Composites by Carbonyl Vapor Deposition
	Lead-Free Brass and Dispersion Alloying via Flux Injection and System for Alloy Substitution
	Enhancement of Catalytic Activity of Counter Electrodes by Composition and Texture Control
	Sensor Development for Smart Ropes and Cables

Tuscaloosa Research Center	Structure and Properties of Advanced Ceramics Processing of Advanced Ceramics Corrosion of Advanced Ceramic Materials
Idaho National Engineering Laboratory	Laser-Assisted Electrochemistry Nanostructure Materials—A Novel Approach to Enhanced Performance Rapidly Solidified Processing of Ferrous Alloys for Improved Properties Fracture Mechanics of Interfaces in Heterogeneous Materials Noncontacting, Nondestructive Evaluation for Materials Characterization

MINERAL INSTITUTES

Mine Systems Design and Ground Control

Mine Drift Diagnosis Using Visual, Thermal, and Sonar Image Processing
Alternative Partial-Extraction, Room-and-Pillar Mining Geometries
In Situ Strength of a Coal Seam Based on Coal Strata Classification
Stability and Seepage in Wet Mines
High-Density Paste Fill for the Sunshine Mine
District-Wide Rock Burst Monitoring and Analysis
Control of Material Flow on Mine Conveyor Networks
Shape Optimization of Underground Openings
Simulator Enhancement for Mine Fire Modeling
Finite-Element Damage Model
Mechanisms and Control of Floor Heave
Fixed-Array, Ground-Probing Radar For Ground Control Monitoring
Analysis of Ground Control Problems Caused by Strong Beds in Longwall Mining
Artificial Intelligence to Evaluate Rock Mass Behavior and Failure in Longwalls
Coal Mine Ventilation Design to Prevent and Control Spontaneous Combustion
Design for Optimum Stability and Productivity in a Multi-Seam Environment
Roof Support System for Development Openings in Alluvial Permafrost

Comminution

Effect of Change of Media Competency on Autogenous Grinding
Improved Comminution Efficiency Through Controlled Blasting During Mining
Rate of Energy Consumption During Single Particle Fracture
Breakage Characteristics of Particles and Mixtures Using Ultrafast Load Cell
Microwave Heating of Minerals to Improve Comminution and Liberation
Effect of Blast Damage on Comminution Using a Split Hopkinson Bar
Computer Simulation and Modeling Breakage of Multiphase Particles
Interaction and Energy Consumption Modes in Pressurized Roll-Mill Grinding
Industrial Hydrocyclone Design
Mass Transport in Wet Overflow Mills
Ultrasonic Comminution Technology
Shape Analysis for Aggregate Production
Power Consumption of Stirred Media Mills

Mineral-Industry Waste Treatment and Recovery

Treatment Methods for Bacterial Leaching of Precious Metals Refractory Ores
Recovery of Mineral Values From Clay Wastes Using Selective Agglomeration
Treatment of Heavy Metallurgical Effluents by Using Column Flotation
Enhancement of the Oxidative and Photochemical Decomposition of Cyanide Species in Precious Metal Treatment Wastes
Removal and Recovery of Metals From Effluents by Ion and Precipitate Flotation
Mapping Effluent Within a Rock Mass Using Wave Diffusion Geotomography
Mitigation of Acid Mine Drainage by an Agglomeration Process
Attenuation of Arsenic in Copper Leach Heaps and Dumps
Treatment of Waste Leady Mattes and Sludges
Fate of Mercury in Precious Metals Mill Tailings
Solvent Extraction of Waste Using Galvanic Stripping
Remediation of Cyanide Contained in Mill Tailings by Anaerobic Bacteria
Determine How the Source of Ore Pyrite Affects Its Acid-Generating Potential
Partitioning-Separation of Arsenic Oxide in the Treatment of Copper Flue Dusts

Pyrometallurgy

Vapor-Transport Chemistry for the Extraction and Recovery of Vanadium
Kinetics of Reduction of Lead From Lead Oxide Slags
Foam Behavior in Metallurgical Reactors
Slag-Resistance Electric Furnace for High-Temperature Processing of Materials
Interfacial Phenomena in Aluminum Alloys and Salt Systems
Standard Gibbs Free Energy of Formation of Binary Oxides by EMF Methods
Intermetallic Compounds by Vapor-Phase Coreduction of Metal Chlorides
Drop Size in Liquid and Liquid Emulsions Formed by High-Velocity Gas Injection
Process Mineralogy of Pyrometallurgical Products
Ladle Refining of Copper Produced by Single-Stage Smelting
Mathematical and Physical Modeling of Flow Phenomena and Mixing in Three-Phase, Counter-Current Metallurgical Reactors
Thermodynamic Properties of Chromium, Tungsten, and Cobalt Carbonyl Systems
Fundamental Aspects of Mercury Extraction and Recovery From Sulfur-Containing Materials

Respirable Dust

Instrumentation for Measurement of Particulate Matter From Diesel Equipment
Wetting Characteristics of Dust Particles in Relation to Dust Abatement
Mineralogical Identification, Sizing, and Profiling of Respirable Coal Particles
Interactions of Coal Dusts and Nonhuman Primate Lungs
Effect of Coal Dust on Lung Surfactant and Type II Cells
Adhesion, Agglomeration, and Deposition of Respirable Dust
Human Alveolar Macrophage and Coal Mine Dust Interaction
Intervention in Fibrotic Mediator Production by the Dust-Exposed Alveolar Macrophages
Improved Procedures for Production of Dust Samples for Biomedical Research
Dust Control in High-Production Longwall Faces
Coal Mine Dust Characterization
Airway Reactivity in Coal Miners
Collaborative Techniques for Improved Free Silica Analysis
Dynamics of Bit Wear and Dust Generation
Inlet Bias in Respirable Dust Samplers—10-Millimeter Dorr-Oliver Cyclone
Relationship of Surface Properties of Respirable Dust to Biological Activity
Relationships Between Respirable Dust Concentrations and Seam Characteristics
Effect of Coal Dust on Type II Cell Interactions With the Extracellular Matrix
Quantification and In Vivo Cytotoxicity of Mixed Coal and Diesel Dusts
Evaluation of Diesel Particulate Control Technology for Underground Mines
Measurements for Tailpipe and Personal Exposure to Diesel Particulates
Particle Droplet Filter Media Interactions in a Flooded-Bed Scrubber
Cellular and Molecular Mechanisms of Silicosis and Coal Workers Pneumoconiosis
Pulmonary Immunological and Inflammatory Mechanisms in Coal Miners Exposed to Silica
Study of Airborne Dust Behavior, Source Generation, and Control Technology in Longwall Faces Employing Bidirectional Cutting Pattern
Evaluation of Two-Phase Flow Systems for Longwall Shearer Dust Control

Marine Minerals

Heavy Mineral Depositional Modeling in the Northern Gulf of Mexico
Drill Systems Development
Determination of Seabed Microtopography by Side-Scan Sonar
Maximizing Returns From Twenty Years of Deep Seabed Minerals Exploration
Advanced Design for a CS^3 Data Collection System
Engineering Characterization of Carbonate Sand in a Pacific Reef Environment
High-Resolution Seismic Reflection Methods in Locating and Mapping Offshore Sand Bodies
Exploration of Marine Placers—Identification-Utilization of Geochemical Signals
Geochemical Characterization of OMCO Nodules From Clarion-Clipperton Zone
Manganese Nodules as a Regenerable Hot-Gas Desulfurization Sorbent

FOR ADDITIONAL INFORMATION

This annual report provides only a broad overview of USBM research activities. For additional information on the research areas, please call:

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