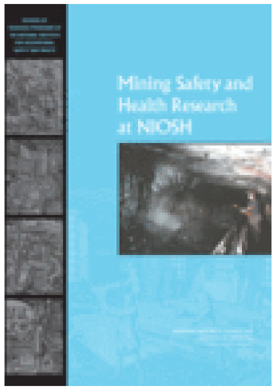

Mining Safety and Health Research at NIOSH: Reviews of Research Programs of the National Institute for Occupational Safety and Health

Committee to Review the NIOSH Mining Safety and Health Research Program, Committee on Earth Resources, National Research Council

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Reviews of Research Programs of the National Institute for Occupational Safety and Health

Committee to Review the NIOSH Mining Safety and Health Research Program

Committee on Earth Resources

Board on Earth Sciences and Resources

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Jonathan G. Price, Nevada Bureau of Mines and Geology, Reno, and M. Donald Whorton, WorkCare, Inc., Alameda, California. Appointed by the National Research Council, they were responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Preface

The single most valuable asset in any organization, including organizations within the mining industry, is its human resources. The ingenuity of employees leads to effective and efficient utilization of all other resources and to achievement of the economic and social goals of the organization. Protection of employees from hazards in the occupational environment is important both from the humanitarian point of view and for the overall welfare of the organization. It is fundamental for sound management, for the health and safety of the miners, and for the survival of the company in a competitive world. An often-quoted saying states: "The safest mine is the most profitable mine."

The enhancement of mining workplace health and safety requires the recognition that mining remains hazardous and that vigilance in addressing the hazards can never be relaxed. Miner health and safety are major concerns for mine management, labor organizations, and government. This concern has manifested itself in four control mechanisms: (1) regulatory control through the passage of laws and regulations; (2) legal and social control through compensation laws for occupation-related injuries and health deterioration; (3) medical control through periodic examinations; and (4) engineering control through the design and operation of mines according to the best recommended practices. An important aspect of all these approaches is the search for new tools and techniques that will further enhance hazard control. Ultimately, to create safe mining environments, improved tools and techniques must be successfully integrated and applied in the industry.

The evaluation of research contributions by the National Institute for Occupational Safety and Health (NIOSH) Mining Research Program is the focus of this report. The National Academies was asked to evaluate the research activities of the NIOSH Mining Program in terms of relevance, the impact of the program on the health and safety of workers, and the significance of research to emerging issues in mining. In response to this request, the Committee to Review the NIOSH Mining Safety and Health Research Program was formed, composed of experts from industry, academia, and labor organizations. The committee comprises recognized experts in surface and underground mining, coal mining, metal and nonmetal mining, mining health and safety, mining research, industrial hygiene, technology transfer, rock mechanics, and acoustical engineering. The committee reviewed extensive documentation provided by NIOSH on Mining Program research; held both open- and closed-session meetings; visited multiple NIOSH research facilities; heard from representatives of industry, government, labor, manufacturers, and consultants; and requested and reviewed written input from stakeholders.

This report finds that good progress has been made in the improvement of mine worker health and safety, with continuous decreases in the incidence and severity of diseases, disasters, and fatal and non-fatal accidents. The NIOSH Mining Program has identified and conducts research in seven areas of greatest need: respiratory disease prevention; noise-induced hearing loss prevention; cumulative musculoskeletal injury prevention; traumatic injury prevention; mine disaster prevention and control; ground failure prevention; and surveillance, training, and intervention effectiveness.

Despite a sharp decrease in available funds between 1998 and 2005, the NIOSH Mining Program has made major contributions to the engineering control of hazards in the workplace and the development and transfer of new knowledge to the mining industry. Yet miners continue to experience diseases, disasters, fatalities, and injuries. As recent coal mine disasters have shown, safety concerns of mine operations require constant monitoring and control.

Mine safety and health research by the federal government should continue to be an important component of efforts to make mines safer in the future. The development of an appropriate balance between addressing currently known problems and preparing for emerging problems is essential for a research agency. The more challenging mining environments expected in the future (e.g., deeper deposits, multiple seams, mining seams beneath previously mined-out seams) will require enhanced health and safety research. The changing workforce demographics and the changing nature of the work itself require adequate resources for the technology transfer and training program development necessary to create a more knowledgeable workforce in which evidence-based innovations are implemented and sustained. Given the impending critical shortage of trained manpower at all levels in the mining industry, there is an immediate need to find and train replacement personnel.

Raja V. Ramani
Commitee Chair

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Abbreviations and Acronyms

AHSEM	Analysis of Horizontal Stress Effects in Mines (software)
AIHA	American Industrial Hygiene Association
ALPS	Analysis of Longwall Computer Stability (software)
ANFO	Ammonium nitrate fuel oil (blasting agent)
ANSI	American National Standards Institute
ARMPS	Analysis of Retreat Mining Pillar Stability (software)
ARTBA	American Road and Transportation Builders Association
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BCOA	Bituminous Coal Operators of America
BLS	Bureau of Labor Statistics
CAP	Crewstation Analysis Programs
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
CMR	Construction, maintenance, and repair
CMRR	Coal mine roof rating
CO	Carbon monoxide
COLD	Chronic obstructive lung disease
CWP	Coal worker's pneumoconiosis

dBA	Decibels (the sound level in decibels after applying the A-weighting filter)
DHHS	Department of Health and Human Services
DO	Designated operation
DPM	Diesel particulate matter
DRDS	Division of Respiratory Disease Studies (NIOSH)
DSHEFS	Division of Surveillance, Hazard Evaluations, and Field Studies (NIOSH)
EC	Elemental carbon
EFSI	Electrical Safety Foundation International
FACE	Fatality Assessment and Control Evaluation (NIOSH)
FTE	Full-time equivalent
HASARD	Hazardous Areas Signaling and Ranging Device
HHE	Health Hazard Evaluation
HLP	Hearing loss prevention
HLPU	Hearing Loss Prevention Unit
HPD	Hearing protection device
ICP	Inductively coupled plasma
ISMSP	International Society of Mine Safety Professionals
ISO	International Organization for Standardization
LHD	Load-haul-dump
LLL	Lake Lynn Laboratory (NIOSH Mining Program)
MESA	Mine Enforcement and Safety Administration
MHRAC	Mine Health Research Advisory Committee
MIS	Mining-induced seismicity
MRS	Mobile Roof Support
MSD	Musculoskeletal disorder
MSHA	Mine Safety and Health Administration
MSHRAC	Mine Safety and Health Research Advisory Committee
MTS	Missile Test Site
MVSSA	Mine Ventilation Society of South Africa
NDL	No days lost
NFDL	Non-fatal days lost

NFPA	National Fire Protection Association
NIHL	Noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
NMA	National Mining Association
NO_2	Nitrogen dioxide gas
NORA	National Occupational Research Agenda
NORA-2	National Occupational Research Agenda (second decade)
NPPTL	National Personal Protective Technology Laboratory
NRR	Noise reduction rating
NSPE	National Society of Professional Engineers
NVLAP	National Voluntary Laboratory Accreditation Program
OSHA	Occupational Safety and Health Administration
OSH Act	Occupational Safety and Health Act
PART	Performance Assessment Rating Tool
PBS	Personal bolter screen
PDM	Personal dust monitor
PEL	Permissible exposure limit
PIB	Public Information Bulletin (MSHA)
PMF	Progressive massive fibrosis
PPE	Personal protective equipment
PRL	Pittsburgh Research Laboratory
psf	Pounds per square foot
r2p	Research to practice
REL	Recommended Exposure Limit
SAE	Society of Automotive Engineers
SCSR	Self-contained self rescuer
SME	Society for Mining, Metallurgy and Exploration
SRL	Spokane Research Laboratory
STE	Statement of Test and Evaluations (MSHA)
STOP	Support Technology Optimization Program (software)
SX-EW	Solvent extraction-electrowinning
TC	Total carbon
TRAM	Training Resources Applied to Mining Conference
TTG	Technology Transfer Group (USBM)

UMWA	United Mine Workers of America
USBM	U.S. Bureau of Mines
USPHS	U.S. Public Health Service
WMA	Wyoming Mining Association
WMSD	Work-related musculoskeletal disorder

Summary

ABSTRACT *The U.S. mining sector employs approximately 331,000 people but has one of the highest fatality rates of any U.S. industry. Fatalities, injuries, and disasters, although less frequent than in the past, continue to occur, and health concerns posed by gases, dusts, chemicals, noise, extreme temperatures, and other physical conditions continue to result in chronic and sometimes fatal illnesses. In the last three decades, improvements in mining technology, equipment, processes, procedures, and workforce education and training have resulted in greater safety and health.*

In conjunction with planned reviews of up to 15 of the National Institute for Occupational Safety and Health (NIOSH) research programs, the National Academies convened a committee of experts to review the NIOSH Mining Safety and Health Research Program (Mining Program) to evaluate the relevance of its work to improvements in occupational safety and health and the impact of NIOSH research in reducing workplace illnesses and injuries. Relevance was evaluated in terms of the priority of work carried out and its connection to improvements in workplace protection. Impact was evaluated in terms of its contributions to worker health and safety. The committee was also asked to assess the program's identification and targeting of new research areas, and to identify emerging research issues.

Although responsibility for controlling workplace exposure to mining health and safety hazards lies with others, the Mining Program can be expected to contribute to reduction of these workplace hazards through its

research and information dissemination. The committee concludes research of the Mining Program is in high-priority areas and adequately connected to improvements in the workplace. A rating of 4 on a five-point scale (where 5 is highest) is appropriate. Contributions of the program to improvements in workplace health and safety during the period evaluated (1997 to 2005) are considered major in some areas (respirable disease prevention, traumatic injury prevention), moderate in some areas (hearing loss prevention, ground failure prevention), and likely in a number of areas (disaster prevention, musculoskeletal injury prevention). Mining Program outputs are evaluated, accepted, and incorporated into stakeholder operations, and training outputs find wide use in the industry. The Mining Program is moderately engaged in technology transfer activities. A score of 4 for impact is appropriate.

To increase its effectiveness, the program should more proactively identify workplace hazards and establish more challenging and innovative goals toward hazard reduction. Interaction with other NIOSH programs should be increased, as should interactions with extramural researchers, and the Mine Safety and Health Administration (MSHA) when research needs are closely aligned with MSHA's shorter-term and legislative requirements. Partnering with industry should be done more broadly such that research results can be more widely applied within the industry. The program should make better use of MSHA and other surveillance data, and work to make these surveillance programs more robust. A more strategic dissemination agenda is suggested that would incorporate training into the strategic goals of all research areas and explicit plans for transfer to small business worker populations.

The committee concludes the NIOSH Mining Program makes essential contributions to the enhancement of health and safety in the mining industry. The ability of the program to expand its research and transfer activities in ways recommended in this report, however, is critically dependent on the availability of funding.

It is predicted that the U.S. mining industry will be challenged to produce more than 1.8 billion tons of coal annually by the year 2030, compared to current production of 1.1 billion tons (Energy Information Administration, 2006). Aggregate (sand, gravel, and stone) industry production is likely to grow, and increasing metal prices and an increased demand for metals and nonmetallic minerals worldwide are also predicted. Increased demand and production will ultimately lead to new technologies—and new hazards—in the workplace. The continued occurrence of accidents, injuries, and illnesses in the mining industry requires continuous and vigorous research on the detection and elimination of hazards that threaten the health and safety of miners. Advances in mining practices and procedures have greatly enhanced mine worker health and safety. The National Institute for Occupational Safety and Health (NIOSH) Mining Safety and Health Research Program (and the former U.S. Bureau of Mines) has played a large role in these improvements. Continued quality research by the NIOSH Mining Safety and Health Research Program (hereafter called the Mining Program) should take into account changing technologies, practices, and procedures in the mining workplace.

In September 2004, NIOSH contracted with the National Academies to conduct a review of NIOSH research programs. The goal of this multiphase effort is to assist NIOSH in increasing the impact of its research in reducing workplace illness and injury and improving occupational safety and health. The National Academies agreed to conduct this review within the Division on Earth and Life Studies and the Institute of Medicine. A committee was appointed to develop a set of guidelines for use in the evaluation of NIOSH research programs. The evaluation criteria are presented in the so-called Framework Document (Appendix A). The Mining Program is the second program to be reviewed using the established guidelines.

The National Academies organized an ad hoc committee to evaluate the Mining Program. The Committee to Review the NIOSH Mining Safety and Health Research Program reviewed the program to evaluate the relevance and impact of its research on workplace health and safety, as well as to identify significant emerging health and safety issues in the mining workplace. Specifically, the committee was asked (1) to assess the Mining Program's progress toward reducing workplace illness and injury, providing numerical scores, on a five-point scale for both relevance and impact of the research (Box S-1); (2) to consider how well the Mining Program targets new research to areas most relevant to future improvements in workplace protection; and (3) to identify significant emerging health and safety issues in the mining workplace.

The committee used the Framework Document criteria for its evaluation. The evaluation was based largely on an evidence package presented to the committee by the Mining Program (NIOSH Mining Program Briefing Book, *http://www.cdc.gov/niosh/nas/mining/*), on presentations made by program managers and researchers during committee meetings and site visits to multiple NIOSH facilities, and on oral and written communications from several stakeholder groups. The committee reviewed documents related to NIOSH and the former U.S. Bureau of Mines. As an aid to its evaluation, the committee theorized what an "ideal" mining research program would comprise and identified the major issues that such a program would address.

BOX S-1
Five-Point Scales Used for the Rating of Relevance and Impact

Rating of Relevance

5 = Research is in highest-priority subject areas and highly relevant to improvements in workplace protection; research results in, and NIOSH is engaged in, transfer activities at a significant level (highest rating).
4 = Research is in high-priority subject area and adequately connected to improvements in workplace protection; research results in, and NIOSH is engaged in, transfer activities.
3 = Research focuses on lesser priorities and is loosely or only indirectly connected to workplace protection; NIOSH is not significantly involved in transfer activities.
2 = Research program is not well integrated or well focused on priorities and is not clearly connected to workplace protection and inadequately connected to transfer activities.
1 = Research in the research program is an ad hoc collection of projects, is not integrated into a program, and is not likely to improve workplace safety or health.

Rating of Impact

5 = Research program has made a major contribution to worker health and safety on the basis of end outcomes or well-accepted intermediate outcomes.
4 = Research program has made a moderate contribution on the basis of end outcomes or well-accepted intermediate outcomes; research program generated important new knowledge and is engaged in transfer activities, but well-accepted intermediate outcomes or end outcomes have not been documented.
3 = Research program activities or outputs are going on and are likely to produce improvements in worker health and safety (with explanation of why not rated higher).
2 = Research program activities or outputs are going on and may result in new knowledge or technology, but only limited application is expected.
1 = Research activities and outputs are NOT likely to have any application.
NA = Impact cannot be assessed; program is not mature enough.

ASSESSMENT OF RESEARCH RELEVANCE AND IMPACT

There has been a marked decrease in disasters, injuries, illnesses, and occupational diseases in the mining industry over the last several decades. This decrease is the result of many efforts including those of mine managers and workers, labor organizations, federal and state enforcement agencies, equipment manufacturers and suppliers, researchers, and others. Research and development are important components of the total Mining Program effort to make mines safer and healthier worksites. In assessing the contributions of the Mining Program to improvements in worker health and safety, the committee was asked to provide scores for both relevance and impact as per criteria in the Framework Document (Box S-1).

On the basis of its review, the committee assigned a score of 4 for relevance and a 4 for impact to the Mining Program.

In evaluating relevance and impact, the committee considered funding, resource allocation, number of employees, and the manner in which stakeholder input is obtained and incorporated into the research program. Program activities were considered in terms of their contributions toward achieving strategic goals and toward the quality and quantity of outputs. Particular attention was paid to the acceptance and use in the industry of developed technologies, guidelines, procedures, and training tools. The manner in which the Mining Program integrated surveillance, research activities, outputs, and technology transfer activities to achieve strategic goals was also considered.

PROGRAM PLANNING AND STRATEGIC GOALS

The seven strategic research areas identified by the Mining Program are (1) respiratory disease prevention; (2) noise-induced hearing loss prevention; (3) cumulative musculoskeletal injury prevention; (4) traumatic injury prevention; (5) mine disaster prevention and control; (6) ground failure prevention; and (7) surveillance, training, and intervention effectiveness. The program's mission, according to the Mining Program Briefing Book, is to "eliminate occupational diseases, injuries and fatalities from the mining workplace." Strategic and intermediate goals and performance measures have been established for each priority area.

The Mining Program mission cannot be accomplished solely through what NIOSH terms "a focused program of research and prevention." Workplace improvements are dependent on the ability to transfer research results into practice, but the Mining Program has no power to require or enforce implementation of its recommendations. External factors affect every aspect of the program, often preventing the realization of projected outcomes. A political climate favorable to the support of mining health and safety research and of the resulting recommendations is necessary. The level of annual funding for the Mining Program, specific appropriations to enhance research facilities, and additional funding for specific research areas are critically dependent on the input from several sources. These include industry, labor, the administration, and members of Congress.

The Mining Program's mission and goals are appropriate, but **the Mining Program should establish more challenging, innovative goals and attendant**

objectives. Strategic and intermediate goals should be stated more precisely, and performance measures should be tied more closely to goals. In some cases, the committee could not establish clear connections between specific projects and goals. Goals and priorities should be reviewed regularly for appropriateness. The Mining Program solicits proposals from internal researchers to initiate new projects. Although these researchers are recognized by their peers for their expertise, they may not have the breadth of knowledge required to develop multidisciplinary proposals encompassing multiple strategic goals, a direction the Mining Program should take to be more effective.

At present, the Mining Program establishes research priorities primarily in response to stakeholder input or current events. This helps ensure the applicability of its research outputs. However, **the Mining Program should take a more proactive approach to identifying and controlling hazards**, including those that arise from changing mining conditions and technologies, thus eliminating the associated potential illnesses and injuries. Using surveillance data in combination with expanded external input to identify key priorities would help the Mining Program develop a more proactive approach to hazard identification and control.

The establishment of more challenging goals, specifying associated objectives and activities, and taking a more proactive stance toward identifying and responding to mining hazards would propel the Mining Program along a strategic course toward becoming an ideal program for the future.

EFFECTIVE INTERACTIONS

The Mining Program should increase interaction with other NIOSH programs including the Division of Respiratory Disease Studies, the Division of Safety Research, and the Division of Surveillance, Hazard Evaluations, and Field Studies. Ideally, research personnel with medical, epidemiological, engineering, geological, and industrial hygiene experience should work together as a research team to help address workplace issues including research about the organization of work. Program management should be more involved in envisioning worthwhile intra- and interprogram interactions. Additionally, full advantage should be taken of the NIOSH Mine Safety and Health Research Advisory Committee by adequately challenging it with substantial assignments. The advisory committee's findings, conclusions, and recommendations should be considered more fully in the Mining Program's decision-making process.

Interaction with the Mine Safety and Health Administration (MSHA) should be enhanced in areas where research needs are closely aligned with MSHA's legislative and shorter-term priorities. The committee recognizes the benefits of partnering with MSHA to improve miner health and safety.

The Mining Program should fully utilize outside technical expertise through a vibrant extramural and contract research program. Given the cost of developing expertise to conduct innovative research, the Mining Program should take advantage of external expertise through an extramural research program. The extramural program should include both externally initiated research and contractors working on NIOSH-initiated research. This approach has an additional benefit of producing highly trained personnel for the industry at large, as well as for its own program.

Effort should be made to partner more broadly such that guidelines and processes are most relevant to the entire mining community. The Mining Program has an extensive list of partners within industry and academia. Partnering with specific mining companies is beneficial and key to technology transfer, but the committee is concerned that resources are directed toward developing solutions to problems that are site specific and not directly applicable through adaptations to the mining industry at large. The committee strongly believes the Mining Program should continue to develop international partnerships in the interest of contributing globally what technologies it can and to incorporate developments made internationally into the domestic workplace.

SURVEILLANCE AND MONITORING

The Mining Program should make better use of MSHA and other existing surveillance data and work to make these surveillance programs more robust. The Mining Program has access to a MSHA-maintained database of mining-related incident, injury, and illness data and conducts some surveillance on a project-specific basis. The committee considers the collection of surveillance data of utmost importance in monitoring mine worker health and safety conditions and in determining the effectiveness of Mining Program activities. An improved surveillance system would allow the Mining Program to evaluate intervention effectiveness, which should be incorporated into the strategic goals of all its relevant research areas.

More robust and better methods of monitoring in situ safety conditions in mines should also be developed. Research is needed to minimize safety risk to underground workers and to evaluate the potential for damage to surface facilities such as dams, buildings, pipelines, and road cuts whose failure could cause injury to persons on or near mine property. Recent advances in remote sensing, telemetering, and diagnostic methods should be evaluated, improved, and made known to mine operators for timely detection and avoidance of underground and surface mine hazards.

OUTPUTS

The Mining Program should place greater emphasis on outputs preferred by mining operators, miners, and other nontechnical users.

TRAINING PROGRAMS AND TECHNOLOGY TRANSFER

The Mining Program efforts in the area of technology transfer (NIOSH's research to practice program), while commendable, are not proportionate to its efforts in the conduct of safety and health research. A good understanding of potential impacts of research outputs is necessary if recommendations are to be adopted by industry and guidelines and standards are to be promulgated by MSHA. While there is an appreciation of this fact, it is unlikely that the technology transfer processes in place will achieve the desired results. Much of the responsibility for technology transfer is in the hands of project researchers who cannot be expected to be expert in the technology transfer issues involved. **A more proactive, aggressive, and strategic dissemination agenda is suggested, one that is informed by research about the diffusion of new technologies, processes, and practices. The Mining Program should determine the likely end users of its research results,** and **develop demonstration projects that show the feasibility and effectiveness of interventions.**

Just as the committee recommends that surveillance be incorporated into all relevant research areas, **training should be incorporated into the strategic goals of all research areas**. To improve training effectiveness, the Mining Program should determine the likely end users of its research results. Most Mining Program outputs are useful for small business, but **plans for technology transfer of all project outputs should explicitly include how small business worker populations will be served**.

Fiscal year 2005 funding for research to practice in the Mining Program was less than 5 percent of the total budget. The need for dedicating adequate resources to developing a more knowledgeable workforce should be appreciated. Better and more focused methods of delivering outputs and documenting resulting intermediate outcomes are needed. Technology transfer activities should be sharpened with new programs and additional resources. New research in technology transfer is needed to determine the most effective ways to improve training procedures and practices and to transfer knowledge to achieve implementation and sustainability.

IMPACT IN THE WORKPLACE

It is difficult to isolate contributions made by the Mining Program to the great improvements in health and safety in mining. Improvements are due to improved mine design, operational procedures, new equipment and technology, new laws and compliance, and educational assistance from MSHA and state regulatory agencies. The Mining Program has had influence in all these areas, but the extent of this influence cannot be quantified.

When improvements in health and safety could not be directly attributed to the Mining Program, the committee considered the indirect influence of the program's research and transfer activities. If program outputs and transfer activities could potentially impact the workplace, some credit for improvements was given. The committee also considered how to assess the contributions of long-standing research programs, some of which date back to the former U.S. Bureau of Mines. The process of moving research from concept to completion can be long, but the time to move from completion to widespread implementation can be even longer. The committee decided to consider some research predating the move of the program from the U.S. Bureau of Mines to NIOSH.

Examples of health and safety improvements resulting from Mining Program efforts include the following:

- **Respiratory disease prevention.** Long-standing research has resulted in significant progress in bringing ambient coal dust concentrations below mandated levels. Data show the prevalence of coal worker's pneumoconiosis has been decreasing for those employees of long tenure (>20 years), but stable for those of shorter tenure (Pon et al., 2003). The Mining Program and the Personal Dust Monitor Partnership are in the final stages of field evaluation of the personal dust monitor. There is general agreement among mine management, labor organizations, and MSHA that the personal dust monitor has great potential to assist the determination of control and evasive measures necessary to guard against high exposures in the workplace.
- **Hearing loss prevention.** Noise-induced hearing loss prevention is a recently renewed research area for the Mining Program. Surveillance projects are well directed toward relating exposures to noise sources, but impact data are unlikely to be available for many years. NIOSH has developed a mobile hearing loss detection lab that can be transported to any worksite to conduct hearing clinics for up to four persons at a time. Trained technical personnel administer hearing loss tests and provide feedback on results. This mobile lab has the instrumentation to perform a wide range of research tasks, and from all indications, it has been used extensively for educating miners on avoiding noise-induced hearing loss in the workplace.

- **Ground failure prevention.** The Mining Program has worked with operators and manufacturers to develop and test more than 40 new roof support technologies between 2000 and 2005. Computer software developed by the Mining Program to analyze pillar stability is now an industry standard and is used by MSHA and state regulatory agencies to evaluate mine permits resulting in safer longwall operations. Other projects such as roof surface controls are likely to produce safety benefits, but end outcomes have not yet been well documented.
- **Cumulative musculoskeletal disorder prevention.** The Mining Program has worked with the International Union of Operating Engineers to collect data on ergonomic-related factors for use in research on improved ergonomic design of mobile equipment. No data exist to document impact on worker health and safety, but several outputs, such as a low-height shuttle car seat design, a more ergonomically designed truck seat, and improved dragline work stations, have been incorporated in the workplace. The Mining Program has also developed a partnership with an operating surface coal mine to reduce work-related musculoskeletal disorders. The program provided guidance, direction, and training on customizing and implementing a sound ergonomic process. Outputs with value to stakeholders have been generated.

It is often impossible to statistically document changes in behavior, or improvements in health and safety, resulting from Mining Program activities. Presentations to the committee, particularly from labor representatives, MSHA, and mining companies, revealed that the results from Mining Program outputs are being evaluated, accepted, and incorporated into operations. Training products are being used in the industry, and the Mining Program is engaged in technology transfer activities.

The committee concludes that Mining Program research focuses on high-priority areas and is adequately connected to improvements in the workplace. The program is moderately involved in transfer activities. Contributions to improvements in health and safety in the workplace are considered major in some areas (respirable disease control, traumatic injury prevention), moderate in some areas (hearing loss prevention, rock safety engineering), and likely in a number of areas. Mining Program outputs are accepted and incorporated into stakeholder operations. Mining Program research and training programs are vital to continued improvements to health and safety in the workplace.

TARGETING OF NEW RESEARCH

To address the second part of its charge, the committee assessed the Mining Program's progress in targeting new research to areas most relevant to future improvements in workplace protection by considering two factors: (1) the relevance of current research and (2) the targeting of new research to areas most relevant for future needs.

To a large extent, the Mining Program is doing research that is relevant to the present and future of the mining industry. Relevant and productive research depends on funding and other external factors, as well as on available expertise and facilities. Short- and longer-term needs should be considered when allocating resources to address current and emerging issues. Flexibility to respond rapidly to needs dictated by current events should be built into the Mining Program, along with greater ability to pursue paradigm-changing research. Notwithstanding, the program has included new research areas in its portfolio. New research in areas such as chemical hazards and improved communications and training, and expanded research in areas such as noise prevention, surveillance, and repetitive injury prevention, show that the Mining Program is, in a limited manner, addressing the needs of the future.

EMERGING ISSUES

To address the third part of its charge, the committee considered emerging issues that may affect future mine worker health and safety. **The Mining Program should stay aware of pertinent current and emerging research, including research being done internationally, and be prepared to act on potential health and safety issues.** Future workforce issues may differ from today's, especially as older workers retire and a new workforce enters the industry. Issues of small-mine workers and the issues associated with increasing numbers of contract workers should also be considered. Continuing to work with industry, organized labor, MSHA, academia, and international partners will help the Mining Program determine future needs. Both internal and external peer review could be useful for selecting projects.

The committee identifies workforce capacity and related issues as the most crucial of emerging issues the Mining Program should deal with, but the committee also considered the physical conditions to which the future mining workforce will be subject. Similar concerns were raised more than 30 years ago during a major revision of the research mission of the U.S. Bureau of Mines (Theodore Barry & Associates, 1972), but it should be noted that operation size, numbers of miners, and technologies in use are quite different today than in the past.

Changes in the industry will result in a number of changes in the physical environment for the mine worker. As the mining industry becomes more automated**, the Mining Program should be prepared to deal with issues associated with increased remote control and automated equipment and systems.** Future mining is likely to be carried out under more difficult conditions and depths in excess of 600 m. Automation is often seen as a means of reducing exposure, but unforeseen consequences of automation should be identified. **The Mining Program should be prepared to provide recommendations to safeguard health and safety as best strategies for mining deep resources are developed.** Environmental and occupational hazards of deeper mines should be evaluated. Similarly, **the health effects of mixed exposures, such as diesel exhaust, hydrocarbons, and noise, as well as the combined effects of mixed noise (continuous and impulse-impact) environments, need to be addressed.** There is also the potential for an increase in radon-related illnesses given a resumption of uranium mining. **As the United States increases its reliance on nuclear energy, the extent and effects of radon and radiation exposure in the presence of these other potential chemical agents should also be considered.**

Other emerging areas of concern include nanoparticles in mine atmospheres, the toxic effects of heat and noise, more physically taxing working conditions (fatigue and increased musculoskeletal disorders), extended shifts, escape and survival equipment, changing communication technology requirements, and the effects of new regulations. The committee is also very concerned about the future performance of the Mining Program itself. **The Mining Program should seriously attend to workforce replacement issues expected within its own organization in the short term to ensure a supply of capable researchers as its older researchers retire.**

The mining industry has long been dealing with problems arising from gas, dust, heat, humidity, ground pressures, machinery, and electricity. There is a need for research that cuts across these issues. For example, as underground coal mine production increases, technologies need to be developed to limit emissions of methane and dust as well as to safely support larger roof spans. Health and safety problems should be approached in a systems framework that encompasses advances in monitoring and characterization technology and a greater understanding of cause-and-effect relationships.

FINAL REMARKS

The committee's review has revealed several areas in which the Mining Program would benefit from self-examination and redirection. Recommendations are given throughout the report, and those that are applicable program-wide are synthesized in Chapter 7, and summarized in Box S-2. The Mining Program makes essential contributions to the enhancement of health and safety in the mining industry. It should take the lead in providing knowledge and expertise in discussions on improving mine health and safety. The ability of the Mining Program to expand its research in ways recommended in this report, however, is critically dependent on the availability of funding.

BOX S-2 Overarching Recommendations

Below are a number of overarching committee recommendations. Recommendations are made throughout the report, and those applicable program-wide are synthesized in Chapter 7. Other recommendations related to specific Mining Program research areas are found in Part II (Chapters 8-14) of this report.

Strategic Goals and Project Selection

Establish more challenging, innovative goals and attendant objectives.
Take a more proactive approach to identifying and controlling hazards.

Interaction Effectiveness

Increase interaction with other NIOSH programs.
Enhance interaction with the Mine Safety and Health Administration (MSHA) where research needs are closely aligned with MSHA's legislative and shorter-term priorities.
Fully utilize outside technical expertise through a vibrant extramural and contract research program.
Partner more broadly such that guidelines and processes are most relevant to the entire mining community.

Outputs

Place greater emphasis on outputs preferred by mining operators, miners, and other nontechnical users.

Surveillance and Monitoring

Make better use of MSHA and other existing surveillance data and work to make these surveillance programs more robust.
Develop more robust and better methods of monitoring in situ safety conditions in mines.

Technology Transfer and Training Programs

Develop a more proactive, aggressive, and strategic dissemination agenda that is informed by research about the diffusion of new technologies, processes, and practices.
Determine the likely end users of Mining Program products.
Develop demonstration projects that show the feasibility and effectiveness of interventions.
Include how small business worker populations will be served.
Incorporate training into the strategic goals of all research areas.

continued

BOX S-2 Continued

Emerging Issues

Stay aware of pertinent current and emerging research, including international research, and be prepared to act on potential health and safety issues.

Be prepared to deal with issues associated with increased remote control and automated equipment and systems.

Be prepared to provide recommendations to safeguard health and safety as best strategies for mining deep resources are developed.

Address the health effects of mixed exposures, such as diesel exhaust, hydrocarbons, and noise, as well as the combined effects of mixed noise (continuous and impulse-impact) environments.

Consider the extent and effects of radon and radiation exposure in the presence of other potential chemical agents as the United States increases its reliance on nuclear energy.

The Mining Program should seriously attend to workforce replacement issues expected within its own organization in the short term to ensure a supply of capable researchers as its older researchers retire.

1

Introduction

The National Academies was asked by the National Institute for Occupational Safety and Health (NIOSH) to conduct a review of up to 15 of its research programs. The Mining Safety and Health Research Program is one of the first to be reviewed under this arrangement. The Committee to Review the NIOSH Mining Safety and Health Research Program was constituted to review the program (hereafter referred to as the Mining Program) with respect to its impact, relevance, and future directions. In particular, the committee addressed the following:

1. Progress in reducing workplace illness and injuries through occupational safety and health research by analyzing relevant data about workplace illness and injury and evaluating the effect that Mining Program research has had in reducing illness and injuries;
2. Progress in targeting new research to the areas of occupational safety and health most relevant to future improvements in workplace protection; and
3. Significant emerging research areas that appear especially important in terms of their relevance to the NIOSH mission.

The committee used the assessment framework developed by the National Research Council-Institute of Medicine Committee to Review the NIOSH Research Programs (hereafter referred to as the Framework Committee). For cases in which impact is difficult to measure, the committee measured performance using existing intermediate outcomes (e.g., changes in stakeholder behavior) to estimate impact.

The committee considered not only what the Mining Program is producing but also whether NIOSH research can reasonably be credited with changes in workplace practices or whether such changes are the result of factors unrelated to NIOSH. At the request of NIOSH, the performance of externally funded research and training programs was not evaluated. This report presents the results of the committee's review. Committee recommendations are made to facilitate the Mining Program's ability to conduct the most relevant research, resulting in the greatest positive workplace impact.

FRAMEWORK COMMITTEE EVALUATION GUIDELINES

The Framework Committee developed guidelines for the evaluation of NIOSH research programs. The resulting Framework Document (Appendix A) is a working document subject to revisions on the basis of input from the various evaluation committees and input from the interested public. The Framework Committee developed a flow chart (Figure 1-1) to guide the evaluation committees. The Framework Document provides the rationale to be used by the evaluation committees in determining final scores for impact and relevance. A final report outline was also suggested. This committee closely followed the suggested guidelines.

INFORMATION GATHERING

To conduct its evaluation, the committee reviewed a substantial amount of material submitted by the Mining Program in the form of the Mining Program Briefing Book (NIOSH, 2005a). This book contains more than 900 descriptive pages of Mining Program goals, activities, and impacts. NIOSH and the Mining Program made 17 presentations to the committee during open session meetings, and the committee interacted with more than 40 Mining Program employees during site visits. The Mining Program also responded to additional written requests for information from the committee. Appendix B lists written and electronic materials received from NIOSH during the course of this review.

In addition to information from the Mining Program, the committee heard nine stakeholder presentations during an open session meeting, including from the acting director of the Mine Safety and Health Administration (MSHA), labor union representatives, equipment manufacturers, and training consultants. Additional input was received in written response to a broad call for input sent to stakeholders identified by the Mining Program, as well as to professional organizations, state regulatory entities and associations, and other individuals recommended by committee members.

Summary statements in this report are based on the synthesis of this informa-

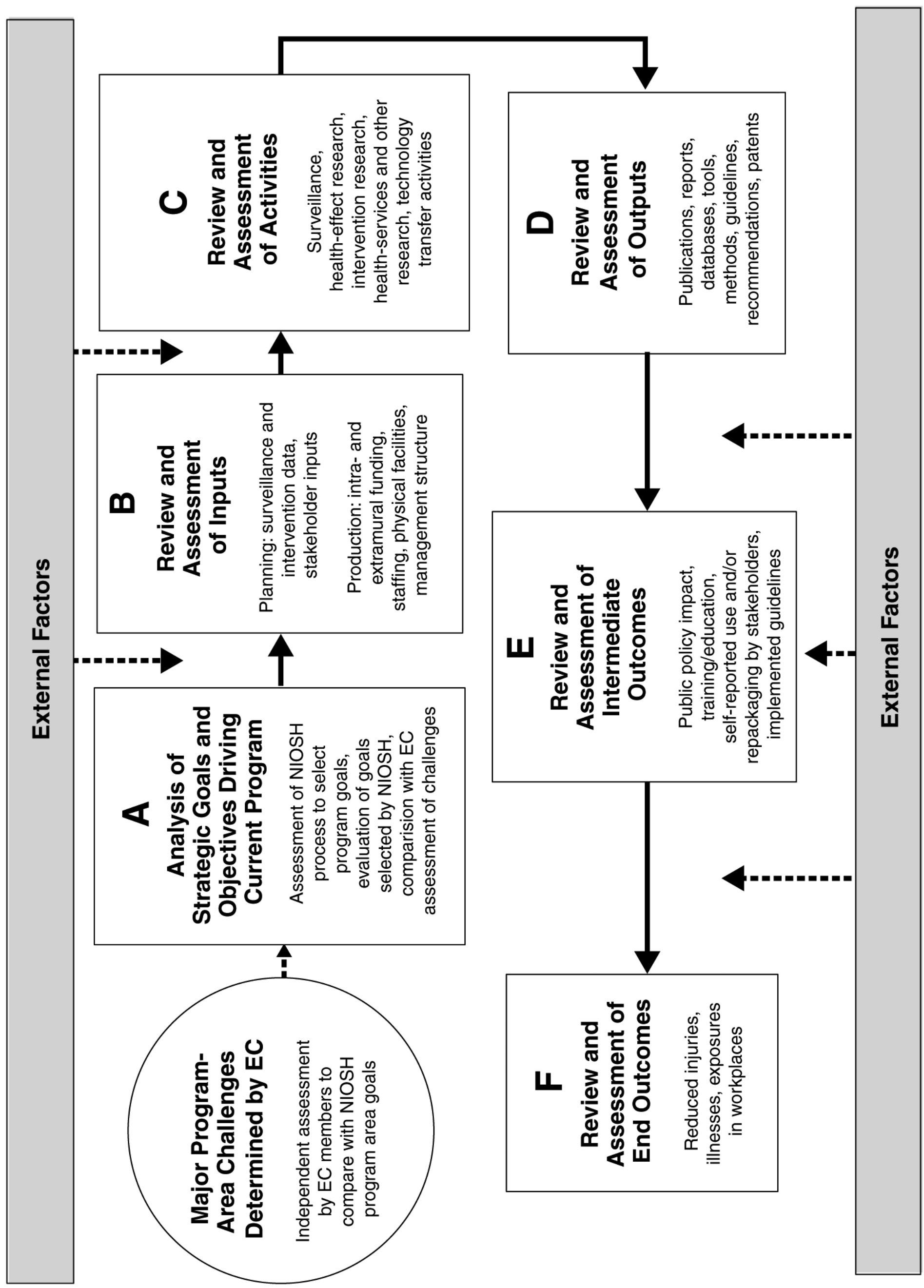

FIGURE 1-1 Flow chart for evaluation of NIOSH research programs. NOTE: EC = evaluation committee.

tion, previously published reports, and the combined expertise of the committee members.

REPORT ORGANIZATION

The Mining Program makes an essential contribution to the mining industry. The critique and recommendations in this report are derived from the need for more of the kind of research it does. The report is relevant to MSHA, policy makers, industry, engineers, scientists, miners and their representatives, and anyone concerned with the health and safety of miners and the economic well-being of the mining industry.

The report is divided into two parts. Part I (Chapters 2 through 7) reviews the Mining Program as a whole. An overview of the Mining Program, with major subheadings parallel to the flow diagram of Figure 1-1, is provided in Chapter 2. Factors that affect the relevance of program research are discussed. The committee presents its assessment of the "ideal" mining program for comparison to the NIOSH Mining Program in Chapter 3. Chapter 4 specifically addresses charge 1 and provides an assessment of relevance and impact. Chapters 5 and 6, respectively, provide the committee's assessment of program progress in targeting new ideas (charge 2) and identifies emerging health and safety issues in the mining industry (charge 3). The committee synthesizes recommendations made throughout the report that are pertinent program-wide to the Mining Program and includes them in Chapter 7.

Part II (Chapters 8-14) provides detailed assessments of each of the Mining Program's seven strategic research areas. The chapters are each organized to parallel the flow diagram in Figure 1-1. Recommendations specific to each program area are provided in Part II.

THE U.S. MINING INDUSTRY

Mining can be divided into two categories, underground and surface, and further classified based on the commodity mined—coal or metallic-nonmetallic. The United States is the second-largest producer of coal in the world, with an annual output of approximately 1.1 billion tons (Energy Information Administration, 2006). Surface mining accounts for approximately two-thirds of the production of U.S. coal. More than 97 percent of metallic and nonmetallic mining is done in surface mines.

The U.S. mining sector employs approximately 331,000 people. Table 1-1 shows the breakdown of the mining workforce by commodity, and includes contractors to show the prevalence of that population in the mining sector. Figure 1-2 shows

TABLE 1-1 Distribution of Mining Workforce by Commodity and Number of Contractors Employed in 2005

Mining Commodity	No. Employed
Coal	81,891
Sand and gravel	45,240
Stone	81,005
Nonmetallic minerals	23,039
Metallic minerals	30,395
Contractors	72,269
Total	333,839

SOURCES: NMA, 2006; contractor data from MSHA, 2005.

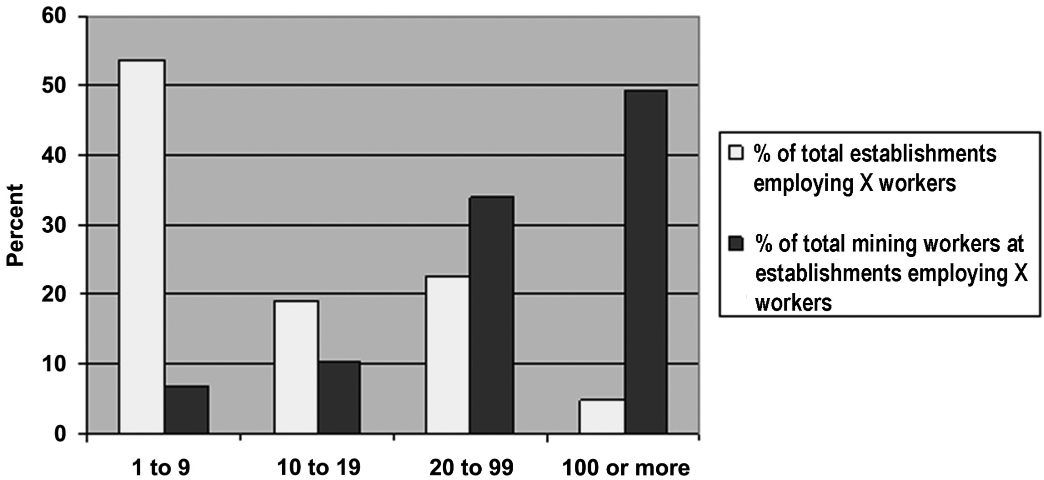

FIGURE 1-2 Chart showing distribution of U.S. mining establishments by worker population, and distribution of mining workforce by size of mining establishment as of March 2004. SOURCE: BLS, 2005a.

the percentage of mining operations employing certain numbers of workers, and the percentage of the total mining workforce employed at mines of certain sizes, as of March 2004. Nearly three-fourths of mining establishments employ fewer than 20 workers. Table 1-2, based on MSHA data,[1] compares the number of mines

[1]See *http://www.msha.gov/stats/PART50/wq/2005/table7.pdf* [accessed March 22, 2007].

TABLE 1-2 Number of Mines by Commodity and Employment, 1996 and 2005

Employment	Coal		Metal		Nonmetal		Stone		Sand and Gravel		Total		% of Total	
Range	1996	2005	1996	2005	1996	2005	1996	2005	1996	2005	1996	2005	1996	2005
1-19	1,633	1,152	188	148	521	514	2,771	3,563	5,773	6,803	10,886	12,180	81	83
20-49	639	535	54	24	131	115	619	635	200	223	1,643	1,532	12	11
50-99	208	199	51	18	65	50	144	158	17	19	485	444	4	3
100-249	118	100	48	36	37	32	102	98	0	0	305	266	2	2
250+	63	56	36	33	20	11	3	2	0	0	122	102	1	1
Total	2,661	2,042	377	259	774	722	3,639	4,456	5,990	7,045	13,441	14,524	100	100
% of total	20	14	3	2	6	5	27	31	44	48	100	100		

SOURCE: Phillip H. Nicks, MSHA, personal communication to Raja Ramani, June 2, 2006.

by commodity and employment for the years 1996 and 2005. Approximately 94 percent of all mines employ fewer than 50 people.

HISTORICAL PERSPECTIVES

Mining Safety and Health

Mining has historically been regarded as a dangerous industry due to the unenviable record of frequent disasters and accidents in its early years. Though mining has one of the highest fatality rates of any U.S. industry (BLS, 2006), it is important to recognize the great improvements in mining technology, equipment, processes and procedures, and workforce education and training that have resulted in greater safety. Major decreases in mine fatalities, fatality rates, and incidence of non-fatal days lost are evident when comparing past and present statistics. Figure 1-3 shows the dramatic decrease in the incidence of fatalities in the mining sector from 1910 through 2004. Fatalities, injuries, and disasters, although less frequent, continue to occur in the industry.

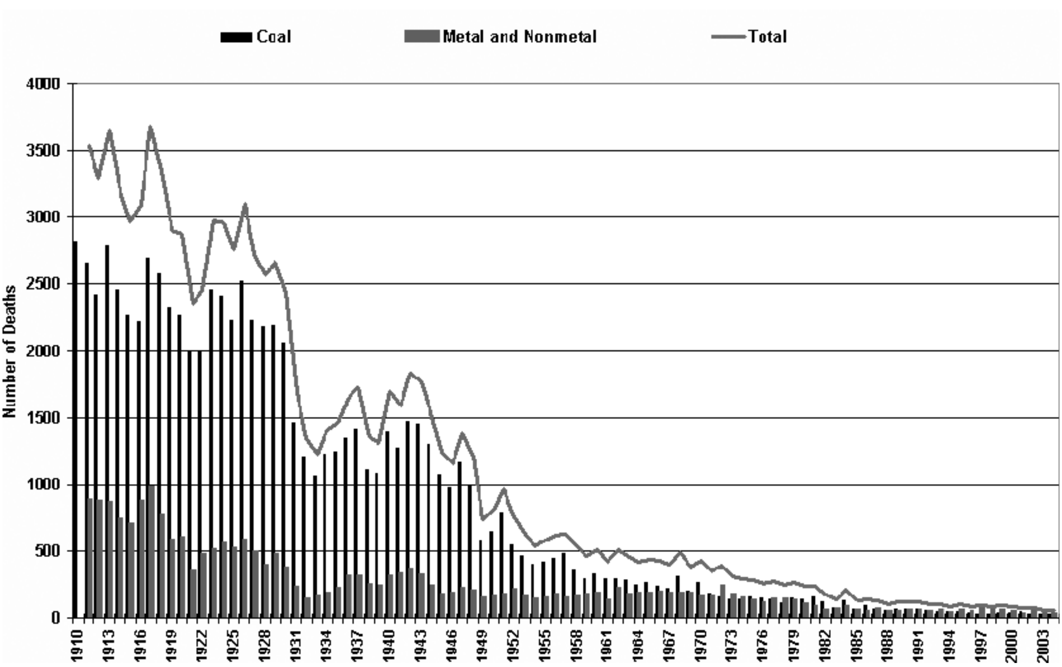

FIGURE 1-3 Mining deaths in the United States, 1910-2004. SOURCE: http://www.msha.gov/stats/charts/chartshome.htm [accessed July 19, 2007].

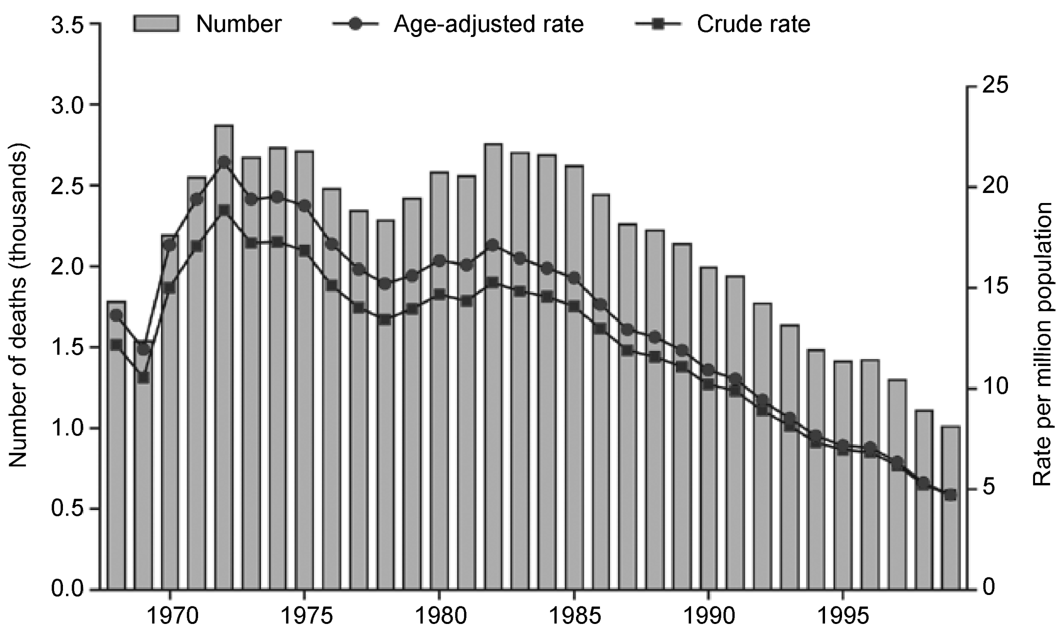

FIGURE 1-4 Numbers of deaths, crude mortality rates, and age-adjusted mortality rates for U.S. residents aged 15 or older, with coal worker's pneumoconiosis recorded as an underlying or contributing cause on the death certificate, 1968-1999. SOURCES: NCHS, 2002; NIOSH, 2002. Available online at *http://www2.cdc.gov/niosh-Chartbook/imagedetail.asp?imgid=322* [accessed October 5, 2006].

Health concerns are also a major issue in the mining industry. Health hazards posed by gases, dusts, chemicals, noise, extreme temperatures, and other physical conditions have been apparent to miners and the industry for a long time, resulting in numerous chronic and sometimes fatal illnesses. Considerable progress has been made in hazard control through improved mine engineering and operation by developing better indices of exposure, by better control of working conditions, and by exposure reduction (i.e., removing the hazard from the worker or the worker from the hazard). Figure 1-4 shows the mortality rate for the period 1968 to 1999 due to coal worker's pneumoconiosis, a fatal lung disease acquired through exposure to respirable coal mine dust.

Mining Safety and Health Research

The story of mining research in the United States is tied inextricably to the creation of the U.S. Bureau of Mines (USBM) by the Organic Act of 1910. The charge to the USBM was to investigate methods of mining, including specifically

- safety of mines and the appliances best adapted to prevent accidents;
- possible improvement of conditions under which mining operations are carried on;
- treatment of ores and other mineral substances;
- use of explosives and electricity; and
- prevention of accidents.

Over the years, USBM activity increased in many areas due to the passage of enabling and industry-specific health and safety legislation. Health and safety research was conducted by the USBM from its inception. From 1941 through 1966 the USBM, within the Department of the Interior, had programs for health and safety inspection, research, and education and training. The inspection program had the authority to enforce regulations in coal mines related to fires, explosions, travel, and inundations. In 1966 the USBM gained similar authority over metal and nonmetal mines. In 1969 the USBM combined its health and safety and mining research programs. In 1973, health and safety enforcement authority was transferred from the USBM to the newly created Mine Enforcement and Safety Administration (MESA) within the Department of the Interior, and reorganized again in 1977 as the Mine Safety and Health Administration (MSHA) in the Department of Labor, where it remains today. The contributions of the USBM to mining, materials processing, metal beneficiation, waste treatment and handling, and mineral statistics, among other areas, is a testimony to its diverse functions.

Complementary to work at the USBM, mining-related health research began in the 1930s within the Division of Industrial Hygiene of the U.S. Public Health Service. A series of epidemiologic studies was started to determine the pathologic effects of various types of dust, including silica, nonsiliceous, and coal dust. These resulted in the development and application of engineering and medical controls at the workplace (Doyle, 1979; Weeks, 1993). In 1969, the Federal Coal Mine Health Act identified an important role for the Secretary of Health, Education and Welfare (now the Department of Health and Human Services, DHHS) in the development and promulgation of health and safety standards and the conduct of studies, research, experiments, and demonstrations on various mine health topics. These provisions remained essentially unchanged until the Federal Mine Safety and Health Act of 1977 was enacted. Meanwhile, the Occupational Safety and Health Act of 1970 created the Occupational Safety and Health Administration (OSHA), within the Department of Labor, and the National Institute for Occupational Safety and Health in DHHS.

The USBM was closed in 1995 by congressional order. The health and safety research programs of the USBM were transferred to the Department of Energy on an interim basis in 1995 and permanently to NIOSH in the Centers for Disease

Control and Prevention (CDC) in 1997. The USBM's work in mining productivity improvement, also responsible for the saving of many lives, was discontinued.

Since becoming part of the CDC, the Mining Program has continued to build on the USBM's excellent foundation for improving mine health and safety. The contributions of the USBM to improved safety in mines are unquestioned in a number of areas including fire and explosion control, ventilation practices, rock dusting, explosives, methane control, airborne dust control, and miner training (NRC, 1990). Consistent with the vision and mission of NIOSH, the Mining Program now works to improve safety and health at mining sites through research and prevention and to eliminate occupational diseases, injuries, and fatalities from mining.

Since 2000, the Mining Program began transitioning into what it describes as a "program-based" approach (NIOSH, 2005a). The Mining Program currently conducts research in seven strategic priorities to direct its research activities and resources: (1) respiratory disease prevention; (2) noise-induced hearing loss prevention; (3) cumulative musculoskeletal injury prevention; (4) traumatic injury prevention; (5) mine disaster prevention and control; (6) ground failure prevention; and (7) potential adverse outcomes from changing conditions in the industry.

Part I

Programmatic Evaluation

2

Description of the Mining Program

The marked decrease in disasters, injuries, and illnesses in the mining industry is due to the work of many, including mining companies and their managers, unions and their representatives, equipment suppliers, and engineering service firms, as well as personnel in government and academic institutions. Government agencies and academics provide important input to the plan-do-check-act (or continuous improvement) control cycle. The National Institute for Occupational Safety and Health (NIOSH) Mining Program is the only federal agency doing health and safety research for the mining industry.

This chapter provides a description of the overall Mining Program in the context of the evaluation flow chart (Figure 1-1). The first five major headings (Goal Definition and Project Selection, Inputs, Activities, Technology Transfer, and Outputs) correspond with boxes A-D, respectively, in Figure 1-1, although technology transfer is considered a subset of box C in that figure. The final major heading (Factors Affecting Relevance) addresses specific topics listed in the framework document (Appendix A) that may impact the program's goal selection, impact, or relevance. Much of the information in this chapter was derived while evaluating the Mining Program's seven strategic research areas, detailed in Part II, Chapters 8-14.

GOAL DEFINITION AND PROJECT SELECTION

The Mining Program uses the Centers for Disease Control and Prevention (CDC)-NIOSH "surveillance cycle" method of operation (NIOSH, 2005a). The use of surveillance data, stakeholder input, and risk or loss control requirements to define research priorities and set overall goals is still in a developmental stage. The Mine Safety and Health Administration (MSHA) is the primary collector and disseminator of fatality, injury, accident, and illness data, and the Mining Program consolidates, interprets, and disseminates the data and its own research findings. Based on research results, the Mining Program then makes recommendations to improve health and safety. In general, the maximum time frame for which the Mining Program sets goals is 15 years. Projects generally have lives of only 3 to 5 years, consistent with the time boundaries established for intermediate goals.

MSHA fatality data, such as shown in Table 2-1, influence the Mining Program's research agenda. Between 2000 and 2004, ground failure, powered haulage, machinery, explosions, and electricity accounted for nearly 90 percent of underground fatalities. Powered haulage, machinery, and slip, trip, and fall of miners accounted for more than 75 percent of the fatalities in surface mining. Other MSHA statistics include both non-fatal days-lost (NFDL), and non-fatal no-days-lost (NDL) injuries and illnesses. According to the MSHA 2004 public file, 81 percent of newly reported occupational illnesses arose from repetitive trauma (43 percent), hearing loss (21 percent), and dust-induced lung disease (17 percent) (MSHA, 2004a).

The interests of the mining community, according to the Mining Program, include ground control, training, machinery and electrical safety, ergonomic practices, and blasting health and safety. Stakeholders identify the need to be responsive to impending or newly enacted regulations, and identify dust monitoring and control, noise-induced hearing loss prevention, diesel emissions control, and di-

TABLE 2-1 Causes of Mining Fatalities (2000-2004)

Underground Mining		Surface Mining	
Event	Percentage of Total Fatalities	Event	Percentage of Total Fatalities
Ground failure	28	Powered haulage	37
Powered haulage	21	Machinery	25
Machinery	17	Slip, trip, and fall	14
Explosions	16		
Electrical	10		
Other	8		

SOURCE: NIOSH, 2005a.

saster prevention and response as four areas of greatest need for Mining Program research.

Low-frequency but high-severity events such as explosions deserve special attention in evaluating research needs. As shown in Table 2-1, explosions account for 16 percent of underground mining fatalities, but individual multiple-fatality events draw much attention. Ground failures, on the other hand, account for 28 percent of underground mining fatalities, but with fewer fatalities per event, receive less attention. Research is needed to assess the likelihood of high-severity events and to develop new measures for monitoring and control, given changes in mining conditions, methods, designs, and technologies.

To enable comparison of disparate outcomes and events and aid decision making, the Mining Program uses a decision-making or project-selection hierarchy to rank the importance of specific events. The hierarchy, in descending order of importance, is as follows (NIOSH, 2005a):

1. Incidents with multiple fatalities
2. Permanent disability and/or disfigurement
3. Serious or severe injury with long and/or painful rehabilitation
4. Lost time and wage events
5. Costly injuries not listed in the above categories
6. Potentially dangerous incidents not resulting in injuries
7. Hazards

Using this approach, the Mining Program identifies respiratory disease prevention, hearing loss prevention, repetitive or cumulative musculoskeletal injury prevention, traumatic injury prevention, disaster prevention, and ground failure prevention as the areas of greatest research need (NIOSH, 2005a). The Mining Program also identified surveillance and training as a seventh research area. Strategic and intermediate goals with time-bound quantitative measures have been defined for each of these areas.

Two recent NIOSH-sponsored studies by external groups on emerging mining technologies prioritize technologies requiring research attention (Peterson et al., 2001; NRC, 2002). Some recommendations in these studies address emerging health and safety issues and may influence the Mining Program's goal setting decisions. Recommendations in these studies are discussed in Chapter 5 of this report.

According to the Mining Program (NIOSH, 2005a), project selection begins with an intramural call for concept papers, which are evaluated for how well the needs of the program are met, the likelihood of success, and any potential impact. Proposals are subject to external peer review. Detailed funding proposals, following Department of

Health and Human Services (DHHS) and CDC research grant protocols, are requested from the authors of the most promising papers. Pilot projects may be funded to determine the viability of certain promising concepts.

INPUTS

Funding and Personnel Resources

The most important resource in any organization is its people. People provide the knowledge, skills, and creativity that make a whole greater than the sum of its parts. The committee reviewed human resource and funding allocations to determine how the Mining Program uses public funds.

NIOSH requested a detailed evaluation of the Mining Program budget not be conducted. Funding for mining research at the U.S. Bureau of Mines (USBM) in 1995 was approximately $52 million, which included $10 million for advanced mining system research and $42 million for health and safety research. Funding for health and safety research was approximately $26 million when it was transferred to NIOSH. Mining Program total funding for 2005 was approximately $30.6 million, with discretionary funds amounting to $6.67 million (compared to $25.4 million and $7.52 million, respectively, in 1998). Table 2-2 shows the distribution of Mining Program funding and full-time equivalents (FTEs) for 2005 among its research areas and strategic goals.

Table 2-3 shows the percentage change in funding levels and FTEs in 2005 compared to 1998. The annual increase in funding was only $1.7 million, between 1998 and 2004, limiting the amount of discretionary funds available to the mining program. In 2005, however, there was a $3.6 million increase in funding, allowing the discretionary budget, which had decreased from the initial $7.5 million to $3.4 million in 2004, to increase to $6.6 million.

The four traditional areas of mining health and safety research—respiratory disease prevention, traumatic injury prevention, ground failure prevention engineering, and disaster prevention—account for more than 56 percent of funding, 60 percent of FTEs, and 70 percent of projects. Problems in these four areas are as old as mining itself and have commanded tremendous attention in the past.

The data in Table 2-3 show a major realignment of funding and FTEs between Mining Program research areas. The table indicates an 8 percent decrease in personnel (the equivalent of 23 FTEs) between 1998 and 2005. The decrease in funding and FTEs in the “multiple goals” category may be indicative of the redistribution of resources to other, more specific goals. Decreases in FTEs in disaster prevention (from 56 to 38) and traumatic injury (from 70 to 37) are quite large and may be partially due to attrition.

TABLE 2-2 Distribution of NIOSH Mining Program Funding and FTEs Among the Strategic Goals[a]

							Discretionary Funds	
Strategic Goal	Funding Amount (million dollars)	Percentage of Funding	FTEs	Percentage of FTEs	No. of Projects	Percentage of Projects	Amount (thousand dollars)	Percentage of Funding
Respiratory disease prevention	4.6	15	38	14	14	20	1,117	17
Noise-induced hearing loss prevention	3.1	10	25	10	7	10	855	13
Repetitive or cumulative musculoskeletal injury prevention	2.0	7	20	8	4	6	150	2
Traumatic injury prevention	4.1	13	37	14	11	15	660	10
Mine disaster prevention and control	3.9	12	38	14	14	20	480	7
Ground failure prevention	4.8	16	46	18	11	15	647	10
Surveillance, training, and intervention effectiveness	3.6	12	30	11	10	14	951	14
Multiple goals[b]	4.5	15	28	11	—	—	1,805	27
Total	30.6	100	262	100	71	100	6,665	100

[a]Amounts and percentages have been independently rounded to the nearest numbers as appropriate.

[b]Multiple goals represent funding for projects and facilities that serve more than one strategic goal. For example, the Lake Lynn Laboratory facilities are used by investigators from the disaster prevention, rock safety engineering, and training groups.

SOURCE: Created from data in NIOSH, 2005a.

TABLE 2-3 Changes in Funding and FTEs in 2005 in Relation to 1998 Levels

	Percentage Increase	
Strategic Goal	Funding	FTEs
Respiratory diseases	83	27
Hearing loss	186	178
Cumulative musculoskeletal disorders	67	25
Traumatic injuries	–21	–47
Disaster prevention	–8	–32
Rock safety engineering	29	–4
Surveillance and training	131	50
Multiple goals	–24	–22
Total	20	–8

SOURCE: Data from NIOSH, 2005a.

Loss of experienced personnel in the near future may create major voids in some research areas. There has been a critical shortage of mining safety and health research professionals for more than a decade (Watzman, 2004), particularly in specialized areas such as explosions, fires, and rescue and recovery research. The committee is concerned the knowledge and experience needed to conduct high-quality disaster prevention research may be compromised without timely hiring and training of new personnel.

Increased funding for respiratory disease prevention research is appropriate in view of emerging issues associated with diesel particulate matter in coal, metal, and nonmetal mines and activities associated with use of the personal dust monitor (discussed in Chapter 8). The growing recognition of issues associated with noise-induced hearing loss, work-related musculoskeletal disorders, and a need for increased surveillance and documentation of hazards in mining results in increased demand for research in these areas (discussed further in Chapters 9, 10, and 14, respectively). There is also a demand for dissemination and training research as mining technologies change, workers are faced with more or different hazards, and the aging workforce is being replaced with inexperienced miners.

Facilities

Committee members visited Mining Program facilities at the Pittsburgh Research Laboratory (PRL), the Lake Lynn Laboratory (LLL), the Spokane Research Laboratory (SRL), and the Missile Test Site (MTS). The committee was given an overview of important research facilities and equipment, and brief descriptions of research projects. This review encompasses only the most important laboratories and equipment observed by the committee.

PRL is a large research complex that has been in place since the founding of the USBM. It has large-scale equipment and specialized laboratory facilities for research, development, and testing purposes, as well as an experimental mine and a safety research coal mine. Among the notable safety research facilities at PRL are the mine roof simulator, the servo-controlled MTS Systems Corporation load frame, the human performance research mine, and motion analysis capture system.

LLL consists of an old surface quarry and underground limestone mine leased by the USBM in 1982. There are extensive facilities for conducting major explosion, fire, ventilation control, emergency escape, and training procedures research. Other research involving practices and full-scale equipment can also be performed. NIOSH is exploring the feasibility of purchasing this facility. The continued and permanent availability of the LLL facility should be pursued.

SRL has been in place since 1951 when the USBM moved its Northwest Region's Mining Division to Spokane. Being close to the deep hard rock mines in the Northwest, SRL's focus had been on ground control problems in those mines, but now encompasses a broader range of mining health and safety topics. Among the notable facilities at SRL are the seismic laboratory, the soil-rock properties laboratory, and the human factors engineering laboratory.

The MTS facility, located about 20 miles west of Spokane, originally a U.S. Department of Defense missile launch location, is a well-secured complex with underground and surface buildings surrounded by adequate space to accommodate large equipment and large-scale mining research. The dynamic materials testing laboratory with a split Hopkinson pressure bar for measuring dynamic strengths in close proximity to explosive forces is located at this site.

The health laboratory facilities at both PRL and LLL are excellent and world class. The Mining Program has excellent facilities for research on noise-induced hearing loss prevention. The equipment and physical infrastructure for acoustics research are excellent. Most notable are the National Voluntary Laboratory Accreditation Program (NVLAP) accredited, 1,300-m^3 reverberation chamber and a new 1,300-m^3 hemi-anechoic facility, both of which are large enough to test full-size underground mining equipment. Facilities for continuous miner and longwall dust control studies and dust and diesel exhaust measurement instrumentation are recognized as among the best in the world by the committee, universities, and industry, based on the uniqueness of the facility and the fact that the facility is used by researchers from the United States and abroad. An industrial hygiene laboratory at SRL contains varied equipment needed for industrial hygiene field investigations and projects. The chemistry laboratory at SRL contains an inductively coupled plasma (ICP) spectrometer.

The Mining Program also owns large mining equipment (continuous miner, roof bolter, and conveyor sections) to perform laboratory-scale research. Facility improvements and acquisition of high-quality testing equipment have increased its research capacity. Tests can now be conducted under better-controlled conditions. Given that discretionary funding is approximately 20 percent (Table 2-3), the Mining Program has made great progress with available resources.

It is worth noting that some Mining Program contributions to safe equipment design, mine design practices and procedures, operational guidelines, and measuring instruments would not have resulted without its access to unique research facilities. With respect to safety research, ground failure prevention research facilities at PRL, particularly the Mine Roof Simulator, are regarded as having contributed to a better understanding of the interaction of mine roof and supports and to the development of more effective roof support design. The facilities at LLL are used by external investigators from the United States and abroad. The ability to conduct full-scale tests to study the initiation, propagation, and control of explosions and fires is unique. The facilities for ergonomic and human factors engineering research at both PRL and SRL are unique and provide state-of-the-art, real-time monitoring and analysis systems for greater safety at the workplace. The seismic and dynamic testing laboratories at SRL and MTS are also unique facilities for studying ground control problems arising from improper understanding and application of explosive forces.

The Mining Program conducts research for several projects in cooperation with mining companies and equipment manufacturers using the mines of participating companies as laboratory facilities. The ability to do mine-scale research is particularly advantageous, and research results are transferred quickly to participating mines. Another advantage of this arrangement is the research infrastructure for future on-site research is in place.

The combination of traditional laboratory equipment, large-scale permanent facilities, and ready access to working mines is regarded by the committee as a particular strength of the Mining Program, allowing the program to conduct research at all scales under realistic conditions. With the rapid advancements in the technology of automated data acquisition and processing, it is a challenge to keep laboratory facilities modern and maintained. The committee recognizes the limited discretionary funds available to the Mining Program. Unless adequate funds are set aside for maintenance and upkeep of the Mining Program's unique facilities, deterioration could impede NIOSH research capability.

Stakeholders and Stakeholder Input to the Committee

Stakeholders are a major source of external review and input into the Mining Program process. The Mining Program has partnerships and links with several international mining research and development institutions, university researchers, professional and industry organizations, unions, and state and other federal agencies. To get viewpoints from as broad a range of stakeholders as possible, a letter requesting input regarding Mining Program relevance and impact was sent to stakeholders identified by NIOSH, as well as to professional organizations, state regulatory entities and associations, pertinent members of the National Academy of Engineering and to individuals identified by committee members. Responses could be phoned in to National Academies staff or sent to the committee by mail, e-mail, fax, or the committee's anonymous online comment form accessible via the National Academies and NIOSH web sites. The committee requested NIOSH provide information regarding the link to NIOSH employees. The committee heard from representatives of mining companies, labor, equipment manufacturers, individuals who provide training services, and federal and state government agencies having jurisdiction over some aspect of health and safety in the mining industry.

The Mining Program and MSHA

The 1977 Federal Mine Safety and Health Act created the Mine Safety and Health Administration in the Department of Labor to carry out the enforcement, rulemaking, training, and technical assistance functions of the act. MSHA is a major NIOSH stakeholder and supports Mining Program objectives.

With regard to NIOSH and MSHA, the 1977 act specifically states (Federal Mine Safety and Health Act of 1977, P.L. 91-173, as amended by P.L. 95-164, Title I, Section 101(a)(1)):

> When the Secretary [of Labor] receives a recommendation, accompanied by appropriate criteria, from the National Institute for Occupational Safety and Health that a rule be promulgated, modified, or revoked, the Secretary must, within 60 days after receipt thereof, refer such recommendation to an advisory committee. . . , or publish such as a proposed rule. . . , or publish in the Federal Register his determination not to do so, and his reasons therefor.

Although the Mining Program and MSHA serve different roles within their respective organizations, their objectives are the same: to eliminate workplace threats to miner health and safety. External factors affect both MSHA and NIOSH, including the political environment, mining technologies and conditions, and major mine incidents or disasters. The intent of relevant statutes seems to be that NIOSH play a significant role in researching solutions to health and safety problems and MSHA take timely action on recommendations from NIOSH. MSHA serves a vital role in the transfer of Mining Program outputs to the mining industry.

Through its enforcement process, MSHA generates a comprehensive database of mine-specific data that inform the mining community of problems on all scales.

This database is a unique asset to both MSHA and NIOSH. Similar data are not widely available for other industries. It is apparent from a review of the developments in several research areas that the Mining Program and MSHA are working together—often in a partnership with industry, labor, and manufacturers—to find realistic solutions to complex problems. MSHA and the Mining Program work together to define the problems and approaches revealed in the analysis of mining emergencies. According to MSHA, however, the National Occupational Research Agenda (NORA) approach, while beneficial for driving health and safety improvements, may not be responsive to MSHA's research priorities from a regulatory perspective or to its more immediate requirements.

The Mining Program and MSHRAC

The Federal Coal Mine Health and Safety Act of 1969 (P.L. 91-173) required the appointment of a mine safety advisory committee by the Secretary of the Interior and a mining health advisory committee by the Secretary of Health, Education and Welfare. The advisory committees would provide the agencies with an evaluation of research agendas and accomplishments and future directions. The advisory committee to the Secretary of Health and Human Services was the Mine Health Research Advisory Committee (MHRAC), made up of representatives from government, labor, industry, and academia. MHRAC was housed in NIOSH and held meetings with stakeholders annually.

With closure of the U.S. Bureau of Mines in 1995 and permanent transfer of mine health and safety research to NIOSH in 1997, MHRAC evolved into the Mine Safety and Health Research Advisory Committee (MSHRAC) with following purposes (NIOSH, 2006a):

> The Mine Safety and Health Research Advisory Committee shall advise the Secretary, HHS; the Director, Centers for Disease Control and Prevention (CDC); and the Director, National Institute for Occupational Safety and Health (NIOSH), CDC, on the conduct of mine health research, including the making of grants and entering into contracts for such research, 30 U.S.C. 812(b)(2), Section 102(b)(2). The Committee shall also advise on the conduct of mine safety research. The Committee shall evaluate the degree to which: 1) the mine research activities of the National Institute for Occupational Safety and Health conform to those standards of scientific excellence appropriate to Federal scientific instructions in accomplishing objectives in mine safety and health; 2) the mine research activities, alone or in conjunction with other known activities inside and outside of NIOSH, address currently relevant needs in the field of mine safety and health; and 3) the research activities produce intended results in addressing important research questions in mine safety and health, both in terms of applicability of the research findings and translation of the findings.

Based on a committee review of minutes from the last several MSHRAC meetings, and the fact that MSHRAC has not met for 2 years (as of May 2006), it is apparent that its great potential has not been fully utilized. MSHRAC's role appears to be largely informational rather than advisory. The committee believes MSHRAC could provide useful feedback to the Mining Program on all aspects of the research program, including evaluation of its relevance and impact, establishing objectives, identifying emerging targets for research, and effective application of research resources.

Intra-NIOSH Interactions

The Mining Program interacts with some NIOSH cross-sector (hearing loss, respiratory disease) and sector (construction) research programs. These are natural allies. The appointment of a single manager for both the Mining and the Construction Programs was described during a presentation by the director of NIOSH as a starting point for improving intra-agency interaction, although it was also pointed out that the programs remain separate and distinct.

The Mining Program would benefit from increased interaction with other NIOSH programs including those within the Division of Respiratory Disease Studies, the Division of Safety Research, and the Division of Surveillance, Hazard Evaluations, and Field Studies. Based on written responses to direct committee questions (NIOSH, 2006b), there is "little" or "no" interaction between the Mining Program and 8 of the other 22 NIOSH research programs, "moderate" interaction with 5 programs, and "strong" interaction with the 9 remaining programs. The nature of the interactions was not made clear. For example, there have been NIOSH-recommended exposure limits for at least four hazards with direct relevance to mining (respirable coal mine dust, silica, noise, and nitrogen dioxide), but it is unclear how the Mining Program interacts with programs developing the recommendations. The potential for interaction has been enhanced with the 2006 reorganization of the NIOSH program portfolio into NORA sector and cross-sector programs.[1] Similar research is now grouped into a sector- or cross-sector based program with discrete strategic goals understood agency wide.

Because researchers should be fully occupied with their own research and development activities, management needs to be responsible for identifying where interactions would be beneficial.

[1]See *http://www.cdc.gov/niosh/NORA/default.html* for the rationale behind the switch to this organizational system.

Surveillance Inputs

NIOSH (*http://www.cdc.gov/niosh/topics/surveillance/default.html*) defines surveillance as

> the systematic, ongoing collection and or acquisition of information on occupational diseases, injuries and hazards; analysis and interpretation of surveillance data; dissemination of data or information derived from surveillance to appropriate audiences for prevention and control; and development of surveillance methodology.

The committee considers surveillance a major activity of any health and safety program. It is not limited to disease observation, but includes all manner of data and information gathering pertinent to achieving the program strategic goals. Surveillance data acquisition, analysis, interpretation, and dissemination of results are all important for an effective program.

The Mining Program uses data collected by MSHA (per 30 CFR Part 50) extensively. All mining-related accidents are reported to the MSHA district manager who decides if an investigation is warranted. In the case of accidents involving fatalities and injuries, or incidents involving, for example, ignitions, fires, or inundations, MSHA conducts an investigation and issues a report. Because of the availability of these data, the NIOSH Fatality Assessment and Control Evaluation (FACE) program does not investigate fatalities in mining. The Mining Program does not conduct its own sentinel event[2] field investigation activities; instead, it relies entirely on MSHA reports on fires and explosions to identify potential issues. The Mining Program also obtains data through the Bureau of Labor Statistics (BLS). The program has access to the Census of Fatal Occupational Injuries database and the Survey of Occupational Injuries and Illnesses. Data from these sources are useful for comparative studies of mining and non-mining occupations.

Other NIOSH programs provide surveillance data to the Mining Program, for example, surveillance data on coal worker's pneumoconiosis (CWP) collected by the NIOSH Division of Respiratory Disease Studies (DRDS) under the 1977 Mine Health and Safety Act. In the course of conducting specific research, Mining Program investigators have collected their own limited surveillance data on dust, diesel particulate matter, and noise exposure, and on musculoskeletal disorders. These data serve several functions, including validating research hypotheses and measuring the effectiveness of control actions. Because the data is collected to meet specific research needs, their use is limited in a broader context.

NIOSH also conducts surveillance through its Health Hazard Evaluation (HHE) program. An HHE is a workplace study conducted on the basis of a specific request

[2]A sentinel event is an unexpected, or risk of an unexpected, death or serious physical or psychological injury.

to assess potential worker exposure to hazardous materials or conditions. Over the past 28 years, there have been approximately 32 HHEs related to mining operations, although only one in the last decade. That HHE, conducted at the request of the United Mine Workers of America, involved an assessment of health effects associated with exposure to a hydraulic fluid emulsion used in longwall shields. A proposed HHE studying underground coal mine worker exposure to hydrogen sulfide will involve the Mining Program, and contribute to the ultimate development of engineering solutions.

Sole reliance on MSHA data is not good under all circumstances, because MSHA data collection is collected for enforcement purposes. Surveillance techniques employed may not be appropriate for specific research purposes.

ACTIVITIES

The Framework Committee defines activities as "the efforts and work of the program, its staff, and its grantees and contractors" and suggests separately evaluating research and transfer activities. Mining Program activities are the subject of detailed evaluation in Chapters 8-14 of this report and are not described here.

Acknowledgment by peers from other government agencies and larger professional circles gives some indication of the relevance of Mining Program research and projects. In the last 10 years, several investigators from PRL and SRL have won prestigious awards for their publications and research accomplishments. In addition to recognition from the Federal Executive Board, U.S. Public Health Service, Centers for Disease Control and Prevention (CDC), and NIOSH, awards have come from professional and technical societies such as the Society for Mining, Metallurgy and Exploration; the American Society of Civil Engineers; the Mine Ventilation Society of South Africa; the Society of Automotive Engineers; the American Rock Mechanics Association; the National Society of Professional Engineers; the American Industrial Hygiene Association; the American Road and Transport Builders Association; and the International Society of Mine Safety Professionals. Products of the Mining Program have garnered several R&D 100 Awards (recognition as one of the 100 most important research innovations of the year) from *R&D Magazine*. The awards cover research in respiratory disease prevention, traumatic injury prevention, ground failure prevention, mine disaster prevention, musculoskeletal disorder prevention, surveillance and training, and technology transfer.

TECHNOLOGY TRANSFER

Resources for technology transfer activities are limited. Increased funding to determine the most effective research to practice (r2p) strategies would aid resource allocation for transfer activities. The r2p program involves a translational process, whether the object to be translated is a complex technology, a procedure or work technique, conceptual (principles) knowledge, or practical (how-to) knowledge that can be embedded in informational products. For many problems in the United States, the state of the science (what researchers collectively know about solutions to a given problem) and the state of the art (what industry and other practitioners collectively do to help their members or constituents with a given problem) coexist more or less autonomously, each realm of activity often having little effect on the other. This situation has been referred to as a "quality chasm" by the Institute of Medicine (IOM, 2001), a "problem of translation" by the National Cancer Institute and the Agency for Healthcare Research and Quality (Kerner et al., 2005), and a challenge of "going to scale" by health policy entrepreneurs (Berwick, 2003).

Government agencies and philanthropic organizations have tended to see the closure of evidence-practice gaps as a problem of doing dissemination, that is, of distributing information about research results through familiar communication channels such as conferences, workshops, continuing education, proceedings, articles, and increasingly, web sites. A different route to redressing evidence-practice gaps is funding research about dissemination, or what in certain federal agencies is termed translational research (Dearing et al., 2006).

In the U.S. industrial and commercial sector, money committed to research and development is dwarfed by investments made to move products and services to the marketplace and consumers. Typically, more than 66 percent of total project costs are spent in packaging, marketing, distribution, and sales support (Kotler and Roberto, 1989). The Mining Program FY 2005 intramural budget was $30.7 million. The money committed to r2p for that same year in mining was approximately $1.25 million. A large proportion of NIOSH resources, as is common for federal agencies, goes to research, with a correspondingly low percentage (about 3 percent) going to ensure that NIOSH-developed and supported innovations benefit mining safety and health. The committee suggests that more funding be dedicated to learning which r2p strategies are most effective in translating the products of NIOSH work to industry. Alternatively, partnerships could be developed to provide industry funding and support for research on translation strategies, which would also help ensure appropriate industry participation in this process. In other countries, especially Australia, industry-funded programs have greatly expanded academic and government efforts in mining health and safety (e.g., CRCMining [an industry-government funded Cooperative Research Center] and the Australian Coal Association Research Program).

Extramural Research

The extramural research program within the Mining Program is relatively new and small. Currently, extramural research funding accounts for approximately one-third of NIOSH research overall, but only a small fraction of the Mining Program (NIOSH, 2006a). A total of 28 grants have been awarded since 1998. These grants were selected on the basis of two mining-specific requests for applications (RFAs) encompassing high-priority areas of mining and an additional general RFA from NIOSH. At the request of NIOSH, the committee did not review the extramural research program, but it recommends a review be conducted.

Extramural investigations encompass epidemiology, health effects, engineering controls, and technology transfer and training. Two technology transfer and training projects (1999-2004, 2005-2009) are the largest extramural projects and amount to approximately $1 million of the Mining Program budget per year. The minutes of the July 2003 MSHRAC meeting suggest these programs require focus. The Mining Program also funds a limited amount of contract research from its intramural program. There have been seven projects in the past 5 years, totaling approximately $2 million. The committee is not able to determine the success of the extramural programs based on information received from the Mining Program.

OUTPUTS

Outputs, as described by NIOSH and the Framework Committee, include recommendations, reports, publications, workshops, databases, and conferences. They may be presented as, among other things, training and education materials, demonstration programs, tools and methods, best practices or technologies developed, and licenses and patents. Quality outputs lead to desirable outcomes. An intermediate outcome reflects an assessment by stakeholders outside NIOSH (e.g., mine operators) of the worth of NIOSH research and/or its products and provides evidence of NIOSH output being put into practice. Some outputs are intended for use by researchers, engineers, scientists, and academics; others are translated more explicitly so that their content or format is more understandable, relevant, attractive, or involving for nonscientific users, including miners, mine managers, equipment operators, consultants, industry vendors, specialty and mass media journalists, and elected officials. All outputs are direct evidence of NIOSH work.

Some activities such as collaborations can also legitimately be conceptualized as outputs, because the collaboration itself is a result of NIOSH efforts. Cooperation, coordination, more intensive collaboration, and eventual formal partnering can be considered important outputs leading to desirable intermediate outcomes. Technology and knowledge transfer is greatly facilitated through such relationships.

It is possible to assess the quality of all types of outputs. Common metrics for assessing the quality of publications, for example, include journal impact factors that numerically score how often the articles in a journal are cited and bibliometric citation counts. Translated outputs such as videos, web sites, brochures, workshops, and new behavioral worksite routines may be tailored to communicate information most effectively to increase the likelihood of knowledge gained, attitude formation, action, and maintenance of a newly adopted and implemented innovation in practice. An indicator of the quality of a translated output is the extent to which the output design is based on systematic feedback from intended users. Summative results of user perception, understanding of learning objectives, and potential for adoption ratings (Dearing and Meyer, 1994) are other output quality assessment tools.

Mining Program Outputs

The Mining Program provided lists of outputs from 1996 to 2005 (NIOSH, 2005a). Outputs are identified by title, author, type, relevant citation, year of publication, and relevant strategic goal. Publications are classified by type, such as peer-reviewed or non-peer-reviewed journal articles, conference proceedings, NIOSH or USBM numbered reports, or *Technology News* articles. Nearly 5 percent are published in *Technology News*, a one-page flyer distributed by NIOSH, usually announcing a milestone in research, technology ready for transfer, or an opportunity for cooperative research and development.

The annual output of the Mining Program has remained fairly stable over the last 10 years, varying from 110 to 176, for a total of 1,428 between 1996 and 2005. Topically, these concerned ground failure prevention (30 percent), traumatic injury prevention (20 percent), mine disasters (17 percent), surveillance and training (16 percent), and respiratory disease prevention (15 percent). Noise-induced hearing loss prevention and cumulative musculoskeletal disorder prevention are the topics of 11 percent. Some outputs encompass more than one strategic area and have been counted more than once.

In terms of distribution by output type, officially published documents excluding web content and policy publications account for 82 percent ($N = 1,175$). Web content and policy publications account for another 2 percent (25) and 3 percent (40), respectively. During this same period, the Mining Program conducted 111 workshops, seminars, or open industry briefings, accounting for 7 percent of outputs. The remaining outputs consist of videos (20), training programs (18), software (8), patents (15), and standards (6). More than 51 percent of the publications are in conference proceedings. About 20 percent are in peer-reviewed journals. NIOSH or USBM numbered publications (e.g., *Reports of Investigations, Information Circulars*) account for about 11 percent.

The topical distribution of outputs is understandable in view of the previous discussion regarding the evolution of the Mining Program. A great deal of attention has been paid in the last 30 years to the problems of ground failure prevention, traumatic injury prevention, and respiratory disease prevention. The committee expects an increased number of outputs in noise-induced hearing loss prevention and cumulative musculoskeletal disorder prevention in future years, given the increased emphasis in these areas. The Mining Program appears to collectively direct its efforts toward the production of more and better research, essential to quality maintenance and recognition by international research organizations. Publications are the dominant output form, and conference papers and peer-reviewed journal articles dominate other less formal types of publication. Media and formats commonly used by nonscientists, non-engineers, and non-academics, however, are in little evidence. The Mining Program seems to focus less on outputs that are more directly applicable in the workplace.

Further discussion of specific outputs is found in the detailed discussion of the program's seven strategic research areas (Chapters 8-14).

FACTORS AFFECTING RELEVANCE

The Framework Document (Appendix A) directs the committee to consider a variety of factors while assessing the relevance of the Mining Program. These factors include the severity and frequency of risk factors, the numbers of workers affected by potential research outputs, the extent to which the program addresses the issues of gender and vulnerable populations, the extent to which the program addresses the needs of small businesses, the appropriateness of health effects versus intervention research, the structure and content of the program, and the consideration by the program of stakeholder input. The next sections discuss these factors.

Vulnerable Populations

The Framework Committee defines vulnerable populations as "groups of workers who have (1) biological, social, or economic characteristics that place them at increased risk of developing work-related conditions and/or (2) inadequate data collected about them. Vulnerable populations include disadvantaged minorities, disabled individuals, low-wage workers, and non-English speakers for whom language or other barriers present health or safety risks (see Appendix A)."

The committee recognizes that certain groups in the mining population deserve special consideration from the Mining Program:

1. Women. MSHA does not track the number of women employed in mines (Vanessa A. Stewart, MSHA, personal communication to Raja V. Ramani, January

30, 2006), but according to the U.S. Bureau of Labor Statistics, women made up approximately 7 percent of the domestic mining workforce in 2005 (BLS, 2005b). This figure does not distinguish office workers, mill and plant workers, and contractor workers from those working in hazardous mining conditions. The Mining Program does not currently conduct significant research targeting specific needs of the female mining population.

2. Mine-related services and auxiliary operations. Large operations usually involve extensive surface facilities, including preparation plants, mills, shops, and yards. While mining health and safety research may have some general applicability to workers in these locations, the major focus of current research is generally on large coal mines. This is understandable based on the history of the regulatory environment, funding, and health and safety statistics. Health and safety issues for workers in mine-related services and auxiliary operations should be considered.

3. Small mine operations. It would be worthwhile for the Mining Program to consider the specific needs of mine workers in operations with fewer than 20 employees. Approximately 83 percent of all miners in 2005 were employed in such operations (Phillip H. Nicks, MSHA, personal communications to Raja V. Ramani, June 2, 2006; see Table 1-2). Historically, this population has experienced a greater rate of injuries and fatalities than workers at larger mines (NRC, 1982), and it has been reported that the health and safety experience of small mines is somewhat poorer than that of larger ones (Lauriski, 2003). Although many mining health and safety problems and solutions may be the same for operations of any size, small operators may have less access to problem-solving resources (for example, engineering and operating expertise, training resources). It is important for the Mining Program to consider this factor when planning and conducting its research and disseminating its research findings.

4. Contract workers Contractors are assuming an increasingly important role in operations such as drilling and blasting, materials handling, and servicing and repair, particularly in surface coal and nonmetallic mining operations. As shown in Figure 2-1, contractor hours increased from approximately 4 to 14 percent of the hours worked from 1984 to 2004, whereas the total hours worked (operator and contractor hours) in mines have decreased by 25 percent (MSHA, 2004a). Since contractor employees are often a more mobile group than regular employees, it is difficult to monitor and quantify their exposure to risk. Additionally, this population may not have ready access to training resources available to the traditional worker. The problem has many facets, not all of which can be addressed through research. Therefore, the Mining Program, MSHA, and industry need to work together to develop effective surveillance and control programs to account for the needs of this population.

5. Retired workers. Many illnesses result long after chronic exposure and may

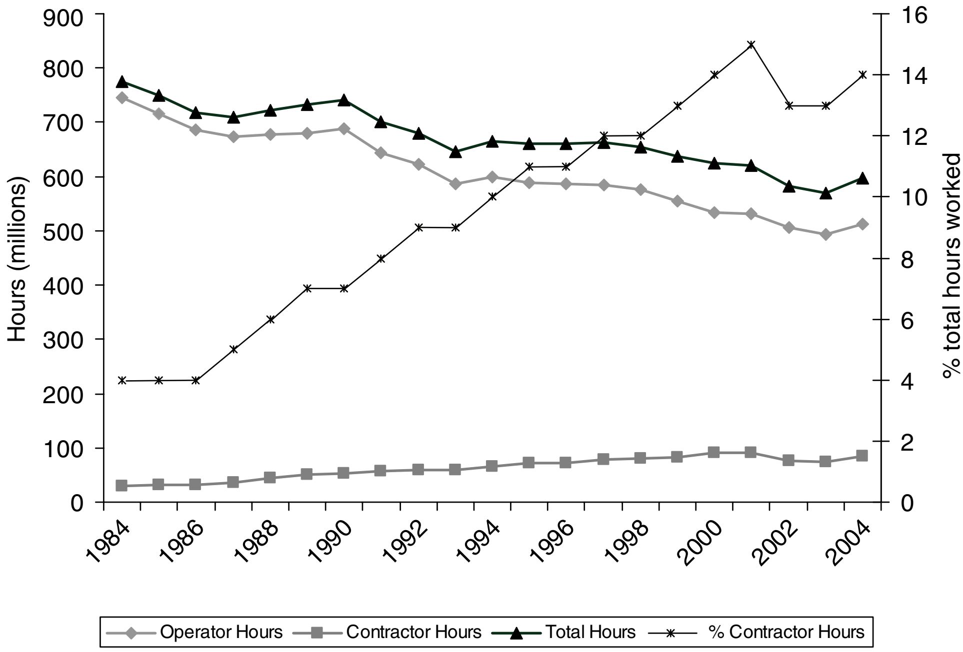

FIGURE 2-1 Number of hours worked by operators and contract workers in the mining industry from 1984 to 2004. Total hours represent the combined number of operator and contractor hours.
SOURCE: MSHA, 2004a.

not manifest themselves until some time after retirement. Retired miners should be regarded as a population with a potential for mining-related health problems or injuries, and the committee recommends efforts to monitor their health status after retirement.

Although the Mining Program has indicated it does not identify "one population within the domestic mining community . . . as more vulnerable than another" (NIOSH, 2006c), the Mining Program is engaged in completing a National Survey of the Mining Population (see Table 14-2) that will ultimately enable the calculation of risk factors and experience-specific injury rates including those associated with vulnerable populations. The Mining Program is also an active participant in NIOSH's efforts to study and respond to the needs of Hispanic miners for whom English is a second language. These factors indicate the Mining Program is making some effort to identify and eventually address the needs of these populations.

Life Stage of Research: Causal Versus Control Research

The Framework Document (Appendix A) makes the following recommendation to the committee regarding research relevance:

> As the health effects are understood, emphasis should shift to intervention research, and from efficacy to effectiveness to research on the process of dissemination of tested interventions. Gaps in the spectrum of prevention need to be addressed; for example, research on exposure assessment may be necessary before the next intervention steps can be taken.

An understanding of this concept leads to what the Framework Committee calls the identification of the "life stage" of research.

Because mining is an old industry, several major health and safety issues have been studied for a long time. The passage of health and safety laws, safer mine designs, a more knowledgeable workforce, and greater monitoring and control of operations from the health and safety viewpoint have resulted in tremendous reductions in incidents, injuries, and illnesses. It is important to define whether there is need for research to identify the problem's *cause* or the problem's *solution*. This is particularly true in the age-old areas of ground failure prevention, traumatic injury prevention, disaster prevention and control, and respirable disease prevention. Changing operating conditions or the introduction of new technologies may result in a lack of understanding of cause and effect. Advances in the ability to monitor physical agents and their safety and health effects may open up new areas for research on old problems.

External Factors

External factors are defined as forces beyond the control of the Mining Program that positively or negatively affect program results. External factors, as shown in Figure 1-1, can be considered input that affects program planning and execution. Examples of external factors affecting the Mining Program include the following:

- **Industry-specific legislation.** The passage of the 1969 and 1977 mine health and safety acts focused funding and research in a number of areas such as respirable dust, ventilation, electrical safety, and self-contained self-rescuer development. Examples of recent focused research include the development of a personal dust monitor, new miner training, mitigation of the growing hazards associated with larger and more powerful equipment and power sources, and reduction of noise-induced hearing loss at the workplace. Requirements for preventing noise exposures in mining were further strengthened by promulgation of 30 CFR Part 62 in 1999. Legislative backing for the implementation of new product designs, work safety procedures, and guidelines developed by the Mining Program is of critical importance.

- **Major incidents and disasters.** Major mine incidents with disaster potential, and mine disasters (e.g., the Quecreek No. 1 Mine non-fatal inundation incident, the Sago Mine explosion disaster), have the potential to affect a research program by creating an urgent need to answer newly framed questions through research. A number of new research initiatives to support either temporary or proposed rules may result, and research priorities may be reordered. The Quecreek incident led directly to mine inundation and void detection research. The Sago Mine disaster has led to enhanced funding of research on in-mine communications and escape and survival research.
- **Political environment.** A supportive political environment is essential to the successful development and implementation of NIOSH technologies and recommendations. As a federal agency, funding for the Mining Program is decided annually. The political environment also contributes to the passage of legislation or the development of new regulations critical to the Mining Program and the successful implementation of its research outputs.
- **Mining technology and conditions.** Major shifts generally occur over an extended period. In the underground coal sector, for example, mines are deeper and shifting to larger panels and high-productivity longwall systems. The increased contribution of surface-mined coal to total production and the growing size of equipment also affect health and safety trends. The introduction of new lixiviants[3] in hydrometallurgy and of bioagents to facilitate the leaching of metal may create new hazards (NRC, 2002). Changing demographics in mining are reflected in an aging workforce and an increasing number of contract hours. These changes bring with them the necessity and opportunity for innovation by mining companies, equipment manufacturers, and government agencies to protect the health and safety of miners.
- **Market forces**. In a free-enterprise society with many small producers, there is little control over prices. This is particularly true in the metallic sector and somewhat true in the coal and nonmetallic sectors. Long periods of depressed prices affect investment in research, new equipment, employment, and production. Spot increases in prices can lead to the opening of new mines or reopening of closed mines, with potential health and safety concerns. The mining industry experiences these forces in a somewhat cyclic, but not entirely predictable, manner.

[3]A solution used to extract a soluble constituent from a solid mixture via washing.

3

The Ideal Mining Safety and Health Research Program

The first step of the evaluation, as directed in Figure 1-1, was the independent committee assessment of the major components of an ideal mining health and safety research program. The committee considered separately the health research and safety research needs of the mining industry. Surveillance was considered vital in all research categories, but for the sake of this exercise, the committee included it within discussions regarding health research. Similarly, training and technology transfer are important in all research categories, but the committee considered them during discussions on safety research.

This chapter summarizes the committee's deliberations regarding the ideal mining safety and health research program. The first section describes the components of an overall ideal program. The next sections reflect the committee's assessment of mine worker health and mine worker safety research needs, respectively. Finally, a brief comparison of the ideal program to the existing National Institute for Occupational Safety and Health (NIOSH) Mining Program is made.

THE IDEAL PROGRAM

The mission of an ideal mining safety and health research program would be the complete elimination of mining-related illnesses, injuries, and fatalities. The program would be part of system that would include the parallel efforts of diverse organizations. Law enforcement, industry management, and labor would work to develop improved health, safety, and productivity procedures and processes.

Research would be pursued intra- and extramurally by government agencies and by industry, academia, equipment manufacturers, and other parties. Technology transfer from other industries would be an important component of effective research and development. Designing mining systems of exceptional safety and reliability, developing a knowledgeable workforce well versed in safe practices and procedures, and monitoring mines through a system of enlightened laws and regulations are the "three essential E's" (engineering, education, and enforcement) of a safe mining system.

The committee classified elements of the ideal mining program into surveillance, health effects research, intervention research, technology transfer, and other transfer activities. Health services or other research dealing with access to occupational health care, while important, is not a major part of this mining research program. The program mission would be accomplished by setting realistic, stepwise strategic goals as milestones toward achieving its mission.

Table 3-1 defines the five components of the ideal mining program and lists the research elements identified as necessary to fulfill its mission. The ideal program would include a large component of technology transfer and intervention effectiveness research to inform itself of the most effective ways of diffusing its research outputs to the mining industry and increasing stakeholder acceptance. To be comprehensive, the ideal mining research program must transfer its outputs to stakeholders in the most effective manner. Without an effective technology transfer program, the research may not contribute to the reduction of hazard exposures, injuries, and illnesses.

HEALTH RESEARCH NEEDS

Worker health continues to be a major issue in mining. An ideal disease prevention program includes identification of the cause of disease, exposure monitoring, exposure control technology development and implementation, and surveillance of disease progression, as well as intervention effectiveness research. Mining-related illness and disease are caused or aggravated by exposure to chemical or physical hazards, the most serious of which are chronic. Long exposure periods are required to contract the diseases, and equally long periods are necessary for surveillance and control. The committee includes respiratory disease (coal worker's pneumoconiosis [CWP], silicosis, chronic obstructive lung disease, and lung cancer), noise-induced hearing loss, and musculoskeletal disorders associated with repetitive motion, awkward postures, and other physical stressors among the mining-related illness and disease requiring attention.

To prioritize the goals of the ideal health program, the committee considered the prevalence of various mining health issues in different mining settings.

TABLE 3-1 Elements of the Ideal Mining Safety and Health Research Program

Mission: Elimination of mining-related injuries, illnesses, and fatalities

Program Component	Definition	Research Elements
Surveillance	The ongoing, systematic collection, analyses, and interpretation of health data essential to occupational health practice, coupled with timely dissemination of these data	• Outcome surveillance (mining injury and illness) • Exposure to health and safety hazards • Improvement of the data collection and surveillance system

Health effects research	Determination of the health outcomes of mining and related activities through study of individual miners, mining populations, and when necessary, cell and animal models	• Epidemiology
		• Toxicology
		• Physical exposure
		  ◦ Heat
		  ◦ Noise
		  ◦ Vibration
		  ◦ Radiation
		  ◦ Other physical agents or actions
		• Lab-based health and safety risk factor research
		• Clinical screening

Exposure assessment research	Measurement of the extent of exposure of miners to physical and chemical agents	• Assessment tools • Assessment strategies

TABLE 3-1 Continued

Program Component	Definition	Research Elements
Intervention research	Research encompassing all approaches to identify and control mining hazards	• Control technology ◦ Engineering controls and alternatives ◦ Administrative controls ◦ Personal protective equipment • Emergency preparedness and response ◦ Communication ◦ Escapeways ◦ Refuge chambers ◦ Other • Work organization ◦ Innovative work schedules ◦ Mine and mine population characteristics ◦ Other • Policy and regulation research ◦ Alternative policies for health, safety, and associated regulations • Community participation (mine workers and mining personnel) • Diffusion and dissemination research ◦ Effectiveness training ◦ Effectiveness of information dissemination ◦ Diffusion technology
Technology Transfer (and other transfer activities)	Diffusion and dissemination research to ensure greater effectiveness in moving from research to practice; delivery of outputs to stakeholders	• Training progress • Computer programs • Reports and papers • Workshops and seminars

Table 3-2 lists the importance of specific mining hazards by commodity group, location, and type of activity. An overall assessment of the importance of each hazard is provided based on the committee's opinion of prevalence.

Table 3-2 indicates noise exposure and risk factors for musculoskeletal disorders are common in all mining sectors and are therefore considered of greatest importance. Airborne mineral dusts remain a very important hazard (coal mine dust in underground coal mines and silica dust throughout the industry). Diesel particulate matter is important in all underground mines that use diesel-powered equipment. Other hazards that occur less frequently include exposure to toxic chemicals and gases, heat stress, and ionizing radiation. Heat stress can be a problem at surface mines when workers are engaged in heavy physical labor on hot days under strong sunlight. Oxygen-deficient atmospheres can occur when oxygen is displaced by simple asphyxiants or consumed by aerobic microorganisms.

SAFETY RESEARCH NEEDS

In order to provide an objective standard for measuring the relevance of current and proposed NIOSH Mining Program research to mining safety research, the committee considered the broad range of safety issues faced by the mining community. The committee divided safety issues into those associated with traumatic injuries, mine disasters, and ground failures and considered, as it did with health issues, the prevalence of various safety issues in different mining settings.

The ideal traumatic injury prevention program would include surveillance for hazards, fatalities, and injuries and the interventions designed for their control. Trends from 1994 to 2003 indicate good progress in the control of mining fatalities and injuries, but numerous fatalities and injuries were still reported in 2004 (MSHA, 2004a, 2006).

Like Table 3-2, Table 3-3 rates the importance of specific types of traumatic injuries, based on the committee's opinion of their prevalence in specific mining sectors and activities. The committee identified accidents involving electricity, ground falls, machinery, rain, and human factors as important areas of concentration. Slip, trip, and fall hazards are common in mining, but since considerable attention is paid to them by other NIOSH programs (e.g., construction), a higher rating was not assigned if relevant knowledge and technology from these other programs are transferred to the Mining Program. Hoisting, inundation, and entrapment are identified as greater hazards in underground mining, and the use of explosives is considered an important issue for surface and metal or nonmetal underground mining. The use of explosives in underground coal mining is not extensive, though explosives may be used for certain operations requiring safe handling and blasting practices.

TABLE 3-2 Committee Assessment of the Level of Importance of Mining Health Research Issues by Commodity Group, Location, and Type of Activity

Issues	Underground Coal	Surface Coal	Underground Metal	Surface Metal	Underground Nonmetal	Surface Nonmetal (including aggregate, stone)	Solution Mining	Coal or Mineral Processing Waste Disposal	Smelting, Other	Overall
Airborne respirable dust hazards										
Coal dust	5	3	—	—	—	—	—	5	—	4
Silica dust	5	5	5	5	5	5	2	5	—	5
Toxic metallic fumes and dust	1	2	3	3	1	2		3	5	2
Diesel particulate matter	5	3	5	3	5	3	2	1	1	4
Other aerosols and gases	1	1	3	1	2	1	5	2	5	2
Mine gases (excluding methane)[a]										
Toxic gases and control	1 or 5[a]	1 or 5[a]	1 or 5[a]	1 or 5[a]	1 or 5[a]	1 or 5[a]	1 or 5[a]	1 or 5[a]	—	—
Hearing loss prevention	5	5	5	5	5	5	3	5	5	5
Chemical hazards	2	1	2	1	2	1	4	2	2	2
Radiation	1	1	2	1	2	1	1	1	1	1
Ergonomics										
Musculoskeletal disorders and back pain	5	5	5	5	5	5	5	5	5	5
Vibration (jolting and jarring)	3	3	3	3	3	3	3	3	3	3
Heat stress	1	1	4	3	1	2	1	1	4	2
Surveillance and sampling	5	5	5	5	5	5	5	5	5	5

[a]Importance will depend on the specific toxic gas and the available control technologies.

NOTE: On a scale of 1 to 5, 1 = least important and 5 = most important.

The importance of specific issues of concern for disaster prevention and response was rated based on committee opinion of prevalence in specific mining sectors (Table 3-4). The issues were divided into prevention and response. Three issues identified as being of greatest concern in mine disaster prevention are explosive dusts, explosive gases, and ignition sources. In terms of disaster response, communication, personnel tracking, and personal protective equipment (PPE)—particularly the self-contained self rescuer (SCSR)—are of prime importance.

Table 3-5 summarizes the committee's effort to identify issues in ground failure prevention. A few issues in this table, such as stress induced by solution mining and

TABLE 3-3 Committee Assessment of the Level of Importance of Injury Prevention Research Issues by Commodity Group, Location, and Type of Activity

Issues	Underground Coal	Surface Coal	Underground Metal	Surface Metal	Underground Nonmetal	Surface Nonmetal (including aggregate, stone)	Solution Mining	Coal or Mineral Processing Waste Disposal	Smelting, Other	Overall
Electrical accidents and injuries	5	5	5	5	5	5	5	5	5	5
Powered haulage (trucks)	5	5	5	5	5	5	—	5	—	5
Ground falls (e.g., roof, walls, ribs)	5	5	5	5	5	5	1	5	—	—
Slip, trip, and falls (miners)	2	2	2	2	2	2	2	2	2	2
Machinery (conveyors [caught-between, etc.])	5	5	5	5	5	5	—	—	—	—
Explosives	2	5	5	5	5	5	—	—	—	—
Hoisting (elevators)	5	1	5	1	5	1	—	—	—	—
Materials handling	5	5	5	5	5	5	5	5	5	5
Inundation	5	3	5	3	5	3	—	2	—	—
Entrapment	5	2	5	2	5	2	—	—	—	—
Training	5	5	5	5	5	5	—	—	—	5
Knowledge	5	5	5	5	5	5	5	5	5	5
Skills	5	5	5	5	5	5	5	5	5	5
Motivation	5	5	5	5	5	5	5	5	5	5
Audiovisual	5	5	5	5	5	5	—	—	—	5
Classroom exercises	5	5	5	5	5	5	—	—	—	5
Virtual reality	2	2	2	2	2	2	—	—	—	—
Human factors (ergonomics)	5	5	5	5	5	5	—	—	—	5
Other (small mines)	5	5	5	5	5	5	—	—	—	5

NOTE: On a scale of 1 to 5, 1 = least important and 5 = most important.

the stability of embankments, are not directly related to traditional surface or underground mining excavations. Three issues directly related to mining excavations identified as being of greatest concern are roof and rib integrity in underground mines, detection of voids in underground mines, and loose rock and mass slope movement in surface mines. Areas of greatest importance for future work include design methodology and better understanding of rock mass reactions.

Mining occurs in an inherently hazardous workplace in which the heterogeneous geologic environment is not readily or precisely predicted. There are several

TABLE 3-4 Committee Assessment of the Level of Importance of Disaster Control Research Issues by Commodity Group, Location, and Type of Activity

Issues	Underground Coal	Surface Coal	Underground Metal	Surface Metal	Underground Nonmetal	Surface Nonmetal (including aggregate, stone)	Solution Mining	Coal or Mineral Processing Waste Disposal	Smelting, Other	Overall
Prevention										
Dust (explosive)	5	2	3	—	3	—	—	—	—	5
Gases (including outbursts, CH_4)	5	2	5	—	5	—	—	—	—	5
Ignition sources (including natural)	5	—	5	—	5	—	—	—	—	5
Mine planning and design (over, under)	3	3	3	5	3	3	—	—	—	3
New technologies (i.e., creation of finer dust)	5	5	5	2	5	5	1	2	5	3
Monitoring and detection	5	2	5	1	5	2	5	1	1	3
Seals and barriers	4	—	4	—	4	—	—	—	—	2
Geologic or hydrogeologic setting (over/under, mine inundation)	4	3	—	—	—	—	—	1	4	4
Ventilation	4	2	4	—	4	—	—	2	—	3
Workforce behavior and motivation	3	3	3	3	3	3	3	—	—	3
Emergency response preparedness (including catastrophic risk assessment)	5	3	5	3	5	2	2	3	3	2
Blasting and explosives practices	2	4	4	4	4	4	—	—	—	4
Response										
Communication	5	—	5	—	5	—	—	—	—	4
Personnel tracking	5	5	5	5	5	5	5	—	—	4
Isolation	4	2	4	2	4	2	1	—	—	2
Suppression (fire response and planning)	4	1	4	1	4	2	1	—	—	3
Mine rescue	5	2	5	2	5	2	2	—	—	2
PPE (SCSR)	4	4	4	4	4	4	4	—	—	4

NOTE: On a scale of 1 to 5, 1 = least important and 5 = most important.

unique hazards arising from operations associated with extracting and processing material from a geological formation. Predicting and controlling these hazards will make mines safer.

TABLE 3-5 Committee Assessment of the Level of Importance of Ground Failure Prevention Research Issues by Commodity Group, Location, and Type of Activity

Issues	Underground Coal	Surface Coal	Underground Metal	Surface Metal	Underground Nonmetal	Surface Nonmetal (including aggregate, stone)	Solution Mining	Coal or Mineral Processing Waste Disposal	Smelting, Other	Overall
Underground stability										
Roof and rib control	5	1	5	1	5	1	1	1	1	5
Extremely weak ground	4	1	4	1	4	1	1	1	1	4
Surface stability										
Loose rock	1	5	1	5	1	5	1	1	1	5
Mass slope movement	1	4	1	5	1	5	1	4	1	5
Design methodology										
Fundamental approaches (modeling, empirical)	5	5	5	5	5	5	3	3	1	5
Sensitivity to input parameters	5	5	5	5	5	5	3	3	1	5
Technology and technique issues										
Rock reinforcement (all types)	5	2	5	3	5	2	1	1	1	4
Mesh or geo-grid	5	3	5	3	5	3	1	1	1	4
Positive support (cribs, posts, cans, props)	5	1	2	1	2	1	1	1	1	3
Rock mass reactions										
Blasting damage	2	4	5	4	5	4	1	1	1	4
Induced stress	5	2	5	2	5	2	5	1	1	4
Cascading pillar failure	1	1	4	1	4	1	1	1	1	4
Voids										
Mine or natural void detection technology	5	2	5	5	5	5	3	2	1	4
Unique research needs										
Fault interactions	5	1	4	1	4	1	1	1	1	4
Large vehicle ground pressure	1	1	1	1	1	4	1	1	1	4

NOTE: On a scale of 1 to 5, 1 = least important and 5 = most important.

COMPARISON OF THE NIOSH MINING PROGRAM TO THE IDEAL

To a large extent, NIOSH Mining Program activities are directed toward intervention research, particularly toward developing engineering controls for mining hazards. With this in mind the committee assumes certain research falls outside the domain of the Mining Program. Fundamental research (e.g., to determine appropriate permissible exposure limits) is vital and should be conducted elsewhere within NIOSH, though it is not clear to the committee what and where relevant research is currently being conducted. Surveillance, health effects research, and technology transfer activities are conducted by the Mining Program, but these constitute a small fraction of the overall effort. Surveillance is conducted as part of specific projects to document exposures and effects. Specific surveillance projects may be undertaken, such as the recently initiated demographic survey of miners and the investigation of chemical hazards in mining. Mining Program involvement in the areas of health effects research and health services is limited.

It is evident to the committee that the Mining Program is an important research component of an overall system to improve health and safety in mines. Quantifying the impact of the Mining Program on industry health and safety improvements is a formidable task. However, without the contributions of the Mining Program, the efforts of others in the mining safety and health community may not be sufficient to result in rapid improvements in mining safety and health.

4

Evaluation of Relevance and Impact of the NIOSH Mining Program

The committee was charged with assigning, on a scale of 1-5, numeric scores for relevance and impact in the workplace in its evaluation of the overall performance of the Mining Program. The scoring criteria were developed by the Framework Committee and are provided in Box 4-1. The committee first considered the relevance and impact of each of the program's seven strategic research areas, then considered the program as a whole. The period evaluated is from 1997, when the National Institute for Occupational Safety and Health (NIOSH) assumed responsibility for mining health and safety research, through 2005. This chapter provides a programmatic assessment of relevance and impact. A more detailed evaluation of the Mining Program's seven strategic research areas is found in Part II (Chapters 8-14) of this report.

Statistics reveal major reductions in the number and rate of illnesses, accidents, and injuries. Technology advances are evident in several areas including mining methods, respirable dust control, ground failure prevention, methane emission control, disaster prevention, and equipment safety. Improvements and advancements are the combined result of the efforts of mine operators and workers, government enforcement agencies, equipment manufacturers, and research and development work by government agencies and universities. The 1995-1997 transition of mining health and safety research from the U.S. Bureau of Mines (USBM) to NIOSH represented a massive reduction or reallocation of personnel, facilities, and programs. The Mining Program not only maintained a research focus on persistent health and safety problems, but initiated new research to address emerging issues.

BOX 4-1
Five-Point Scales Used for the Rating of Relevance and Impact as Defined by the Framework Committee

Rating of Relevance

5 = Research is in highest-priority subject areas and highly relevant to improvements in workplace protection; research results in, and NIOSH is engaged in, transfer activities at a significant level (highest rating).
4 = Research is in high-priority subject area and adequately connected to improvements in workplace protection; research results in, and NIOSH is engaged in, transfer activities.
3 = Research focuses on lesser priorities and is loosely or only indirectly connected to workplace protection; NIOSH is not significantly involved in transfer activities.
2 = Research program is not well integrated or well focused on priorities and is not clearly connected to workplace protection and inadequately connected to transfer activities.
1 = Research in the research program is an ad hoc collection of projects, is not integrated into a program, and is not likely to improve workplace safety or health.

Rating of Impact

5 = Research program has made a major contribution to worker health and safety on the basis of end outcomes or well-accepted intermediate outcomes.
4 = Research program has made a moderate contribution on the basis of end outcomes or well-accepted intermediate outcomes; research program generated important new knowledge and is engaged in transfer activities, but well-accepted intermediate outcomes or end outcomes have not been documented.
3 = Research program activities or outputs are going on and are likely to produce improvements in worker health and safety (with explanation of why not rated higher).
2 = Research program activities or outputs are going on and may result in new knowledge or technology, but only limited application is expected.
1 = Research activities and outputs are NOT likely to have any application.
NA = Impact cannot be assessed; program is not mature enough.

The committee recognizes that the Mining Program mission cannot be accomplished "through a focused program of research and prevention" alone. Workplace improvements require, among other things, implementation of research results into practice. The Mining Program is unable to force change because it cannot require or enforce implementation of its recommendations. The Mining Program does have positive impact, as evidenced by industry acceptance of NIOSH recommendations, either voluntarily or through enabling legislation and the passage of regulations. The continued existence of a political climate favorable to the research programs and to implementation of recommendations is vital.

It is often impossible to document statistically the impact of Mining Program research. This is especially true in the case of recent recommendations related to the prevention of illnesses with long latency periods. Further, attributing all credit to the Mining Program for workplace improvement may not be appropriate. Regardless, based on the evidence reviewed, the committee concludes that the quality and quantity of Mining Program research outputs are often quite high and are connected to improvements in workplace practices (intermediate outcomes) and to potential reduction of workplace illness and injury (end outcomes).

Based on the scoring rationale presented in Box 4-1, the committee assigns the following scores:

Relevance	**4**
Impact	**4**

An extensive review (NRC, 1995) of the former USBM identified specific recommendations that are as pertinent today as they were in 1995. The NIOSH Mining Program has made good progress in following up on the recommendations especially in the areas of technology transfer and use of electronic media. Additional effort is needed in training and developing junior-level personnel to eventually replace more experienced researchers, and utilizing outside technical expertise through carefully controlled contract research. Because the health and safety responsibilities of the USBM are now held by NIOSH, the Mining Program should address these recommendations.

EVALUATION OF RELEVANCE

The Mining Program combines research in areas of long-standing concern (for example respiratory disease, ground failure, traumatic injury prevention, and disaster prevention) and research arising from changing mining conditions (including noise-induced hearing loss prevention, repetitive injury prevention, surveillance, chemical hazards, and training). Emphasis in these newer areas is well placed.

Research has resulted in major reductions in the incidence and severity of a variety of hazards. However, there is a need for research projects that cut across multiple Mining Program research areas. For example, increased production and productivity in underground coal mines can result in greater methane emissions, dust, and exposure of larger roof areas. Health and safety problems have to be approached in a systems framework encompassing all three issues. A review of its research portfolio reveals that the Mining Program, by targeting new research in traditional areas, responds to the needs identified through surveillance and intervention research. Given the fairly fixed nature of total and discretionary resources, the committee concludes that the Mining Program has attempted to reallocate resources, albeit in a limited manner, to continue control research on heritage problems while initiating surveillance research on emerging problems.

The committee believes the Mining Program conducts research relevant to a safer and healthier workplace. However, the committee is concerned about how some intermediate goals and activities move the program toward the achievement of top-level goals. For example, in respiratory disease prevention research, intermediate goals regarding dust exposure control in longwall faces and diesel emission exposures in underground mining could be more ambitious, particularly in view of advances already made in both areas. In another example, the committee notes that hearing loss can result from exposures outside the workplace and that the isolation of such complicating factors should be considered by NIOSH in its evaluation of program effectiveness. In mine disaster prevention and control research, the committee is of the opinion that, in addition to research on control of ignition, explosions, fires, and other events having disaster potential, goals need to be set for increasing the possibility of escape. Despite these comments, the committee concludes that the Mining Program addresses major health and safety issues with a coherent integrated plan to produce stated outcomes.

The committee deliberated extensively on the relevance of the program to workers, including vulnerable populations, workers in small mines, and contract workers. It is difficult for the Mining Program to appropriately balance the needs of such diverse populations. The committee concludes the Mining Program, in cooperation with the Mine Safety and Health Administration (MSHA) and mining companies, has strived with limited success to achieve a balance among these factors.

The Mining Program is involved in education and training research projects that explore issues such as the training needs of different mining populations and the aging workforce. The program is also involved in service functions that include developing and providing access to training materials. The attention given to the education and training needs of an evolving workforce is timely in view of the potentially large number of new and young entrants into the industry. Attempts to capture and transfer the knowledge of experienced miners to new miners are likely to be useful. The Mining Program is on the right track in identifying the Internet as an efficient means of disseminating health and safety information, but given the number of small mines and the special needs of miners and supervisors in that setting, the use of other methods (CDs, videotapes, print materials) should be continued. While it is true that individual investigators may be involved in developing appropriate tools to facilitate the translation of research to practice, it is not clear that they are the best resources in terms of the final product. The committee recognizes that without an effective technology transfer program, many research results may be under- or even unutilized. Based on the percentage of the total Mining Program budget allocated to the translation of research to practice (r2p) as compared to money spent on marketing, distribution, and sales support in other industries and programs (see Chapter 2), Mining Program resources available for technology transfer are very modest.

Relevance Scoring

On the basis of its deliberations, the committee concludes that Mining Program research is in high-priority areas and adequately connected to improvements in the workplace. It is moderately involved in transfer activities. The committee has determined that a relevance rating of 4 on the five-point scale proposed by the Framework Committee is appropriate (see Box 4-1). The program's focus and achievements at the workplace preclude a lower score. Recognizing that the Mining Program is still evolving in a number of areas, the committee developed numerous recommendations for NIOSH to consider under each of its strategic and intermediate goals for the enhancement of program relevance. The committee concludes a higher score would not be appropriate.

EVALUATION OF IMPACT

Evaluating the impact of the Mining Program on workplace health and safety is challenging. Though there have been marked decreases in fatalities, injuries, and illness and great improvements in health and safety conditions in the industry, it is not easy to isolate the contributions of the Mining Program from those of others, particularly of mine workers and management.

When workplace health and safety improvements could not be attributed directly to the Mining Program, the committee tried to determine if practices, procedures, guidelines, and/or equipment were in some way improved as a result of Mining Program activities. As has already been stated, implementation of Mining Program recommendations or products may be impeded by external factors. If the committee felt outputs and transfer activities had the potential to impact the workplace, credit should be given the Mining Program. The committee also considered how to assess the contributions of long-standing research programs, some dating back to the USBM. Moving research from concept to completion can be a long process, but the time to move from completion to widespread implementation can be even longer. Therefore, the committee decided to consider some research predating NIOSH's control of mining research.

Part II (Chapters 8-14) contains an extensive discussion of Mining Program efforts and assessment of their impacts in specific research areas. A brief discussion of research area impacts is included below.

Respiratory Disease Prevention

The Mining Program's principal intervention approach to respiratory disease prevention is engineering control by prevention, removal, suppression, isolation, and dilution of dust. Research in some areas is long-standing. Progress in bringing ambient coal dust concentrations to below mandated levels is significant. The Mining Program and the Personal Dust Monitor (PDM) Partnership are in the final stages of field evaluation of the PDM. There is general agreement among mine management, labor organizations, and MSHA that the PDM has great potential to monitor dust exposures and help determine the control and avoidance measures necessary to guard against exposure to high dust concentrations in the workplace. In 2004, the PDM won one of the 100 research innovations award from *R&D Magazine* (NIOSH, 2005a).

The PDM Partnership itself is a valuable intermediate outcome of Mining Program efforts. Parties who will be involved in PDM implementation—labor unions, workers, industry, the instrument manufacturer, and MSHA—are working together. Former USBM respirable dust laboratories are maintained and kept up-to-date by the Mining Program. The full-scale longwall dust gallery, the full-scale continuous miner dust gallery, and dust instrumentation facilities are considered state of the art and have been duplicated by agencies around the world. The Mining Program continues to have significant impact in respirable dust control in mines and thereby in reducing of the prevalence of coal worker's pneumoconiosis (CWP). Details on respiratory disease prevention research can be found in Chapter 8.

Noise-Induced Hearing Loss Prevention Research

Noise-induced hearing loss prevention research within the Mining Program is relatively new. End outcome data will not be available for many years. Even so, a few activities have the potential to reduce hearing loss among workers. For example, hearing loss simulator software developed by the Mining Program has been incorporated by MSHA into its training program; the Mining Program has promoted the "roll-and-hold" technique for the insertion of foam ear plugs, which has the potential to reduce noise exposure by as much as 9 dB; and surveillance projects are well directed toward relating exposure to noise sources. Additionally, NIOSH has developed a mobile hearing loss detection lab that can be transported to any worksite to conduct hearing clinics for up to four persons at a time. Trained technical personnel administer hearing loss tests and provide feedback on test results. This mobile lab has instrumentation to perform a wide range of research tasks. These are indicators that program outputs are likely to contribute to hearing loss protection in miners. Further details on hearing loss prevention research can be found in Chapter 9.

Cumulative Musculoskeletal Injury Prevention Research

The Mining Program has renewed attention to the application of human factors engineering to reduce cumulative injuries and has developed facilities, such as the human performance research mine, the motion analysis capture system, and the human factors engineering laboratory, to conduct its research. The Mining Program has worked with the International Union of Operating Engineers to collect data on ergonomic-related factors for use in research on improved ergonomic design of mobile equipment. No data exist to document impacts on workplace health and safety, but several program outputs, such as a low-height shuttle car seat design, a more ergonomically designed truck seat, and improved dragline workstations, have been implemented. One manufacturer reports that the program-designed shuttle car seat is preferred by operators. Of particular note is the NIOSH partnership with an operating surface coal mine in reducing work-related musculoskeletal disorders. The Mining Program provided guidance, direction, and training on customizing and implementing a sound ergonomic process with the objective to reduce injuries and proactively avoid problems.

The Mining Program has generated outputs of value to stakeholders, as determined by their acceptance by mining companies and manufacturers. Details on cumulative musculoskeletal disorder prevention research can be found in Chapter 10.

Traumatic Injury Prevention Research

The high incidence of accidents and injuries due to accidental contact with objects or substances indicates the need for monitoring and sensing devices to provide visual and audio alarms to nearby operators and workers. The Mining Program created an informal partnership with equipment and sensor manufacturers, industry, and MSHA and developed a proximity warning device with the potential to reduce these kinds of accidents. MSHA and the Mining Program jointly disseminate information on this device, and MSHA is actively working on getting the device used in the workplace. The device was described as very useful by the representative of a mining company with several large open-pit mines in the West.

Other research has involved initiating a number of surveillance projects on chemical hazards to characterize issues and hazards, and the reduction of injuries associated with haulage and machinery through products and services adopted by the industry and MSHA. There is great potential to improve safety conditions in the industry. Although the Mining Program has developed successful partnerships related to traumatic injury prevention, it has not been as successful in communicating research results to the entire mining community, especially individual mining operations.

Details on traumatic injury prevention research can be found in Chapter 11.

Mine Disaster Prevention Research

The Mining Program has contributed to disaster prevention research through the development of practices and procedures aimed at disaster prevention and enhancing escape and rescue in the event of a disaster. In particular, the development of the dust explosibility meter should lead to the rapid determination of the adequacy of rock dusting. The training module for effective communication with and by miners in the event of an emergency has been widely used by the companies in their training programs. Directional lifelines for enhancing escape from underground mines are increasingly being used. In addition, some research has led to changes in MSHA rules and regulations that directly impact the workplace. Currently, however, only some of the highest-priority areas in mining disaster prevention are addressed through Mining Program research. Research in areas of disaster prevention and response such as communications, miner self-rescue, and emergency response need to be strengthened. The committee judges current mining disaster prevention research to be focused on lesser priorities.

Details of mine disaster prevention research can be found in Chapter 12.

Ground Failure Prevention Research

The Mining Program is responsible for rock safety engineering and reduction of injuries and fatalities caused by rock fall, collapse, and other rock failure events associated with mine excavations. Through collaborative efforts of the Mining Program and mining companies, the initiative, started under the USBM, has resulted in major reductions of injuries and fatalities caused by rock bursts in underground metal mines. Recent development and testing of more than 40 new roof support technologies using the mine roof simulator has substantially improved safety for underground miners. The development and wide distribution of computer software and the development of mobile roof support technology have improved longwall and room-and-pillar operations. The development of rock mass rating criteria has led to safer span widths for underground metal or nonmetal and coal mines. The apparent reduction in rock fall fatalities supports the conclusion that progress is being made toward reduction of hazards. Other Mining Program research activities are likely to provide additional safety benefits.

Development of systems to monitor ground movement and roof falls, better understanding of the effect of blasting on excavation perimeter stability, development of rock surface treatments, and other efforts are likely to provide important new knowledge. Well-accepted intermediate outcomes or end outcomes have not yet been documented. Unfortunately, falls of rock still take a heavy toll in injuries and fatalities, and additional effort is needed to reduce these incidents. An area that requires more attention is r2p.

Details on ground failure prevention research can be found in Chapter 13.

Surveillance, Training, and Intervention Effectiveness Research

A number of technology transfer activities have resulted in outputs already in use in the industry. The Mining Program is developing and distributing many training materials, and the committee heard from several stakeholders regarding NIOSH-developed training materials and resources. For example, Mining Program training materials are used at MSHA's National Mine Health and Safety Academy, which distributes them to the mining community through its regular distribution channels; several aggregate mining companies have incorporated a Mining Program interactive training program aimed at reducing hazards among construction, maintenance, and repair workers into their Part 46 (CFR Title 30) training; and the Commonwealth of Pennsylvania uses a Mining Program-developed computer-based training simulation program for emergency command center leaders in its annual refresher training work. Additionally, on the basis of a survey of safety specialists from mining companies, trainers, and MSHA, the Mining Program developed 10 training videos covering underground and surface mining topics that are used widely in the mining industry. The Mining Program is a major participant and contributor to several mine health and safety and miner training conferences and symposiums.

Although additional work is needed to create a better surveillance system, the Mining Program has contributed to the generation, distribution, and wide use of good-quality training resources for the mining industry. Working closely with a number of stakeholders during development has resulted in wide acceptance of these materials. Research activities are likely to result in improvements in workplace protection.

Details on surveillance, training, and intervention effectiveness research can be found in Chapter 14.

Rationale for Scoring Impact

The contributions of the Mining Program to improvements in workplace health and safety are considered major in some areas (respirable disease prevention, traumatic injury prevention), moderate in some areas (hearing loss prevention, ground failure prevention), and likely in a number of areas (disaster prevention, musculoskeletal injury prevention). Mining Program outputs are evaluated, accepted, and incorporated into stakeholder operations, and training outputs find wide use in the industry. The Mining Program is engaged in technology transfer activities. Based on the Framework Committee criteria for scoring (see Box 4-1), a score of 4 for impact is appropriate. A lower score would not acknowledge the fact the Mining Program has gone beyond mere production of outputs. A higher score is not justified because outcome data are not available for several research areas. Though some outputs have the potential to improve future health and safety conditions in the workplace, the path from output to outcome is affected by external factors.

5

Progress in Targeting New Research Areas

The committee's second charge is to assess the National Institute for Occupational Safety and Health (NIOSH) Mining Program's progress in targeting new research in areas of occupational safety and health most relevant to future improvements in workplace protection. Guidelines provided by the Framework Committee suggest evaluating the relevance of current research and the targeting of new research areas most relevant to future needs.

Chapter 2 describes Mining Program procedures for establishing strategic and intermediate goals and project selection. Relevance of current research is addressed programmatically in Chapter 4 and in greater detail by strategic research area in Part II of this report. This chapter focuses on the Mining Program's targeting of new research and must be viewed in the context of the conditions that influence the research agenda. Mining conditions in the future (e.g., geography, geology, mine size, technology, organization, workforce) will differ from those of the present.

An informed assessment of future health and safety issues is required to ensure current research remains relevant in the immediate future and that near-future research priorities target anticipated longer-term concerns. The committee assessed the potential evolution of current technologies and considered how the Mining Program prepares itself for the future. The committee reviewed a recent study by RAND (Peterson et al., 2001) that summarizes confidential interviews with representatives of 58 mining companies, equipment manufacturers, research institutions, and others associated with the mining industry. According to the study, the priorities for major technological trends were (1) information and communication technologies; (2) remote control and automation; (3) operations and maintenance to improve performance and availability of equipment; and (4) new technologies for unit operations, such as the size of buckets and truck capacities in hauling and loading. Interviewees discussed the critical role of workers and the management and organization of mining facilities as well as the importance of outsourcing, safety through training, and empowering rank-and-file workers and upgrading their roles in problem solving. Concerns expressed included issues associated with the aging workforce, the lack of skilled workers, and the need to increase the multidisciplinary and critical thinking skills of miners in preparation for future mining technologies. The committee shares these concerns.

The committee also reviewed a study by the National Research Council (NRC, 2002) that describes possible future technological developments and associated health, safety, and environmental issues in mining. The study considered how new technologies such as in situ and solution mining, automated systems, and larger equipment and systems may affect working conditions. The committee agrees with the report finding that new technologies, including computer-based monitoring and control, have the potential for improving health and safety, but these same technologies may result in unforeseen hazards, especially if used inappropriately. New hazards are inadequately identified, and known hazards are not avoided because of inadequate monitoring and/or control. The introduction of new equipment and systems in the workplace, mining in virgin areas, and the infusion of new workers all have the potential to create hazards. Adequate engineering controls and a knowledgeable workforce are prerequisites for a safe work environment.

Although, to a large extent, the Mining Program does research relevant to the present and future mining industry, the program does not have the annual discretionary funds required to start large or risky projects necessary to address the needs of the future. The program may receive additional funding for specific research such as a recent congressional appropriation of $10 million for critical disaster response technologies in oxygen supply, refuge chambers, and communication and tracking (Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006, P.L. 109-234, § 7010).[1]

Resources should be allocated appropriately to allow the Mining Program to prepare for emerging issues in addition to addressing current issues. Flexibility needs to be built into the mining program to respond more rapidly to needs dictated by current events (as in response to accidents) or in looking at paradigm-changing approaches to reduce health and safety risks.

[1]See also *http://www.cdc.gov/niosh/mining/mineract/emergencysupplementalappropriation.htm* [accessed March 5, 2007].

STRATEGIC GOALS

After reviewing the strategic and intermediate goals of the Mining Program's seven strategic research areas (see Part II, Chapters 8-14), the committee observes that program strategic goals are most often established in response to circumstances. Such evolutionary responses are driven by workplace incidents, new legislation, response to specific requests by stakeholders, or other circumstances. Given the NIOSH mission and resource limitations, this goal selection process in understandable, although the result is a research portfolio with a major focus on coal mining and large operations (NIOSH, 2005a). The Mining Program should set more challenging and innovative goals and determine the means to achieve them. Part II of this report offers specific examples. It must also be recognized that continued optimization of current mining systems will lead to progressively less favorable health and safety conditions. Industry must look at alternative approaches that offer greater potential for reduced exposure, and the Mining Program needs to be prepared to make appropriate recommendations regarding these approaches.

Fatality, injury, and illness data are of great value for prioritizing research aimed at reducing observed hazards in the workplace. This approach, however, is not proactive in defining and eliminating hazards before injury and illness occur. A large number of unsafe conditions may underlie an injury- or illness-causing incident, and many unreported incidents may occur before resulting in a reported injury or illness. An approach to proactively identify hazards and develop appropriate countermeasures would result in the reduction of exposures and accidents and, therefore, injuries, illness, and fatalities. A source of this kind of incidence data could be Mine Safety Health Administration (MSHA) inspection data currently collected at all mines. Effort should be made by the Mining Program to obtain information about "near-miss" and other gaps in incident statistics, and to identify the appropriate means of interpreting the data to ensure all mine worker populations are represented.

"Look-ahead technologies" employing geophysical and geochemical methods may help to characterize ground conditions ahead of mining (NRC, 2002) and thus detect hazards before workers are exposed. The Mining Program is currently not engaged in exploring these methods at any large scale.

PROJECT SELECTION

Project selection in the Mining Program, described in Chapter 2, begins with researcher-initiated proposals. Projects encompassing multiple strategic goals would allow improved integration of research efforts most conducive for health and safety advances. Though program researchers are enthusiastic about their work and recognized by their peers, they may not have the breadth of knowledge required to develop multidisciplinary proposals.

There is growing concern regarding the availability of qualified research personnel, and advantages of involving outside expertise through a large and vibrant extramural program with both investigator-initiated research and contractors on NIOSH-initiated research. This is especially true given the high costs of developing expertise in all areas where innovative research is required. External grants and contracts would also serve to train personnel for the industry-at-large, as well as for the Mining Program. Extramural research within mineral-related academic programs would prepare young professionals to enter the industry, and allow academic programs to make greater contributions to society.

TECHNOLOGY TRANSFER

As discussed in Chapter 2, the efforts of the Mining Program in the area of technology transfer (research to practice, r2p), while commendable, are not proportional to its efforts in the conduct of research. The effective transfer of NIOSH-developed products, practices, and guidelines to industry is essential for outputs to result in improvements in workplace health and safety. Adoption of products by the industry or promulgation of guidelines and standards by MSHA requires a good understanding of the potential outcomes associated with them. While there is an appreciation of this fact, it is not clear the r2p processes in place will achieve the desired results, given that much of the responsibility for technology transfer is in the hands of project researchers. The problem is particularly acute now in view of changing mining technologies and the developing shortage of trained manpower at all levels.

Fiscal year 2005 funding for Mining Program r2p was less than 5 percent of the total budget. Better and more focused methods to deliver outputs and to document resulting intermediate outcomes are needed. Technology transfer activities should be sharpened with new programs and additional resources. Improvements in current training procedures and practices are necessary, along with new research to determine more effective ways to transfer knowledge and technology. The Mining Program should determine the means of engaging and encouraging researchers and specialists to produce greater and more effective technology transfer mechanisms.

FINDINGS

To a large extent, the Mining Program is doing research that is relevant to the present and future mining industry, but the program's ability to target new research areas may be restricted by limited resources, stakeholder expectations, and other external factors. Notwithstanding, it is evident the Mining Program has been moving toward bringing new areas into its research portfolio. By initiating research on a number of new fronts (e.g., chemical hazards, improved communication and training research) and by targeting more research in areas such as noise prevention, surveillance, and musculoskeletal disorders, the Mining Program has attempted, albeit in a limited manner, to address the needs of the future.

6

Emerging Issues in Mining Safety and Health

The third charge to the committee was to consider significant emerging research areas in mining safety and health that appear especially important in terms of their relevance to the mission of the National Institute for Occupational Safety and Health (NIOSH) Mining Program. Emerging issues can be associated with cultural or industrial factors or trends, such as changes in commodity demand, workforce, or technology. The Mining Program attempts to identify issues emerging in the next 5 to 10 years and has identified production demands, workforce issues, and mining practices as areas of future concern.

The committee foresees changes in the mining industry that can be predicted with certainty; other predictions represent educated conjecture. Mining production is expected to increase dramatically in the next 10 years. New technologies will be developed, new ventilation and ground control practices will be implemented, and new health and safety regulations enacted. At the same time, a large turnover is expected in the mine worker population as older workers retire and younger, less experienced workers join the workforce. Physical conditions such as mine depth, seam inclination, and seam thickness are likely to create a more challenging mining environment. The Mining Program should stay abreast of advances in mining methods and equipment and be prepared to offer recommendations where appropriate.

In the course of evaluating the Mining Program's seven strategic research areas, the committee considered emerging issues for which the Mining Program needs to be prepared. This chapter presents a list of those issues, with brief explanation, organized by research area. An overview of program-wide overarching issues is provided in Chapter 7.

EMERGING AREAS IN RESPIRATORY DISEASE PREVENTION

- Future research may show that nanoparticles are common in the mining environment, or that they are more toxic than larger-sized respirable particles. The Mining Program should stay aware of current and future research in this field and be ready to address potential control technologies associated with nanoparticles in the mining environment, especially methods of both measuring and controlling exposure.
- The recommendations of the Department of Labor advisory committee on the elimination of coal worker's pneumoconiosis (U.S. Department of Labor, 1996) and a NIOSH criteria document (NIOSH, 1995) suggest lowering the standard for coal dust and silica. The Mining Program should be prepared, by working with its stakeholders to decide on a desirable approach, to address the technological challenges that may arise should the permissible exposure limit (PEL) be reduced.
- The Mining Program should be prepared to address how changing work organization (e.g., overtime, extended shifts) may affect the respiratory health of mine workers.
- There are no active underground uranium mines in the United States; therefore miners' exposure to radon and its progeny is minimal. If the nuclear power industry expands, an increase in the demand for uranium and the reactivation of uranium mines can be expected, increasing the exposure of miners working within that sector to radon. Attention to control technologies and disease prevention will be required.

EMERGING AREAS IN NOISE-INDUCED HEARING LOSS PREVENTION

- As production increases due to equipment or process evolution, noise levels will increase. Future coal mining will likely involve thinner coal seams that may include more reject (rock), which produces higher noise levels. Deep mines can become very warm, making hearing protection devices more uncomfortable to wear—particularly for longer work shifts. More comfortable hearing protection needs to be designed to accommodate higher noise levels, deeper and warmer mines, and/or longer shifts.
- Substantial evidence indicates many miners have lost significant hearing (NIOSH, 1976; Seiler et al., 1994; Franks, 1996; Franks et al., 1996). The safety of the aging workforce needs to be protected to ensure they do not suffer further hearing loss, and that communication with them in the mine is not compromised.

- As the aging workforce retires, a new generation of miners will require a tremendous educational effort to train them on the ill-effects of hearing loss and how to prevent it. The Mining Program should be prepared with training materials and appropriate dissemination plans.
- More needs to be learned about the combined effects of mixed exposures (noise and fuel and other vapors) as well as the combined effects of mixed noise (continuous and impulse-impact noise) environments. The Mining Program should stay abreast of research in this area and be prepared to conduct intervention research as problems are detected.
- Given a resumption of uranium mining, ototoxic effects of radiation, both alone and in the presence of other potential chemical agents (e.g., diesel exhaust, hydrocarbons), should be studied. The Mining Program should be prepared to conduct intervention research related to potential ototoxic effects.

EMERGING AREAS IN CUMULATIVE MUSCULOSKELETAL INJURY PREVENTION

- Because mining in the future will be carried out under more difficult conditions (greater depths, thinner seams, more severe environmental conditions), research on the relationships between mining tasks, the demands on mine workers, and changing environmental factors will be necessary. The Mining Program should work proactively to provide interventions to avoid work-related musculoskeletal disorders (WMSDs) as working conditions change.
- Increased use of remote control and automation are likely to result in new WMSDs. The Mining Program should stay aware of the trends in work and work organization to anticipate the risk of, and avoid, WMSDs.
- The changing nature of work organization (e.g., longer shifts) could potentially result in more or different WMSDs that the Mining Program should anticipate and avoid.

EMERGING AREAS IN TRAUMATIC INJURY PREVENTION

- Changing mining conditions, such as increasing mine depths, new mining ventures (e.g., uranium, oil shales), the handling of mine wastes, new fuels or mobile equipment (such as biofuels and fuel cells), the use of satellite information and its applications, and the increased size of mining equipment and electrical voltages, could result in different traumatic injury hazards. The Mining Program should stay aware of research and advances and anticipate the hazards associated with them.
- Removing miners from hazardous areas by improving mining methods

and equipment is a logical means of reducing traumatic injury. The Mining Program should be prepared to facilitate this through work with other research entities and manufacturers to simultaneously design new mining systems and safety equipment.

EMERGING AREAS IN MINE DISASTER PREVENTION AND CONTROL

• Prevention (including the use of improved hazard detection and the identification of new hazard sources), control, escape, survival, response, rescue, and other elements should be addressed in mine design, operations, miner training, personal protective equipment, rescue equipment, etc., in a systems engineering framework to eliminate or reduce the occurrences of disastrous events and enhance the chances of escape, survival, and rescue if they occur. From the collective research perspective, defining a good system is paramount. Multiple, redundant systems are required, particularly for escape and survival. The Mining Program should be prepared to develop a systematic approach to the remote control of mines and mine systems.

• Continuous monitoring of conditions, especially by remote means, will become increasingly vital as the mining environment becomes more complex. The Mining Program should develop the means to continuously monitor data, with the possibility for response via intelligent system analysis, as the level of complexity increases.

• The need to improve emergency escape and survival equipment will increase with a more complex mining environment. Communications, emergency response, and rescue team deployment strategies will all be more difficult in future mining settings. The Mining Program should be aware of internationally developed technologies, while continuing to develop its own as needed, to have the best disaster prevention and response strategies in place as change occurs.

EMERGING AREAS IN GROUND FAILURE PREVENTION RESEARCH

• There are highly sophisticated numerical techniques for modeling variously shaped openings in discontinuous and heterogeneous materials. However, simplifications are almost always required to reduce the problem to a manageable level. A fresh look needs to be taken to model in situ conditions more accurately. The Mining Program should consider further developing the fundamental design methodology with an evaluation of the sensitivity to variability in the input parameters.

• The recent emergency at Quecreek and close calls at other underground mines emphasize the importance of being able to detect voids before mining begins. The Mining Program should investigate the applicability of current or newly developed technology in detecting voids, especially those containing water, and should consider the benefits of developing routine procedures to improve mining in the vicinity of old mines and at-risk geologic conditions.

- At great depths, violent failures of pillars and longwall faces produce extreme hazards to underground workers and contribute to mining-induced seismicity. The potential for bursting could be reduced by appropriate mine layout and mining sequencing. Mining Program research into the relative merits of various mine design scenarios would likely reduce hazards and optimize resource recovery.
- Explosives are commonly used to drive openings for underground metal mines and for some stone mines. Unwanted damage beyond the perimeter of the opening often results from fractures that extend from the blastholes into the surrounding rock mass. These fractures weaken the roof and walls of the opening and contribute to unexpected rock falls. Research is needed to improve understanding of the fracturing process and to develop better design methods to limit collateral damage. Research is also needed to remove blast-damaged rock through better scaling methods and protection of workers by improved surface treatments.

EMERGING AREAS IN SURVEILLANCE, TRAINING, AND INTERVENTION EFFECTIVENESS RESEARCH

- Exposure monitoring of processes that are increasing in use, but not well characterized, is needed. For example, in situ leaching and increased solvent extraction-electrowinning[1] (SX-EW) in copper and other metal mining should become a major focus, given the shift toward the use of this method. The Mining Program should identify these types of processes and be prepared to identify or develop best exposure monitoring techniques.
- As monitoring becomes more efficient, the effects of mixed exposures should be evaluated. The effects of combined exposure to dusts and chemicals on the health of miners and the effects of various combined components of diesel exhaust, particularly as new pollution control equipment changes the chemical characteristics of the exhaust, need to be understood. There are guidelines and suggestions for multimode exposure in other industries. Mining does not have either a standard or a guideline. This could be a worthwhile area for future Mining Program research.
- As stated several times, the mining environment is changing. Given the move toward deeper mines, the Mining Program should evaluate the environmental and occupational hazards of deeper mines (especially heat exposure).
- Advances in information technology bring new opportunities for informa-

[1]Electrowinning is the process of extracting metals from solution by electrolysis.

tion dissemination. The Mining Program should study the effectiveness of new educational materials, including virtual reality training, to ascertain if the increased cost of these techniques is associated with greater change in miner awareness and reduction in hazardous work activities.

7

Synthesis of Recommendations

The National Institute for Occupational Safety and Health (NIOSH) Mining Program makes essential contributions to the enhancement of health and safety in the mining industry. The recommendations provided in this report are focused on further expanding these contributions. The Mining Program should be leading discussions on mine health and safety improvements.

Recommendations specific to the Mining Program's seven strategic research areas are provided in Part II (Chapters 8-14) of this report. This chapter is a synthesis of recommendations applicable program-wide.

PROGRAM PLANNING AND STRATEGIC GOALS

The ultimate goal of the Mining Program should be the complete elimination of mining occupational disease and injury. To move closer to this goal, **strategic and intermediate goals and attendant objectives should be made more challenging and innovative.** The Mining Program should accelerate the development of engineering controls aimed at meeting MSHA personal exposure limits for mining-related hazards. Strategic thought should be given to stakeholder needs so that intended and likely end users are clearly identified as research is conceptualized. The Mining Program should continue to develop new technologies and enhanced training programs, but the latter should be strengthened to recognize and correct substandard conditions and practices that contribute to mine accidents. While research on issues associated with coal mining continues to be of high priority, research in other mining sectors should also be emphasized. Strategic planning should occur on a regular basis to discuss potential Mining Program responses to emerging trends in production and processes. To maintain a viable research program at reasonable cost, NIOSH and the Mining Program should ensure the permanent availability of the Lake Lynn Facility.

The Mining Program should take a more proactive approach to identifying and controlling hazards. At present, the Mining Program sets most of its research priorities in response to stakeholder input or events, which helps ensure the applicability of the resulting research outputs. However, using surveillance data in combination with expanded external input to identify key priorities would help the Mining Program develop a more proactive approach to hazard identification and control.

EFFECTIVE INTERACTIONS

The Mining Program interacts with numerous researchers, regulators, and other stakeholders and goes to great lengths to establish successful and mutually beneficial relationships. The following recommendations are intended to improve these interactions.

Intra-Agency Interactions

The Mining Program should increase interaction with other NIOSH programs, including the Respiratory Disease Program, and individual programs within the Division of Safety Research and the Division of Surveillance, Hazard Evaluations, and Field Studies. Ideally, research personnel with medical, epidemiological, engineering, geological, and industrial hygiene experience should work together as a research team to help address workplace issues including work organization research. Additionally, full advantage should be taken of NIOSH's Mine Safety and Health Research Advisory Committee (MSHRAC) by adequately challenging it with substantial assignments. MSHRAC's findings, conclusions, and recommendations should be considered more fully in the Mining Program's decision-making process.

Interaction with Regulators

The committee recognizes the high level of cooperation between the Mining Program and the Mine Safety and Health Administration (MSHA) and notes this partnership is essential for advancements in miner health and safety. Based on presentations from the acting director and others at MSHA (Dye et al., 2006), the committee believes **the Mining Program should enhance interaction with MSHA in areas where research needs are closely allied to MSHA's legislative and shorter-term requirements** associated with enforcement, rulemaking, education and training, and technical assistance**.** The effect of regulatory measures on the reduction of mining injuries and illnesses should be evaluated and considered in program planning.

Partnerships

Partnering with specific mining companies is beneficial and key to technology transfer, but **efforts should be made to partner more broadly such that guidelines and processes are most relevant to the entire mining community.** Further, more partnering with manufacturers of specialized mining and mineral processing equipment (e.g., dust and noise control equipment) would be beneficial.

Partnerships with universities should be pursued to develop training materials for mining engineering students and occupational or environmental health students, similar to the way evidence-based lessons are communicated to medical students. Additional stakeholders, such as the American College of Occupational and Environmental Medicine, should be added to the Mining Program's list of collaborating professional associations, and partnerships should be sought with those giving voice to the needs of vulnerable populations. The Mining Program should work with international partners to determine the most effective regulatory and work practices. The extent to which the Mining Program should directly assist developing countries in evaluating exposures should be determined and a program developed to prioritize requests if this area is funded.

Extramural Research

The Mining Program should fully utilize outside technical expertise through a vibrant extramural and contract research program. This would serve to broaden the knowledge base and the overall effort toward achieving Mining Program goals. An extramural research program may prove especially vital given the critical need to increase capacity in mining health and safety.

OUTPUTS

The Mining Program should place greater emphasis on outputs preferred by mining operators, miners, and other nontechnical users. Through systematic but small-scale formative evaluation, the Mining Program should learn more about current information-seeking behavior, media use, and sources of influence in the personal decision making of its stakeholders. The quality of outputs for nontechnical users should similarly be determined. Feedback from representative members of potential user groups should be gathered to assess and improve prototypes of outputs prior to release. Measures of output quality should be considered for collection and tracking.

SURVEILLANCE AND MONITORING

The committee considers the collection of surveillance data of utmost importance in monitoring worker health and safety conditions and determining the effectiveness of Mining Program activities. **The Mining Program should make better use of MSHA and other existing surveillance data and work to make these surveillance programs more robust.** For example, the demographic survey data of mine workers should ideally be collected annually to allow for longitudinal analysis. An improved surveillance system would allow the Mining Program to evaluate intervention effectiveness, which should be incorporated into all its strategic goals.

More robust and better monitoring methods of in situ safety conditions in mines should also be developed. Research is needed to minimize safety risk to underground workers and evaluate the potential for damage to surface facilities such as dams, buildings, pipelines, road cuts, and other structures whose failure could cause injury to persons on or near mine property. Recent advances in remote sensing, telemetering, and diagnostic methods need to be evaluated, improved, and made known to mine operators for timely detection and avoidance of underground and surface mine hazards.

To aid in tracking research and training effectiveness, the Mining Program should think of collaborative research as a type of output with the potential to result in intermediate outcomes. These interactions should be tracked and regularly reported. Monitoring and reporting of all intermediate outcomes should be expanded and improved so that stakeholder responses to program outputs are understood. Measures of output quality, as well as quantity, should be collected and tracked.

TRAINING PROGRAMS AND TECHNOLOGY TRANSFER

Just as the committee recommends surveillance be incorporated into all relevant research areas, **training should be incorporated into the strategic goals of all research areas.** To improve training effectiveness, **the Mining Program should determine the likely end users of its research results.** Technology transfer could be enhanced by targeting mine operators and workers who effectively influence the decisions of others. A literature-based review of studies concerning the measurement of opinion leadership, the testing of alternatives in this procedure, and the use of sociometric (who-to-whom) network analysis software for easier and more accurate mapping of influence across and within mines is recommended. NIOSH should also review new research on issues of worker empowerment, worker control in education and training, and technological changes and new forms of work organization that significantly change working conditions. Further research should be conducted in worker-centered peer training using a safety systems approach. This research should include the use of worker peer trainers and train-the-trainers models, worker participation in curriculum development including lessons learned from systems failures, workers conducting program evaluations, and worker participation in health and safety program administration. These issues should be taken up by NIOSH project staff with workers and their representatives.

With respect to information dissemination, **a more proactive and strategic dissemination agenda is suggested, one that is informed by research about the diffusion of new technologies, processes, and practices. The Mining Program should develop demonstration projects to show the feasibility and effectiveness of interventions.** Most Mining Program outputs are useful for small business, but **plans for technology transfer of all project outputs should explicitly include how small-business worker populations will be served.** To reach this population, the Mining Program should work with MSHA's Technical Assistance Program. New information about evidence-based health and safety innovations should be disseminated specifically to smaller mines and equipment manufacturers.

EMERGING ISSUES FOR THE MINING WORKPLACE

As part of its charge, the committee considered emerging issues affecting future mine worker health and safety. **The Mining Program should stay aware of pertinent current and emerging research, including international research, and be prepared to act on potential health and safety issues.** Future workforce issues may differ from current issues, especially as older workers retire and a new, younger workforce enters the industry. To determine future research areas, the Mining Program should continue to work with industry, organized labor, MSHA, academia, and international partners. Both internal and external peer review could be useful for selecting projects.

The committee identified workforce capacity and related issues as the most crucial of emerging issues the Mining Program should deal with, but the committee also considered the physical conditions to which the future mining workforce will be subject. Similar concerns were stated more than 30 years ago during a major revision of the research mission of the U.S. Bureau of Mines (Theodore Barry & Associates, 1972), but it should be noted that the current industry situation is quite different from the past in terms of operation size, numbers of miners, and technologies in use. Research on the relationships between mining tasks, demands on mine workers, and changing environmental factors is needed. The committee provides the following four general recommendations related to future physical conditions:

1. As the mining industry becomes more automated**, the Mining Program should be prepared to deal with issues associated with increased remote control and automated equipment and systems.** Future mining is likely to be carried out under more difficult conditions. Automation is often seen as a means of reducing exposure, but unforeseen consequences of automation should be identified.
2. To meet expected demand for coal, mining will progress to depths in excess of 600 m. **The Mining Program should be prepared to provide recommendations to safeguard health and safety as best strategies for mining deep resources are developed.** Environmental and occupational hazards of deeper mines should be evaluated.
3. **The health effects of mixed exposures, such as diesel exhaust, hydrocarbons, and noise, as well as the combined effects of mixed noise (continuous and impulse-impact) environments, need to be addressed.**
4. **As the United States increases its reliance on nuclear energy, the extent and effects of radon and radiation exposure in the presence of these other potential chemical agents should also be considered.**

The committee is also very concerned about the future performance of the Mining Program itself. **The Mining Program should seriously attend to workforce replacement issues expected within its own organization in the short term to ensure a supply of capable researchers as its older researchers retire.** Increasing extramural research may be part of the solution. Special attention may be needed to maintain a small but viable core group of professionals within the Mining Program to ensure research in fundamental areas such as strata control, the atmospheric mine environment, injury and disaster prevention, and mining systems is not seriously affected by attrition. To increase the number of individuals with expertise in exposure monitoring and control, the Mining Program should encourage the training of mining engineers in industrial hygiene and the inclusion of mining-specific topics in industrial hygiene training. Future research should focus on combining all sources of data with an intelligent decision-making system, for example, to enable real-time system control decisions made with all relevant monitoring data input. Mine operators and workers need the ability to collectively access the wisdom of the industry and its experts. This type of operation system could facilitate better decision making regarding a variety of health and safety issues, across the mining industry for all sectors and mine sizes.

The committee recognizes the Mining Program's positive role in providing new technologies for a safer mining environment and new training materials for the mining industry. The recommendations in this report are offered with the expectation that they will help the program refocus or redirect some of its efforts to more effectively impact the health and safety of the mine worker.

Part II

Evaluation of Strategic Research Areas

In this part of the report, the committee provides a detailed analysis of each of the Mining Program's seven strategic research areas. The format of each chapter corresponds with the evaluation flow diagram presented in Figure 1-1. A qualitative assessment of relevance and impact of each of the research areas is provided, but no scores are given. Recommendations specific to each program area are provided.

8

Review of Respiratory Disease Prevention Research

Key Findings and Recommendations for Respiratory Disease Prevention Research

- In general, research in this area is in high-priority subject areas and has generated important new knowledge. The program is well engaged in transfer activities and is adequately connected to improvements in workplace protection.
- The ultimate research goal should be the complete elimination of all occupational respiratory diseases in the mining population.
- Interaction with other NIOSH research programs and divisions should be increased.
- The NIOSH Mining Program should accelerate the development of engineering controls for respirable dust (including quartz) and diesel particulate matter.
- The Mining Program should identify those occupations and tasks that result in chronic overexposure to silica dust.

RESEARCH IN MINING RESPIRATORY DISEASE REDUCTION

Respiratory diseases have always been a health risk for mine workers. All mining processes create fine dusts, some of which is respirable. Prolonged exposure to high levels of respirable dust can lead to the development of respiratory diseases such as coal worker's pneumoconiosis (CWP), silicosis, and chronic obstructive lung disease (Morgan, 1984; Christiani, 2005a, b). The Mining Program and the former U.S. Bureau of Mines (USBM) developed appropriate strategies to control and eliminate these diseases. Other divisions of the National Institute for Occupational Safety and Health (NIOSH), such as the Division of Respiratory Disease Studies (DRDS), the National Personal Protective Technology Laboratory (NPPTL), and the Health Hazard Evaluation Program (HHE), are also involved in the development of strategies for preventing mining-related respiratory disease.

CWP, silicosis, and lung cancer are chronic, irreversible, disabling, and sometimes fatal. With the exception of exposure to very high levels of silica, which can cause acute silicosis, the occurrence of these disease outcomes typically depends on cumulative exposure over decades. Monitoring the prevalence and progression of respiratory diseases, and measuring exposures and the many disease confounders, must occur over equally long periods.

Diesel particulate matter (DPM) and radon gas represent other hazards to miners' lungs. The major components of DPM are solid carbon (including elemental and organic carbon), liquid and solid hydrocarbons (including polyaromatic hydrocarbons), sulfate, and moisture. High concentrations of DPM add to the risk of CWP and may also increase the risk of lung cancer. Radon gas and its radioactive decay products are present in uranium and other mines, and exposure increases the risk of lung cancer.

STRATEGIC GOALS AND OBJECTIVES

The strategic goal of the Mining Program's respiratory disease prevention research (NIOSH, 2005a) is to "reduce respiratory diseases in miners by reducing health hazards in the workplace associated with coal worker pneumoconiosis, silicosis, and diesel emissions." The performance measure of this goal (NIOSH, 2005a) is the reduction of

> . . . respirable coal dust overexposures of operators of longwall and continuous mining machines, roof bolters, and surface drills by 50% and the overall silica exposure of crusher operators and stone cutters by 50% within 10 years. The goal will also be achieved by reducing coal miner exposure to DPM by 80% and metal and nonmetal miner DPM overexposure rates by 50% within 10 years.

The baseline for this performance measure is not immediately discernible from materials provided to the committee by the Mining Program.

Three problems come to mind in reviewing the strategic goal and performance measures: (1) Limiting attention to respirable dust exposure in specific mining occupations obscures exposure that occurs to miners in other occupations. It is appropriate, for example, to focus attention on exposure of all workers on longwall sections, not simply shearer operators. (2) The most troublesome exposure of roof bolters and surface drill operators is to silica, not respirable coal mine dust. Additionally, it is respirable coal mine dust—a mixed dust—not respirable coal dust, that is the measured etiologic agent. (3) In coal mines, ambient exposure to DPM is not measured by NIOSH or by the Mine Safety and Health Administration (MSHA), and it is currently not clear how best to measure reduction of exposure to DPM. Therefore it is difficult to see how to measure progress toward this goal.

Table 8-1 summarizes the Mining Program's six intermediate goals and performance measures associated with respiratory disease prevention research. Committee comments are also provided.

The considerable reduction of airborne respirable dust concentrations in coal mining and the decrease in the prevalence rates of disease indicate control strategies have been effective. Respirable dust sample data collected by MSHA and mine operators also indicate a significant reduction in exposure.

The strategic goal for well-recognized diseases such as silicosis and CWP is to eliminate disease incidence. Health risks associated with exposure to DPM should also be reduced. This means the Mining Program needs to develop a complete understanding of the incidence rate of diseases such as silicosis and CWP, as well as control measures that will further reduce exposure to respirable coal mine dust, silica, and diesel engine emissions.

REVIEW OF INPUTS

Inputs to the Mining Program include Recommended Exposure Limits (RELs) for respirable dust in coal mines and for silica in all mines established by others. The coal mine workers medical surveillance program of the DRDS also provides valuable input to the mining program by documenting trends and clusters in the occurrence of CWP.[1] Primary and secondary prevention of CWP and silicosis require reduction of exposure for all miners and additional reduction for miners with early signs of disease (e.g., positive chest X-ray for CWP).[2] The primary source of worker dust exposure data is sampling data collected by MSHA and mine operators, per the 1969 Coal Mine Act and then the 1977 Mine Act. Despite their limitations, these data collectively represent some of the best available information on exposure, epidemiologic, and toxicological findings. Though MSHA data indicate a general reduction in exposure to respirable coal mine dust since the 1980s, MSHA informed the committee of a cluster of CWP cases in one region of the country—a good reason for the development of a program to determine CWP causes and control measures. Exposure to silica remains a problem in metal and non-metal mines (Weeks and Rose, 2006).

[1]"Trends and clusters" is conventional terminology for characterizing the purpose of medical surveillance, after *A Dictionary of Epidemiology* by John M. Last. Similarly the term "occurrence" is also conventional terminology for characterizing what it is that epidemiology or surveillance does (i.e., measures whether or not an outcome occurs).

[2]Primary disease prevention refers to the prevention of disease occurrence; secondary disease prevention refers to the prevention of disease progression.

TABLE 8-1 Intermediate Goals and Performance Measures of the Respiratory Disease Prevention Program and Committee Comments

Intermediate Goal[a]	Performance Measure[a]	Committee Comments
1. Develop real-time, person-wearable monitoring technology for respirable coal dust	This goal will be achieved if a real-time, person-wearable dust monitor (PDM) is commercially available and in use by 2009	The intermediate goal as stated is an activity. Use of the PDM may allow workers to immediately respond to exposure, enable mining companies to monitor concentrations versus production, and enable regulators to detect excursions above mandated levels—all possible once the PDM is widely in use for specified purposes. The Mining Program should be prepared to make appropriate recommendations to MSHA and individual operators as decisions are being made about the use of the PDM
2. Reduce exposure of longwall miners to coal dust	This goal will be achieved if the frequency of overexposure is reduced by 50% over the next 6 years (baseline is 2003)	Feasible, but not very ambitious in view of past accomplishments in this area. Overexposures may be site specific and may require site-specific approaches. The relationship between occasional overexposure and disease occurrence is not clear. A more appropriate approach may be to develop technologies to reduce ambient levels, making overexposure occurrence a rare event
3. Reduce coal miner exposure to silica and coal dust	This goal will be achieved if improved control technologies reduce the frequency of overexposure of continuous miner operators, roof bolter operators, and surface drill operators by 50% within 5 years (baseline is 2003)	Same as above

4. Reduce silica dust exposure of workers in metal and nonmetal mines and mills	This goal will be achieved if improved control technologies reduce silica exposures by 50% for crusher operators in mines and mills, workers in enclosed equipment cabs, and stone cutters in dimension stone plants within 4 years (baseline is 2003)	Performance measures should not be restricted to those stated; other workers have high exposures as well (Weeks and Rose, 2006)
5. Reduce miner exposure to diesel emissions in underground mines	This goal will be achieved if (1) underground coal miners' exposure to DPM is reduced by 60% within 6 years and (2) the frequency of overexposure of metal and nonmetal miners to DPM is reduced by 40% (assuming the current 400 μg/m^3 standard) (baseline is 2003)	Feasible but, since neither MSHA nor NIOSH monitors ambient exposure in coal mines, it will be difficult to measure
6. Reduce exposure to dust, silica, and diesel emissions in large-opening mines through the development of improved ventilation science	This goal will be achieved if 20% of large-opening mines incorporate these improved ventilation designs within 5 years	No relationship between the goal and the performance measure; not clear what is meant by "improved ventilation science"

[a]SOURCE: NIOSH, 2005a.

The current Mining Program budget for respirable dust research is $4.5 million per year with only about $1 million for the discretionary budget. The total staff is 34. The laboratory facilities at both Pittsburgh Research Laboratory (PRL) and Lake Lynn Laboratory (LLL) are excellent and world class; however, staffing and budget allocations will have to be increased if mining-related respiratory diseases are to be eliminated.

Input from major stakeholder groups is strong and substantial in many areas resulting in, for example, the successful PDM and Diesel Partnerships. However, creative working relationships with other divisions in NIOSH (e.g., DRDS; NPPTL; the Division of Surveillance, Hazard Evaluations, and Field Studies [DSHEFS]), with MSHA, or with mine operators and unions are not always obvious in NIOSH mining respiratory disease prevention research. There is no apparent input from small mine operators or workers, yet workers at these mines are at high risk. In the opinion of the committee, based on members' knowledge of the research conducted within NIOSH programs, dust and diesel exhaust control efforts should be better integrated with surveillance work at DRDS or other health effects research conducted at DSHEFS to ensure the best use of developed monitoring technologies and surveillance.

Although there seems to be limited interaction between the Mining Program and other NIOSH programs with respect to respiratory disease prevention, and little input from small mine operators, the Mining Program is exceptionally receptive to major stakeholder input.

REVIEW OF ACTIVITIES

The Mining Program describes 14 current projects in mining respiratory disease reduction in materials submitted to the committee (NIOSH, 2005a). These projects are summarized and briefly evaluated in Table 8-2. There is no distinction made by the Mining Program regarding to what extent the work is carried out within other NIOSH research programs.

Surveillance of disease occurrence and monitoring of exposure and control effectiveness are important elements of an effective disease control program. Screening and surveillance are conducted by other divisions within NIOSH and are essential aspects of prevention. In any case, both aspects are part of the Mining Program and provide a model for prevention of any occupational disease because they link assessment of both exposure and outcome.

TABLE 8-2 Respiratory Disease Prevention Projects and Committee Assessment of Relevance and Impact

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
Projects Related to Personal Exposure Measurements				
1. Assessment of Personal Particulate Exposure	All	Development of two devices: 1. A PDM providing real-time measurement of silica and coal dust exposure of miners	Development of a PDM is a good start, enabling the measurement of daily and cumulative dust doses of designated operations	Depending on implementation by MSHA, this device could be very useful for identifying dust sources and reducing miners' exposure. The prevention of overexposure is expected
		2. A method to measure diesel exhaust particulate from engine tailpipes	A relevant, practical, and effective means of controlling exposure to DPM	A feasible way to measure and control exposure to DPM and simultaneously identify its source (e.g., the engine being measured)
2. Miner's Response to Personal Dust Monitor Feedback	1	Systematically document how workers react to and use PDMs by conducting one-on-one interviews with 20 miners at each of five mines. Outputs will be training materials for future users of the PDM	The PDM introduces new information to miners and mine operators, and their reactions are basically unknown. The PDM is a good start but a larger resource base is needed to cover all mine workers	Timely and accurate information about exposure is most important for controlling exposure and preventing disease

continued

TABLE 8-2 Continued

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
Projects Related to Better Dust Control Technologies				
3. Advance Spray Dust Capture Principles for Mine Dust Control	2, 3, 4	Reduce mine worker exposure to coal and/or silica dust by increasing dust capture efficiency of mine water spray systems	Marginal relevance	Past research in this area has been very successful, but the committee's opinion is that the reduction in dust concentrations due to additional research on spray pressures and orientation is likely to be marginal
4. Dust Control for Longwall Mining	2	Reduce respirable dust at longwall operations by optimizing control parameters that impact dust generated by the shearer, evaluate shield dust entrainment in high-velocity airstreams up to 2,000 feet per minute, conduct benchmarking surveys on longwall faces to quantify dust levels from various sources, define current operating practices, and determine the relative effectiveness of control technologies	Since exposure on longwall sections is highest and most troublesome, this emphasis is appropriate and the relevance of this work is high	Impact is expected to be high, but generic dust control methods may have to be adapted to section-specific characteristics such as coal friability, moisture, seam height, etc.

5.	Improving Ventilation Technology in Large-Opening Mines	4, 6	Methods developed and evaluated to (1) identify proper fans to use in large-opening mines; (2) integrate ventilation needs into mine planning process to aid use of efficient generic ventilation designs; (3) develop computer program to determine air flow volume to meet statutory DPM requirements based on equipment used at individual mine sites; and (4) improve construction methods and materials used for stoppings that direct air to critical areas of large-opening mines to reduce exposure to airborne contaminants	Moderately relevant	Impact is expected to be low to moderate. Improved ventilation should be complemented by better dust and DPM controls
6.	Reducing Underground Miners' Exposure to Diesel Emissions	5	In-mine evaluations of DPM control technologies and development of a research facility employing a mobile engine dynamometer used in operating-like conditions, but resulting in near-laboratory-quality data.	Very relevant. Based on presentations at NIOSH workshops, controlling DPM exposure should use integrated, multifaceted, mine-specific methods, and each method has to be evaluated with this integrated approach in mind	Low to moderate impact expected. If the new technology can be developed, it will improve health and cut the cost of control equipment
7.	Selection and Evaluation of Diesel Emission Controls for Outby Underground Coal Mine Equipment	5	In-mine and laboratory evaluation of DPM control technologies involving (1) selection of potentially viable emission controls, (2) resolution of issues related to their use, and (3) information dissemination and education to facilitate implementation	Highly relevant. See comments above	Control technologies will be more efficient, cost-effective, and affordable

continued

TABLE 8-2 Continued

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
8. Silica Dust Control in Metal and Nonmetal Mining	4	Research to (1) develop optimized pressurization and filtration systems and implementation guidelines for enclosed cabs; (2) develop cost-effective method and instructional video for cleaning work clothes in an enclosed booth; (3) evaluate existing dust controls and develop improved ventilation controls for iron ore processing plants; and (4) demonstrate effectiveness of improved mine-wide and localized ventilation systems in limestone mines for diluting dust and reducing residence time	Highly relevant. Based on Mining Program descriptions of the work to date, the committee has some concern that underground gold mines, having highest exposure, are being overlooked	Though the program will be effective in reducing the dangers from silica dust in specific circumstances, the approach does not appear to address silica dust problems comprehensively and has the appearance of being unsystematic and ad hoc
9. Control of Silica Dust Exposure in Underground Coal Mining	3	Development of controls to reduce silica dust exposure of operators of continuous mining and roof bolting machines. This includes the evaluation of wet-head continuous miners, introducing water sprays behind cutting bits of continuous miners, and development of canopy air curtain for roof bolters	The approach seems appropriate for underground coal mines. On the other hand, these control methods are not unique to silica. Controls for silica would include developing methods for reducing the frequency of cutting into silica-bearing roof and for analyzing roof rock for its silica content	This could have the greatest impact on reducing silica concentrations if the technology can be developed and implemented

10. Surface Mine Dust Control	4	Improving understanding of dust generation principles, evaluation and improvement of current control technologies, and development of new technologies to reduce silica exposure of surface miners, including the use of air spray nozzles to maximize dust capture, wet drilling technology to minimize dust liberation, and determination of optimum drilling parameters to minimize dust generation	Relevant	Expected to ultimately reduce the generation of surface mine dust
Projects Related to Characterization of Respirable Mine Dust				
11. Characterizing Diesel Emissions in Underground Mines	5	Correlation of DPM concentration to actual elemental carbon or total carbon content of the sample	Relevant. More effort is required to develop a means of measuring DPM in metal and nonmetal mines	A moderate impact is expected
12. Ultrafine Aerosols from Diesel-Powered Equipment	5	In-mine and laboratory evaluation of control technologies on physical and chemical properties and toxicity of nanometer and ultrafine diesel aerosols. Measurement of size distribution and number, chemical composition, and genotoxicity of nanometer and ultrafine aerosols will be conducted to provide better understanding, and relevant metrics for monitoring worker exposure to DPM as well as industry acceptance of control technologies	It may be worthwhile to determine what mass fraction of respirable dust is associated with "ultrafine" particles. It may also be worthwhile to determine if the relevant measure of the toxic effects of nanoparticles could be something other than mass, such as particle surface area or count. Toxicity other than genotoxicity should be assessed, including cardiovascular effects	Impact cannot be ascertained at this time; the work is exploratory in nature

continued

TABLE 8-2 Continued

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
Projects Related to Lifestyle Intervention Programs Including Cessation of Smoking and Medical Surveillance				
13. Coal Workers' Health Surveillance Program (CWHSP)	3 (indirectly)	Early detection and prevention of CWP	Highly relevant	Limited impact without substantial increase of effort in this area
14. A Cohort Mortality Study with a Nested Case-Control Study of Lung Cancer and Diesel Exhaust Among Nonmetal Miners	5 (indirectly)	Investigation of the risk of lung cancer in relation to quantitative measures of DPM and determination if there is an elevated risk of mortality from other causes among miners exposed to DPM	Highly relevant; this is an important study because it provides better information about exposure to DPM and confounders and it is based on a large population	Impact is expected to be high

[a]SOURCE: NIOSH, 2005a.

The committee makes the following observations regarding respiratory disease prevention activities within the Mining Program:

- Current activities are directed at meeting the permissible exposure limit (PEL) standards in the 1977 Mine Health and Safety Act. The committee is aware of recommendations in the NIOSH Criteria Document (NIOSH, 1995) and the report of the Advisory Committee of the Secretary of Labor on coal mine dust and silica standards (U.S. Department of Labor, 1996). Both of these reports recommend reducing the PELs for respirable dust and silica.
- Routine monitoring for exposure to mineral dusts and diesel engine exhaust is conducted almost entirely by MSHA as part of its efforts to ensure compliance with applicable established exposure limits. Development of measurement methods, however, is largely a Mining Program activity. NIOSH has a statutory mandate to evaluate and certify devices for measuring exposure to respirable dust (30 CFR Part 74) and in this capacity, since 1970, has evaluated and refined the performance of the personal dust sampler unit.
- NIOSH has made, and continues to make, important contributions to measurement and control of DPM. The Mining Program also manages quality assurance for these instrument methods and for analytic methods to measure silica concentration.
- NIOSH is working on the means to measure miners' exposure to DPM. Since DPM is mostly carbon, coal dust and other carbon sources in mines present significant confounding impediments to measuring ambient DPM levels in mines. NIOSH has made progress addressing these sampling issues, but has yet to determine if it is pertinent or feasible to measure the concentration of total carbon (including organic and elemental carbon) or only of elemental carbon in metal and nonmetal mines.
- Activities designed to control exposure to silica have been more diffuse and difficult to evaluate. Activities have been devoted to specific occupations in the coal industry and in metal and nonmetal mining. Specifically, exposure to silica has been high for bagging operations, but with the development of less dusty methods, exposure has been reduced. Similarly, exposure of drill operators (present in coal, metal, and nonmetal mines, and in highway and other types of construction) has been reduced with the development of wet drilling methods and collaring methods developed by the Mining Program and mandated by MSHA (e.g., 30 CFR 58.620, 30 CFR 72.620).
- Between 2001 and 2005, the respirable coal dust samples in underground coal mines exceeding the 2.00 mg/m^3 standard ranged from 10 to 16 percent with a mean of 12.7 percent. The percentage of samples that exceeded the statutory silica concentration over the same period ranged from 28 to 36 percent with a mean of 32 percent—a valid cause for concern. These problems may be associated with site-specific factors needing mine-specific solutions.

• Extensive and effective model and demonstration studies have resulted in new equipment and procedures.

• The most successful research activities conducted in respiratory disease prevention are those that involve substantial interaction with stakeholders; for example, research that led to a rapid decrease in airborne respirable coal mine dust concentrations in continuous and longwall sections was conducted with substantial input from mine operators and equipment manufacturers. Specific examples of research outputs are scrubbers for continuous miners, spray fans on continuous miners, and shearer-clearer system for longwall shearers.

• Vulnerable working populations, including workers at small mines and young or inexperienced miners, have received limited attention. Given the age distribution of the current mining population and the increased demand for coal, many new miners may be hired soon, some of whom may not be fluent in English. Limited attention has been paid to training these populations.

• The committee is not clear about the extent to which internal or external peer reviews are conducted, and quality assurance procedures appear to be ad hoc for each project, rather than following program-wide criteria.

Overall, the committee believes Mining Program activities in respiratory disease prevention research address the most common and serious issues.

REVIEW OF RESEARCH OUTPUTS

The Mining Program has continued the USBM tradition of quality publications regarding respiratory disease prevention in professional journals and proceedings, technical reports, and handbooks. Much of this work has recently been compiled into a useful document entitled *Handbook for Dust Control in Mining* (Kissell, 2003). Extensive and effective model and demonstration studies have resulted in new equipment and procedures. Outputs are generally user-friendly in terms of design and are relevant to all mine workers. At least some are reports of "breakthrough" research findings with very positive intermediate and end outcomes. Many outputs address high-priority areas, have generated important new knowledge, and serve the mining industry well. Such outputs include the longwall shearer clearer, a wet scrubber for continuous mining machines (in collaboration with Peabody Energy), and a protocol for sampling and analyzing respirable silica (in collaboration with CONSOL Energy).

REVIEW OF TRANSFER ACTIVITIES

Transfer of knowledge, procedures, equipment, and methods of controlling respirable dust in coal mines has accelerated and persisted in response to mandates in the Coal Mine Act of 1969 (carried over to the Mine Safety Act of 1977) and due to the activities of the former USBM and the NIOSH Mining Program. Transfer of technology by the Mining Program, in partnership with stakeholders, has been very efficient, and technology transfer seminars on dust control research and development have also been very well attended.

Transfer activities associated with the development of the PDM have occurred along with technology development. Development of the PDM involved numerous meetings of all stakeholders in the PDM partnership, through all phases of developing this instrument (concept, design, development, in-mine evaluation, and modifications). This project can serve as an unprecedented illustration that both development and technology transfer benefit from strategic and well-organized partnerships between NIOSH, industry, instrument manufacturers, unions, and regulatory agencies.

Research on DPM exposure control has shown it to be a complex problem, solvable with the appropriate choice and maintenance of engines, fuel quality, emission controls, and mine ventilation. The Mining Program has held several technology transfer seminars related to DPM control for coal, metal, and nonmetal operators, recruiting engineers from other countries.

In general, there appears to be a coherent planned program to transfer technology related to respiratory disease prevention. Information is reaching the relevant stakeholders and workplaces throughout the industry. Less is known about the adoption and sustained implementation of Mining Program recommendations in the workplace.

REVIEW OF INTERMEDIATE OUTCOMES AND CAUSAL IMPACT

In the opinion of the committee, the development of the personal dust monitor (PDM), and methods to control exposure to diesel particulate matter are examples of success. The PDM provides the most important innovation for measuring dust since the conversion to gravimetric dust measurement. Diesel exhaust is a widespread hazard. Control of diesel exposure is important for miners and could be applied in other industry sectors.

Since CWP is caused by exposure to respirable dust, reduction of exposure is the principal means of preventing disease. Furthermore, since CWP is a chronic disease typically occurring only after many years of exposure, it is important to take a historical view of the effects of exposure reduction and to evaluate the prevalence of disease by the duration of mining experience. The effects of recent reductions in dust exposure will not be manifest for many years.

While there has recently been an increase in CWP in some coal mines in Virginia and West Virginia (Attfield et al., 2004; Antao et al., 2005, 2006), CWP rates have decreased by more than 70 percent in U.S. coal mines during the last 35 years, from 11 percent in 1970 to 2.6 percent in 2003-2005 (Pon et al., 2003). During the same period, the average respirable dust exposure for continuous miners was reduced from 6 to 1 mg/m^3, while longwall face dust exposure was reduced from 4 to 2 mg/m^3. The rate of reduction in recent years has not been as dramatic as in earlier years, but the downward trends persist nevertheless.

Methods have been developed for controlling exposure in selected mining operations, such as drilling and bagging of sand. Detailed data for silicosis reduction are not available.

REVIEW OF END OUTCOMES

The ultimate goal of any mining respiratory disease prevention program should be complete elimination of all mining-related respiratory diseases. Epidemiologic research of CWP has been conducted by DRDS for more than 30 years. Given the chronic and insidious nature of this disease, a similar time span for determining and developing control measures is appropriate. There has been a significant decline in CWP rates, taking into account the age and exposure duration of individual miners, shown in Figure 8-1. This chart demonstrates that the prevalence of CWP (≥ Category 1/0), stratified by years of experience as a miner, declined significantly from 1987 to 2002. This indicates success in respiratory disease prevention.

Since there is no surveillance of silicosis occurrence, aside from monitoring its appearance on death certificates (a method with limited reliability), the effects of measures to reduce exposure to silica dust cannot be evaluated. Also, since DPM is currently defined as a "potential carcinogen" and lung cancer has several prominent causes, it is difficult to organize surveillance to specifically measure DPM control effectiveness. NIOSH, however, in collaboration with the National Cancer Institute, is studying the link between lung cancer and exposure to DPM in a group of miners exposed neither to silica nor to radon and its progeny. Although this project is conducted by DRDS, the Mining Program has played an important role in recruiting operators to participate in characterizing exposure.

The Mining Program (and before 1996, the USBM), with the collaboration of mine operators, miners, and their unions, played a critical role in achieving reductions in respiratory diseases by developing feasible and effective means of reducing exposure to respirable dust.[3] Results of respiratory disease research within the

[3]Developing control methods is a necessary, but not a sufficient, condition for preventing disease. Other aspects, not discussed in this report, involve programs managed by other divisions within NIOSH and include development of exposure limits, disease surveillance to both evaluate and document progress, and research into the pathophysiology of disease. Aspects managed by other departments of government include enforcement of exposure limits, creation of the right of miners with CWP to work in less dusty environments, and compensation for miners disabled by pneumoconiosis.

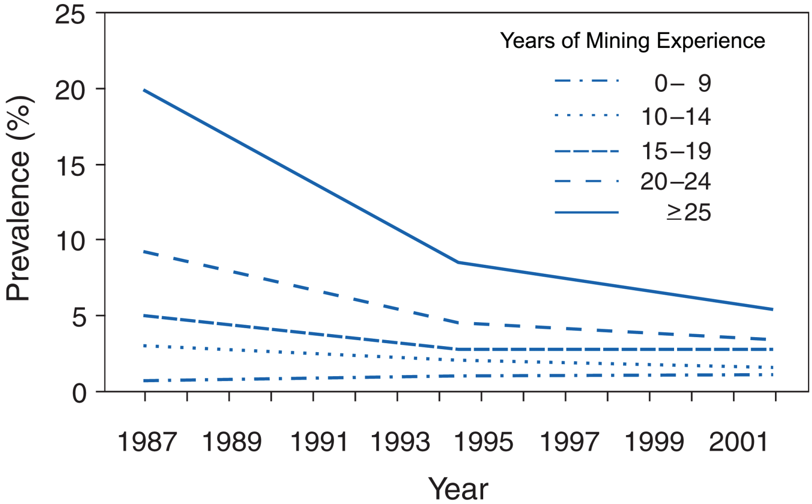

FIGURE 8-1 Trends in prevalence of CWP (≥ Category 1/0) over time (1987-2001). Data are stratified by years of mining experience—U.S. National Coal Workers' X-Ray Surveillance Program, 1987-2002. SOURCE: Adapted from Pon et al., 2003.

Mining Program are applicable to other industries and have already been applied in tunnel driving and dust control at the nuclear waste repository in Nevada.

ASSESSMENT OF RELEVANCE AND IMPACT

Mining Program efforts in respiratory disease prevention have made at least a moderate contribution on the basis of end outcomes or well-accepted intermediate outcomes and have had impact on the worker. In some areas, such as the effort to reduce CWP, the research program has made a major contribution to worker health and safety. In general, the research program has generated important new knowledge and is well engaged in transfer activities. End outcomes are not always documented. Research is generally in high-priority subject areas and adequately connected to improvements in workplace protection.

PROGRESS IN TARGETING NEW RESEARCH

On the basis of the review of current projects, the committee believes there is a need for the Mining Program to redirect its efforts in several projects toward issues more relevant to the industry in coming years. The scope of the work needs to be expanded in a number of areas. Reference has already been made to expanding the scope of research in silica and dust control to larger occupational work groups than now addressed. A more effective and appropriate approach to control workplace overexposure is to develop technologies to reduce ambient concentrations that would make overexposure a rare event. Research on measurement and control of diesel exhaust should be conducted by the Mining Program to enhance the impact and relevance of its work. Issues related to methods of DPM control need to be addressed, as made evident from differing state and MSHA requirements.

The Mining Program should devote more time and attention to several aspects of miners' exposure to silica dust. Specifically, the Mining Program should identify those occupations and tasks that result in chronic overexposure (e.g., exposure above the MSHA PEL) and instances of short-duration exposure to high concentrations (acute overexposure). Once those occupations and tasks are identified, the development of engineering controls should follow. In collaboration with DRDS, the Mining Program needs to develop methods for evaluating exposure conditions associated with cases of acute or accelerated silicosis. The Mining Program should also develop methods for measurement of miners' exposure to freshly fractured silica on the job and, collaborating with DRDS, for evaluating the health risks to humans of exposure to freshly fractured silica.

The Mining Program should develop alternative uses of the PDM for surveillance and research purposes. The PDM has increased the capacity to monitor exposure with significantly greater depth and breadth. Given this capacity—to measure exposure for extended shifts, to measure exposure on a daily basis, to measure inter- and intra-shift variability in exposure, and to project exposure to the end of a work shift—the ways in which this instrument can be used to enhance health and safety at the workplace should be explored.

Signature Accomplishments: Development of the Personal Dust Monitor and Reduction of the Prevalence of CWP

Since about 1978, the USBM, and later the Mining Program, have worked, intermittently, on the development of a direct-reading dust sampler that would provide miners and mine operators real-time information about dust exposure using an instrument more resistant to spurious readings than the previous sampling technology. Over the past decade, this work has intensified in a very productive partnership involving mine operators, mine worker unions, MSHA, and the device manufacturer. This work has resulted most recently in the personal dust monitor, now shown to be accurate, feasible, and otherwise suitable for use in underground coal mines. The PDM could provide a powerful tool to help reduce dust exposure and could result in the most significant change in dust sampling methodology in more than 50 years. This instrument was developed specifically for use in underground coal mines. It can also be used at surface and metal or nonmetal mines and in other industries where there is exposure to airborne particles.

Another signal accomplishment is a significant reduction in exposure to respirable coal mine dust with consequent reduction in the prevalence of CWP. In 1970, exposure to dust was about 6 mg/m^3 for continuous miner operators. Now, exposure at most continuous mining sections is about 1 mg/m^3. Reductions have been achieved on longwall sections, though not on a similarly dramatic scale (Weeks, 1993). As a consequence, the prevalence of CWP among experienced coal miners was 11 percent in 1970[a] and, according to the most recent data, is now 2.6 percent (Pon et al., 2003). This improvement was accomplished through the combined efforts of many including the Mining Program, which developed and made information available on many practical, feasible, and effective means of reducing exposure to dust in coal mines. This is a noteworthy and unqualified success story.

[a]See *http://www2.cdc.gov/NIOSH-chartbook/imagedetail.asp?imgid=223.*

9

Review of Noise-Induced Hearing Loss Prevention Research

Key Findings and Recommendations for Noise-Induced Hearing Loss Prevention Research

- The moderate reductions in noise exposures resulting from partial cabs on surface drilling rigs, coated flight bars on continuous miners, a new dust collector fan design, a jacketed tail roller, and substituting mist for water in roof bolters are important.
- The Mining Program should accelerate development of engineering controls for mining activities aimed at meeting the NIOSH Recommended Exposure Limit for noise exposure.
- The rank-ordering of noise exposures for all mining occupations should be performed based on relative exposure levels and the number of people affected.
- More research should be conducted on speech intelligibility in the midst of high-noise areas and while wearing hearing protection devices, noise control for metal or nonmetal mining, and noise control in longwall mining.
- Individuals who have experienced hearing loss (particularly older miners) need to be protected from further hearing loss.
- Verbal and possibly nonverbal communication should be improved to ensure the safety of hearing impaired individuals is not compromised.
- New noise partnerships should be pursued with stakeholders in mining segments other than coal mining.

Occupational hearing loss continues to be one of the most pervasive problems facing today's workers. More than 30 million Americans across many fields are regularly exposed to hazardous noise levels (Franks et al., 1996; NIH, 2002). In the mining industry, hearing loss is the second most reported injury, representing 20.9 percent of diseases newly reported to the Mine Safety and Health Administration (MSHA) in 2004 (MSHA, 2006). In addition, 25 percent of the mining population is reported to be exposed to levels exceeding the permissible exposure limit (PEL) of 90 dBA (sound level in dB after applying the A-weighting filter). In response, noise is considered by the National Occupational Research Agenda (NORA; *http://www.cdc.gov/niosh/nora*) to be a high-priority research area for disease and injury prevention, and it continues to be a top priority in NORA-2 (NIOSH, 2005b).

In 1997, MSHA established health standards for occupational noise exposure aimed "to prevent the occurrence and reduce the progression of occupational noise-induced hearing loss among miners" (30 CFR Part 62). The 2001 promulgation of Title 30 in the Code of Federal Regulations (30 CFR Part 62), Occupational Noise Exposure, emphasizes the primacy of engineering and administrative noise controls and fuels increased interest in noise-induced hearing loss prevention research by all stakeholders, including universities, manufacturers, government offices, industry associations, labor, mining companies, professional associations, and foreign entities.

STRATEGIC GOALS AND OBJECTIVES

Strategic goal 2 of the National Institute for Occupational Safety and Health (NIOSH) Mining Program is to "reduce noise-induced hearing loss (NIHL) in the mining industry," with the ". . . ultimate long-term measure of success . . . the elimination of new cases of NIHL." While it will take decades to assess whether the Mining Program has achieved this goal, the Mining Program has more immediate and quantifiable goals of reducing noise exposure by 25 percent in 5 years and 50 percent in 10 years. These goals, while noble, are not under the direct purview of NIOSH or its Mining Program and can be achieved only with the cooperation of all stakeholders (manufacturers, other government agencies, management, and labor). For example, hearing loss that results from other sources can be hard to separate from occupational sources and would threaten the success of this goal. More appropriate objectives, such as the four intermediate goals listed in Table 9-1, involve producing the technologies and awareness that have the potential to reduce NIHL.

The intermediate goals in Table 9-1 are adequate and address the primary barriers to solving the noise problem. Adequate time lines and performance measures were given for each intermediate goal. Some goals—such as 1 and 2— are quantifiable, based on delivering the outputs of the research program (e.g., measured sound powers produced by a machine), monitoring the MSHA database for reports of hearing loss, and performing follow-on surveillance. Other goals—such as 3 and 4—are more difficult to quantify because they involve attitudinal and subjective data.

TABLE 9-1 Intermediate Goals and Performance Measures of NIHL Prevention Research and Committee Comments

Intermediate Goal[a]	Performance Measure[a]	Committee Comments
1. Develop and maintain a noise source-worker exposure database for prioritizing noise control technology	This goal will be achieved through development of a database of noise source-exposure relationships and equipment noise for all mining commodities and its use by the mining industry and MSHA by 2008	In its current form, not directly tied to reducing noise exposure (primary goal). There are no quantifiable performance or success measures given. End result is not actionable by NIOSH: it cannot force stakeholders to adopt and use the information
2. Develop engineering noise control technologies applicable to surface and underground mining equipment	The goal for existing noise controls will be achieved by disseminating comprehensive procedures for the evaluation and application of suitable noise controls in underground and surface metal, nonmetal, and coal mines within 3, 4, and 5 years, respectively. The goal for noise control development will be achieved if the industry implements effective new noise controls that reduce the noise overexposure of miners by 25% (versus the baseline values) by 2009	Same comments as for goal 1, above; actually reducing noise exposure by 25% is not actionable by NIOSH, but NIOSH can increase awareness of noise control technologies
3. Empower workers to acquire and pursue more effective hearing conservation actions	This goal will be achieved through measures of dissemination and use of communication, training, and empowerment tools by 2006. A key measure will be the actual noise dose reduction attained through increased prevention behavior and use of dose monitoring systems	Needs quantifiable performance measure
4. Improve the reliability of communication in noisy workplaces	This goal will be achieved to the extent that key stakeholders acquire, accept, and implement the guidelines on alleviating communications issues by 2006	Same comments as for goal 1 above

[a]SOURCE: NIOSH, 2005a.

REVIEW OF INPUTS

Planning Inputs

MSHA data (MSHA, 2006) support the seriousness of NIHL in the mining industry. Noise exposures and incidence of hearing impairment are higher than average among miners. NIOSH has entered into a Noise Partnership with many stakeholders that include the United Mine Workers of America (UMWA), the Bituminous Coal Operators of America (BCOA), the National Mining Association (NMA), MSHA, and several mining equipment manufacturers and suppliers (NIOSH, 2006d).[1] Planning inputs to the Mining Program NIHL research program are considered adequate because NIHL is established as the most prevalent disease among the nation's workforce. No distinction has been made as to whether certain mining populations are more vulnerable than others, although the entire mining population is exposed and at risk.

Production Inputs

Resources committed to NIHL research have increased in some cases and decreased in others. Hearing loss prevention saw a substantial increase in full-time equivalents (FTEs) from 9 in 1998 to 25 in 2005 (see Table 2-3). While the total budget for the noise program increased, discretionary spending dropped from 30 percent in 1998 to a low of 12 percent in 2004. Discretionary spending then increased to 22 percent in 2005 due to a substantial budget increase by Congress that year, with the additional funds used to support more staff and to construct new facilities, such as the hemi-anechoic chamber. Since in-house research is supported with discretionary funds, presumably any decrease will negatively impact in-house research efforts. In terms of the overall budget, more than 10.2 percent of the 2005 Mining Program budget was spent on hearing loss prevention (HLP) compared to the 4.7 percent spent for HLP in 1998, reflecting the increased emphasis on this subject.

[1]The noise partnership was formed in response to the passage of a new noise rule in 1999 (30 CFR Part 62). The partnership provides opportunities for collaborative research with stakeholders related to the Hearing Loss Prevention Program at NIOSH's Pittsburgh Research Laboratory. The program goal is to reduce noise exposures of the nation's miners through research efforts associated with worker noise exposure and related sources, noise control technologies, worker empowerment and education, and improved hearing protection devices.

REVIEW OF ACTIVITIES

Hearing loss prevention activities in the Mining Program relate to the seven projects listed in Table 9-2. Each of the projects relates to a corresponding intermediate goal. These projects provide a good mix of surveillance, study, and evaluation of health hazards; development and evaluation of controls; education; technology transfer; and training. Some of the most important issues identified earlier are being addressed in the engineering NIHL prevention studies (3, 4, and 7) and have the potential to significantly reduce noise exposures in mining.

Hearing loss surveys indicate most drill operators over 40 years of age have NIHL (NIOSH, 2005a). One problem addressed by the Mining Program is that as mining productivity increases through the use of larger and faster equipment and process developments, noise levels and exposures increase as well.

REVIEW OF RESEARCH OUTPUTS

A total of 67 of the 1,428 (4.7 percent) Mining Program outputs are related to hearing loss prevention. While the productivity seems low compared to other areas of the Mining Program, it is not surprising, given that the noise program was recently rekindled—from 3 workers in 1998 to more than 20 in 2001—and that it takes time to perform the surveillance required to identify key problems. Outputs appear to address concerns of populations affected by excessive noise levels. Furthermore, the information outputs and tools (software, videos) can be adopted by small business to include in their training programs. Some cross-agency collaboration (Pittsburgh Research Laboratory; Division of Applied Research and Technology; Division of Surveillance, Hazard Evaluations, and Field Studies; and others) is reported, although cross-agency collaboration could be strengthened.

Of the 67 outputs, 13 are linked to intermediate outcomes discussed later. A variety of outputs have been produced and the findings disseminated through a number of venues. Printed media include more than two dozen conference and journal publications, safety bulletins, NIOSH Information Circulars, a book chapter, and a public report. The Mining Program has also produced numerous in-house reports that have been shared with industry partners to help improve their noise management strategies. At least one stakeholder reported posting noise contour maps developed by NIOSH so that employees can see first hand where the high-noise areas are in the processing plants. In addition, NIOSH has produced three promising and feasible control technologies that are included in the MSHA Public Information Bulletin (PIB) 30 CFR Part 62. Equipment manufacturers and mine operators look to such documents to solve their noise problems. Other products include training aids, such as the hearing loss simulator software, various web documents, a training video, and others.

Nearly 10 workshops have been conducted around the country, including one for the Noise Partnership, one for the National Ground Water Association Expo, and many for state or regional well-water associations. The outputs convey surveillance findings, address educational challenges, and target high-priority NIHL prevention topics through engineering or administrative controls. The wide variety of products ensures that all segments of the population can be reached. Noticeably absent, however, are patents related to noise control research. While cumbersome in many respects (cost, time, licensing agreements, collaborative environment, etc.), they would ensure that NIOSH gets due credit for its research developments.

REVIEW OF TRANSFER ACTIVITIES

Transfer activities include a mix of conference presentations and publications, collaborations with industry partners, development of databases outlining exposure assessments, development of engineering and administrative controls, and educational products. A coherent plan to transfer activities is being executed. A wide variety of publication types (conference and journal papers, book chapters, information bulletins or circulars, and reports) has been created. This diverse mix of publications reaches all segments of the mining industry, including equipment manufacturers, academics, mine operators, labor, and safety or hygiene officials. The Internet is well used to disseminate publications and training aids, such as software and videos. Some stakeholders testified that the Mining Program is a "technical conduit" for new technology, and there is anecdotal evidence to show that it has been successful at communicating. Stakeholders also emphasized that noise should continue to be a high-focus area for mining research.

A few transfer activities merit special attention. The Noise Partnership, between the Mining Program and its stakeholders, conducts semiannual workshops to facilitate two-way information exchange. The Hearing Loss Prevention Unit (mobile audiology van) has visited 42 locations around the country and performed hearing tests on more than 5,400 workers, including more than 1,900 miners. This van serves a dual purpose: in addition to conducting hearing tests, it serves as a research aid using data gathered from the hearing tests. A Hearing Loss Simulator software program allows workers to experience first hand the effects of hearing loss that can be expected for their given exposure levels. Finally, instructing miners in the "roll-pull-hold" method of inserting foam earplugs, while not particularly new, offers a fun and "catchy" method of remembering the correct way of inserting earplugs. The last two activities—the Hearing Loss Simulator and the roll-pull-hold method—are activities aimed directly at miners. In addition, many stakeholders provided anecdotal evidence that these NIOSH activities have made an impact in the workplace.

TABLE 9-2 Noise-Induced Hearing Loss Prevention Projects and Committee Assessment of Relevance and Impact

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
1. A Health Hazard Study of Surface Drilling Operations	1	Noise dosimetry and time-at-task measurements to determine the extent of noise exposures from each process in surface drilling. Development of a universal, partial cab for surface drilling rigs	Recent data have shown that most well drillers over the age of 40 have NIHL	Results have the potential to reduce noise exposures of well drillers through administrative and engineering controls
2. Cross-Sectional Survey: Noise Exposure Patterns and Sources	1	Surveillance establishing noise exposure profiles for various mining occupations, mining equipment noise emission profiles, and exposure-response relationships	The magnitude of the problem and critical areas requiring research will be assessed. A baseline to gauge future noise control efforts will be established	Survey results will identify and rank-order the most critical noise problems in the industry and provide a baseline to gauge future performance
3. Definition and Assessment of Engineering Noise Controls	2	Evaluate the efficacy of various noise control technologies	In situ measurements will offer realistic measures of performance	Publication of in situ measurement results could prove helpful to manufacturers of other large equipment outside the mining industry
4. Engineering Noise Controls for Roof Bolting Machines	2	Determine and implement appropriate engineering controls to reduce excessive exposure to noise on the job and prevent additional cases of NIHL related to roof bolting machine operators	Roof bolter operators suffer the third-worst overexposure to noise (MSHA, 2006)	Controls could reduce exposures to roof-bolter noise and bring them into compliance

5.	Health Communication Interventions for Hearing Loss Prevention	3	This effort addresses problematic attitudes and behaviors regarding personal protective equipment and safeguarding hearing through knowledge and skills training	These efforts are complemented by two other substantial educational products: hearing loss simulator software and the “roll-and-hold” method of inserting foam hearing protectors	An additional 9 dB in the noise reduction rating (NRR) was achieved by the roll-and-hold method in a laboratory setting. Education can empower miners to care for their hearing
6.	Hearing Loss Prevention: Hearing Protection and Audibility Considerations	4	Develop recommendations and strategies for mine operators and mine workers that will improve the audibility of spoken communication and hazard or warning signals in the mining environment while preventing additional cases of NIHL	More advanced muffs, with active electronics and internal microphones, can provide active cancellation of noise signals as well as noise measurements behind the hearing protection device (HPD). Actual attenuations provided by HPDs tend to be highly variable and much lower than the reported values, owing to imperfect usage (Berger et al., 2000)	The project has the potential to improve communication, which is hampered by the use of conventional HPDs
7.	Pilot Study on Coal Cutting Noise Related to Continuous Mining Machines	2	Determine the significance of cutting noise relative to the noise exposure of continuous mining machine operators	Continuous miners create the greatest number of noise overexposures (MSHA, 2006). While conveyor and dust scrubber noise has been addressed, no attention has been given until now to the noise generated by cutting coal. The contribution of cutting noise will be determined by in situ underground measurements	Publication of in situ measurement results could prove helpful to manufacturers of other large equipment outside the mining industry

[a]SOURCE: NIOSH, 2005a.

REVIEW OF INTERMEDIATE OUTCOMES AND CAUSAL IMPACT

Three intermediate outcomes for hearing loss prevention are listed in the Mining Program Briefing Book (NIOSH, 2005a):

1. Motivating prevention behaviors with the NIOSH Hearing Loss Simulator,
2. Noise reduction of roof bolting machines using wet and mist drilling, and
3. Reducing noise on continuous mining machines using coated flight bars.

The Hearing Loss Simulator software appears to be a very successful training aid, judging from the number of requests (>300), including organizations such as the National Hearing Conservation Association, Council for Accreditation in Occupational Hearing Conservation, equipment manufacturers, and safety organizations from 11 different countries. It is clear that the software tool has general appeal for educating workers and officials on the perils of hearing loss, while empowering the worker through education. Reports from users of the software tool describe a greatly increased understanding of the effects of NIHL and changed attitudes toward protecting their hearing. The Hearing Loss Simulator software has been far-reaching, having received a lot of interest outside the mining community and around the globe.

Reduced exposure to noise will result in reduced NIHL (ISO, 1990; ANSI, 1996). New control technologies (mist drilling,[2] and coated flight bars for continuous miners[3]) have been developed with significant noise reductions. The mist-drilling system provides a more sustainable mining practice by using less water than traditional methods. In addition, the mining environment is made more comfortable and potentially safer, since pooled water on the mine floor is reduced. Engineering measurements show that the sound power levels of roof bolters and continuous mining machines have been reduced, which in turn has resulted in reduced noise levels (and exposures) at the operator position (NIOSH, 2005a). Unlike long-term exposure and audiometric records, laboratory data are objective and directly attributable to NIOSH efforts, since they demonstrate the before and after noise exposures. Significant reductions of 2 to 7 dBA for the roof bolter and 7 dBA for the continuous miner were reported. Laboratory tests also show reductions of 8 to 15 dBA from the partial cab being developed for the drilling rig. Typically, field tests will show less improvement, although these results are encouraging nevertheless. Similarly the "roll-pull-hold" method of inserting foam earplugs is reported to improve the effec-

[2]See NIOSH Information Bulletin P04-18, 2005, available at *http://www.msha.gov/regs/complian/PIB/2004/pib04-18.pdf* [accessed November 10, 2006].

[3]See NIOSH Information Bulletin P04-18, 2005, available at *http://www.msha.gov/regs/complian/PIB/2004/pib04-18.pdf*.

tive noise reduction rating (NRR) by 9 dB in a laboratory setting. Note that for each 5 dBA reduction in noise exposure, the corresponding dose would be cut in half (for the 5 dB exchange rate promulgated in 30 CFR Part 62). NIOSH advocates use of a 3 dB exchange rate, which if adopted would result in more significant reductions in dose per given reduction in sound level (NIOSH, 1998), albeit for higher overall doses. The committee would expect a reduction in NIHL with industry acceptance and implementation of NIOSH recommendations.

It is not clear to the committee why the Mining Program does not better advocate the use of earmuffs or circumaural hearing protectors, which have been shown to deliver a significantly higher percentage of the laboratory attenuation in the field than earplugs (NIOSH, 1998; Berger et al., 2000). Earmuffs are generally more reliable and less dependent upon user skill, training, and motivation, but admittedly are construed as more uncomfortable by some workers.

Perhaps most importantly, the proposed equipment changes for engineering noise-induced hearing loss prevention appear economically and technically feasible. Further, some are designated by MSHA as providing “promise” of reducing noise exposure (MSHA, 2004b). Due to the strong collaborative efforts between labor, industry, manufacturers, and government, equipment changes were adopted quickly. Coated flight bars are manufactured and available through Joy Mining Machinery, which also makes a retrofit mist drilling kit for the J. H. Fletcher & Co. roof bolter. Reportedly, these products are already in use and are being evaluated in situ, but no quantitative data are given.

No distinction between gender differences or protecting vulnerable populations has been made. Considerations of particularly vulnerable groups should be built into research designs from the beginning to produce information on any special problems that may cause vulnerability. It should also be noted that reducing noise exposures should theoretically provide benefit to all segments of the mining workforce.

REVIEW OF END OUTCOMES

The desired end outcome, as expressed by the Mining Program, is to reduce the incidence of NIHL in the mining population. Aside from the limitations to achieving these goals mentioned earlier, it will take decades to assess the impact of the noise program outputs, which are just emerging. It is too early to establish any trends. Field tests to evaluate innovations are ongoing. As for the end outcomes associated with the Hearing Loss Simulator, the best evaluation data were self-reported, based on attitudinal surveys given to workers before and after using the software. More extensive research is planned to better quantify the effects of this and other research.

ASSESSMENT OF RELEVANCE AND IMPACT

It is difficult to rate the budding noise research group within the Mining Program, but ratings are based on the moderate contribution of intermediate outcomes, as well as the promise that current projects have to continue to deliver innovations for noise control. It will take multiple decades to realize the ultimate end outcome—the reduction or elimination of NIHL. Reductions in noise exposure are generally accepted to translate into a reduction in noise dose, and given the lack of data regarding the actual reduction rates of NIHL, the committee is using exposure reduction as a proxy to measured end outcomes. The moderate reductions in noise exposures to operations from adding a partial cab to surface drilling rigs, coating the flight bars of continuous miners, new dust collector fan design, jacketed tail roller, and substituting mist for water in roof bolters (drills) are significant (9, 7, 5, 3, and 2-7 dBA, respectively). The most popular makes of roof bolter and continuous miner were targeted for modification so that research results have the greatest chance of adoption by the mining industry. The simplified roll-pull-hold method of foam earplug insertion (the most popular type of hearing protection device [HPD]) has resulted in a reported 9 dB increase in NRR under ideal circumstances. The ongoing surveillance program has established the most pressing noise problems in the mining industry as well as baseline measurements to eventually assess the efficacy of control technologies.

Aside from refining the goals under the purview of NIOSH, the rank ordering of noise exposures for *all* mining occupations should be determined based on relative exposure levels and the number of people affected. To date, no investigation of vulnerable populations, gender differences, and so forth, has been conducted, presumably to make most efficient use of the resources available. The Mining Program should continue to ensure that it reaches all segments of the mining community with new information, especially smaller mines and equipment manufacturers. More research should be conducted on speech intelligibility in the midst of high-noise areas and while wearing HPDs. New noise partnerships should be organized with the metal and nonmetal mining sectors and more NIHL research should be conducted for this mining segment. Longwall mining, though affecting relatively few, is a particularly noisy occupation that should ultimately be addressed.

PROGRESS IN TARGETING NEW RESEARCH

The Mining Program assesses research needs in multiple ways: (1) by studying the MSHA accident and injury database (MSHA, 2006); (2) by conducting noise surveys; and (3) by collecting input from stakeholders. Noise surveys include noise contour mapping, dosimetry, and time-at-task observations (the "gold standard" of surveying). Stakeholder interaction is enhanced through the Noise Partnership group, previously mentioned. It appears that the Noise Partnership is heavily focused on coal mining noise. If this is the case, it should be expanded to include metal and nonmetal mining.

Signature Accomplishment:
Education and Training Through Mobile Audiometric Testing

The Hearing Loss Prevention Unit (HLPU), developed by the Mining Program, consists of a sound-insulated 32-foot trailer containing four independent, computer-controlled audiometric testing stations. The HLPU travels around the country to conferences and to remote mine locations educating miners and their families about noise-induced hearing loss and hearing protection. Not only can it conduct hearing evaluations, but it is also used by the Mining Program for training—such as teaching workers the proper way to insert hearing protectors—and for research projects. A counseling area inside the booth contains audiovisual equipment used to present educational materials. The HLPU can be configured to perform a wide range of research tasks, including hearing test feedback as part of training programs, training in proper use of hearing protectors, and supporting more effective hearing loss programs aimed at protecting the hearing of the nation’s miners.

The Hearing Loss Prevention Unit developed by the Mining Program.

10

Review of Research on the Reduction of Cumulative Musculoskeletal Injuries[1]

Key Findings and Recommendations for Research on Cumulative Musculoskeletal Injuries

- The Mining Program is doing work in this area that is highly relevant to mining and other industries. Research is in the high-priority areas of equipment and work design.
- Interaction between the cumulative musculoskeletal research group and other NIOSH programs and divisions should be increased.

According to the National Institute for Occupational Safety and Health (NIOSH), musculoskeletal disorders (MSDs) include a group of conditions that involve the nerves, tendons, muscles, and supporting structures such as intervertebral disks. They represent a wide range of disorders that can differ in severity from mild, periodic symptoms to severe, chronic, and debilitating conditions. Work-related musculoskeletal disorders (WMSDs) arise from such risk factors as frequent or heavy lifting; pushing or pulling heavy objects; prolonged awkward postures; vibrations; and repetitive, forceful, or prolonged exertion of the hands. Examples of MSDs include low back pain, tendonitis, and carpal tunnel syndrome (NIOSH Facts, *http://www.cdc.gov/niosh/muskdsfs.html*). The solution to the WMSD problem is often sought through the application of ergonomics. Ergonomics is the science of fitting workplace conditions and job demands to the capabilities of workers.

Mining tasks and the mining environment are characterized by several unique factors. Major mining tasks involve handling either mining products or the mate-

[1]Because the committee did not include an ergonomics expert, it commissioned a white paper from Dr. Barbara Silverstein, M.P.H., C.P.E. of the Washington State Department of Labor and Industries regarding the impact and relevance of ergonomics related research conducted within the NIOSH Mining Program. Her paper is included as Appendix C of this report and was carefully considered by the committee during the preparation of its review.

TABLE 10-1 Illness and Non-Fatal Days Lost Data for Mine Operators from 1993 to 2002

Illness Data	No.	Percent	NFDL Data	No.	Percent
Cases	6,419		Cases	84,629	
Repeated trauma disorders	3,314	52%	Nature of injury		
Part of body affected			Sprain, strain, ruptured disc	38,727	46%
Wrist	1,445	23%	Joints, tendon, muscle inflammation	421	1%
Ears	1,154	18%	Part of body affected		
Back	430	7%	Back	21,030	25%
Knee	251	4%	Knee	8,114	10%

SOURCE: MSHA, 2006.

rials associated with activities such as roof support, ventilation control, or power supply installation. Cutting, drilling, loading, and hauling equipment are a common part of miners' work, but they are often done in confined places with poor clearances and on poor or uneven floors that create unfavorable conditions for body postures. Some working conditions create hazards associated with whole-body vibrations or slips and falls. Other environmental factors such as limited visibility, dust, noise, heat, and humidity, coupled with shift and extended hours, are also associated with mining injuries. Mining equipment operators often are exposed to heavy and repetitive jarring and jolting motions.

Table 10-1 shows reported illness and non-fatal days lost (NFDL) injury data for mine operators between 1993 and 2002 (mill and office workers were not included). Repeated trauma disorders account for a majority of illnesses. In terms of parts of the body, ears are affected about 35 percent of the time, whereas wrist, back, and knee account for almost all other cases of repeated trauma (64 percent). Mining NFDL records indicate that nearly half of days lost were associated with sprains and strains, and approximately one third of days lost were associated with either back or knee injuries. Given that wrist, back, and knee injuries show up prominently in mining injury data, the work-related risk factors for these injuries need to be identified to reduce or eliminate them.

STRATEGIC GOALS AND OBJECTIVES

The reduction of repetitive or cumulative musculoskeletal injuries in mine workers as one of the Mining Program's major strategic goals. The performance measure for achievement of this strategic goal is a 30 percent reduction in MSDs by 2014, from the baseline data of 2003. The two intermediate goals in this research area are summarized in Table 10-2. The committee recognizes that injury reduction research is enhanced by the increased application of human factors research

TABLE 10-2 Intermediate Goals and Performance Measures of the Reduction of Repetitive and Cumulative Musculoskeletal Injuries and Committee Comments

Intermediate Goal[a]	Performance Measure[a]	Committee Comments
Quantify job demands and physical capabilities of miners to develop improved recommendations for work design	This goal will be achieved by providing 10 improved designs and work practices for reducing musculoskeletal exposure in mining jobs by 2009	(1) The relationships between the goal and the performance measure is unclear. (2) Relationship between quantification of performance measure and performance measure itself is unclear
Develop and field-test ergonomic interventions to reduce worker exposure to musculoskeletal risk factors	This goal will be achieved by reducing the repetitive injury rate by 25% at test mine sites by 2009, using the 2003 rate as baseline	Given data available on injury rates during the last decade, the performance measure chosen to meet this goal could be more ambitious

[a]SOURCE: NIOSH, 2005a.

results[2] and ergonomic principles in mining. Achievement of performance measures is dependent on the acceptance of Mining Program recommendations regarding design, work practices, and ergonomic interventions.

Table 10-3 compares illness and NFDL injury data for 1996 and 2005. The data provide insight into progress in the reduction of repeated trauma disorders and NFDL injuries. The number of unreported illnesses and injuries is not known, nor is it known how many incidents may be occurring prior to injury or illness inducing events. In view of the reduction in injuries noted in Table 10-3, performance measures for the strategic goal and the program's second intermediate goal could be more challenging.

REVIEW OF INPUTS

Primary input comes from the Mine Safety and Health Administration (MSHA) surveillance data on injuries and lost work days. Other sources of input include

[2]Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance (*http://www.iea.cc/ergonomics/*).

TABLE 10-3 Comparison of Total Reported Illness and NFDL Injury Data for 1996 and 2005

	1996	2005	Reduction (%)
Illness Data			
Number of illnesses	409	206	40
Repeated trauma disorders	232	155	33
Body part			
Wrist	104	69	34
Back	41	16	70
Knee	22	16	27
NFDL Data			
Number of NFDL	8,641	5,325	38
Sprain or strain	3,872	2,347	39
Joints and muscles	36	17	53
Back	2,106	1,037	52
Knee	770	573	26
Wrist	122	116	5

SOURCE: Vanessa A. Stewart, MSHA, personal communications to Raja V. Ramani on June 12, 2006, and June 14, 2006.

mining companies, manufacturers, and worker unions. Specifically, NIOSH has worked with mining companies and equipment manufacturers on specific processes, procedures, and equipment development and demonstration projects. The Mining Program has also formed a partnership with a coal company to enhance the introduction of a process to reduce WMSD risk factors.

Research on the reduction of cumulative musculoskeletal disorders is allocated approximately $2.0 million of total annual funding with discretionary funding of about $150,000. Currently, there are 20 full-time equivalents (FTEs) and four projects associated with this research area, which represents approximately 7 percent of the total Mining Program funding, 8 percent of the total FTEs, and 2 percent of total discretionary funding. Compared to 1998 statistics, these figures represent an increase of 67 percent in funding and 25 percent in FTEs.

Expertise in the program includes physiology, bioengineering, mining, industrial and mechanical engineering, sociology and psychology, and industrial hygiene, though does not include expertise in epidemiology and cognitive ergonomics. Although the Mining Program describes a large overlap between its own interests and those of the NIOSH Musculoskeletal Research Program (NIOSH, 2006b), the level and nature of input from that program to the Mining Program could not be determined by the committee with the information received. The committee was not certain that such interactions filled gaps in expertise.

Several specialized facilities are available at the Pittsburgh and Spokane Research Laboratories for cumulative research. The facilities include equipment for motion analysis, shock tests, strength tests, simulation of mining tasks, and whole-body vibration.

The attention paid to identify risk factors in the mining environment and mining work that cause cumulative musculoskeletal disorders is well deserved. The increase in funding and FTEs, while very modest, is to be commended.

REVIEW OF ACTIVITIES

Mining Program research activities to reduce WMSDs are aimed at designing tasks, tools, equipment, machine controls and displays, and training programs to be compatible with workers' physical capabilities and limitations in the working environment. Properly designed tasks and equipment, in combination with appropriately trained workers, can reduce or eliminate overexertion, overuse of muscles, and bad posture at the worksite. Engineering control is the principal means of enacting improvements.

The projects in this research area are concentrated on identifying and documenting risk factors for WMSDs and associated ergonomic issues in mining, as well as developing recommendations for reducing exposure to risk factors for cumulative injuries. Two lines of research can be seen in the cumulative injury program: the adaptation of off-the-shelf items for mining industry applications; and research on understanding the physiological and biomechanical aspects of mining work.

Two major research activities of the last decade included improved seat design for shuttle cars in underground coal mines and a collaborative effort with a surface coal mining company for implementation of a process to reduce exposure to WMSD risk factors. The Mining Program's role in this latter effort was limited to guiding and directing the coal company's efforts in customizing and implementing an ergonomics process. Table 10-4 describes the four active projects being conducted within this research area.

The following need to be considered to reduce the incidence of musculoskeletal disorders: (1) the task or work to be accomplished; (2) the individual(s) who will do the work; (3) the environment in which the work is accomplished (physical, chemical); (4) the technology and machines used in the performance of the task; and (5) the organization of the task, including such factors as hours of work, shift work, degree of social interaction, and level of supervision (Perez, 1999). The Mining Program incorporates these considerations into its activities. Laboratory and field studies are combined with physical and computer modeling to characterize and analyze WMSD risk factors associated with mining. Approaches to increase miner awareness of WMSD risk factors, and the introduction of ergonomic processes into operations, have included the development of training programs and partnerships with mining companies and industry-wide organizations. While some project-specific suggestions regarding study design are given in Table 10-4, including suggestions regarding study methodology and implementation for a greater diversity in ergonomic intervention strategies, expertise beyond that currently available within the Mining Program may be required for implementation.

Some mining tasks involve sedentary work, heavy lifting, a combination of environmental factors (e.g., noise, dust, heat, and humidity), or the effects of extended working hours (as a company practice or a result of overtime) and fatigue. All of these topics require research on their contributions to WMSDs. It is important to state that the cumulative injury program is a very small part of the Mining Program. While it may be possible to incorporate some of the topics identified here into the current program, additional resources would be required.

REVIEW OF RESEARCH OUTPUTS

The Mining Program reports 85 outputs from the MSD prevention research group between 1996 and 2005–approximately 6 percent of all Mining Program outputs. The outputs are mostly articles appearing in various journals, though a small number occur in other formats such as videos, software, training programs, checklists, and guidelines. Approximately 20 percent of these publications are related to risk factor case studies regarding machines associated with underground and surface mining unit operations and mines in general. Approximately 15 percent of outputs are associated with studies concerning biomechanics and body extremities. Approximately 33 percent of outputs are associated with strength testing, body postures, and human factors. Equipment design accounts for approximate 12 percent of the outputs. Case studies and descriptions of partnership results should be useful industry-wide.

REVIEW OF TRANSFER ACTIVITIES

The cumulative injuries prevention research area has utilized a number of means to reach stakeholders. In addition to the publications referred to above, the Mining Program web site presents information on several topics concerning ergonomics. Brief descriptions of general MSD issues are followed by more specific discussions topics, such as workplace and equipment design and engineering and administrative controls. References to several NIOSH publications are provided.

Mining Program investigators have conducted training sessions at the request of mining companies and have conducted workshops at worker unions' health and safety conferences. Direct contact with the users is likely to result in greater

TABLE 10-4 Cumulative Musculoskeletal Disorder Prevention Projects and Committee Assessment of Relevance and Impact

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
1. Ergonomics Evaluation and Improvement of Mobile Equipment	1, 2	Reduction of musculoskeletal disorders among operators of mobile equipment in surface mining and construction operations. The tasks are to (1) conduct an epidemiologic survey of heavy-equipment operators through a work and health questionnaire, (2) characterize whole-body vibrations at the seat-driver interface and their effects on the operator's postural stability in the seat, (3) estimate the landing force required to exit from mobile equipment, and (4) evaluate the ergonomic design of cabs and means of egress from and entry to the cabs	While the comparison of pre-intervention conditions with post-intervention conditions is useful to document any improvements, establishment of a control and a non-control group would be desirable for the purposes of documenting the effectiveness of the intervention	The project outputs should be useful to improve detection of MSD potential in equipment operators and to improve designs and procedures for cabs and means of egress and entry
2. Ergonomics Process Effectiveness in Mining	2	Development of recommendations for design of equipment and workplaces, and appropriate training modules, in partnership with two mining companies. Ergonomic processes will be implemented and evaluated in mines. Metrics will be developed to assess the growth and effectiveness of the process	There is little question that partnering with specific mining companies is beneficial, but efforts should be directed to develop general guidelines and processes for the entire mining community	The level of awareness of miners of the importance of ergonomics and the application of ergonomic processes in mining is expected to increase. An associated decrease in WMSD incident rates is also expected. These improvements will impact only those miner populations directly involved in investigations

3.	Reduce Injury and MSD Risk from Human-Machine Interactions	1	The reduction of WMSD risks associated with use of continuous miners, roof bolters, and load-haul-dump equipment in underground mining through improved design of machines and of operator tasks. Risks being studied include appendage-mining machine contact, stresses to the back associated with various kneeling and standing postures, and the effect of repetitive and forceful motions associated with equipment in motion. The study includes physical and computer modeling, motion analysis techniques, and operator task analysis	This research is relevant and addresses many types of WMSDs associated with mining	The study will lead to the development of a risk assessment methodology for equipment operators at underground mine working faces
4.	Successful Aging for Miners Through Ergonomics (SAME)	1, 2	The project is aimed at all miners to ensure avoidance of workplace hazards associated with aging. Tasks identified include the development of (1) a training program for miners to increase their awareness of, and preparedness for, changes that occur with the aging process; (2) suggestions for boot designs, work procedures, and safer methods for ingress and egress from equipment to reduce slips and falls; and (3) a better tool to assess the risk of back injuries in miners and their engineering interventions	The project addresses several tasks, not all related to aging. Given that the current median age of miners is approximately 46 years, it is appropriate to look at research to determine the avenues available for management to take these realities into account in the framework of organizational ergonomics	This training program to make miners more aware of the impacts of aging on performance should be useful to the entire miner population

[a]SOURCE: NIOSH, 2005a.

implementation of recommended practices than recommendations published in journals.

Program collaboration with mining companies and equipment manufacturers has led to the introduction of ergonomic processes in the workplace (such as WMSD risk assessment tools) and the adoption by manufacturers of new equipment designs (e.g., dragline operator workstations, shuttle car operator seats). Videos on the latter products have also been made for use in training sessions and general distribution.

Investigators in the MSD prevention research area of the Mining Program actively disseminate their research results to the community of fellow researchers and to the mining industry. Their efforts seem to be well-directed, based on research outcomes discussed in the next section.

REVIEW OF INTERMEDIATE OUTCOMES AND CAUSAL IMPACT

As a result of research within the Mining Program, there are a number of findings with regard to WMSD risk factors in the mining industry. NIOSH investigators note that miners spend a lot of time at work on their knees or in awkward, squatting positions, spawning a number of studies on knee injuries and the development of effective prevention strategies. Mining Program studies on the risk of WMSDs associated with mobile equipment, such as jarring, jolting, whole-body vibrations, and ingress and egress, have resulted in a number of improvements to equipment and work procedures. Implementation of ergonomic processes in several mines in different environments through partnerships with mine operators has led to the design of improved workstations and further development of training and evaluation programs.

Joy Mining Machinery, a major supplier of underground coal mining machinery, reports the NIOSH-designed shuttle car seats are preferred by shuttle car operators over other available designs. The introduction of ergonomic processes (22 interventions in 3 years) resulting from the partnership with Bridger Coal Company has had many positive outcomes, including requests from other companies to introduce the processes in their own operations. According to the Mining Program (NIOSH, 2005a), 800 additional people from different organizations have been trained on risk factor awareness. The Bridger Coal/Mining Program partnership also resulted in the Mining Program's decision to redesign the dragline operator workstation to better fit human limitations and task requirements.

Given the limited number of underground and surface mining equipment manufacturers, the potential for transferring the shuttle car and dragline design improvements to other mining equipment in surface and underground mining is high.

REVIEW OF END OUTCOMES

There are no clearly discernible end outcome data that can be directly associated with this research area. However, it is appropriate to conclude that the program is having positive impacts in the workplace in selected areas. The Mining Program informed the committee (NIOSH, 2005a), for example, that the percentage of employees reporting discomfort at the Bridger Coal Mine decreased by 15 percent over a 3-year period. It would be useful to collect and analyze injury experience data directly related to WMSDs on specific operations and tasks in order to develop a stronger association with specific interventions.

A number of quantitative indicators attest to the adoption of NIOSH-designed shuttle car seats by manufacturers and mining companies. The number of replacement seats ordered for equipment currently in use underground and the number of shuttle cars sold with the new NIOSH-seat design are approximately 150 and 300, respectively. The WMSD injury rates of shuttle car operators should be tracked to study the effectiveness of the improved design.

The cumulative musculoskeletal injury research area has generated a large amount of knowledge in the area of WMSDs in mining. The manner in which this knowledge can be put into practice by mining companies, equipment manufacturers, and training organizations has been demonstrated to a limited extent by the program itself. The outputs of this program are relevant to several other industries, particularly construction and agriculture, where the equipment and tasks are similar to those in mining. To ensure that these benefits accrue to the larger worker population, increased interaction between the Mining Program and other NIOSH programs should be explored.

ASSESSMENT OF RELEVANCE AND IMPACT

The present cumulative injury research program has concentrated on increasing awareness of ergonomic processes, development of better designs for mining equipment, and a greater understanding of mining tasks and their demands on the human body. From the discussion above, it is clear the program is doing work that is highly relevant to mining and other industries. Research is in the high-priority areas of equipment and work design. There is ample evidence of good engagement of mining companies, industry organizations, manufacturers, and union personnel in the definition of problems and the transfer of outputs. While there are no specific end outcome data to report, several major contributions have the potential to improve health and safety in the mining workplace.

PROGRESS IN TARGETING NEW RESEARCH

Partnerships guide the direction of WMSD reduction research, indicating responsiveness to stakeholders. The committee, however, considers the Mining Program's targeting of its WMSD reduction research to be largely reactive rather than proactive, resulting in accomplishments that are not necessarily applicable industry-wide. Since there is similarity in mining, civil engineering, and agricultural equipment, it would appear that there is a broader scope for the definition of WMSD issues and solutions through more rigorous and formal interactions between various NIOSH research programs and the MSD health effects group.

11

Review of Traumatic Injury Prevention Research

Key Findings and Recommendations for Traumatic Injury Prevention Research

- High-priority areas have been addressed through activities that generated new knowledge and technology.
- The Mining Program should increase the amount of new technology development that targets mining-specific issues in traumatic injury prevention.
- The traumatic injury prevention research group should proactively analyze mining trends for new safety issues.
- Education, training, and technology transfer techniques need to be evaluated to have the greatest impact.
- Attention is needed in the areas of automatic and remote control technologies.

STRATEGIC GOALS AND OBJECTIVES

Reducing injuries and hazards that cause traumatic injuries are important elements of the ideal mining health and safety research program discussed in Chapter 3. Trauma is defined by the National Institute for Occupational Safety and Health (NIOSH, 2006e) as

> an injury or wound to a living body caused by the application of external force or violence. Acute trauma can occur with the sudden, one-time application of force or violence that causes immediate damage to a living body.

One of the Mining Program's seven strategic goals is to reduce traumatic injuries in the workplace. The performance measure for this goal is a 30 percent reduction in traumatic injuries by 2014 from the 2003 baseline. The Mining Program intends to reach this goal by carrying out research activities addressing the five intermediate goals listed in Table 11-1. The strategic goal of reducing traumatic injuries is straightforward and well defined. All five intermediate goals are achievable. In 2006, NIOSH conducted workshops for the second decade of the National Occupational Research Agenda (NORA-2) and identified equipment accidents, automation, and training effectiveness as priorities—areas already included in the intermediate goals for traumatic injury prevention research within the Mining Program. Ground failure control research is a separate research area within the Mining Program.

There were 55 fatalities, 8,183 non-fatal-days lost (NFDL) injuries, and 3,867 no days lost (NDL) injuries reported in 2004 (MSHA, 2006). The need for continued reduction of traumatic injuries is evident. Based on MSHA statistics, powered haulage, machinery, and materials handling are specific areas that require attention. With changes in mining technology and equipment size, traumatic injury prevention is likely to demand more attention.

The traumatic injury prevention research group, however, lacks the leadership that facilitates the development of new technologies. Research is essentially applied and stems from new technologies developed by other NIOSH programs; thus, research on traumatic injuries has been limited and does not allow the Mining Program to adequately address immediate mining-specific problems.

REVIEW OF INPUTS

Major planning input for traumatic injury prevention research comes from the Mine Safety and Health Administration (MSHA) in the form of accident and injury data. Other sources of planning input include other federal agencies (e.g., directives from the Department of Health and Human Services and the Centers for Disease Control and Prevention [CDC] as they adhere to guidance from federal advisory groups), stakeholders (e.g., labor unions, trade organizations), academia, and state agencies.

The number of personnel working on traumatic injuries ranged from a high of 70 in 1998 to a low of 37 in 2005, with approximately $40 million in total expenditures. During that time, discretionary expenditures ranged from $778,000 to $350,000, and funding for traumatic injury prevention research decreased by 21 percent. In the same period, NIOSH funding increased by 20 percent and full-time equivalent employees (FTEs) decreased by 8 percent. Compared to the overall Mining Program, traumatic injury prevention research has experienced large changes in funding and FTEs. Changes may be due to a greater-than-normal attrition of personnel; goals being achieved in traumatic injury statistics; and increased emphasis on the emerging areas of hearing loss, surveillance, training, and cumulative injuries. With changes in mining conditions, equipment size, and technology, there

TABLE 11-1 Intermediate Goals and Performance Measures of Traumatic Injury Prevention Research and Committee Comments

Intermediate Goal[a]	Performance Measure[a]	Committee Comments
1. Develop interventions for preventing electrocutions and burn injuries	This goal will be achieved through a 25% reduction in the 2003 baseline electrical injury rate by 2009	A rate reduction from 0.018 to 0.014 is considered an achievable goal. The target should be complete elimination
2. Develop interventions for preventing machine safety and powered haulage injuries	This goal will be achieved by a 25% reduction in the 2003 baseline traumatic injury rate pertaining to machine safety and powered haulage-related injuries by 2009	Rate reductions from 0.301 to 0.226 for machinery and from 0.330 to 0.248 for powered haulage are considered achievable goals
3. Investigate wearable sensor technologies[b] that empower the miner to take proactive steps in decreasing his or her exposure to work-related injuries	This goal will be achieved by a 25% reduction in the 2003 baseline injury rate related to machinery, slips, and falls by 2009	Rate reductions from 0.301 to 0.226 for machinery and from 0.807 to 0.605 for slips, trips, and falls are considered achievable goals (NIOSH, 2006f)
4. Reduce the incidence of injuries and fatalities resulting from the use of explosives	This goal will be achieved if flyrock training materials are transferred to 75% of the blasting specialists in the mining industry by 2006. The transfer will be achieved if the Mine Safety and Health Administration incorporates these materials as part of its annual mining health and safety training	The goal and performance measure are quite disparate. While flyrock training may take place, there is no assurance that the goal will be attained
5. Develop interventions, best practices, and strategies for improving miners' training with respect to hazard recognition, risk factor awareness, and emergency response	This goal will be achieved to the extent that the research findings and training interventions published by the Mining Program (1) become adopted by mine safety and health trainers and (2) are referenced and advocated by mine training and safety professionals	Adoption and referencing of NIOSH materials by training and safety professionals are among the most successful stories of the Mining Program

[a]SOURCE: NIOSH, 2005a.
[b]The Mining Program refers to sensors which will enable the miner to obtain real-time environmental and biometric information without forcing the miner into hazardous settings.

may be new sources of hazards, the need for proactive analysis of safety issues, and the need for newer surveillance training programs.

REVIEW OF ACTIVITIES

In 2006, traumatic injury prevention research involved 11 activities, at a cost of $4.13 million. The activities, their purpose, and brief assessments are listed in Table 11-2. These activities, along with others to be conducted under NORA-2, are designed to achieve the overarching strategic goal of a 30 percent reduction in traumatic injuries by 2014, using the 2003 NFDL traumatic injuries rate as reference.

REVIEW OF RESEARCH OUTPUTS

Table 11-3 provides a comparison by type of traumatic injury prevention research outputs and total Mining Program outputs between 1996 and 2005 (NIOSH, 2005a). The table suggests this research area has been very active in obtaining patents, and developing guidelines, standards, training, videos, and web documents. The seven patents are for different warning devices based on essentially the same technology. Outputs from electrical research activities were used to promulgate regulations. Many publications—Report of Investigations, Information Circulars, and Bulletins—subsequently resulted in presentations at numerous national and international meetings.

Mining Program outputs have covered every facet of traumatic injuries. High-priority areas were addressed through activities that generated important new knowledge and technologies, such as proximity warning devices that provide audio and visual alarms in the vicinity of mobile equipment. Outputs related to high-voltage equipment include recommendations addressing high-priority areas, and allowed for the promulgation of MSHA's regulation for high voltage on longwalls, and the proposal of new MSHA regulation related to high voltage on continuous miners. Patents for proximity warning devices and similar technologies indicate that the Mining Program continues to pursue original ideas to create products useful to the industry. Most of the remaining outputs relate to applications for both individual large and small mining operations, but do not represent breakthrough results. All outputs have undergone, at the minimum, NIOSH's internal peer review process, and several have received national and international recognition for contributions to the reduction of traumatic injuries.

REVIEW OF TRANSFER ACTIVITIES

Like its predecessor—the U.S. Bureau of Mines (USBM)—NIOSH transfers most of its research results into publications and training materials. By working with MSHA, important research results have been incorporated into enforcement and into engineering and education regulations and guidelines. No data are yet available to evaluate how well the research to practice (r2p) program functions as a mechanism to transfer information related to traumatic injury research.

REVIEW OF INTERMEDIATE OUTCOMES AND CAUSAL IMPACT

Below is a list of intermediate outcomes resulting from work in this research area (NIOSH, 2005a):

- A NIOSH *Technology News* article (NIOSH, 2001) advised blasters to place carbon monoxide (CO) monitors in the basements of homes and businesses near blast sites. Since 2001, there have been no blasting-related CO poisonings. CO monitors have alerted residents before the onset of illness in two recent cases. Blasters are becoming educated in the need to minimize CO generation.
- The Mining Program, in cooperation with MSHA, developed guidelines for the safe use of waste motor oil for making ammonium nitrate fuel oil blasting agent. The Institute of Makers of Explosives has adopted this standard, and the recycling of waste motor oil for this use has become an accepted industry practice.
- MSHA requests for Mining Program assistance in accident investigations resulted in research that identified the need to modify boosters by incorporating tape over the detonator, and the modification was implemented by manufacturers.
- The Mining Program recommended a nitrogen dioxide (NO_2) gas monitoring protocol in response to requests by the Wyoming Mining Association (WMA) Red Smoke Committee; this was submitted by WMA to the Wyoming Department of Environmental Quality and incorporated into WMA's Powder River Basin Short-Term Exposure to NO_2 Study. Research results have been incorporated into Powder River Basin mining plans. The frequency of orange blasting product clouds has decreased by about 90 percent since the Mining Program began working with Powder River Basin mines.
- Two manufacturers have added, or plan to add, undercarriage power line contact alarms as both add-on and stand-alone products as a result of Mining Program research on overhead power line hazard and contact alarms.
- The Electrical Safety Foundation International, in collaboration with the Mining Program and other partners, produced a training pamphlet regarding overhead power line electrical safety intended for small contractors and Hispanic

TABLE 11-2 Traumatic Injury Prevention Projects and Committee Assessment of Relevance and Impact

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
1. Evaluating Roadway Construction Work Zone Interventions	2	Develop a warning device and a warning system for miner's exposure near mobile vehicles and equipment	Moderate	Technology already available and needs to be implemented
2. Lockout or Tagout, Jammed and Moving Machinery Controls	1	Develop a warning device for miners, especially maintenance workers, to lockout and tagout equipment in hazardous areas	High	Industry-wide application when developed
3. Mobile Mining Equipment Warning Systems	2, 3	Reduce accidents to miners working with lift trucks	Moderate	Technology already available and needs to be implemented
4. Protocol for Evaluating Quality of Explosives in the Field	4	Develop a suite of protocols that miners and inspectors can use to determine the safety of explosives	Moderate	Improve blasting applications and safety
5. Reducing Electric Arc-Induced Injuries in Mining	1	Reduce the number of injuries from electric arcs	High	Reduce electrical accidents

6.	Remotely Controlled Bulldozers on Coal Stockpiles	2	Investigate the feasibility of using remote controls on bulldozers operating on coal stockpiles	Moderate	Technology already available and needs to be implemented
7.	Safety Enhancements for Off-Road Haulage Trucks	2	Develop and test interventions to prevent accidents when dump trucks are used in surface mines, and disseminate this information to the mining community	Moderate	Manufacturers improve truck safety options
8.	Safety Solutions to Prevent Mining Materials Handling Accidents	2	Reduce accidents in handling materials in surface and underground metal and nonmetal mines	Low	Mine specific
9.	Smart Wearables for Hazardous Work Environments	3	Investigate technologies that can be used in clothing for miners that can provide awareness of dangers	Low	Mining operation specific
10.	Surface Blasting Safety and Health	4	Combine previous research on hazards from using explosives in surface mines associated with flyrock and fumes	Moderate	Improve blasting applications and safety
11.	Virtual Reality for Mine Safety Training	5	Create training materials in virtual reality that can be used and evaluated in operating mines	Moderate	Education and training plans and techniques improved

[a]SOURCE: NIOSH, 2005a.

TABLE 11-3 Research Outputs Related to the Traumatic Injury Prevention Research Compared to the NIOSH Mining Program (1996-2005)

Output Type	Traumatic Injury Prevention Program	Mining Program
Patents	7	15
Publications	284	1,428
Guidelines	9	25
Software	2	18
Standards	4	6
Training	6	18
Video	8	20
Web documents	18	40
Workshops and Seminars	11	111

SOURCE: NIOSH, 2005a.

workers. Pamphlets are available at the contractor's sales desks of Home Depot, Lowe's, and equipment rental companies. More than 800 copies have been sold. Plans to produce the pamphlet in Spanish are in progress.

- The Mining Program provided MSHA with technical information used to write 30 CFR 18 and 75, Electric Motor-Driven Mine Equipment and Accessories and High-Voltage Longwall Equipment Standards for Underground Coal Mines (Federal Register, 2002), establishing new mandatory electrical standards for the installation, use, and maintenance of high-voltage longwall mining systems in underground coal mines.
- The Mining Program identified electrical arc faults and power lines as major sources of injury. Both the electrical industry and extramural research are beginning to recognize and address these issues. NIOSH publications have been cited in written materials on these topics.
- The Mining Program conducted research on the use of lasers in flammable atmospheres and helped form the basis for American National Standards Institute and International Electrochemical Commission standards.
- Collaborative work by the Mining Program and others led to the development of improved Crewstation Analysis Programs (CAP) software in the mid-1990s to evaluate machine-mounted illumination systems. CAP software is used by all major U.S. mine lighting manufacturers and by MSHA in its Statement of Test and Evaluation (STE) procedures.
- NIOSH-originated procedures to test and integrate protocols for use of proximity warning systems are being applied by the mining industry, MSHA, and equipment manufacturers. The Mining Program has contributed to writing of an

International Organization for Standardization (ISO) standard for performance requirements and tests of proximity detectors.

- The Hazardous Areas Signaling and Ranging Device (HASARD) is a personal warning device developed through the Mining Program's collaborative research to warn workers of their proximity to mobile remote-controlled machines. Licenses have been granted to three firms, and two more are pending. A cooperative research and development agreement is pending with a South African firm.
- Mining Program collaborative research developed documents relating to the safety life cycle for programmable electronic mining systems based on International Electrotechnical Commission standards. Various manufactures have integrated Mining Program research into best practices and business plans, and MSHA and state agencies have incorporated research results into permitting approval processes. Other NIOSH divisions have incorporated these methodologies, and the research is being applied to projects in Australia.

Each of the intermediate outcomes listed above has resulted in training and changes in stakeholder work practices for large and small mining operations.

REVIEW OF END OUTCOMES

As previously discussed, trends from 1994 to 2003 indicate good progress in the reduction of mining fatalities and injuries (MSHA, 2004a; 2006), including traumatic injury control. For example, between 1995 and 2004, fatality rates associated with haulage decreased from 10.72 to 5.90, and NFDL rates decreased from 0.503 to 0.316. Decreases also occurred in other categories, such as materials handling, machinery, and ground falls. The reductions are the result of efforts of many in the mining community, and the role of Mining Program research is difficult to quantify. However, it is clear that removing miners from exposure to hazardous gases resulting from blasting, or modifying explosives to make them safer, reduces traumatic injuries. Similarly, by improving electrical regulations, using warning devices, and following good-practice procedures when working with power lines and electrical equipment, traumatic injuries are also reduced. Finally, prevention of traumatic injuries is successful when miners are warned of the proximity of mining equipment, and protected while operating them. All of these contributions, when packaged into traditional and innovative training materials and distributed to the mining community, achieve some measure of the reduction of traumatic injuries and fatalities.

The Mining Program's development and dissemination of training materials via publications, meetings, and computer programs have provided valuable tools for identifying and reducing traumatic electrical injuries.

ASSESSMENT OF RELEVANCE AND IMPACT

The Mining Program has shifted its approach to research: it is conducting fewer long-term research projects (>5 years) in favor of more short-term research projects (<5 years with most <3 years). The current process of identifying, proposing, selecting, and approving its activities is designed to continue the short-term approach, which appears to focus on applied rather than basic research. This may be preferable for a research organization such as NIOSH, but its selection and execution of research activities associated with traumatic injury reduction more resemble technical assistance, particularly when solving the problems of individual stakeholders. This method is not necessarily amenable to considering alternative safety approaches to reducing risk. NIOSH has been successful in partnering with major labor unions and their members, major mining companies, foreign countries, and academia, but has failed to communicate its research results to the entire mining community, especially individual small and large mining operations.

PROGRESS IN TARGETING NEW RESEARCH

The causes and control of traumatic injuries need continued attention as a result of changing scales of mines, equipment, and operations. Particular attention is needed in the areas of automatic and remote control so as to develop more effective safe operations. The Mining Program could take a more proactive approach in defining research needs through increased risk and loss analysis.

The Mining Program often uses surveillance data, stakeholder input, and risk and loss control requirements to define research priorities and its overall goals (NIOSH, 2005a), but these are not adequate for identifying research needed in traumatic injury prevention. As mentioned earlier, traumatic injury prevention research has undergone significant reductions of personnel and funding. Surveillance is limited to the MSHA database, and stakeholder knowledge may be limited to select mining health and safety situations. These limit program efforts in risk and loss analyses. Injury prevention is a major issue in several other industrial sectors, and the potential is great for transfer of knowledge and experience to the Mining Program from other NIOSH programs.

Signature Accomplishments: Injury Prevention

The interactive training program "3-D Hazard Recognition Training: A New Approach to Preventing Injuries Associated with Construction, Maintenance and Repair Activities" *(http://www.cdc.gov/niosh/mining/products/view-masterreeltrainingexercises.htm)* was developed in cooperation with aggregates mining companies and Pennsylvania State University, authenticated by mine safety experts, extensively field-tested with miners, and distributed through the Mine Safety and Health Administration. Training led to an increase in miners' knowledge, compared to those who did not take the training. Major aggregate producers, including Vulcan Materials and Hansen Aggregates, have incorporated the training into their Part 46 training classes. The program has been used at more than 1,500 mining operations throughout the United States, and more than 5,000 copies have been requested. It is being used to train workers not only in the mining industry, but also in construction, gas, and oil extraction. It has been translated into Spanish by the Center to Protect Workers' Rights and has also been requested internationally.

12

Review of Mine Disaster Prevention and Control Research

Key Findings and Recommendations for Mine Disaster Prevention and Control Research

- Historically, mine disaster prevention research within the Mining Program has been of the highest relevance and has had the highest positive impacts on the worker.
- The Mine Disaster Prevention and Control Research needs to place more focus on areas such as communications, miner self-rescue, and emergency response.
- A systems approach to mine management and rescue is needed that will continuously provide marker data and response via intelligent system analysis.
- The Mining Program needs to continue its efforts in disaster prevention and further strengthen its efforts in the area of disaster response.
- The Mining Program should be more involved in monitoring the work of, and partnering with, international bodies to determine the domestic applications of work done abroad.

STRATEGIC GOALS AND OBJECTIVES

The Mining Program and its predecessors have been the primary researchers for mine disaster prevention for the better part of the twentieth century. Mine disaster prevention and control research within the Mining Program addresses mine disasters, which are defined by the Mining Program as five or more fatalities per incident *(www.cdc.gov/niosh/mining/statistics/disall.htm)*. The program goal, as stated, is to "reduce the risk of mine disasters (fires, explosions, and inundations); and minimize the risk to, and enhance the effectiveness of emergency responders," and will be achieved with a 25 percent reduction in the number of injuries and deaths attributed to mine fires, explosions, inundations, and rescue response activities between 2010 and 2014, compared to the average yearly totals from 1990 to 2001 (NIOSH, 2005a). The Mining Program has also identified four intermediate goals and performance measures in this research area, summarized in Table 12-1. The committee assumes that the goals as stated are considered by the program as intermediate milestones toward its ultimate goal of the complete elimination of mining-related illness and injury.

This strategic goal is in alignment with the National Institute for Occupational Safety and Health (NIOSH) agency-wide strategic goals to conduct research to reduce work-related illnesses and injuries.

The traditional hazards in the area of mine disasters are well known. Emerging hazards will arise as the production of resources enters into a higher level of geologic complexity. The strategic goal is in alignment with the major current challenges facing the mining industry including fire, explosion, inundation, and ground failure prevention. The overarching goal does not, however, mention enabling the miner's ability to self-rescue, although it is a subcategory within intermediate goal 4 (Table 12-1). Prevention, response, and self-rescue are all of high importance in the inherently dangerous mining environment. This component of intermediate goal 4 would be more appropriate as a high-level goal. The intermediate goals are somewhat interrelated to achieving the ultimate goal, though they do not currently produce a strongly integrated program plan.

According to materials submitted to the committee by the Mining Program, major barriers to accomplishing this strategic goal include the following:

1. An incomplete understanding of the root causes of mine fires, explosions, and inundations;
2. The lack of totally effective engineering controls to prevent, detect, and mitigate mine disasters; and
3. The lack of education and training of the general mining workforce pertaining to methods to predict, prevent, and deal with a mine emergency.

Barriers not identified by the Mining Program include (1) the indirect relationship between the work of NIOSH and direct impact in the workplace and (2) an incomplete understanding of weather-related ignition sources.

Based on the discussion of the ideal mining program in Chapter 3, the Mining Program needs to continue its efforts in disaster prevention and further strengthen its efforts in the area of disaster response.

TABLE 12-1 Intermediate Goals and Performance Measures of Mine Disaster Prevention and Control Research and Committee Comments

Intermediate Goal[a]	Performance Measure[a]	Committee Comments
1. Reduce the number of reportable (½ hour or longer) fires in U.S. mines by 25% in 5 years through the development of new or improved strategies and technologies in the areas of mine fire prevention, detection, control, and suppression	Reduction in the number of fires in the coal and metal or nonmetal mining sectors between 2010 and 2014 by 25% compared to the average yearly totals from 1990 to 2001, as measured by Mine Safety and Health Administration (MSHA) mine fire statistics	Has a direct opportunity to impact disasters because fires in underground mining are life threatening if not controlled immediately. The history of fire reduction is positive and long term; some effort should be focused on prevention to address the increasing number of frictional initiations
2. Develop and facilitate the implementation of interventions to address currently identified shortcomings in the coal mining explosion prevention "safety net"	Reduction in the number of injuries and deaths attributed to mine explosions between 2010 and 2014 by 25% compared to the average yearly totals from 1990 to 2001, as measured by MSHA accident statistics	This safety net contains multiple components of frictional ignition sources, workforce experience, difficult conditions, and technical or operational changes in techniques and technology. The intermediate goal has a clear relation to achieving the strategic goal
3. Reduce or eliminate inundations in U.S. coal mines within 7 years through the development of bulkhead (structures to impound water in mines) design guidelines to be published by 2009. Also, to help reduce the safety hazard to miners from inundations, publish mine design guidelines that would mitigate or prevent inundations by 2009	(1) Improved mine designs and comprehensive bulkhead design, inspection, and monitoring guidelines are developed and adopted by the industry (MSHA) within 5 years and (2) reduction in the number of mine inundations related to bulkhead failures by 50% within 7 years (baseline is 20-year period between 1983 and 2002)	Has the ability to impact the goal if research is directed at new and better materials rather than design parameters. MSHA lists a number of approved explosion-proof seals (Lowrie, 2002). What is not in place are material selection and construction practice improvements so that available designs can be implemented readily across mining sectors at a reasonable cost. The design criteria for stoppings that can contain or prevent propagation of an explosion need to be identified

4.	Assist the mining community to maintain and improve mine escape, rescue, and emergency response capabilities through realistic training exercises and the development and implementation of new or improved training aids and exploration, rescue, and escape technologies	(1) Participation of 75 mine rescue teams and 2,500 miners in NIOSH-led training to improve their safety, skills, effectiveness, confidence, and teamwork for rescue and emergency operations; and (2) incorporation of improved NIOSH-developed strategies and technologies for mine rescue and response into practice and deployment activities by at least 25% of U.S. mine rescue teams	This intermediate goal is the most relevant in achievement of the strategic goal. It addresses the spectrum of research necessary to enhance the effectiveness of emergency responders and reduce the risk to those individuals. It needs to be strengthened in the area of tools for the miner to self-rescue

[a]SOURCE: NIOSH, 2005a.

REVIEW OF INPUTS

In recent years the Mining Program has changed from an inwardly focused agency to one that willingly participates in partnerships and seeks input from all facets of industry, labor, and regulatory agencies. Successful partnerships in diesel exhaust emission reductions, personal dust monitoring, and noise controls have been met with enthusiastic industry-wide support, and the results include practical solutions to some problems that have vexed the industry for years. These types of partnerships have not been used by the disaster research prevention group until recent months with the formation of an industry-government partnership with the National Mine Rescue Association.

NIOSH, the Mine Safety and Health Administration (MSHA), and the National Mine Rescue Association have formed a partnership to review and revise, as needed, the procedures for mine rescue efforts in the event of an emergency. Recent episodes at the Sago (West Virginia, 2006) and Aracoma Alma (West Virginia, 2006) mines have highlighted some glaring deficiencies in the existing protocols for incident management. The cell phone age has made it necessary for companies and government regulators to adjust communications procedures, as well as update mine rescue response tactics. This effort is well under way, with representatives of each group addressing ways to improve the effectiveness of mine rescue teams and the management of emergencies. Experienced mine rescue veterans comprise the working groups, and the preliminary results have been encouraging.

The Mining Program does not appear to take full advantage of disaster prevention research done internationally, though it has been a regular contributor at the Biennial International Conference of Safety in Mines Research Institutes. Monitoring the work of, and partnering with, international bodies would help the Mining Program determine the domestic application of work done abroad. Partnerships and information exchange enable better familiarity with the international community. Examples of international work with potential domestic application include research on refuge chambers (DJF Consulting Limited, 2004), emergency response (Brenkley et al., 1999), and self-escape vehicles (Davis, 2006).

The mine disaster prevention research group has responded over time to developing an understanding of the root causes of mine fires and explosions. This has provided input into further research and resulted in intermediate outcomes.

Inputs to the mine disaster research group are varied and include stakeholder requests for assistance, stakeholder information-gathering meetings, response to disasters as participants in industry and government workgroups, analysis of fires in the mining industry, and fatality and injury analysis data from MSHA. Stakeholder input in the area of disaster research appears to be moderately adequate in that it relies predominantly on the analysis of fires and of fatality and injury data and the results of investigations. A more proactive approach should be taken by the Mining Program, including an analysis of MSHA citations where mines fail to meet regulations consistently in specific areas and a review of geologic settings and operational methodologies leading to increases of incidents. Finding a means to receive input from all sectors with a focus on mines, given limited resources, is the key to industry-wide response.

REVIEW OF ACTIVITIES

Current research projects fall into one of the four intermediate goals listed in Table 12-1. In the goal of reducing reportable fires (intermediate goal 1), work is being conducted in training, fire-resistant materials, early-warning devices, ignition sources (e.g., spontaneous combustion), fire suppression, and decision making. This work is relevant but could be enhanced to include more aggressive prevention of ignition. Work on intermediate goal 2 broadly includes research in the area of coal mine explosion prevention through improved ventilation, methane monitoring, rock dust evaluation, and degasification. Some areas of research in this intermediate goal are more relevant than others. Work in the area of degasification considerably lags common practices in the industry. Current work by the Mining Program in the addition of inert gas to smother mine fires has been practiced by industry since 1949 (Adamus, 2002).

Intermediate goal 3, the prevention of mine inundation, is less relevant because the work is related predominantly to design parameters of stoppings and bulkheads, rather than the identification of better materials. Additional focus for research would include cost-effective and efficiently installed materials that can be used in all mining sectors. Reduction in inundations requires the application of technology to identify voids and the potential for inundation in advance, for example, via accurate surveying control and geophysical methods, which already exist and are in use at some mines. Efforts are required to make this technology available at all mines.

Intermediate goal 4, research related to emergency response, lacks focus. Prior to 2006, the significant reduction in the number of major mine disasters resulted in the Mining Program shifting its research emphasis to more health-oriented topics. The number of outputs in the area of disaster prevention decreased. The 2006 fatal mine disasters have forced the industry and the Mining Program to consider progress made in implementing new technologies in such areas as through-the-ground communications systems, miner tracking systems, rescue chambers, new technologies for self-contained self-rescuers, and the need for a greater oxygen supply on the belt of miners and in storage caches. All of these areas need directed and sustained effort.

Table 12-2 lists projects undertaken by the Mining Program in the area of mine disaster prevention research. The Mining Program has been very active in acquiring data and testing proposed solutions in the field in response to stakeholder interests. This has been particularly true in the diesel exhaust, noise control, and personal dust monitor partnerships.

REVIEW OF RESEARCH OUTPUTS

The Mining Program reports 236 outputs resulting from disaster prevention research generated between 1996 and 2005 (NIOSH, 2005a). Of these, the committee expects that external publications, patents, workshops, and industry briefings to be moderately likely to lead to intermediate outcomes if deployed appropriately. The major outputs resulting from disaster prevention research, in terms of volume, are technical publications, presentations at professional meetings, and proceedings. Audiences are limited at technical symposia. The outputs address some but not all of the high-priority areas; the strengths are in the area of mine fires, and training at the Lake Lynn facility for rescue teams. The most useful output formats are *Technology News*, workshops, and open industry briefings. These are delivered directly to the interested parties in real time. The readable design of *Technology News* effectively communicates relevant and timely information concerning breakthroughs in new technologies.

A critically important output was recently released to industry. The Coal Dust Explosibility Meter has the potential to prevent the propagation of explosions by enabling real-time evaluation of the explosibility of coal and inert dust mixes (Sapko and Verakis, 2006). Other notable outputs include a computer-based emergency simulation exercise (MERITS), the Emergency Communications Triangle training materials focusing on the content of emergency warning messages, and the evaluation of the lifeline and development of directional cones for self-rescue.

NIOSH has issued many criteria documents[1] in need of action. These papers have great weight in the regulated community. In cases where the regulatory bodies have not acted on the recommendations, they are incorrectly referred to as fact when differing parties champion their views. If these documents have been published for extended periods of time, they should be withdrawn and/or revised based on new information. Currently, there appears to be no mechanism to accomplish this.

[1]Criteria documents are published by NIOSH in partial compliance with the Occupational Safety and Health Act of 1970 (P.L. 91-596), which declares that NIOSH will recommend occupational safety and health standards describing exposure concentrations considered safe for various periods of employment. Criteria documents are published by NIOSH to provide the scientific basis for recommended standards (*http://www.cdc.gov/niosh/docs/98-126/* [accessed February 15, 2007]).

REVIEW OF TRANSFER ACTIVITIES

Moving technologies from the research phase into practice throughout the mining industry, and from one sector of the industry to another, is a challenge. Technologies and engineering controls are critically tied to the geologic setting and mining methods employed.

Technology transfer of specific mine disaster prevention research has always proven difficult because of the diverse nature of mining. The typical method of knowledge transfer is publication or presentation at technical symposia. The Mining Program presents papers in these forums and supports them in many ways. Attendance at trade shows and professional society meetings, however, has been declining. Although it makes sense to continue presenting in these venues, a variety of output media are necessary to reach broad and diverse industry groups. The audiences for *Technology News* and the Mining Program web site *(www.cdc.gov/niosh/mining)* are more widespread. Continuous stakeholder awareness of resources is necessary for goals to be achieved.

Technology News provides executive summaries of NIOSH mining safety and health research milestones, making them easy to review, and includes complete contact information for the topic discussed. These are distributed to stakeholders as they are published through mailing and e-mail lists. The impermanent nature of mining employees leads the committee to believe the mailing lists may be outdated. The web site that NIOSH maintains is in need of redesign. It is difficult to find particular information and should include an easier way to access Information Circulars and other publications of interest to the industry. Perhaps a better search engine could improve the ability to find desired information.

REVIEW OF INTERMEDIATE OUTCOMES AND CAUSAL IMPACT

In analyzing the technical issues raised by recent mine disasters and events with disaster potential, the Mining Program should provide the knowledge and technical expertise to specify the most sensible way to improve mine safety. U.S. Bureau of Mines (USBM) and Mining Program work in this area has been incorporated in other industries (e.g., in grain elevators).

Intermediate outcomes resulting from recent research include the following:

- Enhancement of the mining industry's awareness of the dangers of underground mine fires;
- Improvement of the effectiveness of rescue teams;
- MSHA's acceptance of the American Society for Testing and Materials (ASTM) E-162 Radiant Panel Test as a major criterion in the selection and use of

TABLE 12-2 Mine Disaster Prevention Projects and Committee Assessment of Relevance and Impact

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
1. Closed-Circuit Escape Respirator Standard	4	Develop testing standards for the respirator and self-contained self rescuer (SCSR)	Adequate	Better understanding of the functioning of the SCSR is likely to lead to some improvement
2. Coal Mine Face Methane Control and Monitoring	2	Eliminate methane ignitions at working face. Technology transfer to others (e.g., MSHA)	Adequate	Without a focus on elimination of methane, impact will be moderate
3. Design Guidelines for Mine Ventilation Stoppings	3	Develop guidelines for ventilation stoppings that withstand in-service load conditions	Somewhat relevant, but many guidelines already exist	Impact not likely if the focus is not on materials and installation that can be applied readily throughout the industry
4. Fire Hazard Reduction in the Metal and Nonmetal Mining Industry	1	Fire-resistant materials, early warning, training, and education	High	Results should lead to further improvements in fire reduction
5. Investigation of Methane Control Issues in Underground Mines	2	Investigate and quantify mine design and geotechnical factors leading to methane emission and subsequent control	Loosely connected. There is a need for advancing ventilation research and combining it with methane drainage techniques in a systematic control of methane	Limited impact anticipated because research is lagging industry practice
6. Lake Lynn Laboratory	1, 2, 3, 4	Provide a modern laboratory for health and safety research	High	Major impact but needs to target investigations pertinent to all stakeholders

7. Long-Term Field Evaluation (LTFE)	4	Monitor reliability of SCSR	Adequate surveillance work	Minimal impact expected—new SCSR needed
8. Mine Rescue and Response	4	Rescue team training	High	Major impact expected
9. Prevention and Mitigation of Gas or Dust Explosions	2	Explosion propagation, dust meter	High—research is needed in natural causes of explosions	Future improvement likely with the release of the dust meter
10. Prevention and Mitigation of Mine Inundations	3	Bulkhead design	Adequate, but need practical application of the designs that already exist. No mine design work in progress	Limited impact expected
11. Reducing Fire Hazards in U.S. Coal Mines	1	Spontaneous combustion	High	Impact likely if focus is on prevention
12. Remote Methods for Addressing Coal Mine Fires	1	Suppression of fires	Adequate	Major impact on fighting fires once started
13. SCSR Training Modules	4	Care and maintenance	High	Limited by functionality of existing SCSR designs
14. Smoke Management and Fire Modeling for Underground Mines	1, 4	Fire simulator for making ventilation decisions	Adequate	Impact likely if all mines have up-to-date model at time of an event that could lead to a disaster and for rescue decision making. This is not currently required by regulation

[a]SOURCE: NIOSH, 2005a.

these materials based on NIOSH research on flammability of noise control materials in operator cabs;

- Incorporation of research findings into the 2004 revised National Fire Protection Association (NFPA) mining fire protection standards (NFPA 120 standard on underground coal and NFPA 122 standard on metal and nonmetal);
- American National Standards Institute (ANSI) standards governing the power thresholds for laser-based optical and telecommunications equipment (fiber-optic networks) as a direct result of the Mining Program's research on ignition of flammable atmospheres by such lasers;
- Work resulting in the permissible use of mobile equipment in evacuation during main fan outages in Pennsylvania;
- An emergency ruling by Congress (the Mine Improvement and New Emergency Response Act of 2006, P.L. 109-236) requiring use of the NIOSH-evaluated Directional Lifelines for Mine Evacuations; and
- Implementation of automatic fire suppression systems on conveyor belt drives and underground diesel storage areas.

Additional intermediate outcomes that are better focused on achieving the end outcome of 25 percent fewer fatalities and injuries would be the implementation by the industry of a new SCSR and communications technology.

REVIEW OF END OUTCOMES

The stated performance measure for this strategic goal is the reduction of the number of injuries and deaths attributed to mine fires, explosions, inundations, and rescue and response activities by 25 percent between 2010 and 2014, compared to the average yearly total from 1990 to 2001 (compiled from MSHA accident statistics). There were 21 fatalities attributed to two accidents[2] from 1990 to 2001.[3] Long-term trends in data collected on incidents have shown continuous improvement in the frequency and severity of mine disasters, with the incidence of injury and the number of fatalities setting record lows in 2005. However, recent events and the dramatic upsurge of fatal accidents need to be reviewed and the causes determined. The 17 fatalities resulting from two disasters (Sago Mine, Upshur County, West Virginia, 12 fatalities, January 2, 2006; Darby Mine, Darby, Kentucky, 5 fatalities, May 20, 2006) during the first half of 2006 are troubling.

There is an indirect relationship between the work of the Mining Program and

[2]Southmountain Coal Mine No. 3 (Norton, Virginia) experienced an explosion that killed eight people on December 17, 1992. The Jim Water Resources, Inc. No. 5 coal mine (Brookwood, Alabama) experienced an explosion that killed 13 people on September 23, 2001.

[3]*http://www.cdc.gov/niosh/mining/statistics/disall.htm.*

impact in the workplace. The Mining Program cannot directly attribute any lives saved to the research it performs. It can attribute an increased body of knowledge to this work. The required use of lifelines during emergencies is expected to contribute to saving lives given appropriate enforcement. The Dust Explosibility Meter should influence the state of rock dusting and could be a factor in limiting the propagation of an explosion, but a direct measure of lives saved is not possible.

ASSESSMENT OF RELEVANCE AND IMPACT

The committee realizes that mine disaster prevention is a complex area requiring expertise in several fields such as (1) mining engineering; (2) fires and fire control engineering; (3) methane, coal, pyrite, and other explosives—their initiation, progression, and control; and (4) the impact of all of these on normal mine operations, disaster response and management, and so forth. A major aspect of preventing an incident from growing into a disaster involves human behavior, training, and response effectiveness. Research expertise and facilities are not easily developed. Specialized staffing and funding for this area require constant attention.

Historically, mine disaster prevention research within the Mining Program has been of the highest relevance and has had the highest positive impacts on the worker. Currently, only some of the highest-priority areas in mining disaster prevention are addressed through Mining Program research. Some research has led to changes in MSHA rules and regulations that directly impact the workplace, but research in areas such as communications, miner self-rescue, and emergency response is not adequate.

The committee judges mining disaster prevention research to be focused on lesser priorities. Current research may result in new knowledge, but only limited application of that knowledge is expected.

PROGRESS IN TARGETING NEW RESEARCH

The Quecreek mine inundation incident and the disasters at Sago and Alma Mine No. 1 revealed weaknesses in a number of disaster prevention and response areas. Several of these can be addressed by a greater and more rigorous application of existing advances in disaster prevention and emergency response practices, although research is needed on several fronts including disaster prevention, communications, escape and survival systems, and response equipment, rescue teams, in situ assessment of geologic conditions, monitoring of atmospheres behind seals, and evaluation of mining methods. In all of these areas, there may be some potential for transfer of technology and practices from the international community (e.g., Australia, Poland, South Africa, Canada). However, because of differences in laws, regulations, and cultural or other practices, direct application may not be feasible.

Communication has been recognized as a major source of problems in need of great attention to provide effective disaster response and escape. The subject of emergency communications has been of particular concern for two committees of the National Research Council (NRC) that dealt with mine rescue and survival issues (NAE, 1970; NRC, 1981). More recently, the Pennsylvania Governor's Commission on Abandoned Mine Voids and Mine Safety—the Quecreek Commission—addressed the issue of emergency communications (Commission on Abandoned Mine Voids and Mine Safety, 2002). The 1981 NRC report pointed out a number of issues and potential approaches: underground-to-surface communications, communication between rescue teams and trapped miners, and permanently installed seismic systems that could be used on a day-to-day basis. According to the Quecreek Commission, there was no lack of basic technical knowledge, but the availability of practical engineering designs (which may have to be site specific) was a major limitation.

An NRC report on evolutionary and revolutionary techniques for mining (NRC, 2002) also stressed the need for the development of a communications system to each miner based on real-time data and analysis. While the report recognized major developments in monitoring systems for the atmosphere, equipment, and pager systems, it recommended the integration of these systems for specific and immediate safety information and instructions to individual miners. It is generally acknowledged that the most effective emergency communications system is one that is used for routine communication. Research by the Mining Program into the development of practical designs of effective communications systems that would be useful for routine communications but withstand the damaging effects of mine disasters is recommended.

Although long-term trends have shown continuous reduction in the frequency and severity of mine disasters, recent events and the dramatic upsurge of fatal accidents in 2006 should be reviewed, and reasons for the upsurge determined. The Mining Program needs to examine the causes of the incidents and the reasons for the inadequate escape and rescue responses.

Signature Accomplishment: Disaster Prevention Research

Coal mine operators are required to maintain an incombustible content of at least 65 percent in the entries and 80 percent in the returns (30 CFR 75.403). The U.S. Bureau of Mines and Mining Program research efforts have focused for some time on coal dust explosibility and rendering the dust inert through the application of incombustible material. The recent release of the hand-held Dust Explosibility Meter developed by NIOSH in collaboration with MSHA is a signature accomplishment of the NIOSH Mining Program (Sapko and Verakis, 2006). The meter directly assesses the effectiveness of rock dusting, avoiding a two-week wait for laboratory analysis. Although it will not replace in-depth laboratory analysis, it will provide a more immediate determination of the adequacy of rock dusting. If the prototype is made available commercially and utilized throughout the coal mining industry, safety should be improved.

13

Review of Ground Failure Prevention Research

Key Findings and Recommendations for Ground Failure Prevention Research

- Research is in high-priority areas, has resulted in new knowledge, and is connected to improvement in workplace protection.
- The Mining Program should be involved in developing better methods of periodic or continuous monitoring of slope movement by evaluating recent advances in radar, photogrammetric, and other methods.
- Future ground failure prevention research should include research into unwanted consequences of blast-weakened materials.
- Research is needed to minimize risk to underground workers and potential damage to surface structures associated with mining-induced seismicity.
- The Mining Program should consider ways to improve sophisticated numerical techniques for modeling variously shaped openings in heterogeneous and discontinuous materials at different degrees of saturation.
- The Mining Program should be involved in developing best strategies for deep mining (>600 m).

STRATEGIC GOALS AND OBJECTIVES

With a few exceptions, ground failure prevention research within the Mining Program is limited to the reaction of the perimeter of excavations in the earth's crust. Such excavations are produced in the mining of coal, metal and nonmetal, and aggregate and can be underground or on the surface.

Mining has the highest fatal injury rate of any U.S. industry, and ground failures are a significant cause of those injuries and deaths (NIOSH, 2005a). The reduction of ground failure fatalities and injuries is one of the National Institute for Occupational Safety and Health (NIOSH) Mining Program's strategic goals. The performance measures of success for this goal are "(1) mine fatalities by ground failures are reduced by 50% within 8 years, (2) injuries by ground and roof support system failures are reduced by 25% within 5 years and by 50% within 8 years, and (3) unplanned roof falls are reduced by 20% within 5 years and by 40% within 8 years" (NIOSH, 2005a). Table 13-1 summarizes the mining program's intermediate goals and their performance measures in this research area and provides committee comments regarding their appropriateness.

In the opinion of the committee, Mining Program research in this area is innovative in both establishing intermediate goals and formulating research methodologies. Although some of the issues in Table 3-4 are not currently being addressed by the Mining Program, the intermediate goals and current Mining Program research projects all closely relate to issues the committee assessed as most relevant (see Chapter 3). Improvement is needed in broadening the intermediate goal statements. In some cases, the intermediate goal is too restrictive. Very specific performance measures facilitate assessment, but broadening the intermediate goals would clarify the relevance of complementary efforts.

The intermediate goals established for ground failure prevention research are forward looking and focused appropriately on emerging safety issues.

REVIEW OF INPUTS

Table 13-2 summarizes MSHA fatality statistics as a measure of relative frequency of accident types for coal and metal or nonmetal mining. The data indicate ground control conditions contribute significantly to fatalities in coal mining and, to a lesser extent, in metal and nonmetal mining. Ground failure fatalities range from 11 to 52 percent of the total number of coal mining fatalities per year, with an average of about 29 percent between 1997 and 2005. The number of similar fatalities for the same period in the metal and nonmetal sectors ranged from 0 to 13 percent per year. The data support the concern that ground failures represent a significant cause of injuries and fatalities and can be a burdensome mine operating cost.

The committee concludes that Mining Program personnel are working with metal-nonmetal and coal mine personnel to identify areas of greatest concern. Current and planned research deals with issues raised by stakeholders particularly in the areas of monitoring highwalls and slopes in surface mines, avoiding inundations when mining is close to water impounding structures and abandoned mines, surface treatments to improve long-term stability of underground openings, monitoring roof conditions in underground stone mines, and reducing damage caused by conventional blasting, to mention only a few examples. The program needs to, however, prepare itself for attrition. Because many seasoned Mining Program

TABLE 13-1 Intermediate Goals and Performance Measures of Ground Failure Prevention Research and Committee Comments

Intermediate Goal[a]	Performance Measure[a]	Committee Comments
1. Improve understanding of rock mass failure mechanics	Models will be developed and applied to explain the coal mine entry and caving-overburden response (3-year time frame) and the failure modes caused by horizontal stresses in stone mines (4 years). Additionally, the models and related knowledge (including appropriate design and intervention approaches) are transferred to the industry within 6 years	By limiting the types of mining investigated and the geologic environments of study, as has been done, the intermediate goal is achievable. Much more work is needed to expand the intermediate goal to the mining industry as a whole.
2. Develop better roof surface control technology	Number of rock fall injuries in coal mines will be reduced by 50% over the next 5 years	Intermediate goal is aggressive, and training and monitoring need to be integral to the technology. No logical basis for selecting 50% as the target. The performance measure should be a sustained decreasing trend in rock fall injuries
3. Develop better design-based control technology for multiple-seam coal mines	(1) Multiple-seam design guidelines will be provided to the mining industry within 3 years, and (2) severe multiple-seam interactions will be reduced by 80% within 8 years	Smaller mines may not be able to utilize developed technologies that are design-based, even if available within the time frames. No logical basis for selecting 80% as the target. The performance measure should be a sustained decreasing trend in accidents resulting from multiple-seam interactions
4. Develop new ground control technology for mines with low-strength roofs	Ground control technologies are adopted by the target mine population, resulting in a 50% reduction in roof falls at these mines. Technologies will be applicable to the estimated 25% of U.S. coal mines that encounter weak roof conditions	Intermediate goal is too restrictive. Problems with weak roofs occur in mines other than those in the Illinois and northern Appalachian coal basins

5.	Improve selection of best support systems for specific geologic environments	(1) Characterize 15 new standing supports over the next 5 years, and develop more efficient standing support systems that are implemented in the mining industry; and (2) new decision logic for support selection and implementation is adopted by large segments of the mining industry	Manufacturers are cooperating, as are mining companies, making achievement of this intermediate goal likely
6.	Develop a sensor-based risk management systems for roof falls in stone mines	Sensor-based risk management system for roof falls will be developed and used in 20% of underground stone mines within 4 years	Funding and time constraints within the industry may hinder sustained reduction of roof fall accidents
7.	Reduce injuries caused by rock bursts	Developed ground control technologies are adopted by 50% of the target mine population	Mining companies are enthusiastically adopting these technologies, resulting in substantial safety improvement. The intermediate goal is likely to be achieved. Additional work is needed to reduce coal burst accidents in underground longwall operations

[a]SOURCE: NIOSH, 2005a.

TABLE 13-2 Coal and Metal or Nonmetal Mining Fatalities Related to Ground Failure

Year	Roof Fall		Rib or Face Fall		Highwall Failure		Loose Rock Highwall		Stockpile Slide		Total Fatalities		Percentage of All Mining-Related Fatalities	
	Coal	M/NM	Coal	M/NM	Coal	M/NM	Coal	M/NM	Coal	M/NM	Coal	M/NM	Coal	M/NM
1997	5	2	3	1	0	2	0	0	0	0	30	61	27	8
1998	13	2	1	1	1	0	0	0	0	0	29	50	52	6
1999	10	3	3	2	3	2	0	0	0	0	34	53	47	13
2000	3	0	1	1	1	1	0	0	0	0	38	48	18	4
2001	9	4	2	0	0	0	0	0	0	0	42	30	26	13
2002	5	0	2	0	0	1	1	0	0	0	27	42	30	2
2003	2	0	1	0	0	0	0	0	0	0	28	26	11	0
2004	3	0	2	0	0	1	0	0	1	0	28	27	21	4
2005	9	0	0	0	0	0	0	0	0	0	22	35	41	0
Cum	59	11	15	5	5	7	1	0	1	0	278	372	29	6

NOTE: M/NM = metal and nonmetal. SOURCE: *http://www.msha.gov/fatals/fab.htm* [accessed March 13, 2007].

researchers in ground failure prevention are approaching retirement age, the development of junior-level personnel should be accelerated to maintain momentum.

REVIEW OF ACTIVITIES

There are 11 ongoing research projects in the area of ground failure prevention research (NIOSH, 2005a), briefly summarized and evaluated in Table 13-3. The intermediate goals referred to in this table are consistent with those in Table 13-1.

Identifying projects 2 and 10 on Table 13-3 as "complementary" to intermediate goals should not relegate them to a less important status than other projects. The committee considers the activities in ground failure prevention research to be highly relevant. Two efforts deserving special recognition are activities associated with the mine roof simulator and rock burst research. The simulator has also been a critical resource in testing new roof support ideas and has resulted in accelerated commercial development of more than 40 new roof support technologies over the past 5 years. Seismic monitoring and basic research into strategies to reduce bursting potential will continue to serve the mining industry in the future.

Ground failure prevention project descriptions provided by the Mining Program (NIOSH, 2005a) often contain clear reference to the stakeholder group to whom the efforts apply (e.g., projects 4 and 8 in Table 13-3). The project scopes are broad enough to avoid being considered consulting projects for individual mines, but narrow enough to focus on specific issues. It is not clear, however, how these issues fit into a coordinated research agenda. It may be possible to have a more general project scope that would include two or more applications with greater efficiency in effort and resources.

REVIEW OF RESEARCH OUTPUTS AND TRANSFER ACTIVITIES

Table 13-4 summarizes the types of outputs generated through ground failure prevention research in the Mining Program.

Ground failure prevention output represents approximately 24 percent of the total Mining Program output during the period evaluated. Publications are the primary form of output and include both peer-reviewed journal articles and conference proceedings. The emphasis on publishing research results in the refereed literature provides opportunities for professionals in the field to review and evaluate the work of the Mining Program. Furthermore, the Mining Program has utilized current technology to transfer results through electronic media and print.

Peer review of publications helps ensure the quality of research, but conference articles and proceedings generally reach end users more quickly. Several symposiums and meetings are held on an annual basis by professional organizations and

TABLE 13-3 Ground Failure Prevention Projects and Committee Assessment of Relevance and Impact

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
1. Development and Evaluation of Innovative Roof Support Technologies	5	Testing various devices developed by support manufacturers using the Mining Program's unique Mine Roof Simulator	Highly relevant to improving workplace protection; the Mining Program is engaged in transfer activities	Major contribution expected
2. Fragmentation Methods and Ground Control Safety	Comple-mentary to overall strategic goal	Investigate blast patterns and rock damage caused by blasting	High-priority area, but the Mining Program is not currently involved in transfer activities	Activities are ongoing and likely to produce improvements
3. Fundamental Studies of Factors Responsible for Falls of Ground	6	Advancing understanding of ground falls and development of monitoring systems to detect the onset of instability	High-priority area, and transfer activities have begun	Microseismic monitoring likely to result in improvements; publications produced
4. Guidelines for Eliminating Hazardous Ground Conditions from Underground Stone Mines	6	Evaluation of field data to determine safe limits for roof spans and pillar dimensions and the effect of mine air temperature and humidity on pillar performance	Highly relevant to improving workplace protection. The Mining Program is engaged in transfer activities	Results have produced safer designs. Positive impact expected in the workplace
5. Ground Stability Through Advanced Mine Design	1, 3, 5 (indirectly)	Deep-cover coal pillar recovery, high horizontal stress control, and multiple-seam mining	Highly relevant to improving workplace protection; the Mining Program is engaged in transfer activities	Statistics show a reduction in fatalities

6. Identification and Control of Rock Burst Hazards	7	Wall strain, electromagnetic emissions, and microseismicity are being investigated to determine if they can be used to identify rock burst failure mechanisms and warn of impending failure	Highly relevant to improving workplace protection, and the Mining Program has been engaged in transfer activities. Research should be expanded to include bumps in deep coal mining (a more pressing problem in the future)	Past and current work has resulted in reduction in injuries and fatalities
7. Preventing Injuries from Falling Rock in Underground Coal Mines	2	Development of surface treatments, specifically application of screens, along with methods of avoiding injury caused by installation of screens, and identification of geologic materials that deteriorate with time	Relevant and directly related to improvements in workplace safety	Publications produced, likely to improve workplace safety
8. Reduction of Groundfall Hazards in Nevada	2, with overlap in 1 and 4[b]	Mine design criteria including rock mass ratings and span widths and the use of fiber-reinforced shotcrete as a surface treatment to improve stability	Highly relevant to improving workplace protection; the Mining Program has engaged in transfer activities	Design manual adopted by mines in four states
9. Roof Fall Evaluation and Mediation in Weak Rocks	4[b]	How roof supports perform in weak rock, how fracturing is induced by excavation, and how fracturing can be arrested	High priority in developing improved analytical design techniques for underground mines	Hardware developed now being deployed
10. Slope Stability Hazard Recognition	Complementary to overall strategic goal	Improve safety near slopes in surface mines and near openings in large underground mines	Identified as relevant by stakeholders	Publications produced, computer program developed, and video produced. New monitoring equipment could substantially improve workplace safety

continued

TABLE 13-3 Continued

Project Title[a]	Intermediate Goal	Description[a]	Relevance	Impact
11. Stability Assessment with Seismic Monitoring	7	Better awareness of unusual ground response to mining and forensic analysis of major ground movement	Highly relevant, likely to result in better understanding of potential damage to surface structures	Assistance is now being provided to Colorado mines

[a]SOURCE: NIOSH, 2005a.
[b]Intermediate goal 4 was developed specifically for the Illinois and northern Appalachian coal basin, but projects may have wider range of application.

TABLE 13-4 Summary of Ground Failure Prevention Outputs (1998-2005)

Year	Publications (peer reviewed and conference proceedings)	Patents	Software	Workshops and Training	Web	Video	Total
1996	46	1	0	0	0	0	47
1997	36	0	0	5	1	0	42
1998	37	0	0	5	0	0	42
1999	35	0	0	5	0	1	41
2000	27	0	3	7	1	1	39
2001	49	2	0	5	1	1	58
2002	28	1	0	3	1	1	34
2003	35	0	3	4	1	0	43
2004	33	0	3	4	0	2	42
2005	30	1	2	1	0	0	34
Total	356	5	11	39	5	6	422

SOURCE: NIOSH, 2005a.

technical interest groups on such topics as ventilation, ground failure prevention, longwall mining, health and safety, and miner training. In the experience of the committee, mining practitioners generally seek out these conferences and workshops in preference to peer-reviewed journals. The ratio of conference articles to well-recognized proceedings and peer-reviewed publications is about 2:1, which is reasonable given the makeup of stakeholders. The Mining Program is to be complimented for encouraging and supporting travel to national meetings to present research results.

According to the Mining Program Briefing Book, ground failure prevention research receives approximately 16 percent of the total program budget but has produced nearly 24 percent of the outputs. The ground failure prevention portion of the mining program discretionary budget is approximately 10 percent. These statistics indicate good productivity.

The Mining Program has done an admirable job of improving technology transfer and making ground failure prevention research results available on electronic media.

REVIEW OF INTERMEDIATE OUTCOMES AND CAUSAL IMPACT

Defined deliverables or outputs resulting from research efforts have intrinsic value, but only to the extent that they are translated into practice. Table 13-5 relates outputs of the ground failure prevention research group to specific intermediate outcomes observed from 1996 to 2005.

TABLE 13-5 Outputs and Intermediate Outcomes Related to Ground Failure Prevention Research Outcomes

Output	Description	Related Intermediate Goal	Intermediate Outcome
Coal Mine Roof Rating (CMRR) System and software package (2000)	Methodology and procedure for characterizing mine roof materials	1	The Mining Program developed ground control design tools based on CMRR. CMRR accepted as a standard in the United States and other countries
Published descriptions of horizontal stress concentrations in longwall headgates and methods to prevent failure; Analysis of Horizontal Stress Effects in Mines (AHSEM) software (2001)	Control of horizontal stress in mining to reduce injuries and fatalities	1	Wide circulation of publications, Mining Program development of software, Mining Program-developed control technologies widely used in the mining community. Major headgate failures largely eliminated in longwall mines
Design charts for selecting applicable web and barrier pillar widths; Analysis of Retreat Mining Pillar Stability (ARMPS) computer program (2003)	Design guidelines for safe highwall mining systems, pillar recovery	Indirectly related to 5	Several leading companies routinely use ARMPS or new design charts for highwall mining. ARMPS incorporated into guidelines for mine design to avoid massive pillar collapses
Promotion of roof fall forecasting techniques in stone mining sector	Mitigating ground fall hazards in underground stone mines	6	Project is ongoing; monitoring activities at more mine sites than in past years; new mine layouts implemented at several sites
Hardware and computer logic for Mobile Roof Support (MRS) warning systems and guidelines for safe use	MRS for retreat room-and-pillar mines	4	Technology incorporated into MRS system design by a major commercial manufacturer. Currently used in 34 coal mines
Support Technology Optimization Program (STOP) (2004)	Decision making for selection and placement of mine roof supports	5	Approximately 1,000 copies of software distributed. Used internationally

Analysis of Longwall Pillar Stability (ALPS) computer program	Statistical analysis of mining case histories to provide design guidelines for safe pillar design, roof support, and tailgates	4	ALPS, in combination with STOP, is industry standard for longwall pillar and support design in the United States. A derivative product is used in Australia. Used extensively by the Mine Safety and Health Administration (MSHA) and state regulatory agencies, and part of the curriculum in at least four mining schools
Personal bolter screen (PBS) (2003); Make It Safer with Roof Screen video (2004)	Reducing rock fall injuries to coal miners	2	Ongoing effort. PBS available through two roof support manufactures; more than 200 copies of the video requested
31 technical papers and presentations	Rock burst control in deep mines using overhand mining methods and seismic monitoring	7	Ongoing and long-term effort. Adoption of Mining Program-recommended measures in some rockburst-prone mines

SOURCE: NIOSH, 2005a.

Most, if not all, of the intermediate outcomes listed in Table 13-5 relate directly to achieving the strategic and intermediate goals of this research area. The intermediate outcomes address issues identified by the committee and are consistent with the goals of the "idealized" ground failure prevention research program summarized in Table 3-4. Consequently, the intermediate outcomes are well focused and address subjects of the highest priority, thus justifying a high rating in relevance.

The Mining Program lists 12 potential intermediate outcomes designed to reduce accidents associated with ground falls in the next 5 to 10 years (NIOSH, 2005a). Performance standards for these outcomes have been stated in terms of percentage reduction of fatalities and injuries. Because of overlapping contributions of regulatory agencies, industry safety programs, labor initiatives, and advancements from academia, it will be very difficult to quantify the contribution of the Mining Program to any future reduction in the number of accidents. It is better, therefore, to establish specific measurable goals for each current or future intermediate outcome. This has been done primarily in terms of planned publications and workshops, whose contributions in meeting the strategic goal may never be quantitatively measurable but are almost certainly to be of value overall.

The Mining Program has identified the following research that will continue into the future:

- **Improved highwall stability to reduce surface mine hazards.** This effort is a continuation of current activities and focuses on concerns expressed by stakeholders. Potential outcomes are planned through 2005. The need for better methods of periodic or continuous monitoring of slope movement is a worthy effort. It does not clearly fit into any of the current intermediate goals; an intermediate goal appropriate for this topic should be established.
- **Reducing injuries by improving shotcrete design criteria.** Developing a set of design criteria for application of shotcrete as a means of rock support is a continuation of current efforts and clearly fits intermediate goals 2 and possibly 4. Research and field tests are warranted due to the prevalence of injuries and occasional fatalities caused by loose roof rock between primary supports. Outputs are planned through 2007.
- **Improved pillar design in metal and industrial mineral mines to reduce ground control hazards.** Recovery of pillars is commonly practiced in the national and international mining communities. Minimizing the size of support pillars in order to maximize resource recovery is a worthy goal as long as it can be done safely. This research is a logical extension of current work and is related to intermediate goal 6. Outputs are planned through 2009. A more general statement of goal 6 should clearly include this work.

- **Avoiding inundation: developing guidelines for mining near bodies of water.** Mining-induced seismicity (MIS) occurs in coal, metal, and nonmetal underground mining. MIS is a serious, potentially high-consequence event that can result in injuries to underground miners and possible failure of water-impounding surface structures. Failure of surface structures is a major concern for several western coal operations. Related research is currently being done by the Mining Program, and this is a worthy topic for future research. Outputs are planned through 2009. The effort is related to intermediate goal 7, but a more general goal should be established that clearly includes this effort.
- **Improved mine safety through optimized extraction.** The extent of damage in the perimeter of mine openings created by conventional blasting is poorly understood. Such damage is acknowledged as a primary cause of loose rock in underground roofs and ribs and on surface mine slopes. Fundamental research is needed to establish more effective guidelines for blasting practices that focus on reducing collateral damage. Research in this area can contribute substantially to achieving the strategic goal. This is an extension of current research and outputs are planned through 2007, but there is no clear statement covering this effort in the list of intermediate goals.
- **Multiple-seam mining design guidelines.** Recent work in this area was reported as part of the Mining Program's intermediate outcomes. The list of intermediate goals clearly indicates this as an important contribution to achieving the strategic goal. A large number of underground coal mines are currently, or will be in the near future, dealing with multiple-seam mining. It is therefore, a worthy topic for Mining Program research, and outputs in the form of publications, software, and workshops are planned through 2008.
- **Design of mine ventilation stoppings.** Current mining law requires that stoppings withstand a transverse load of at least 39 pounds per square foot (psf). Air blast resulting from roof falls or mine explosions can produce overpressure in excess of 39 psf resulting in failure of the stoppings. Failure can precipitate more widespread consequences in the form of pollution of the mine atmosphere with toxic gases and/or catastrophic explosions and fires. With the recent fatalities at the Sago mine, there is no question that this could be a high-priority topic for the Mining Program. It is unclear, however, why the design of stoppings is included under ground failure prevention. Perhaps it would more logically be included under mine disasters. No ground failure prevention intermediate goal is clearly related to this topic.
- **Roof span and pillar layout guidelines for stone mines.** This effort is a continuation of current research with promising future outcomes. It is closely related to intermediate goals 6 and possibly 5. A large number of underground limestone mines in this country rely heavily on past practice for roof spans and pillar layout.

An analysis of practice coupled with numerical modeling is a worthy focus for research, and outputs are planned through 2008.

- **Reducing ground fall hazards in coal mines with low-strength roofs.** Investigating the exacerbating influence of low-strength roofs is the subject of current research. As previously mentioned, this effort deals with problems in a specific geographic region. Involvement of industry partners certainly justifies the planned 4-year effort and planned outputs through 2009. The research clearly falls under intermediate goal 4. It is not clear how the outcomes of this research can be measured quantitatively, but it should play a significant role in reducing injuries in the applicable underground environment.
- **Highwall mining stability guidelines.** Outcomes resulting from this project have been described above. Two mining companies and consultants use the results of this study, and additional outcomes are planned in the form of modified software and workshops in 2006. These efforts will likely contribute to achieving the strategic goal, but there is no clearly stated intermediate goal covering this research program.
- **Increasing roof fall forecast times with sensor-based monitoring techniques.** Increasing fundamental knowledge of how roof falls behave and the development of warning systems are extensions of current research described above. This effort clearly falls under intermediate goal 6, and additional publications are planned in the coming 2 years.
- **Reducing ground fall hazards in metal mines with weak rock.** Ground fall in metal mines in Nevada, Idaho, and Montana is the focus of this work started in 2002. Outputs in the form of publications and presentations were planned through 2005. The decrease in injuries resulting from ground fall for the period 2000-2004 relative to 1995-1999 is significant especially in view of the recent increase in underground metal mine activity in these areas. Although the Mining Program's contribution to this trend is not quantitative, it undoubtedly has improved mine safety. The effort is clearly related to intermediate goal 4.

The committee heard from multiple industry representatives who expressed particular satisfaction with software available through the NIOSH web site and with videos that effectively present safety concepts. Videos, web pages, and publications available over the Internet demonstrate a commitment to provide output in electronic format as recommended in the National Research Council (NRC, 1995) review of the USBM. Stakeholders generally praised the ground failure prevention research in the Mining Program. Standards and guidelines have been adopted, both in the United States and abroad, based on output in this research area, and technologies have been implemented in the workplace.

REVIEW OF END OUTCOMES

There have been a substantial number of publications during the past 10 years, and of eight software packages have been produced during the past 3 to 4 years. The number of web-based downloads and the transfer of software in workshops and training sessions suggest that the software is now in the hands of industry practitioners. The extent to which this software is used in mine planning has not been measured objectively. However, the demand for short courses dealing with application of the software and the use of the software by the Mine Safety and Health Administration and state regulatory agencies indicate a high level of interest. The apparent decline in ground control fatalities over the past 10 years provides reason to believe this effort is having a positive impact.

Pillar recovery in underground room-and-pillar coal mines has historically been a significant source of serious or fatal injuries due to miners advancing out beyond supported roof as coal pillars are recovered. The Mining Program has made significant advances in developing methodologies and practices for properly utilizing industry-developed Mobile Roof Support modules to provide temporary roof support to protect personnel. Mining Program guidelines for pillar recovery have been incorporated in Appalachian and Illinois Basin coal mines. The use of mobile roof supports is, or should be, standard practice for pillaring operations in all underground coal mines. The benefits have been well received in publications, manuals, and seminars. The efforts of the Mining Program, the former U.S. Bureau of Mines (USBM), and industry have contributed to a substantial reduction of injuries and fatalities in burst-prone mines.

The statistics for ground fall fatality rates and ground fall incident rates show a downward trend over the past 10 years. It is not immediately clear how much of this favorable trend can be attributed to intervention by the Mining Program. Mining Program efforts very likely have played a significant role in improving mine safety.

ASSESSMENT OF RELEVANCE AND IMPACT

Most certainly, the efforts of the Mining Program have made at least a moderate contribution (as defined in the Framework Document, Appendix A) to end outcomes or well-accepted intermediate outcomes. The intermediate outcomes have resulted in new knowledge, and the Mining Program is actively engaged in transfer of this knowledge to the mining industry and regulatory authorities. Consequently, the Mining Program ground failure prevention effort justifies a high rating for impact.

As described earlier, the intermediate goals of ground failure prevention research address issues identified in the earlier NRC (1995) review of the USBM and deal specifically with critical areas identified by this committee in establishing a comprehensive ground failure prevention program. Research is in high-priority areas and is connected to improvement in workplace protection. Consequently, the Mining Program ground failure prevention program deserves a high rating for relevance.

PROGRESS IN TARGETING NEW RESEARCH

Ground failure prevention research is a heritage program, with future research needs identified primarily through concerns expressed by stakeholders and the prevalence of injuries caused by changing mining methods and geologic conditions. The Mining Program has identified several research areas it is pursuing. Examples of appropriately targeted new research include renewed work on highwall safety, improved strategies for multiple-seam mining, and blast damage control and surface treatment to minimize loose rock hazards. The Mining Program is also focusing on future research to reduce pillar and roof hazards in underground stone and industrial mineral operations in response to the projected demand for these commodities.

Because of challenges posed by mining in increasingly severe geologic environments and in closer proximity to existing and abandoned mines, the Mining Program needs to expand its new research to include developing more robust numerical techniques for modeling mine openings in complex geologic materials; better void detection technologies; and strategies to improve design and safety in deep (>600 m) coal deposits.

14

Review of Surveillance, Training, and Intervention Effectiveness Research

Key Findings and Recommendations for Surveillance, Training, and Intervention Effectiveness Research

- Research is in high-priority areas and is likely to result in improvements in workplace protection.
- The surveillance, training, and intervention effectiveness research group should establish intermediate goals related to training, focused on training effectiveness.
- Research to improve the data collection process and make it more useful for the identification of root causes of problems should be conducted.
- Research needs to be conducted on a consistent means of determining intervention effectiveness.

STRATEGIC GOALS AND OBJECTIVES

Surveillance is an essential component for the identification in health and safety areas that require attention and for the evaluation of program effectiveness. The strategic goal dealing with surveillance, training, and intervention effectiveness in the Mining Program is to "determine the impact of changing mining conditions, new and emerging technologies, and the changing patterns of work on worker health and safety." Fortunately, the Mine Safety and Health Administration (MSHA) provides the best available industry-wide database on injuries, illnesses, and exposures—a tremendous asset for the National Institute for Occupational Safety and Health (NIOSH) Mining Program.

Table 14-1 lists the intermediate goals falling within this strategic goal. Intermediate goal 1 is unlikely to achieve the implied goal, because the goal stated is actually a task. The implied goal is to acquire demographic information about miners in order to make better use of the MSHA data set on fatal and non-fatal injuries. One

TABLE 14-1 Intermediate Goals and Performance Measures of Surveillance, Training, and Intervention Effectiveness Research and Committee Comments

Intermediate Goal[a]	Performance Measure[a]	Committee Comments
1. Conduct a demographics survey of mine workers	This goal will be achieved by completing and publishing a comprehensive demographic survey of the mining industry by 2009	Such a survey will be invaluable, not only for denominator data, but for guiding research and training activities that are necessary to prevent a sharp increase in occupational health and safety problems in the evolving workforce. The intermediate goal is stated as a task. The implied goal is to acquire demographic information about miners in order to make better use of MSHA data. As stated, this intermediate goal can be achieved by conducting a survey, but the information may not be adequate
2. Document organization of work changes in the domestic and global mining industry and assess their impact on worker health and safety	This goal will be achieved if the impacts of organization of work changes have been identified and recommendations for mitigating adverse impacts are issued over the next 5 years	The proposed surveillance research will permit evaluation of the effects of new regulations and work practices. The most effective of these can then be considered for adoption in the United States and other countries
3. Examine emerging technologies for potential health and safety benefits and risks	NIOSH sponsored two recent major studies of emerging technologies by RAND Corp. in 2001 (Peterson et al., 2001) and by the National Research Council in 2002. The identified emerging technologies will be monitored, and efforts will continue to track new developments and their impact on mining safety and health	This is a low-level effort given the relatively slow infusion of new technologies in mining and will not require a separate project effort in the foreseeable future

4.	Develop a more rigorous program to assess the effectiveness of NIOSH-developed interventions	This goal will be achieved by (1) establishing intervention effectiveness measures for all program areas within 2 years; (2) undertaking intervention effectiveness studies within 3 years and publishing them within 1 year of completion of each study; (3) studying mathematical tools that analyze the econom ic impact of interventions and, within 2 years, selecting and integrating one or more tools into the appropriate research projects; and (4) developing and evaluating a model for the aggregates industry within 4 years, distributing it publicly within 5 years, and if successful, undertaking similar efforts for other sectors of mining	The development of a new surveillance system will help measure intervention effectiveness
5.	Reduce fatalities and injuries among mine rescuers resulting from physiological stresses caused by extreme environmental combinations of climatic, geothermal, and ambient conditions in western metal and nonmetal mines	This goal will be achieved through (1) development of appropriate recommendations for the mining industry to alleviate the health risks associated with physiological stress caused by extreme environmental conditions within 3 years and (2) adoption of the recommendations by 25% of the affected mines within 5 years	The focus on extreme environmental conditions and exposures is appropriate. The major focus has been heat stress. The use of pre-rescue activity body temperature to identify at-risk individuals in mine rescue activities would reduce the risk to both the individual and the team due to the failure of an individual to perform. The research also identified a forced-rest regimen based on resting heart rate that can greatly reduce the risk of heat strain-related injuries by limiting the metabolic heat load
6.	Reduce injuries and illnesses caused by chemical hazards found in mining by conducting epidemiologic studies that track disease and illness	This goal will be achieved if the impacts of the changes have been identified and recommendations for mitigating adverse impacts are issued over the next 10 years	This goal will be facilitated if an improved injury, disease, and illness database for the mining industry is developed by 2008. Exposure monitoring of physical and chemical agents and evaluation of physiologic or toxicologic responses to these exposures should be used to supplement the disease and illness database for identification of hazardous work processes

[a]SOURCE: NIOSH, 2005a.

could conduct the survey, and thus achieve the goal, but still acquire inadequate information. Intermediate goal 4 should be used to support the remaining goals by providing a consistent means to determine intervention effectiveness. While intermediate goals 2, 3, 5, and 6 are important, an ideal mining program would take the approach of identifying hazardous work processes using a systematic approach, and then evaluating the effects of these specific exposures and changes in mining conditions, technologies, and work patterns on injuries or illnesses (see Chapter 3). Exposure monitoring, including but not limited to industrial hygiene sampling and heat stress evaluation, should be used as part of the surveillance system to identify potential health risks.At present, there are no intermediate goals related to training, which should be a component of all strategic goals. The emphasis of the Mining Program research in this area should be on evaluation of training program effectiveness and the identification of the most effective methods of training workers prior to hazard exposure. The intermediate goals would also benefit from the addition of specific criteria by which completion could be judged.

The description of intermediate goals related to the surveillance system is also inadequate. Development of key research questions is required and should include means of identifying hazardous work processes and exposures. In determining future research, the Mining Program should continue to work with industry, organized labor, MSHA, academe, and international partners. Both internal and external peer review as described by the Mining Program in its procedures documentation will be useful for selecting projects. While not a focus of research, the Mining Program should partner with universities to develop training materials for mining engineering students and occupational or environmental health students.

Surveillance, training, and intervention effectiveness are cross-cutting issues essential to achieving other strategic goals. Projects listed by the Mining Program under "other safety research" are intramural applied studies concerning the communication of mine safety information and education and the collection of information about mine safety hazards. The former dissemination activities are logically related to the latter surveillance activities, since what is reported back and prioritized as hazardous might then presumably be the subject for subsequent attention through publications, web sites, and training. Organizational and individual behavioral responses might then result, which could contribute to attainment of the stated strategic goals and objectives.

REVIEW OF INPUTS

Surveillance, training, and intervention effectiveness research is a relatively new area in the Mining Program; therefore allocation of total funds to the component projects has not been substantial until the recent past. The total budget for this research area in 2005 was $3,646,400, having increased from $1,581,200 in 1998. Combining the Pittsburgh Research Laboratory (PRL) and Spokane Research Laboratory (SRL) employees, there were 19 individuals (and two vacant positions, at the time of this review) working on surveillance and statistical support and 7 individuals working on extramural coordination and information dissemination, although 30 full-time employees were listed as working in this area in materials supplied to the committee. Resources for the projects listed are, in all cases, modest. This is particularly true for the Internet dissemination and health communication work.

REVIEW OF ACTIVITIES

The need for research in this area was clearly indicated during stakeholder presentations to the committee. Mining remains a dangerous occupation, requiring continued surveillance. Table 14-2 lists surveillance, training, and intervention effectiveness research projects conducted by the Mining Program.

The Mining Program did not describe to the committee the quality assurance process followed by individual researchers. The research projects, as they have been presented to the committee, are consistent with the overall strategic goal but do not address all the intermediate goals. Intermediate goal 3 (examination of emerging technologies for potential health and safety benefit or risks) apparently does not have projects associated with it. Two of the projects presented do not fall easily within any of the intermediate goals. Since the surveillance research has not been carried out to determine which exposures or work processes in the mining industry have the greatest potential to lead to adverse health effects (other than dust and noise exposure), it is not possible to ascertain that the chosen projects are the most relevant. As the surveillance program develops further, this information will become more accessible. The intermediate goals, however, are certainly relevant and important.

The committee considered other activities that could be included in this area of research, given appropriate resources:

- Disease in retired miners should be investigated, since the effects of many exposures may not be seen until after miners have left the workforce.
- Substance abuse in the mining workplace is an important subject identified by MSHA as an area requiring focus.
- There should be continued study of the need for training programs in languages other than English.
- As the Education and Training for an Evolving Mining Work Force project progresses, further research should be conducted into worker-centered peer train-

TABLE 14-2 Surveillance, Training, and Intervention Effectiveness Research Projects and Committee Assessment of Relevance and Impact

Project Title[a]	Intermediate Goal	Purpose[a]	Relevance	Impact
National Survey of Mining Population	1	Conduct a survey of mines and their employees for each of the five major mining sectors (coal, metal, nonmetal, stone, and sand and gravel)	Highly relevant—would provide denominator data for the numerator data in the MSHA injury database, enabling calculation of occupation, age, and experience-specific injury rates by cause and other risk factors	The project is unlikely to acquire sufficient information with the current methods given that this is a one-time survey that will become obsolete rapidly. It would be better to create a sustainable annual data collection process
Surveillance of Mine Safety Hazards	1	Provide surveillance services, data management, and outcome evaluation guidance to SRL researchers to help ensure that research decisions and directions are evidence based and in agreement with NIOSH goals and stakeholder priorities	Relevant—but should be combined into a larger surveillance program with the focus of improving the usefulness of the MSHA database in a sustainable fashion and identifying hazardous exposures and injury, illness, and disease clusters	Should support the intervention effectiveness evaluations of other research programs and demonstrate responsiveness to stakeholder questions

Education and Training for an Evolving Mining Workforce	2	Conduct training needs assessment studies to identify and improve good educational measures for miner training	Highly relevant given the current and ongoing turnover in the mining workforce. Correctly identifies the training needs of a demographically changing mining workforce as a critical problem area requiring intensive research. Involved clearly defined stakeholder input. Could benefit by staff review of new research on the issues of worker empowerment, worker control or lack of control in education and training, and technological changes and new forms of work organization that are significantly changing working conditions	Too preliminary for the reporting of research outputs. A significant number of training needs assessment studies have been conducted and are under way. As of February 2005, a number of informational materials had been produced, seminars have been held for safety and health professionals and on-the-job trainers, and an on-the-job training program has been created to improve transfer of information from experienced miners to new employees
Disseminating Safety and Health Interventions via the Internet	4	Develop methods for indexing content on the Mining Program web site to improve customer access to that information	Highly relevant—the Internet is an efficient channel for the dissemination of information; information design principles can improve the appearance, readability, search efficiency, and information-seeking satisfaction of web site users. Strongly supported by industry representatives on the review committee	Too preliminary to report research outputs

continued

TABLE 14-2 Continued

Project Title[a]	Intermediate Goal	Purpose[a]	Relevance	Impact
Evaluation of Heat Stress and Interventions in Surface and Underground Mines	5	Determine if a relationship exists between overexposure to heat during mining and related activities and increased risk of injury	Highly relevant—addresses the strategic goal of enhancement and safety of emergency response	Extremely productive within a limited time. Has already resulted in adoption by a significant number of rescue teams in the United States and Canada
Hazard Evaluation and Technical Assistance	5	Provide flexibility in technical assistance within a framework that allows researchers to identify latent or emerging hazards	Relevant—helps to answer specific exposure, exposure control, and illness or disease questions posed by specific companies and helps provide NIOSH access to mine sites that might not otherwise be available. Would benefit from a system for choosing which problems to undertake. Should not provide a routine service more appropriately provided by private industrial hygiene consultants	Provides many benefits to the Mining Program and the industry. A mechanism should be identified to share findings with other companies

Chemical Hazards in Mining	6	(1) Investigate and evaluate potential chemical hazards in mining workplaces, (2) develop control or mitigation methods for chemical hazard exposures, (3) develop new analytical methods to determine metal concentrations in mining workplaces accurately, and (4) communicate the health effects associated with chemical exposures of workers	Relevant—identification of exposures is a form of surveillance and could help identify areas requiring additional attention. This project also has a specific focus on welding, a source of concern across many industries, especially welding with manganese or stainless and confined space welding	These projects would benefit from good industrial hygiene input. Could potentially be combined in a larger research effort with Hazard Evaluation and Technical Assistance and Surveillance of Mine Safety Hazards. Should have a focus on welding-related exposures and disease, including exposure to manganese and Parkinson's disease, which would also require evaluation of retired miners
Chemical Hazards in Coal Mining	6	Evaluate the feasibility of using two existing information sources created pursuant to MSHA and Environmental Protection Agency regulations to update estimates of coal miners' exposure to hazardous chemicals	Same as above	Complementary to Chemical Hazards in Mining project
Health Communications Program	Does not fit intermediate goals	Provide health communications services and guidance to SRL and PRL researchers to facilitate the continuous exchange of information and transfer research results to the widest range of customers	Highly relevant given the current turnover in the mining workforce. Directly related to the transfer of information to workers, using novel techniques	Has preliminary data suggesting the value of its general approach in a small sample of mines. The toolbox training modules have been requested by MSHA for inclusion in the Small Mines manuals
Workplace Stress Among Underground Coal Miners	Does not fit intermediate goals	Work to identify biomarkers of stress	It is not clear how once developed and validated, if this is possible, the biomarker would be used practically in the mining setting	Does not appear to be well coordinated with other projects in Mining Program

[a]SOURCE: NIOSH, 2005a.

ing (e.g., Labor Institute and Paper, Allied-Industrial, Chemical and Energy Workers International Union, 2005) using training models focused on the elimination and reduction of hazards in a systems of safety approach (e.g., the Small Group Activity Method, Merrill, 1995). Research should include the use of worker peer trainers and train-the-trainers models; worker participation in curriculum development, including lessons learned from systems failures; worker conduct of program evaluations (e.g., Participatory Action Research, Green et al., 1995; McQuiston, 2000); and worker participation in health and safety program administration. The workplace consists of a network of safety systems, and nearly all incidents result from failures of those systems, thus health and safety interventions have to focus on improving those systems (Roland and Moriarty, 1983; Meshkati, 1995; Perrow, 1999). It is further recommended that NIOSH project staff take up these issues with workers (and their representatives, when the worksite is unionized).

- The work organization program should focus on other end points beyond stress, including cardiovascular disease and possibly depression.

External partners have participated in some projects, including the Twentymile Coal Company, Pennsylvania Services Corporation, J. H. Fletcher and Company, Morton Salt, Rurher's Quarry, the State of Pennsylvania Department of Environmental Protection, and MSHA. In some projects, the role of stakeholder input is less clear.

REVIEW OF RESEARCH OUTPUTS

Since 1995, there has been significant output by those working on surveillance, training, and intervention effectiveness research within the Mining Program. The program has reported developing more than 80 publications, training modules videos, workshops, and software products with help from universities, mining companies, MSHA, and other providers of mining training. Outputs focus on high-priority areas and, where appropriate, target vulnerable groups such as new miners. Outputs reflect the productivity of many current activities, although a number of these outputs are associated with activities included under other strategic goals of the Mining Program. Many activities have not yet generated significant output, but future outputs are expected to increase in quality and relevance. Given data provided by the Mining Program, it was not possible to determine the full extent of cross-agency, cross-institute, or internal-external collaboration. Very few of the publications on surveillance and intervention research were in peer-reviewed journals, but publication in formats such as technical journals may be more broadly distributed.

A few specific project outputs should be highlighted:

- The Health Communications Program takes advantage of the use of humor and storytelling techniques in videos. This is novel and may increase training effectiveness markedly. Gathering information on training effectiveness should certainly remain a research goal. While this program does not identify itself as serving small business, the toolbox training modules have been requested by MSHA for inclusion in its Small Mines manuals.
- The Education and Training for an Evolving Workforce project had produced, as of February 2005, 15 documents and 33 presentations addressing the project's four tasks. More interesting and effective information material may lead to greater attention from miners than would otherwise be the case. An on-the-job training program was created to improve sharing information from experienced miners to new employees. An across-the-board preference for active learning (hands-on practice, simulation, etc.) was found at mine sites. Two seminars were developed to provide professional development opportunities for safety and health professionals and on-the-job trainers. Both translated adult education theory into practical strategies that can be used to train miners of any age. A computer-based training intervention to train new miners in map reading skills is under development.

While the overall research output is appropriate given the newness of the projects and the modest level of funding, these conditions also make the determination of impacts quite preliminary. Ideally, an improved overall surveillance program would be used to monitor changes in injury or illness rates in the particular area focused on by each output, although due to budget limitations this may only be possible for selected outputs. At the very least, surveys could be carried out with industry partners to determine how many were aware of specific outputs and if they had implemented any of the recommended changes.

REVIEW OF TRANSFER ACTIVITIES

Members of the committee agree that the Mining Program has stimulated major changes in the way mine safety and health training has been practiced since 1977, including greater emphasis on collaborative and active problem-solving learning, greater realism in training scenarios, greater fidelity of visual illustrations, and greater use of authenticated and field-tested training materials. The Mining Program is also engaged in finding better training processes and methods, including computer simulations, virtual reality models, interactive problem-solving stories, degraded stereoscopic (three-dimensional) images of hazardous conditions, and videotaped interviews with miners. Understanding which of these various modalities are most effective for communicating health and safety information for all mining-related workers and supervisors should continue as an objective of the Mining Program.

Transfer activities occurring within this strategic goal are valued by external program stakeholders and are being used in at least a modest number of workplaces, though how many is not documented. New knowledge has been documented, indicating positive outcomes resulting from them. Although these transfer activities can claim some success, there is no description of how they fit together into a larger education-technology transfer program. Ideally, shared expertise across these programs could lead to greater effectiveness.

REVIEW OF INTERMEDIATE OUTCOMES AND CAUSAL IMPACT

Research and transfer activities need to target specific intermediate outcomes for the overall surveillance program. This should include improving MSHA surveillance through collection of denominator data, development of specific surveillance goals in concert with strategic partnerships, collection of the data necessary to determine the effectiveness of each intervention, and collaboration with international partners to better harmonize data collection. The current intermediate goals all focus on surveillance, yet the five potential intermediate outcomes pertinent to this strategic goal, as described by the Mining Program to the committee, relate predominantly to training:

1. Improving miner safety by developing toolbox training sets,
2. Improving miner safety by developing interactive computer simulation training,
3. Improving the accuracy of determining worker exposure to airborne silver,
4. New miner training, and
5. Improved technology transfer via the web.

The Mining Program is recognized as a center of excellence for training activities, but has not yet made extensive use of its surveillance program to produce intermediate outcomes. Given the recent organization of some of these projects not enough time has passed for them to have impact on the workplace.

Other intermediate outcomes include the following:

- U.S. and Canadian mine rescue teams have adopted temperature pre-screening and heart rate tools to avoid adverse effects from heat stress.
- The toolbox training demonstrated a significant increase in safety knowledge. As reported by NIOSH, participatory storytelling was found to be more

effective for younger miners, while a more traditional lecture-based format was more effective with older miners (presentation by Dr. Elaine Cullen, NIOSH, to committee, January 13, 2005). Although no statistical tests were reported, two of the most recent training videos Aggregate Training for the Safety Impaired and The Sky Is Falling reported an increase in safety knowledge of trainees. In future evaluations by NIOSH, the inclusion of statistical analysis of these changes will be needed.

- In a survey of 52 responding organizations that purchased the Interactive Problem Solving Stories: A New Approach to Preventing Miners' Occupational Injuries and Illnesses exercises from the National Mine Health and Safety Academy, 60 percent of the respondents rated the exercises as more useful than traditional instructional materials, 40 percent as equally useful, and 0 percent as less useful. Most trainers (79 percent) thought that the exercises helped them to make better use of workers' knowledge and experience during training (NIOSH, 2005a).

REVIEW OF END OUTCOMES

Several surveillance, training, and intervention effectiveness research activities in the Mining Program are too new to have measurable end outcomes at this time. Development of an improved surveillance system should assist greatly in measuring end outcomes for all activities of the Mining Program. The committee has heard directly from numerous stakeholders that they have positively utilized several of the tools developed by the program for specific training purposes. One operator, for example, described work done with researchers at PRL and MSHA analyzing construction, maintenance, and repair (CMR) accidents from the MSHA database. After developing training tools and teaching safety and health personnel how to use them, CMR accidents went from 66 percent to 55 percent of all incidents (presentation by Kelly Bailey, Vulcan Materials Company, to committee, February 21, 2005).

REVIEW OF OTHER OUTCOMES

Other than a focus on older workers, new recruits, and some attention to safety issues associated with Spanish-speaking workers (NRC, 2003), none of the projects have a specific focus on vulnerable populations, and vulnerable populations have not been clearly defined in the mining industry. More studies on non-English-speaking workers in the U.S. mining industry could help define whether this population is truly more vulnerable. Most of the Mining Program products will be useful for small business, but each project should explicitly describe how these worker populations will be served. There is also a great opportunity to improve mining health and safety internationally by providing training materials to other countries.

The extent to which NIOSH should work to directly assist developing countries in evaluating exposures should be determined as part of the strategic planning process, and a program could then be developed to prioritize requests if this area is funded. Examples of past efforts in this area include the 2001 assistance to Mexico's Instituto Nacional de Salud Pública to assess mercury exposure at reprocessing plants, the 1999 assistance to Ecuador to assess occupational exposure of gold miners, and a similar project in Venezuela in 1998.

ASSESSMENT OF RELEVANCE AND IMPACT

The Mining Program is engaged in transfer activities leading to the adoption of recommendations and technologies by stakeholders. Surveillance and determination of intervention effectiveness are essential highest-priority components of a mining research program. Although the Mining Program is also engaged in transfer activities within this specific strategic goal, additional work is needed to create a better surveillance system. The activities in this specific goal have made a moderate contribution to impact on workers on the basis of intermediate outcomes and transfer activities. The relevance and impact of all projects depends on the types of projects that industry is willing to partner, execute successfully, and use.

The committee feels that the present research program activities and outputs are likely to produce improvements in worker health and safety. Research being done under this strategic goal is in high-priority subject areas and is likely to result in improvements in workplace protection.

PROGRESS IN TARGETING NEW RESEARCH

Surveillance, training, and intervention effectiveness research is a new and not well-developed research area within the Mining Program. The committee does not expect it to have a well-developed process for targeting new research at this time, but acknowledges it should develop a plan for the future. New projects should be chosen based on the results of a NIOSH surveillance program, requests from industry, evaluation of international developments such as new mining techniques and regulations, and addressing stakeholder needs (including MSHA), which this program is currently doing. The Mining Program should consider the potential for interaction with other NIOSH research programs and take advantage of surveillance conducted by these programs relevant to the mining industry. Research choices should be informed by surveillance data that indicate increased exposure and risk of injury and illness, as well as the results of well-designed epidemiologic studies. Research to improve the data collection process and to make it more useful for the identification of the root causes of problems could ultimately result in the reduction of injury and illness in the mining industry. The identification of disease and injury incidence related to workplace exposures would help to indicate where application of resources could achieve the best results. Research into the effectiveness of Mining Program training and educational programs is also necessary.

Signature Accomplishments: Communications

Working in partnership and with funds or in-kind services provided by industry, MSHA, the International Society of Mine Safety Professionals (ISMSP), mining associations, and state agencies, NIOSH developed a list of critical needs topics and created 10 mine safety and health training videos from 1999 through 2004. Approximately 12,000 videos have been shipped to mine safety and health trainers in more than 36 countries. Thirteen articles and papers have been published by SRL on this work since 2000; 35 presentations have been given at national and international conferences; and 2 reports have been prepared by outside researchers under contract to evaluate the effectiveness of the videos as training tools. Industries as diverse as insurance, tunnel building and construction, the military, and even university occupational safety and health programs have started to use the training videos. NIOSH videos have been recognized for their outstanding contribution to safety and health training and have earned several national awards. These include the NIOSH top honors for Educational Materials (Alice Hamilton Awards) in 2000 and 2001, the Centers for Disease Control and Prevention Communicators' Roundtable Award for Electronic Media in 2002, a Guiding Light award from ISMSP in 2002, the ISMSP Highest Degree of Safety Award in 2000, and a Telly award in 2003.

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Appendixes

A

Framework for the Review of Research Programs of the National Institute for Occupational Safety and Health*

This is a document prepared by the National Academies' Committee for the Review of NIOSH Research Programs,[1] also referred to as the Framework Committee. This document is not a formal report of the National Academies—rather, it is a framework proposed for use by a number of National Academies committees that will be reviewing research in various research programs and health-outcomes programs. This version will be posted on the website of the National Academies and NIOSH for review. It is a working document that will be subject to change by the Framework Committee aimed at improving its relevance on the basis of responses received from evaluation committee members, NIOSH, stakeholders, and the general public before and during the course of the assessments conducted by independent evaluation committees of up to 15 research programs and health-outcomes programs.

*Version of 12/19/05.

[1]Members of the National Academies' Committee for the Review of NIOSH Research Programs include: David Wegman (Chair; University of Massachusetts Lowell School of Health and Environment), William Bunn, III (International Truck and Engine Corporation), Carlos Camargo (Harvard Medical School), Susan Cozzens (Georgia Institute of Technology), Letitia Davis (Massachusetts Department of Public Health), James Dearing (Kaiser Permanente), Fred Mettler, Jr. (University of New Mexico School of Medicine), Franklin Mirer (Hunter School of Health Sciences), Jacqueline Nowell (United Food and Commercial Workers International Union), Raja Ramani (Pennsylvania State University), Jorma Rantanen (Finnish Institute of Occupational Health), Rosemary Sokas (University of Illinois at Chicago School of Public Health), Richard Tucker (Tucker and Tucker Consultants, Inc. and University of Texas at Austin), and James Zuiches (North Carolina State University).

All public comments submitted to the Committee for the Review of NIOSH Research Programs will be included in the Public Access File for this study as provided in the National Academies Terms of Use (www.nationalacademies.org/legal/terms.html). Please keep in mind that if you directly disclose personal information in your written comments, this information may be collected and used by others.

For inquiries related to this document, or for the most current document version, please contact Evan Douple (edouple@nas.edu) or Sammantha Magsino (smagsino@nas.edu) of the National Academies.

CONTENTS

ACRONYMS

ABLES	(Adult Blood Lead Epidemiology and Surveillance)
ACOEM	(American College of Occupational and Environmental Medicine)
AOEC	(Association of Occupational and Environmental Clinics)
BLS	(Bureau of labor Statistics)
CDC	(Centers for Disease Control and Prevention)
EC	(Evaluation Committee)
FACE	(Fatality Assessment Control and Evaluation)
FC	(Framework Committee)
HHE	(Health Hazard Evaluations)
MSHA	(Mine Safety and Health Administration)
NEISS	(National Electronic Injury Surveillance System)
NIOSH	(National Institute for Occupational Safety and Health)
NORA	(National Occupational Research Agenda)
NORA1	(National Occupational Research Agenda 1996-2005)
NORA2	(National Occupational Research Agenda 2005-forward)
OSHA	(Occupational Safety and Health Administration)
OSHAct	(Occupational Safety and Health Act of 1970)
OSH Review Commission	(Occupational Safety and Health Review Commission)
PART	(Performance Assessment Rating Tool)
PEL	(Permissible Exposure Limits)
SENSOR	(Sentinel Event Notification System of Occupational Risks)
TMT	(Tools, Methods, or Technologies)

In September 2004, the National Institute for Occupational Safety and Health (NIOSH) contracted with the National Academies to conduct a review of NIOSH research programs. The goal of this multiphase effort is to assist NIOSH in increasing the impact of its research efforts in reducing workplace illnesses and injuries and improving occupational safety and health. The National Academies agreed to conduct this review and assigned the task to the Division on Earth and Life Studies and the Institute of Medicine.

The National Academies appointed a committee of 14 members, including persons with expertise in occupational medicine and health, industrial health and safety, industrial hygiene, epidemiology, civil and mining engineering, sociology, program evaluation, communication, and toxicology; representatives of industry and of the workforce; and a scientist experienced in international occupational-health issues. The Committee on the Review of NIOSH Research Programs, referred to as the Framework Committee (FC), held meetings during 2005 on May 5-6 and July 7-8 in Washington, DC, and on August 15-16 in Woods Hole and Falmouth, MA.

This document is not a report of the National Academies; rather, it presents the evaluation framework developed by the FC to serve as a guideline and structure for NIOSH program reviews by Evaluation Committees (ECs) to be appointed by various divisions and boards of the National Academies. The ECs will use this framework in reviewing as many as 15 NIOSH research programs during a 5-year period. This is a working document. It is shared with NIOSH and the public. The framework and criteria may be modified by the FC on the basis of responses it receives from the ECs and other sources. It is incumbent upon the ECs to consult with the FC if portions of the evaluation framework presented here are inappropriate for the specific program under review.

I. OVERVIEW OF CHARGE

At the first meeting of the FC, Lewis Wade, NIOSH senior science advisor, emphasized that the reviews should focus on evaluating NIOSH's research programs impact and relevance to health and safety in the workplace. In developing a framework, the FC was asked to address the following:

1. Evaluation committee assessment of progress in reducing workplace illnesses and injuries facilitated by occupational safety and health research through (a) an analysis of relevant data about workplace illnesses and injuries for the program activity, and (b) an evaluation of the effect that NIOSH research has had in reducing illnesses and injuries. The evaluation committees will rate the performance of each

program for impact of the program in the workplace. Impact may be assessed directly or, as necessary, using intermediate outcomes to estimate impact. Qualitative narrative evaluations may also be appropriate under certain circumstances.

2. Evaluation committee assessment of progress in targeting new research to the areas of occupational safety and health most relevant to future improvements in workplace protection.
3. Evaluation committee identification of significant emerging research areas which appear especially important in terms of their relevance to the mission of NIOSH.

Those three charges constitute the scope of work of the individually appointed, independent ECs formed by the National Academies.

I.A. NIOSH Strategic Goals and Operational Plan

As a prelude to understanding the NIOSH strategic goals and operational plan, NIOSH research efforts should be understood in the context of the Occupational Safety and Health Act (OSHAct) under which it was created. The OSHAct identifies workplace safety and health to be a national priority and gives employers the responsibility for controlling hazards and preventing workplace injury and illness. The act creates an organizational framework for doing this, with complementary roles and responsibilities assigned to employers and employees, OSHA, the States, the OSH Review Commission, and NIOSH. As one component of a national strategy the act recognizes NIOSH's roles and responsibilities to be supportive and indirect—NIOSH's research, training programs, criteria and recommendations are all intended to be used to inform and assist those actually responsible for hazard control (OSHAct Section 2b and Sections 20 and 22).

Section 2b of the OSHAct describes thirteen interdependent means of accomplishing the national goal, one of which is "by providing for research . . . and by developing innovative methods . . . for dealing with occupational safety and health problems." Sections 20 and 22 give the responsibility for this research to NIOSH. In addition, NIOSH is given related responsibilities including: the development of criteria to guide prevention of work-related injury or illness, development of regulations reporting on the employee exposures to harmful agents, the establishment of medical examinations programs or tests to determine illness incidence and susceptibility, publication of a list of all known toxic substances, the assessment of potentially toxic effects or risk associated with workplace exposures in specific settings, the conduct of education programs for relevant professionals to carry out the OSHAct purposes, and assisting the Secretary of Labor regarding education programs for employees and employers in hazard recognition and control.

The NIOSH mission is "to provide national and world leadership to prevent work-related illness, injury, disability, and death by gathering information, conducting scientific research, and translating the knowledge gained into products and services". To fulfill its mission, NIOSH has established the following strategic goals:[2]

- **Goal 1: Conduct research to reduce work-related illnesses and injuries.**
  - ♦ Track work-related hazards, exposures, illnesses, and injuries for prevention.
  - ♦ Generate new knowledge through intramural and extramural research programs.
  - ♦ Develop innovative solutions for difficult-to-solve problems in high-risk industrial sectors.
- **Goal 2: Promote safe and healthy workplaces through interventions, recommendations, and capacity-building.**
  - ♦ Enhance the relevance and utility of recommendations and guidance.
  - ♦ Transfer research findings, technologies, and information into practice.
  - ♦ Build capacity to address traditional and emerging hazards.
- **Goal 3: Enhance global workplace safety and health through international collaborations.**
  - ♦ Take a leadership role in developing a global network of occupational health centers.
  - ♦ Investigate alternative approaches to workplace illness and injury reduction and provide technical assistance to put solutions in place.
  - ♦ Build global professional capacity to address workplace hazards through training, information sharing, and research experience.

In 1994, NIOSH embarked on a national partnership effort to identify research priorities to guide occupational health and safety research for the next decade. The National Occupational Research Agenda (NORA) identified 21 high-priority research areas (see Table 1). NORA was intended not only for NIOSH but for the entire occupational health community. Approaching the 10-year anniversary

[2]See also http://www.cdc.gov/niosh/docs/strategic/.

TABLE 1 NORA High-Priority Research Areas by Category

Category	Priority Research Area
Disease and injury	Allergic and irritant dermatitis
	Asthma and chronic obstructive pulmonary disease
	Fertility and pregnancy abnormalities
	Hearing loss
	Infectious diseases
	Low-back disorders
	Musculoskeletal disorders of upper extremities
	Trauma
Work environment and workforce	Emerging technologies
	Indoor environment
	Mixed exposures
	Organization of work
	Special populations at risk
Research tools and approaches	Cancer research methods
	Control technology and personal protective equipment
	Exposure-assessment methods
	Health-services research
	Intervention-effectiveness research
	Risk-assessment methods
	Social and economic consequences of workplace illness and injury
	Surveillance research methods

of NORA, NIOSH is working with its partners to update the research agenda. In the second decade of NORA, an approach based on industry sectors will be pursued. NIOSH and its partners will form sector research councils that will work to establish sector-specific research goals and objectives. Emphasis will be placed on moving research to practice in workplaces through sector-based partnerships.

Figure 1 is the NIOSH operational plan presented as a logic model[3] of the path from inputs to outcomes for each NIOSH research program. The FC adapted the model to develop its framework. NIOSH will provide similar logic models relevant to each research program evaluated by an EC.

I.B. Information from Other Evaluations

The FC is aware that several NIOSH programs have already been subjected to evaluation by internal and external bodies. Those evaluations range from overall assessments of NIOSH, such as the recent 2005 Performance Assessment Rating

[3]Developed by NIOSH with the assistance of the RAND Corporation.

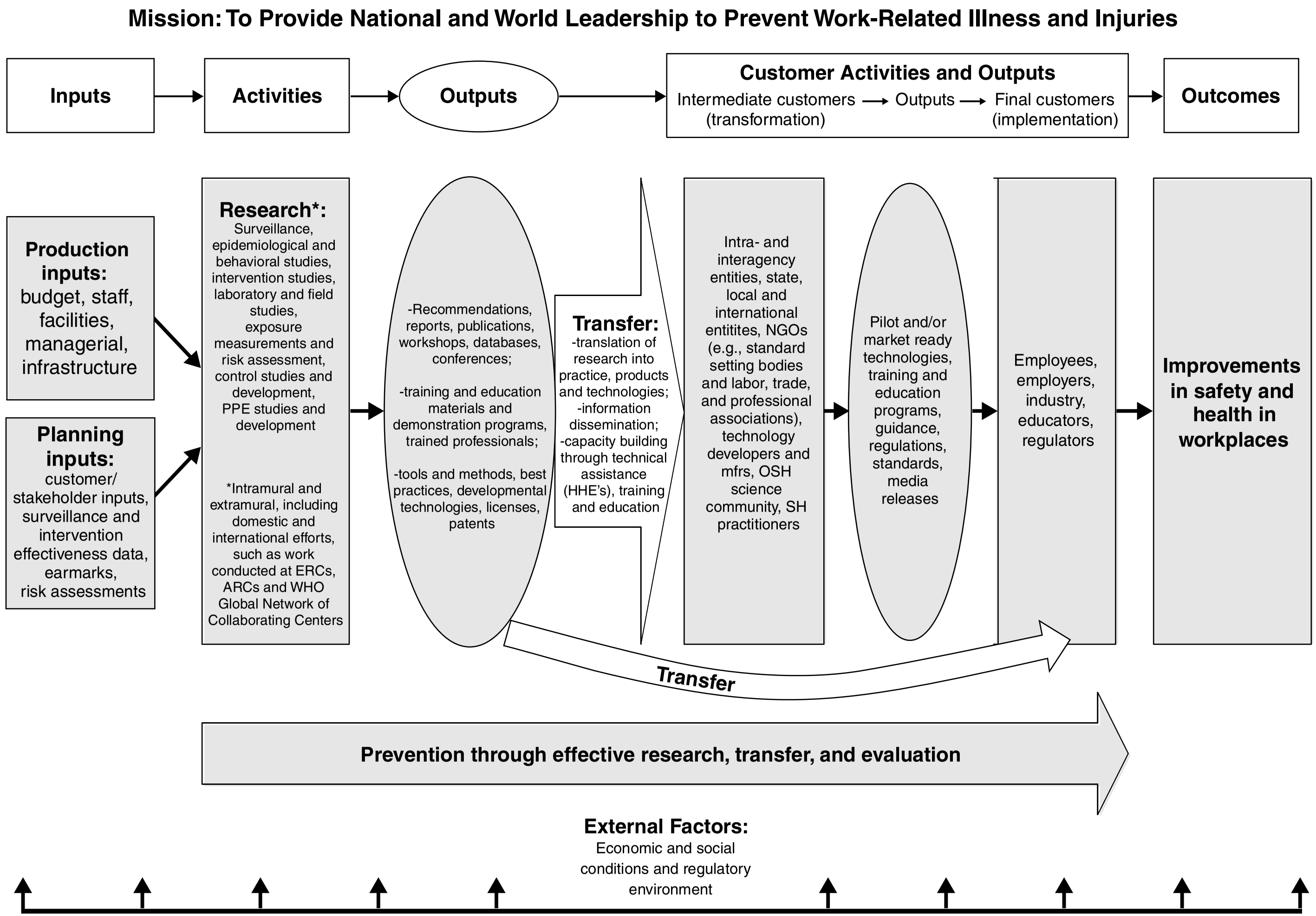

FIGURE 1 The NIOSH operational plan presented as a logic model

Tool (PART) review,[4] to evaluation of research program elements such as any external scientific program reviews. The ECs should review all available prior reviews. Although it is important to consider all prior reviews in the present evaluation to aid in understanding the evolution of the programs and program elements, the ECs' evaluations of NIOSH's programs are independent of the prior reviews and evaluations.

I.C. Evaluation Committees

Individual ECs will be formed through a process consistent with the rules of the National Academies for the formation of balanced committees. The committees will be composed of persons with expertise appropriate to evaluating specific NIOSH research programs and may include representatives of stakeholder groups (such as labor unions and industry) and experts in technology transfer and program evaluation. The committees will conduct appropriate information-gathering sessions to obtain information from the sponsor (a NIOSH research program), stakeholders affected directly by the NIOSH research, and relevant independent parties. Each EC will consist of about 10 members, will meet about three times, and will prepare a report. The National Academies will deliver the report to NIOSH within 9 months after the individual EC is formed. EC reports will be subjected to the National Academies report-review process.

I.D. Evaluation Committees' Information Needs

The ECs are expected to conduct information-gathering as appropriate on

- Background and resources of the program:
  - History of program, including results of previous reviews.
  - Program funding, by year, for the current year and the last 10 years.
  - Program funding, by objective or subprogram.
  - Extramural-grant awarding, cooperative agreement and contracting process, solicitation of research ideas, and advisory activities.
- Program goals and objectives.
- Internal NIOSH processes and research:
  - Intramural surveillance, research, and transfer activities.
  - Process to solicit and approve intramural research proposals.

[4]PART focuses on assessing program-level performance and is one of the measures of success for the Budget and Performance Integration initiative of the president's management agenda (see CDC Occupational Safety and Health at http://www.whitehouse.gov/omb/budget/fy2006/pma/hhs.pdf).

- NIOSH-funded extramural research:
  - Requests for proposals, cooperative agreements and research contracts distributed.
  - Awardee products, including close-out reports, surveillance, research, and transfer activities, peer-reviewed publications, and patents.
- Products and technology transfer:
  - Data related to program publications, conferences, recommendations, patents, and so on.
  - Past and planned mechanisms for transferring outputs to outcomes.
  - Interventions, recommendations, and information-dissemination and technology-transfer activities designed to get research findings used to improve occupational safety and health.
  - Outcomes of research, alerts, standard-setting, investigations, and consultations; for example—documented reductions in risk after program-supported interventions, employer and industry behavior changes made in response to research outputs, and worker behavior changes in response to research outputs.
- Impact on worker safety and health—data necessary to evaluate program impact on health outcomes (work-related injuries and illnesses) and exposures.
- The most severe or most frequent adverse health and safety outcomes or exposures in the research program and the most accessible improvements with respect to health and safety.
- Interactions within NIOSH and with other stakeholders:
  - The role of program research staff in NIOSH policy-setting, Occupational Safety and Health Administration (OSHA) and Mine Safety and Health Administration (MSHA) standard-setting, and voluntary standard-setting and other government policy functions.
  - Other institutions and research programs with overlapping or similar portfolios and an explanation of the relationship between the NIOSH work and staff and those of other institutions.
  - Stakeholder perspectives (OSHA, MSHA, union and workforce, industry, and so on.)
  - Key partnerships with employers, labor, other government organizations, academic institutions, nonprofit organizations, and
  - International involvement and perspective.
- Systems to identify emerging problems and emerging research, including plans.

II. SUMMARY OF EVALUATION PROCESS

The ECs are charged with assessing the relevance, quality, and impact of NIOSH research programs. In conducting their evaluations, the ECs should ascertain whether NIOSH is doing the right things (relevance) and doing them right (quality) and whether these things are improving health and safety in the workplace (impact).

II.A. The Evaluation Flow Chart (Figure 2)

To address its charges, the FC has developed a flow chart (Figure 2) that breaks the NIOSH logic model into discrete, sequential program components to be characterized or assessed by the ECs. The components to be assessed are as follows:

- Major program-area *challenges.*
- Strategic *goals and objectives.*
- *Inputs* (such as budget, staff, facilities, the institute's research management, the NIOSH Board of Scientific Counselors, the NORA process, and NORA work groups).
- *Activities* (efforts by NIOSH staff, contractors, and grantees, such as hazard and health-outcome surveillance, exposure-measurement research, health-effects research, intervention research, health services, other research, and technology-transfer activities).
- *Outputs* (the products of NIOSH activities, such as publications, reports, conferences, databases, tools, methods, guidelines, recommendations, education and training, and patents).
- *Intermediate outcomes* (responses by NIOSH stakeholders to NIOSH products, such as public or private policy change, training and education in the form of workshop or seminar attendance, self-reported use or repackaging of NIOSH data by intermediary stakeholders, adoption of technologies developed by NIOSH, implemented guidelines, licenses, and reduction of workplace hazardous exposures and other risk factors).
- *End outcomes* (such as reduction of work-related injuries or illnesses, or hazardous exposures in the workplace).

Drawing on the program logic model, the flow chart, and EC members' expertise, the ECs will delineate important determinants of a NIOSH research program's agenda and the consequences of the NIOSH research activity. Determinants are conceptualized as inputs and external factors. Examples of external factors are

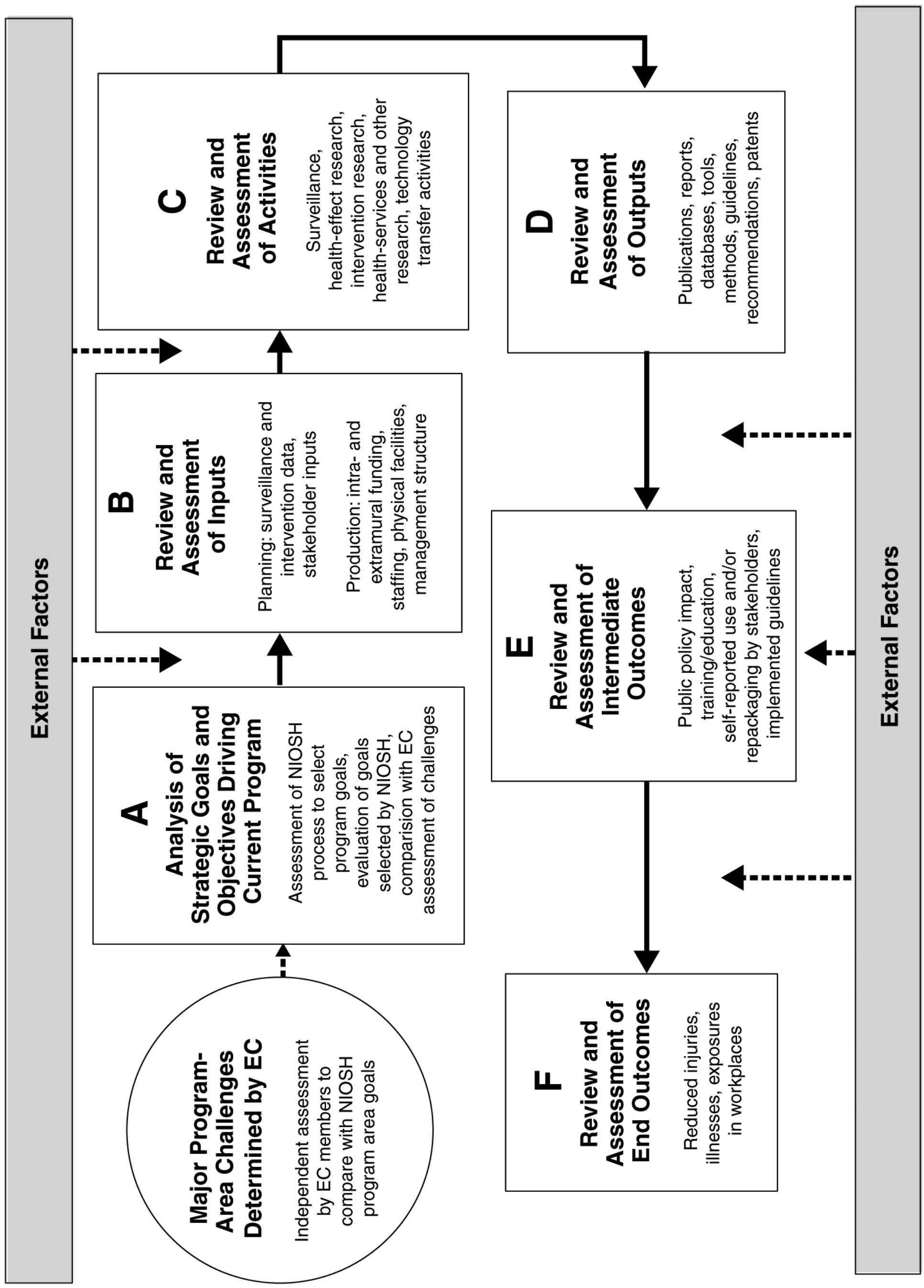

FIGURE 2 Flow chart for the evaluation of the NIOSH research program

the research activities of industry and other federal agencies and the political and regulatory environment, which can affect all components of the research program (Figure 2). *For purposes of this review, the results of inputs and external factors are the program research activities, outputs, and associated transfer activities that may result in intermediate outcomes and possibly eventual end outcomes.*

The FC has used the NIOSH logic model to develop the flow chart to define the scope and steps of an EC evaluation. The FC's vision of how a program evaluation should occur is incorporated in a summary manner in the flow chart and discussed extensively in later sections. For example, the FC identified two types of outcomes: (a) *intermediate outcomes*, which represent implementations (what external stakeholders, such as employers, do in reaction to the products of NIOSH work, including new regulations, widely accepted guidelines, introduction of control technologies in the workplace, changes in employer or worker behaviors, and changes in diagnostic practices of health-care providers), and (b) *end outcomes*, which are improvements (reductions in work-related injuries, illnesses, and hazardous exposures). For the purpose of evaluation, the FC does not differentiate between NIOSH's "intermediate customer" and "final customer" activities (Figure 1); instead it combines them into a single category (Box E, Review and Assessment of Intermediate Outcomes, Figure 2). Training and development programs were appropriately defined as outputs by NIOSH in the logic model, but the FC finds more value in focusing on response to such offerings as intermediate outcomes (Box E) in the flow chart. The number of workers exposed to training activities represents a type of implementation of NIOSH outputs in the workplace. In evaluating each program or major subprogram, the EC must collect, analyze, and evaluate information on items described in each of the boxes of Figure 2. Further details on the evaluation are described in Section III of this document.

II.B. Steps in Program Evaluation

The FC has concluded that useful evaluation requires: (a) a disciplined focus on a small number of questions or hypotheses typically related to program goals, performance criteria, and performance standards; (b) a rigorous method for answering the questions or testing the hypotheses; and (c) a credible procedure for developing qualitative and quantitative assessments. The evaluation process developed by the FC is summarized here and described in detail in Section III of this document.

1. Gather appropriate information from NIOSH and other sources.
2. Determine timeframe that the evaluation will cover (see III.B.1).
3. Identify program-area major challenges and objectives (see III.B.2). All NIOSH research programs, whether based on health outcomes or sectors, are designed to be responsive to the safety and health problems

in today's or tomorrow's workplace. In the NIOSH vision, mission, values, and goals, each research program should have its own objectives. The ECs will provide an independent assessment of the major program challenges and determine whether they are consistent with the research program's stated goals and objectives.

4. Identify subprograms and major projects in the research program. It is important for each EC to determine how necessary it is to disaggregate a program to achieve a manageable and meaningful evaluation of its components and the total program. Each research program may need to be broken down into several recognizable subprograms or major projects if an effective evaluation is to be organized. It may be advantageous for an EC to disaggregate a program into subprograms that NIOSH identifies.
5. Evaluate the program and subprogram components sequentially as discussed in Section III, using the flow chart (Figure 2) as a guide (Sections III.B.3 through III.B.8). This will involve qualitatively assessing each phase of a research program by using the questions and guidance provided by the FC and professional judgment.
6. Evaluate the research program's potential outcomes not yet appreciated (Section III.B.9).
7. Evaluate and score the program outcomes and important subprogram outcomes specifically for contributions to improvements in workplace safety and health. A worksheet is provided with specific items for consideration (Section III.B.10).
8. Evaluate and score the overall program for impact (Section III.B.10). Final program ratings will consist of a numerical score and discussion of its rationale.
9. Evaluate and score the overall program for relevance (Section III.B.10). Final program ratings will consist of a numerical score and discussion of its rationale.
10. Identify significant emerging research areas (Section III.C). On the basis of the expert judgment of EC members and information gathered from stakeholders (such as, labor, industry, academe, and government agencies) and from appropriate NIOSH sentinel-event field-investigation activities, the EC will respond to Charge 3 by identifying and describing emerging research that appears especially important in its relevance to the mission of NIOSH. The EC will assess the extent to which NIOSH's program is responsive to today's and tomorrow's needs and determine whether there are any gaps in response.
11. Prepare report by using the template provided in Section IV as a guide.

II.C. Assessing Relevance

FC members identified numerous *possible* factors to consider in assessing the relevance of NIOSH research programs, such as:

- The severity, frequency, or both of the health and safety outcomes addressed and the number of people at risk (magnitude) for these outcomes.
- The extent to which NIOSH research programs have identified and addressed gender issues and the concerns related to vulnerable populations. Vulnerable populations are defined as groups of workers who have (1) biological, social, or economic characteristics that place them at increased risk of developing work-related conditions and/or (2) inadequate data collected about them. Vulnerable populations include disadvantaged minorities, disabled individuals, low-wage workers, and non-English speakers for whom language or other barriers present health or safety risks.
- The extent to which NIOSH research programs have addressed the health and safety needs of small businesses.
- The "life stage" of the problems being addressed. As the health effects are understood, emphasis should shift to intervention research, and from efficacy to effectiveness to research on the process of dissemination of tested interventions. Gaps in the spectrum of prevention need to be addressed; for example, research on exposure assessment may be necessary before the next intervention steps can be taken.
- The structure, in addition to the content, of the research program. A relevant research program is more than a set of unrelated research projects; it is an integrated program involving an interrelated set of surveillance, research, and transfer activities.
- Appropriate consideration by NIOSH of stakeholder inputs.

II.D. Assessing Impact

Causal attribution is a major aspect of program evaluation. It is necessary for the ECs to assess, to the extent possible, NIOSH's contribution to end outcomes. Data on reductions in work-related injuries, illnesses, and hazardous exposures will be available for some programs. In some cases, they may be quantifiable. It is possible, however, to evaluate the impact of a NIOSH research program whether the outcomes are intermediate outcomes or end outcomes. Intermediate outcomes may be used as proxies for end outcomes in assessing impact if there is no direct evidence of improvements in health and safety as long as the ECs qualify their findings. The ECs will describe the realized or potential benefits of NIOSH's programs. Examples of realized intermediate outcomes include: new regulations, widely accepted guidelines, work practices, and procedures, all of which may contribute measurably to enhancing health and safety at the work place.

The contribution of a NIOSH program to technology now in use or being implemented is another important part of impact assessment. NIOSH's contribution can be assessed as major or important, moderate, likely, limited, or none. If technology development is in progress or has been abandoned, for whatever reason, the benefits are only potential or consist of knowledge gain.

III. EVALUATION OF NIOSH RESEARCH PROGRAMS—THE PROCESS

III.A. Analysis of External Factors Relevant to the NIOSH Research Program

As depicted in the logic model (Figure 1), the end outcome of reduced injuries, illnesses, or exposures is effected through stakeholder activities and outputs. All those involve the use of NIOSH outputs by stakeholders in industry, labor, other government agencies, and so on. It is evident that actions beyond NIOSH's control ~~by~~ industry, labor, and other entities ~~ha~~ve important bearings on the incorporation in the workplace of NIOSH's outputs to enhance health and safety. The implementation of research findings may depend on existing or future policy considerations.

III.A.1. Overview

External factors may be considered as forces beyond the control of NIOSH that may affect the evolution of the program. External factors dominate the evolution of the path from NIOSH inputs to occupational health and safety outcomes (Figure 1). External factors can also be considered inputs to the evaluation of each aspect (planning, implementation, transfer, and others) of NIOSH research programs (Figure 2).

Identification of external factors by the ECs is essential to providing a context for NIOSH program evaluation. External factors may best be assessed through the expert judgment of EC members regarding the knowledge base, the research program, and implementation of interventions as these relate to the needs in the occupational health or safety area targeted by the research program. The ECs, however, may choose additional approaches to assess external factors.

The FC recommends the ECs ask NIOSH to identify and describe external factors early in the evaluation sequence. Factors external to NIOSH might have been responsible for achieving some outcomes, and they might also have presented formidable obstacles. The ECs must address both possibilities.

III.A.2. Considerations for Discussion

Some external factors may involve constraints on research activity related to target populations, methodological issues, and resource availability. For example, evaluators might examine whether

- Projects addressing a critical health need are technologically feasible. A workforce with appropriate size and duration, magnitude, and distribution of exposure for measuring a health effect may not exist. For example, no population of workers has been exposed for 30 years to formaldehyde at the current OSHA Permissible Exposure Level (PEL), so the related cancer mortality can not yet be directly assessed.
- Research is inhibited because NIOSH investigators are unable to access an adequate study population. Under current policy, NIOSH must either obtain an invitation by management to study a workplace or seek a judicial order to provide authority to enter a worksite. (Cooperation under court order may well be insufficient for effective research.)
- Research is inhibited because the work environment, materials, and historical records cannot be accessed even with management and workforce cooperation.
- Adequate or established methods do not exist for assessing the environment.
- Records needed for historical-exposure reconstruction cannot be accessed or do not exist.
- Intervention research is inhibited because an appropriate employer partner cannot be identified to institute the intervention.
- The NIOSH contribution to a certain area of research is reduced because other institutions are working in the same area.
- NIOSH resources are inadequate to tackle the key questions.

Evaluation of the impact of NIOSH research outputs on outcomes may require consideration of external factors that might have impeded or aided implementation, measurement, and so on. For example, evaluators might consider whether

- Regulatory end points are unachievable because of obstacles to regulation or differing priorities of the regulatory agencies. For example, recommendations for improved respiratory protection programs for health-care workers might not be implemented because of enforcement policies or lack of acceptance by the administration of health-care institutions.
- A feasible control for a known risk factor or exposure is not im-

plemented because the costs of implementation are too high or the economic incentives under current circumstances do not favor such actions.

- Improvements in end points are unobservable because baseline and ongoing surveillance data are not available. For example, the current incidence of occupational noise-induced hearing loss is not known although surveillance for a significant threshold shift is feasible. (NIOSH conducts surveillance of work-related illnesses, injuries, and hazards, but comprehensive surveillance is not possible with existing resources.)
- Reductions in adverse effects of chronic exposure cannot be measured. For example, 90% of identified work-related mortality is from diseases, such as cancer, that arise only after decades of latency from first exposure; therefore, effects of reducing exposure to a carcinogen cannot be observed in the timeframe of most interventions.
- A regulation is promulgated that requires a technology that was developed but not widely used.

III.B. Evaluating NIOSH Research Programs (Addressing Charges 1 and 2)

III.B.1. Identifying Period of Time to Be Evaluated

Through study of materials presented by the NIOSH research program and other sources, an EC will become familiar with the history of the research program being evaluated and its major subprograms, program goals and objectives, resources, and other pertinent information.

It is useful for the ECs to consider three general timeframes in conducting their reviews:

- 1970-1995, the period from the founding of NIOSH to the initiation of the NORA process (pre-NORA period).
- 1996-2005 (NORA 1 period).
- Current period and forward (NORA 2 period).

It will be important for the ECs to get a general sense of the history of the NIOSH research program and its impact, but their efforts should be focused on the impact and relevance of NIOSH programs from 1996 on. It is recognized that many of the intermediate and end outcomes since 1996 are the consequence of research outputs accomplished earlier. Both the relevance of the research program targets of NORA 1 and the proposed NORA 2 objectives for the next decade should be considered.

NIOSH is in the midst of a substantial restructuring of the NORA agenda, and expert judgment about relevance and prospective impact of current research programs will be most useful to the agency. The timeframes provided here are only for general guidance; the exact dates of the period to focus on in reviewing programs will depend on the specific research program under review.

III.B.2. Identification of Major Challenges (Circle in Figure 2)

Early in its assessment process, an EC should independently identify the major challenges for its research program. These would be the matters the EC believes should have priority in the research program being evaluated. In arriving at a list of challenges, the EC should rely on surveillance findings, including NIOSH investigations of sentinel events (through health-hazard or fatality-assessment programs), and its own expert judgment. Those should be supplemented with determinations or recommendations by appropriate advisory sources regardless of whether these sources have contributed to NIOSH program deliberations. This process will allow the EC to compare its assessment of challenges to be addressed by NIOSH with NIOSH program goals, and to evaluate the congruence between the two as a measure of relevance (Charge 2).

III.B.3. Analysis of Research Program Strategic Goals and Objectives (Box A in Figure 2)

The research program goals and objectives should be evaluated, with a focus on how each research program's goals are related to NIOSH's agency-wide strategic goals and to the major current challenges and emerging problems identified in the step above. Differences may exist between the importance or relevance of an issue and the influence NIOSH-funded research might have in addressing the issue. The EC should recognize that NIOSH research priorities may be strategic rather than based on the assessment of the state of knowledge.

Some aspects of the NIOSH research program's strategic goals and objectives would have been already subjected to evaluation by internal or external bodies. Research program relevant evaluations that should be requested include the NIOSH annual program review by the Leadership Team; the NORA research program proposal pre-award external review, NORA post-award program external review, and external scientific program review.

Questions to Guide the Evaluation Committee

1. Are the strategic goals and objectives of the program well defined and clearly described?
2. In the last decade, how well were program goals and objectives aligned with NORA 1 priorities?
3. How do the current strategic goals and objectives of the program relate to the current NIOSH strategy, including NORA 2?
4. Are the research program goals, objectives, and strategies relevant to the major challenges in the research program and likely to address emerging problems in the research program (as determined by the EC)?
   a. Did past program goals and objectives (research and dissemination/transfer activities) focus on the most relevant problems and anticipate the emerging problems in the research program?
   b. Are the current program goals and objectives targeted to the most relevant problems and likely to address emerging problems in the research program?
5. How does the program identify emerging research areas?
   a. What information is reviewed by NIOSH?
   b. What advisory or stakeholder groups are asked to identify emerging areas?
   c. What new research areas have been identified in the program?
   d. Were important areas overlooked?

Assessment

The EC will provide a qualitative assessment discussing the relevance of the area's goals, objectives, and strategies as related to the research program's major challenges and emerging problems.

III.B.4. Review of Inputs (Box B in Figure 2)

Inputs are categorized as planning or production inputs in the NIOSH logic model. Planning inputs include stakeholder inputs, surveillance and intervention data, and risk assessments. Production inputs include intramural and extramural funding, staffing, management structure, and physical facilities.

Inputs for program evaluation include existing intramural and extramural information and, potentially, surveys or case studies that might have been developed specifically to assess progress in reducing workplace illnesses and injuries and to provide information relevant to targeting research appropriately to future needs. The ECs should request the relevant planning and production inputs from NIOSH.

Planning inputs

Planning inputs can be qualitative or quantitative. Sources of qualitative inputs include

- Federal Advisory Committee Act panels (Board of Scientific Counselors, Mine Safety and Health Research Advisory Committee, National Advisory Committee on Occupational Safety and Health, and so on).
- NORA research partners, initial NORA stakeholder meetings, later NORA Team efforts (especially strategic research plans), and the NORA Liaison Committee and federal liaison committee recommendations.
- Other federal research agendas, industry, labor, academe, professional associations, industry associations, and Council of State and Territorial Epidemiologists.
- OSHA and MSHA strategic plans.

Attention should be given to how comprehensive the inputs have been and to what extent gaps have been identified or considered.

Sources of quantitative inputs include

- Intramural surveillance information, such as descriptive data on exposures and outcomes (appropriate data may be available from a number of NIOSH divisions and laboratories).
- Health Hazard Evaluations (HHEs).
- Reports from the Fatality Assessment Control and Evaluation (FACE) program.
- Extramural health-outcome and exposure-assessment data from (1) OSHA and MSHA (inspection data) and the Bureau of Labor Statistics, U.S. Department of Defense, and U.S. Department of Agriculture (fatality, injury, and illness surveillance data); (2) state government partners, including NIOSH-funded state surveillance programs, such as Sentinel Event Notification System of Occupational Risks (SENSOR), Adult Blood Lead Epidemiology and Surveillance (ABLES), and state-based FACE; and (3) non-government organizations, such as the Association of Occupational and Environmental Clinics (AOEC) and

the American College of Occupational and Environmental Medicine (ACOEM).

- Appropriate data from NIOSH-funded, investigator-initiated extramural research.

Production Inputs

For each research program under review, NIOSH should specify an identifiable portion of the NIOSH intramural budget, staff, facilities, and management that has been allocated by divisions and offices that play a major role in the research program. Production inputs should be described primarily in terms of intramural research projects and staff, relevant extramural projects (particularly cooperative agreements and contracts), and HHEs and related staff. Consideration should also be given to budget inputs for program evaluation and to leveraged funds provided by partners, such as National Institutes of Health and the Environmental Protection Agency joint requests for applications or program announcements and OSHA, MSHA, and Department of Defense contracts with NIOSH to conduct work.

Assessment of those inputs should include consideration of (1) the degree to which allocation of funding and personnel has been reasonably consistent with the resources needed to conduct the research and (2) the extent to which funding for the relevant intramural research program activity has been limited by lack of discretionary spending beyond salaries (travel, supplies, external laboratory services, and so on). The assessments, therefore, should consider the adequacy of the qualitative and quantitative planning inputs and the use and adequacy of production inputs, particularly (1) and (2) above.

Questions as a Guide for the Evaluation Committee

1. Were the planning, production, and other input data adequate?
2. How well were the major planning, production, and other program inputs used to promote the major activities?
3. Were the sources of inputs and the amount and quality of inputs adequate?
4. Was input obtained from stakeholders representing vulnerable working populations and small businesses?
5. Were production inputs (intramural and extramural funding, staffing, management, and physical infrastructure resources) consistent with goals and objectives of the program?

Assessment

The EC will provide a qualitative assessment that discusses the quality, adequacy, and use of inputs.

III.B.5. Review of Activities (Box C in Figure 2)

Activities are defined as the efforts and work of the program, its staff, and its grantees and contractors. For purposes of the present evaluation, activities of the NIOSH program under review should be divided into research and transfer activities. Research activities may be further categorized as surveillance, health-effects research, intervention research, health-services research, and other research (see sample classification of research activities in Table 2). Transfer activities include information dissemination, training, technical assistance, and education designed to translate research outputs into content and formats designed for application in the workplace to produce improvements in occupational safety and health. Depending on the scope of the program under review, activities may also be grouped by research program objectives or subprograms.

Conventional occupational-health research focuses appropriately on health effects and technology. A focus on socioeconomic and policy research and on surveillance and diffusion research is also needed to effect change because not all relevant intermediate outcomes occur in the workplace. There are important outcomes farther out on the causal chain that NIOSH can affect and thereby influence health and safety in the workplace. Some examples of types of research that might also prove important in addressing NIOSH's mission are

- Socioeconomic research on cost shifting between worker compensation and private insurance.
- Surveillance research to assess the degree of significant and systematic underreporting of select injuries and illnesses on OSHA logs.
- Research on methods to build health and safety capacity in community health centers that serve low-income and/or minority-group workers, and to improve recognition and treatment of work-related conditions.
- Transfer research to change health and safety knowledge in teenagers while they are in high school to improve the likelihood of reduced injuries when they enter the workforce.
- Community-based participatory research on differences between recently arrived immigrants and US-born workers regarding perceptions of acceptable health and safety risks to target programs to meet the workforce training needs of immigrant workers.

TABLE 2 Examples of NIOSH Program Research and Transfer Activities

Surveillance
(including hazard and health surveillance and evaluation of surveillance systems)

Health-effects research
Epidemiologic research
Toxicologic research
Laboratory-based physical and safety risk factor research
Development of clinical screening methods and tools

Exposure-assessment research
Intervention research
Control technology
- Engineering controls and alternatives
- Administrative controls
- Personal protective equipment

Work organization research
Community-based participatory research
Policy research (such as alternative approaches to targeting inspections)
Diffusion and dissemination research
- Training effectiveness
- Information-dissemination effectiveness
- Diffusion of technology

Health-services and other research
- Access to occupational health care
- Infrastructure research—delivery of occupational-health services, including international health and safety
- Socioeconomic consequences of work-related injuries and illnesses
- Worker compensation

Technology-transfer and other transfer activities
- Information dissemination
- Training programs

The ECs should review the list of research and transfer activities (projects) for the research program under review that have been completed, are in progress, or have been planned. Surveillance activities should be included in this review. An EC should request that the NIOSH program under review provide a list of activities, grouping the projects into research activities as in Table 2, and specify whether they are intramural or extramural. For extramural projects, the key organizations and principal investigators' names should be requested, as should whether the projects were in response to a request for proposal or a request for application. For an intramural project, the EC should ask NIOSH to provide a list of key collaborators (other government agency, academe, industry, and/or union partners).

The ECs should evaluate each of the research activities outlined in Table 2 to the extent that each forms an important element of the program research. In the case of a sector research program (for example, mining, construction) in which health-effects research is not being reviewed, the ECs should determine what research inputs are being used by the program to develop its targets and then assess the value of the inputs.

Questions to Guide the Evaluation Committee in Assessing Research Activities

1. What are the major subprograms or groupings of activities within the program?
2. Were the activities consistent with program goals and objectives?
3. Were the research activities relevant to the major challenges in the research program?
   a. Did they address the most serious outcomes?
   b. Did they address the most common outcomes?
   c. Did they address the needs of both genders, vulnerable working populations, and small businesses?
4. Were the research activities appropriately responsive to the input of stakeholders?
5. To what extent were partners involved in the research activities?
6. Are the resource allocations appropriate, and appropriate at this time, for the research activities?
7. To what extent did peer reviews (internal, external, and precourse or midcourse) affect the activities?
8. Is there adequate monitoring of quality assurance procedures to ensure credible research data, analyses, and conclusions?

Questions to Guide the Evaluation Committee in Assessing Transfer Activities

1. Is there a coherent planned program of transfer activities?
2. Are the program's information dissemination, training, education, technical assistance, or publications successful in reaching the workplace or relevant stakeholders in other settings? How widespread is the response?
3. To what extent did the program build research and education capacity (internal or external)?

Assessment

For this part of the assessment, the EC will provide a qualitative assessment discussing relevance and quality. This evaluation must include consideration of the external factors identified in Section III.A that constrain choices of research projects. The EC will consider the appropriateness of resource allocations with respect to issues' importance and the extent to which the issue is being addressed. A highly relevant and high-quality program would be comprehensive, address high-priority needs, produce high-quality results, be highly collaborative, and be of value to stakeholders. Programs may be progressively less relevant or of lower quality as those key elements are not up to the mark or are missing. The discussion should cover those aspects in sufficient detail to arrive at a qualitative assessment of the activities. Assessment of the transfer activities must include considerations of program planning, coherence, quality, and impact.

III.B.6. Review of Outputs (Box D in Figure 2)

As shown in Figure 1, research inputs and activities lead to outputs. An output is a direct product of a NIOSH research program that is logically related to the achievement of desirable and intended outcomes. Outputs are created for researchers, practitioners, intermediaries, and end-users, such as consumers. Outputs can be in the form of publications in peer-reviewed journals, recommendations, reports, Web-site content, workshops and presentations, databases, educational materials, scales and methods, new technologies, patents, technical assistance, and so on. Outputs of NIOSH's extramurally funded activities should also be considered. Examples of major outputs are provided in Table 3.

Depending on the intended audience, outputs may be tailored to communicate information most effectively to increase the likelihood of comprehension, knowledge, attitude formation, and behavioral intent. The extent of use of formative evaluation data (data gathered prior to communication for the purpose of improving the likelihood of the intended effects) or intended user feedback in the design of the output can be considered an indicator of output quality.

In addition to outputs themselves, many related indicators of the production, reference to, and utility of outputs can be conceptualized and made operational. Examples include the extent of collaboration with other organizations in the determination of research agendas, the conduct of research, the dissemination of research results, and interorganizational involvement in the production of outputs. Coauthorship is a measure of the centrality of NIOSH researchers in the broader research community.

TABLE 3 Examples of a Variety of Scientific Information Outputs

Peer-reviewed publications by NIOSH staff
Total number of original research articles by NIOSH staff
Total number of review articles by NIOSH staff (including best-practice articles)
Complete citation for each written publication
Complete copies of the "top five" articles
Collaboration with other public- or private-sector researchers
Publications in the field of interest with other support by investigators also funded by NIOSH (for example, ergonomic studies with other support by an investigator funded by NIOSH to do ergonomics work, in which case NIOSH should get some credit for seeding interest or drawing people into the field)

Peer-reviewed publications by external researchers funded by NIOSH
Total number of NIOSH-funded original research articles by external researchers
Total number of NIOSH-funded review articles by external researchers (including best-practices articles)
Complete citation for each written report
Complete copies of the "top five" articles
Collaboration with other government or academic researchers

NIOSH reports in the research program
Total number of written reports
Complete citation for each written report
Complete copies of the "top five" reports

Sponsored conferences and workshops
Total number of sponsored conferences
Total number of sponsored workshops
For each sponsored conference or workshop, describe:
- Title, date, and location
- Partial vs complete sponsorship (if partial, who were cosponsors?)
- Approximate number of attendees and composition of participants
- Primary "products" of the event (such as publication of conference proceedings)

NIOSH's assessment of value or impact

Databases
Total number of major databases created by NIOSH staff
Total number of major databases created by external researchers funded by NIOSH grants,
For each database:
- Title, objective (in one to four sentences), and start and stop dates
- Partial vs complete sponsorship (if partial, who were cosponsors?)
- Study or surveillance-system design, study population, and sample size
- Primary "products" of the database (such as number of peer-reviewed articles and reports)
- Complete copies of the "top two" publications and/or findings, to date, from each database

continued

TABLE 3 Continued

Recommendations
Total number of major recommendations
For each:
- Complete citation (article, report, or conference where recommendation was made)
- Summary in one to four sentences
- Percentage of target audience that has adopted recommendation 1, 5, and 10 years later
- Up to three examples of implementation in the field

Identifications of "top five" recommendations to date

Tools, methods, or technologies (TMT)
Total number of major TMT (includes training and education materials)
For each:
- Title and objective of TMT (in one to four sentences)
- Complete citation (if applicable)
- Percentage of target audience that has used TMT 1, 5, and 10 years later
- Up to three examples of implementation in the field

Identification of "top five" TMT to date

Patents
Total number of patents
For each:
- Title and objective patent (in one to four sentences)
- Complete citation
- Percentage of target audience that has used product 1, 5, and 10 years later
- Up to three examples of implementation in the field

Identification of "top five" patents to date

Miscellaneous
Any other important program outputs

The EC should ask NIOSH to provide information on all relevant outputs for the specific program for the chosen time period.

Questions to Guide the Evaluation Committee

1. What are the major outputs of the research program?
2. Did the research program produce outputs that addressed the high-priority areas?
3. To what extent did the program generate important new knowledge or technology?
4. Are there peer-reviewed publications that are widely cited and considered to report "breakthrough" results?

5. Were outputs relevant to both genders, vulnerable populations and health disparities?
6. Were outputs relevant to health and safety problems of small businesses?
7. Are products user-friendly in terms of readability, simplicity, and design?
8. To what extent did the program help to build the internal or extramural institutional knowledge base?
9. Did the research produce effective cross-agency, cross-institute, or internal-external collaborations?

Assessment

For this part of the assessment, the EC should provide a qualitative assessment discussing relevance, quality, and usefulness. A highly ranked program will be one with outputs that address needs in high-priority areas, contain new knowledge or technology that is effectively communicated, contribute to capacity-building both inside and outside NIOSH, and are relevant to the pertinent populations. The discussion should cover those aspects in sufficient detail to support the qualitative assessment of the outputs.

III.B.7. Review of Intermediate Outcomes (Box E in Figure 2)

Intermediate outcomes, for the purposes of this evaluation, are related to the program's association with behaviors and changes at individual, group, and organizational levels in the workplace. An intermediate outcome reflects an assessment of worth by stakeholders outside NIOSH (such as managers in industrial firms) about NIOSH research or its products.

Intermediate outcomes include the production of standards, or regulations based in whole or in part on NIOSH research (products adopted as public policy or as policy or guidelines by private organizations or industry); attendance at training and education programs sponsored by other organizations; use of publications by workers, industry, and occupational safety and health professionals in the field; and citations of NIOSH research by industrial and academic scientists.

More difficult-to-collect intermediate outcomes that may be valid indicators of quality or utility include self-report measures by users and relevant nonusers of NIOSH outputs. These indicators include the extent to which key intermediaries find value in NIOSH databases for the repackaging of health and safety information, the extent to which NIOSH recommendations are in place and attended to in workplaces, and employee or employer knowledge of and adherence to NIOSH recommended practices.

A research program might be evaluated in terms of whether it is recognized as a national center of excellence, is one of the larger and best research programs in the country, is recognized only in terms of particular staff or a particular laboratory, duplicates other, larger facilities, or is not unique or has little capability or capacity.

Questions to Guide the Evaluation Committee

1. Has the program resulted in stakeholder training or education activities that are being used in the workplace or in school or apprentice programs? If so, what is the response to what is being done, and how widespread is the response?
2. Has the program resulted in standards, regulations, public policy, or voluntary guidelines that have been transferred to or created by the workplace in response to NIOSH outputs?
3. Has the program resulted in new control technology or administrative control concepts that are feasible for use or have been adopted in the workplace to reduce risk factors?
4. Has the program resulted in new personal protective equipment that is feasible for use or has been adopted in the workplace to reduce risk factors or exposures?
5. Has the program contributed to changes in health care practices to improve recognition and management of occupational health conditions?
6. Has the program resulted in research partnerships with stakeholders leading to changes in the workplace?
7. To what extent did the program's stakeholders find value in NIOSH's products (as shown by document requests, web hits, conference attendance, and so on)?
8. Has the program resulted in changes in employer or worker practices associated with the reduction of risk factors?
9. Does the program or a subprogram provide unique staff or laboratory capability that is a necessary national resource? If so, is it adequate or does it need to be enhanced or reduced?
10. Has the program resulted in interventions that protect both genders, vulnerable workers or address the needs of small businesses?
11. To what extent did the program contribute to increased capacity at worksites to identify or respond to threats to safety and health?

Assessment

Only a qualitative assessment of product development, usefulness, and impact is required at this point in the EC report. Some thought should be given to the relative value of intermediate outcomes, and the FC recommends applying the well-accepted hierarchy-of-controls model. The discussion could include comments on how widely products have been used or programs implemented. The qualitative discussion should be specific as to the various products developed by the program and the extent of their use by specific entities (industry, labor, government, and so on) for specific purposes. Whether the products have resulted in changes in the workplace or in the reduction of risk factors should be discussed. The recognition accorded to the program or the facilities by its peers (such as recognition as a "center of excellence" by national and international communities) should be considered in the assessment. A program to be highly ranked should have a high level of performance in most of the relevant questions in this section. Whether the impact was caused by NIOSH alone or in combination with external agents should also be considered in the evaluation. An aspect of the evaluation can be whether the impact would have probably occurred without NIOSH's efforts.

III.B.8. Review of End Outcomes (Box F in Figure 2)

End outcomes are defined by measures of health and safety and of impact on process and programs. The FC recognizes that a major challenge in assessing the causal relationship between NIOSH research and specific occupational health and safety outcomes is that NIOSH does not have direct responsibility or authority for implementing its research findings in the workplace. Furthermore, the benefits of NIOSH research program outputs can be realized, potential, or limited to knowledge gain. For example, negative studies contribute to the knowledge base and the generation of important new knowledge is a recognized form of outcome, in the absence of measurable impacts.

Outcome impact depends on there being a "receptor" for research results, including regulatory agencies, consensus and professional organizations, and employers. The ECs should consider questions related to the various stages that lead to outputs, such as

1. Did NIOSH research identify a gap in protection or a means of reduction of risk?
2. Did NIOSH convey that information to potential users in a usable form?
3. Was the research applied?
4. Did the results work?

End outcomes, for purposes of this evaluation, are changes related to health, including decreases in injuries, illnesses, deaths, and decreases in exposures or risk factors resulting from the research in the specific program or subprogram. Quantitative data are preferable to qualitative, but qualitative analysis may be necessary.

Sources of quantitative data include

- Bureau of Labor Statistics (BLS) data on fatal occupational injuries (Census of Fatal Occupational Injuries) and nonfatal injuries and illnesses (Annual Survey of Occupational Injury and Illnesses).
- NIOSH intramural surveillance systems, such as the National Electronic Injury Surveillance System (NEISS), the coal worker x-ray surveillance program, and agricultural worker surveys conducted by NIOSH in collaboration with the US Department of Agriculture.
- State-based surveillance systems, such as the NIOSH-funded ABLES, and the SENSOR programs (for asthma, pesticides, silicosis, noise-induced hearing loss, dermatitis, and burns).
- Selected state workers-compensation programs.
- OSHA, which collects exposure data, in the Integrated Management Information System.

The FC is unaware of surveillance mechanisms for many occupationally related chronic illnesses such as cancers arising from long exposure to chemicals and other stressors. For many outcomes, incidence and prevalence are best evaluated by investigator-initiated research.

The strengths and weaknesses of the various sources of outcome data should be recognized by the ECs. Quantitative accident, injury, illness, and employment data and databases are subject to error and bias and should be used by the ECs for drawing inferences only after critical evaluation and examination of whatever corroborating data are available. For example, it is widely recognized that occupational illnesses are poorly documented in the BLS Survey of Occupational Injuries and Illnesses, which captures only incident cases among active workers. Most illnesses that may have a relationship to work are not exclusively so related, and it is difficult for health practitioners to diagnose work-relatedness; few are adequately trained to make this assessment. Many of these illnesses have long latency and do not appear until years after people have left the employment in question. Surveillance programs may systematically undercount some categories of workers, such as contingent workers. Challenges posed by inadequate or inaccurate measurement systems should not drive programs out of difficult areas of study, and the ECs will need to be aware of such a possibility. In particular, contingent and informal working arrangements that place workers at greatest risk are also those on which surveillance information is almost totally lacking, so novel methods for measuring impact may be required.

In addition to measures of illness and injury, levels of exposure to chemical and physical agents and to safety and ergonomic hazards can be useful. Exposure or probability of exposure can serve as an appropriate proxy for disease or injury when a well-described occupational exposure-health association exists. In such instances, decreased exposure can be accepted as evidence that the end outcome of reduced illness has been achieved. That is particularly necessary in cases (such as exposure to asbestos) in which latency between exposure and disease outcome (lung cancer) makes effective evaluation of the relevant end outcome infeasible.

As an example of how exposure levels can serve as a proxy, the number of sites that exceed an OSHA Permissible Exposure Limit (PEL) or an American Conference of Governmental Industrial Hygienists threshold limit value is a quantitative measure of improvement of occupational health awareness and reduction of risk. In addition to exposure level, the number of people exposed and the distribution of exposure levels are important. Those data are available from multiple databases and studies of exposure. Apart from air monitoring, such measures of exposure as biohazard controls, reduction in requirements for use of personal protective equipment, and reduction of ergonomic risks are important.

Clearly, the commitment of industry, labor, and government to health and safety are critical external factors. Several measures of this commitment can be useful for the EC: monetary commitment of the groups, attitude, staffing, and surveys of relative level of importance. To the extent that the resources allocated to safety and health are limiting factors, the ECs should explicitly assess NIOSH performance in the context of constraints.

Questions to Guide the Evaluation Committee

1. What are the amounts and qualities of end-outcomes data (such as injuries, illness, exposure and productivity affected by health)?
2. What is the temporal trend in those data?
3. Is there objective evidence of improvements in occupational safety or health?
4. To what degree has the NIOSH program or subprogram been responsible for improvements in occupational safety or health?
5. If there is no time trend in the data, how do findings compare with data from other comparable US groups or the corresponding populations in other countries?
6. Is there evidence that external factors have affected outcome measures?

7. Has the program been responsible for outcomes outside the United States that have not been described in another category?

Assessment

For this part of the assessment, the EC should provide a qualitative assessment discussing the evidence of reductions in injuries and illnesses or their appropriate proxies (impacts).

III.B.9. Review of Other Outcomes

There may be health and safety impacts not yet appreciated, and other beneficial social, economic, and environmental outputs, including potential NIOSH impacts outside the United States. Many NIOSH study results and training programs may be judged to be important, or there may be evidence of implementation of NIOSH recommendations, outside the United States.

Questions to Guide the Evaluation Committee

1. Is the program likely to produce a favorable change that has not yet occurred or not been appreciated?
2. Has the program been responsible for other social, economic, security, or environmental outcomes?
3. Has the program's work had an impact on occupational health and safety in other countries?

Assessment

Evaluation by the EC may consist of a discussion of other outcomes, including positive changes that have not yet occurred; other social, economic, security, or environmental outcomes; and the impact that NIOSH has had on international occupational safety and health. It might also consider the incorporation of international research results into the NIOSH program of knowledge transfer for industry sectors.

III.B.10. Summary Evaluation Ratings and Rationale

An EC should use its expert judgment to rate the relevance and impact of the research program and its important subprograms by first summarizing its assessments of the subprograms and overall program according to the several items listed in Table 4. Table 4 is only a *worksheet* intended as an aid to the EC in its evalua-

TABLE 4 Evaluation Committee Worksheet to Assess Research Programs and Subprograms

Please respond to each with "major or important," "moderate," "likely," "limited," or "none."

Background Context for Program Impact

1.1 Evidence of reduction of risk factors in the workplace (intermediate outcome) and evidence that external factors affected reduction

1.2 Evidence of reduction in workplace exposure, illness, or injuries (end outcome) and evidence that external factors affected reduction

			Subprogram			
Addressing Charge 1	Activity Category	**Program**	**1**	**...**	**...**	**n**
1.3 Contributions of NIOSH research and transfer activities to changes in work-related practices	Research					
	Transfer					
1.4 Contributions of NIOSH research and transfer activities to reductions in workplace exposure, illness, or injuries	Research					
	Transfer					
1.5 Evidence of external factors preventing application of NIOSH research results	Research					
	Transfer					
1.6 Contribution of NIOSH research to enhancement of capacity in government or other research institutions	Research					
	Transfer					
1.7 Contributions of NIOSH research to productivity, security, or environmental quality (beneficial side effects)	Research					
	Transfer					
Addressing Charge 2						
2.1 Relevance of current and recently completed research and transfer activities to future improvements in workplace safety and health	Research					
	Transfer					
2.2 Progress in targeting research to areas of study most relevant to future improvements in occupational safety and health	Research					
	Transfer					

tion. Its purpose is to encourage the EC to summarize its work in one place and to concentrate on the subprograms and the items that will contribute to the final impact and relevance scores.

To set the context for this step in the evaluation of the impact of the research program in preparation to respond to charge 1, the EC will first need to consider the available evidence of changes in work-related risks and adverse effects and external factors related to the changes. That information should be organized as a prose response to items 1.1 and 1.2 in Table 4.

Next, the EC should review the responses to the questions in Sections III.B.6 through III.B.8 and systematically rate the impact of the research program and its subprograms by responding to items 1.3-1.7 in Table 4. To complete the table, the EC response should use one of the following five terms: "major or important," "moderate," "likely," "limited," or "none" (since 1995). The EC should evaluate separately the impact of the research and the impact of transfer activities. High ratings on items 1.3-1.7 require the committee's judgment that the program has contributed to outcomes. For example, outcomes have occurred earlier than they would have or are better than they would have been in the absence of the research program, or outcomes would have occurred in the absence of external factors beyond NIOSH's control or ability to plan around.

The EC should then assess the relevance of the research program and subprograms in preparation for addressing charge 2. The EC should review the responses to the questions in Sections III.B.2 through III.B.5 and rate the relevance of the research program and its subprograms by responding to items 2.1 and 2.2 in Table 4. The same five terms should be used ("major or important," "moderate," "likely," "limited," or "none") to evaluate separately the relevance of the research and the relevance of the transfer activities. Transfer activities occur in two contexts: (1) NIOSH efforts to translate intellectual products into practice and (2) efforts by stakeholders to take advantage of NIOSH products.

Final Program Ratings

To provide the final assessment of the research program for charge 1 (impact) and charge 2 (relevance), the ECs will use their expert judgment, their responses to the questions in Table 4, and any other appropriate information to arrive at one overall rating for the impact of the research program and one for its relevance to the improvement of occupational safety and health. In light of substantial differences among the types of research programs that will be reviewed and the challenge to arrive at a summative evaluation of both impact and relevance, however, the FC chose not to attempt to construct a single algorithm to produce the two final ratings.

Having completed Table 4, the EC should undertake its final assessment of the impact and relevance of the program. Final program ratings will consist of the numerical scores and prose descriptions of why the scores were given. As explained below, the ECs will summarize their responses to charges 1 and 2 by rating the relevance and impact of the NIOSH research program on five-point scales in which 1 is the lowest and 5 the highest rating. The FC has made an effort to establish mutually exclusive rating categories in the five-point rating scale; when the basis of a rating fits more than one category, the highest applicable score should be assigned. ECs will need to consider the impact and relevance of both NIOSH completed research and research in progress. In general, the assessment of impact will consider research completed, and the assessment of relevance will include research in progress related to likely future improvements. When assessing the relevance of the program, the EC should keep in mind how well the program has considered the frequency and severity of the problems being addressed, whether appropriate attention has been directed to both genders, vulnerable populations or hard-to-reach workplaces, and whether the different needs of large and small businesses have been accounted for.

The FC has some concern that the impact scoring system proposed below might be considered a promotion of the conventional occupational-health research paradigm that focuses on health-effect and technology research and not give much emphasis to socioeconomic and policy research and to surveillance and diffusion research (as opposed to activities) needed to effect change. Clearly, not all intermediate outcomes occur in the workplace. There are important outcomes much farther out on the causal chain that NIOSH can affect, and not all these can be defined as well-accepted intermediate outcomes. NIOSH, for example, has an important role to play in generating knowledge that may contribute to changing norms in the insurance industry, in health-care practice, in public-health practice, and in the community at large. The ECs may find that some of these issues need to be addressed and considered as important to influence the external factors that limit application of more traditional research findings. Given the rapidly changing nature of work and the workforce and some of the intractable problems in manufacturing, mining, and some other fields, the ECs are encouraged to think beyond the traditional paradigm.

Rating of Impact

5 = Research program has made a major contribution to worker health and safety on the basis of end outcomes or well-accepted intermediate outcomes.

4 = Research program has made a moderate contribution on the basis of end outcomes or well-accepted intermediate outcomes; research program generated important new knowledge and is engaged in transfer activities, but well-accepted intermediate outcomes or end outcomes have not been documented.

3 = Research program activities or outputs are going on and are likely to produce improvements in worker health and safety (with explanation of why not rated higher).

2 = Research program activities or outputs are going on and may result in new knowledge or technology, but only limited application is expected.

1 = Research activities and outputs are NOT likely to have any application.

NA = Impact cannot be assessed; program not mature enough.

Rating of Relevance

5 = Research is in highest-priority subject areas and highly relevant to improvements in workplace protection; research results in, and NIOSH is engaged in, transfer activities at a significant level (highest rating).

4 = Research is in high-priority subject area and adequately connected to improvements in workplace protection; research results in, and NIOSH is engaged in, transfer activities.

3 = Research focuses on lesser priorities and is loosely or only indirectly connected to workplace protection; NIOSH is not significantly involved in transfer activities.

2 = Research program is not well integrated or well focused on priorities and is not clearly connected to workplace protection and inadequately connected to transfer activities.

1 = Research in the research program is an ad hoc collection of projects, is not integrated into a program, and is not likely to improve workplace safety or health.

III.C. Identifying Significant Emerging Research (Addressing Charge 3)

Among the most challenging aspects of conducting research for the purpose of prevention of injury and illness is identifying new or emerging needs or trends and formulating an active research response that appropriately uses scarce resources in anticipation of those needs. Each EC should review the procedures that NIOSH has in place to identify needed research relevant to the NIOSH mission.

Each EC should review the success that NIOSH has had in identifying and addressing research to emerging issues. The review should include examination of leading indicators from appropriate federal agency sources, such as the Environmental Protection Agency, the Department of Labor, the National Institute of Standards and Technology, the National Institutes of Health, the Department of Defense, and the Department of Commerce. Those indicators should track new technologies, products, and processes and disease or injury trends.

One source of inputs deserving particular attention is the NIOSH HHE reports. NIOSH's HHE program is a separate legislatively mandated program that offers a potential mechanism to identify emerging research needs that could be incorporated as an input in each of the programs evaluated. The ECs should consider whether appropriate consideration has been given to findings from the HHE investigations as they are related to the research program under review.

Some additional indicators might include NIOSH and the NIOSH-funded FACE, the AOEC reports, the US Chemical Safety Board investigations, SENSOR and other state-based surveillance programs, and others. In addition, appropriate federal advisory committees and other stakeholder groups should be consulted to provide qualitative information.

The EC members should use their expert judgment both to evaluate what NIOSH has identified as emerging research targets (charge 2) and to respond to charge 3 by providing recommendations to NIOSH for additional research that NIOSH has not yet identified. An EC's response to charge 3 will consist primarily of recommendations for research in subjects that the EC considers important and of the committee's rationale.

Questions to Guide the Evaluation Committee

1. What information does NIOSH review to identify emerging research needs?
   a. What is the process for review?
   b. How often does the process take place?
   c. How are NIOSH staff scientists and NIOSH leadership engaged?
   d. What is the process for moving from ideas to formal planning and resource allocation?
2. How are stakeholders involved?
   a. What advisory or stakeholder groups are asked to identify emerging research targets?
   b. How often are such groups consulted, and how are suggestions followed up?
3. What new research targets have been identified for future development in the program under evaluation?
   a. How were they identified?

b. Were there lessons learned that could help to identify other emerging issues?
c. Does the EC agree with the issues identified and selected as significant and with the NIOSH response, or were important issues overlooked?
d. Is there evidence of unwise expenditure of resources on unimportant issues?

IV. EVALUATION COMMITTEE REPORT TEMPLATE

The following outline flows from the FC's review of the generalized logic model prepared by NIOSH, the request for information from NIOSH programs, and the assessment model described earlier in this report.

I. **Introduction**:
This section should be a brief descriptive summary of the history of the program (and subprograms) being evaluated, with respect to pre-NORA, NORA 1, and current and future plans of the research program presented by NIOSH. It presents the context for the research on safety and health; goals, objectives, and resources; groupings of subprograms; and any other significant or pertinent information. (A list of the NIOSH materials reviewed should be provided in an appendix to the EC report.)

II. **Evaluation of programs and subprograms (charges 1 and 2).**
A. Evaluation summary (includes a brief summary of the evaluation with respect to impact and relevance, scores for impact and relevance, and summary statements addressing charges 1 and 2).
B. Strategic goals and objectives: Describes assessment of the subprograms and overall program for relevance.
C. Review of inputs: Describes adequacy of inputs to achieve goals.
D. Review of activities: Describes assessment of the relevance and quality of the activities.
E. Review of research program outputs: Describes assessment of relevance, quality, and potential usefulness of the research program.
F. Review of intermediate outcomes and causal impact: Describes assessment of the intermediate outcomes and the causal attribu-

tion to NIOSH; includes the likely impacts and recent outcomes in the assessment.

G. Review of end outcomes: Describes the end outcomes related to health and safety and provides an assessment of the type and degree of causal attribution to NIOSH.

H. Review of other outcomes: Discusses other health and safety impacts that have not yet occurred; other beneficial social, economic, and environmental outcomes; and international dimensions and outcomes.

I. Summary of ratings and rationale (see Table 4).

III. Identification of needed research (charge 2):
The EC should assess the progress that the NIOSH program has made in targeting new research in the fields of occupational safety and health. There should be a discussion of the assessment process and results.

IV. Emerging research areas (charge 3):
The EC should assess whether the NIOSH program has identified significant emerging research areas that appear especially important in terms of their relevance to the mission of NIOSH. The EC should respond to NIOSH's perspective and add its own recommendations.

V. Recommendations for program improvement:
On the basis of the review and evaluation of the program, the EC may provide recommendations for improving the relevance of the NIOSH research program to health and safety conditions in the workplace and the impact of the research program on health and safety in the workplace as related to the research program under review.

Appendix A: List of the NIOSH and related materials collected in the process of the evaluation

V. FRAMEWORK COMMITTEE FINAL REPORT

At the conclusion of all individual program reviews, the FC will prepare a final report summarizing the findings of all the evaluating committees and providing NIOSH with an overall evaluation. All program ratings will be summarized and might be plotted graphically or with a Web chart.

The following is a proposed outline of the FC's final report:

I. Summary of national needs identified by the research programs reviewed.
   A. On the basis of the best available evidence, place those needs in the context of the overall estimated potential work-related disease and injury burden.
   B. Discuss the choices made and alternatives that might be the focus of current or future attention.
   C. Comment on programs not selected by NIOSH for evaluation by the National Academies.

II. Assessment of how well the program goals.
   A. Were matched to the research program needs.
   B. Were adjusted to new information and inputs as the field of interest changed or program results became available.

III. Assessment of NIOSH overall performance in the research programs reviewed.
   A. Distribution of available inputs.
   B. Activities and outputs.
   C. Intermediate outcomes.
   D. Summary assessment of significant differences among the programs
   E. International impact.
   F. Leveraging of the NIOSH research activity with respect to other public and private research programs.
   G. Assessment of relative importance of external factors in permitting or preventing intermediate or end outcomes; attention paid to accounting for and planning within the constraints of external factors (not simply assigning lack of progress to external factors).

IV. Overall assessment of NIOSH impact on progress in reducing occupational injury and illness.
   A. Breakthrough knowledge.
   B. International impact.
   C. Addressing disparities.
   D. Targeting residual risks and intractable risks.
   E. Coordinating NIOSH research activity with respect to other public and private research programs.
   F. Impact on occupational safety and health.

V. Summary, Conclusions, and Recommendations.

B

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C

NIOSH Mining Ergonomics Research Program Review[1]

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NIOSH MINING PROGRAM STRATEGIC RESEARCH PLAN: REDUCTION OF REPETITIVE AND CUMULATIVE MUSCULOSKELETAL INJURIES

This review is based on reading materials prepared by the National Institute for Occupational Safety and Health (NIOSH) Mining Program; a meeting with the mining program associate director, the acting director, and ergonomics researchers from the Pittsburgh and Spokane laboratories; and reviewing mining research program web sites from Australia, the United Kingdom and Canada along with relevant literature.

STRATEGIC GOALS AND OBJECTIVES

The Mining Program seeks to eliminate occupational injuries, illnesses, and fatalities in the mining industry via research and prevention activities in partnership with key stakeholders.

[1]Because the committee did not include an expert in ergonomics, the committee commissioned Dr. Barbara Silverstein, MPH, CPE of the Washington State Department of Labor and Industries to produce a white paper detailing her assessment of Mining Program research related to the reduction of Repetitive or Cumulative Musculoskeletal Injuries. The following report was submitted and carefully considered by the committee during the preparation of its own review.

Goal: By 2014, reduce repetitive and cumulative musculoskeletal injuries by 30 percent based on 2003 injury rate.

The intermediate goals of the mining ergonomics program are to

1. Quantify job demands and physical capabilities of miners to develop improved recommendations for work design; and
2. Develop and field-test ergonomic interventions to reduce worker exposure to musculoskeletal risk factors.

The performance measures are to

1. Provide 10 improved designs and work practices by 2009; and
2. Reduce the repetitive and cumulative musculoskeletal injury rate by 25 percent at test mine sites by 2009.

While most traumatic onset injuries have been decreasing in the mining industry, Bureau of Labor Statistics (BLS) and Mine Safety and Health Administration (MSHA) data indicate that work-related musculoskeletal disorders (WMSDs) due to heavy, awkward, or repetitive manual handling and vibration represent a significant proportion of illnesses and injuries in mining. Not all data sources clearly define musculoskeletal disorders. Data from MSHA and BLS (BLS, 2006a, 2006b) indicate that in the past 8 years, there has been a decrease in musculoskeletal disorders in mining by more than 30 percent, thus making the proposed goal quite achievable. Between 1999 and 2003, 4,079 back injuries with 173,000 lost or restricted work days were reported in surface mining, primarily among truck drivers, dozer operators, and front-end loaders; an additional 6,060 overexertion injuries were reported, many in the same occupations (National Safety Council, 2004). According to BLS data (BLS, 2004a) there were 2,380 lost time overexertion injuries in mining in 2004. Among all injuries reported, 25.8 percent occurred after 8 hours of work (BLS, 2004b). While these data are not broken down by injury type, it is reasonable to hypothesize a relationship between overexertion and extended work hours.

Ergonomics research and education activities can contribute enormously to identifying root causes of these disorders and to developing and testing potential solutions and disseminating results to employer and employee partners, as well as equipment manufacturers and regulatory agencies. Although federally funded mining ergonomics research has a longer history, this review is focused on the period since these activities came under NIOSH purview in 1997.

Ergonomics takes into account all the components of a work system (tech-

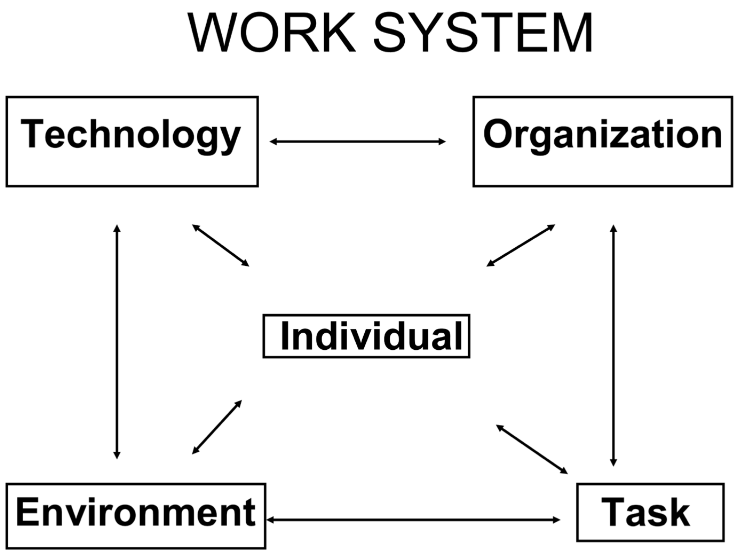

FIGURE C-1 Components of a work system. Based on Smith and Sainfort, 1989.

nology, organization, task, environment, and individual) and their interactions in order to achieve a balanced system (see Figure C-1). It is within this context that the NIOSH mining ergonomics research portfolio is viewed. More specifically, the focus is related to the strategic goal of reducing cumulative injuries such as work-related musculoskeletal disorders.

The major environmental factors include, for example, uneven surfaces, cramped conditions, noise, temperature, and lighting, which in turn have an impact on constrained and awkward postures, as well as exhaustion. Organizational factors include, for example, hours and shifts of work, degree of social interaction (isolated, team), and degree of structural constraints in determining how the work is carried out. Organization has a direct relationship to the frequency and duration of postures and forces required to do the work. Successful completion of the task determines the output of the work. The technology determines how the work can be completed and can often result in reduced force, repetition, and awkward or sustained postures. At the same time, introduction of new technology may affect physical load bearing, and change predominantly heavy, repetitive work over a long duration to more sedentary work with short bursts of very heavy work. Individuals bring different knowledge, skill, size, strength, experience, and intuition, as well as physical and mental fitness, to the work. Maximizing the balance between these five components of the work system improves worker health, productivity, and product quality. Imbalance can result in worker injury, poor quality, and/or reduced productivity. Imbalance can lead to both acute traumatic onset injures and cumulative musculoskeletal disorders. Ergonomics research needs to continually evaluate and improve work system balance.

Major ergonomics challenges in the mining industry include rough, heavy, poorly maintained machinery; fatigue; extended work hours; repetitive tasks; undemanding and overdemanding tasks; shift work; errors; and access for maintenance.

The multidisciplinary ergonomics program (nine people in Pittsburgh and three in Spokane) includes expertise in physiology, bioengineering, mining, industrial and mechanical engineering, sociology-psychology, and industrial hygiene, but not cognitive ergonomics. While there is a "human factors" group conducting research in the area of extended shifts on stress, there is no cognitive ergonomics in this group either. Additionally, some interdisciplinary work is being conducted to make maximum use of existing resources. For example, ongoing lighting research may have an impact on the interplay between slips and musculoskeletal disorders. The work of these researchers is being published in peer-reviewed ergonomics and safety journals and presented at professional and industry conferences, as well as at specific worksites. The research and related work are primarily in areas of laboratory-based physical and safety risk factor research, control technology, intervention effectiveness, diffusion and dissemination of research, and transfer activities.

There are impressive laboratories for ergonomics research in the Pittsburgh facility including motion analysis, strength testing, and a human performance research mine with access to mining equipment.

Ergonomics researchers have effectively collaborated with other research groups within the Mining Program and with extramural partners to address overlapping issues. The basic WMSD prevention strategy advocated by the mining ergonomics group includes the following:

1. Partnering with mining stakeholders,
2. Developing solutions with the mines,
3. Advancing ergonomics research and tool development,
4. Ensuring research to practice (r2p) via workshops and industry briefings, and
5. Research impacts of emerging issues such as an aging, experienced workforce and a new inexperienced workforce.

The basic approaches taken to facilitate r2p include

1. Identify immediate or intermediate solutions to problems identified by the industry via off-the-shelf products or from examples used in other industries;
2. Use awareness training and educational activities to transmit the above solutions to the industry partners;
3. Conduct investigative research to identify unknown physiological or biomechanical effects of tasks or use of new technology, using laboratory and simulation testing and field-testing potential solutions.

This approach is quite reasonable to maintain good working relationships where research can be conducted. Care should be taken to ensure that this relationship is not just a consultancy. Research involves the development of generalizable knowledge. Research in this environment would be strengthened by systematic follow-up after possible solutions are introduced to worksites (e.g., evidence of implementation may be documented, but site-specific health effects do not seem to be monitored nor are appropriate comparison groups identified). Improving intervention study designs would increase the generalizability of findings.

The research program moves between simulation studies, laboratory studies, and field studies. Examples of current NIOSH mining ergonomics laboratory and field research examples focus on the following:

Environment

Researchers have recognized that not only is the workforce getting older but highly experienced miners are leaving the mine, leaving more inexperienced miners and mining engineers with increasingly long hours as production demands increase (due to high commodity prices) and more adverse conditions (smaller and/or deeper). Recognizing that teleoperations (remote-controlled) may be needed to address acute traumatic injury risk, ergonomics researchers are aware of the need to evaluate the cognitive side of implementing this technology in a dynamic hazardous environment.

Technology

- *Multifactor evaluation and improvement of mobile equipment-operator interface* (related to whole-body vibration, postural sway, posture, and landing force getting out of the cab)
- *Development and testing of low seam shuttle car seat* intervention for reducing jarring and jolting injuries

- *Evaluating vertical and horizontal appendage speeds on roof bolters and recommending machine design modifications*—this is an example of identifying the need in the field and moving to simulation in the laboratory

Organization

The effectiveness of implementing a participatory ergonomics process in lowering exposure to hazards and reducing WMSDs must be evaluated. The most physically difficult jobs were identified by participants at industry conference focus groups. Five-minute toolbox materials were developed to present problems and possible solutions and test these in the field. Organizationally, this intervention seeks to assess the integration of ergonomics into overall safety-health-work life program structures in small and large mines. In larger companies, a corporate-wide risk assessment tool has been developed along with injury investigation procedures. Attempts are being made to produce ergonomically sound design specifications that will affect purchasing decisions. In the medium-size mining company, after ergonomic risk factor awareness training, 55 concern cards were completed, 22 interventions were completed, an initial 15 percent decrease in postural discomfort resulted where interventions were introduced, and other interventions are currently in progress. Interventions included new equipment and work station adjustment. There was a setback in a smaller mine company that is planning on going from surface to underground mining, although a number of interventions were implemented prior to change in production and product. These are interesting case studies with different organizational structures that may result in generalizable knowledge on program and process implementation and sustainability in this industry. However, more rigorous follow-up of intervention effectiveness will be required to test these methods.

Worker-Task Interface

- Recognizing that age is associated with greater number of lost workdays due to WMSDs, researchers developed and are evaluating a program for *successful aging among miners through ergonomics* (SAME) using awareness training and identifying engineering controls for the prevention of cumulative and acute traumatic injuries with a current focus on knee and back injuries. This area of research demonstrates the integration of the three research methods to focus on solving problems identified in the field and via surveillance: developing a biomechanical knee model and evaluating exit from equipment tasks and tread design

in order to reduce slip-fall hazards. At the same time, researchers have developed a low-back exposure assessment tool for use by mines. They are testing age awareness training in the field.
- *A small case study* has been conducted on implementing an engineering intervention to reduce WMSDs in a dozer blade changing task.

All of these studies use multiple methods (computer simulations, task analyses, operator input, direct measurement, field testing, and employee-employer participation and feedback), taking into account the context in which the machinery or intervention will be used by the operators.

Applied engineering research is the focus of the Mining Program with approximately 20 percent of the 15,000 mines visited in a year. The ergonomics research program uses surveillance data to monitor trends and suggest gaps in research or transfer of research to practice. It also spends a considerable amount of time and resources in the field at different mining sites or meetings and conferences to gather input from stakeholders about their needs (union, company, equipment manufacturers, associations, and external researchers). A third source of inputs is from other countries where mining is also important. This includes various networking mechanisms as well as having visiting researchers participate in NIOSH research projects.

Examples of Research Outputs

Technology Assessment

- Comparison of physical load and method using fiberglass versus steel bars for hand scaling (sand and salt mines)—depends on location of work height
- 15 percent global adoption of low seam shuttle car design so far
- Dragline workstation design, and testing—now requested by equipment companies and mines

Exposure Assessment Tools

- Low-back risk factor checklist development
- Assessment of cab entry and exit risks for back and other overexertion risks
- Cab design checklist for mobile equipment used by operating engineers

Process Tools

- Participatory ergonomics implementation methods in mining based on three different types of company size and organization styles.

New Knowledge

- Lighter-weight manual scaling bars do not necessarily produce lower physical load on the worker. It depends on the position of the bar with respect to the work and the worker. Workers should position themselves on platforms so the scale points are below knee level. Actually, elimination of manual scaling should be the focus of this research.
- A roof screen prevents rock fall, but transporting and installing the screen present heavy musculoskeletal loads. During screen transport, analyses show that dragging the screen increases muscle activity more than carrying the screen, and during installation, using rails to slide the screen reduces the load on the back for only that intervention but not for the overall task. Future research will seek to build a roof bolter mockup and develop improved interventions.
- Miners spend a lot of time on their knees or in awkward squatting postures. These likely accounts for the high incidence of knee injuries seen in the surveillance data. Knee pads present some difficulty for miners and are not always used. In order to understand the mechanisms of injury and the possible improvement in knee pads or some other prevention technology, researchers are constructing a biomechanical knee model to gain more insight into the tasks and barriers to knee injury prevention, develop better knee pads, develop a method to test knee pads, and provide training and better interventions as they become available. Fully implementing this research should result in direct reduction of knee injuries in this industry (of course, it would be better, although perhaps impossible, to develop methods to eliminate the need for kneeling and squatting for prolonged periods).
- Simulation and fresh frozen cadaver spine testing for compression and endplate failure confirmed the role of torso flexion in low back pain (LBP) and led to developing of improved LBP risk assessment tools.

Review of Transfer Activities

The ergonomics program appears to be very involved in dissemination of information and products based on its research and development activities. The primary mechanisms used for information transfer include the NIOSH web site (e.g., Ideas to Reduce WMSDs); conference presentations; workshops for engineers, unions, and companies; peer-reviewed papers and conference proceedings; demonstrations; successful inclusion of mining ergonomics materials into web sites of stakeholders; and equipment company salesmen using ergonomics with customers.

Examples of Intermediate Outcomes and Causal Impact

NIOSH identified some 85 publications or presentations related to ergonomics and MSD risk identification, controls, or ergonomics program processes between 1996 and 2004. Examples of underlying work resulting in these publications include the following:

- Ergonomics process adoption at large ($N = 9{,}000$) and intermediate ($N = 350$) size mining companies, via 21 training sessions and trainee submission of risk factor report cards on jobs, with 22 interventions implemented with good results. The systematic evaluation of risk factor reduction has not been completed by the researchers. However, a repeat discomfort survey indicated 15 percent reduction in discomfort. In the larger company, a metric for program evaluation is being implemented, with job improvements being posted on the company intranet. These activities have led to requests by other companies, unions, and associations to be trained in the participatory ergonomics process. This work led to 11 publications or presentations.

  Examples of specific intervention case studies that have been implemented include a dragline work station, water cannon pit station, and seated work control station improvements to prevent carpal tunnel syndrome related to 8-12 hours per day of joystick manipulation.
- Methods adoption
  - Use of the lumbar support in low seam shuttle cars. This equipment is now available from a large equipment manufacturer. This work also resulted in seven publications or presentations.
  - Use of concern cards in obtaining employee input into the ergonomics process
  - Use of WMSD risk assessment tools in several mines.
  - Integration of participatory ergonomics approaches in a number of mines

There has been some difficulty in the program's ability to track dissemination and implementation efforts based on publications and presentations. This is not unique to this research group. It has been more responsive than many to industry-specific requests for research and evaluation of technology to improve the health and safety environment in a dynamic, hazardous industry.

Additionally, in a Google search of "mining+ergonomics+research," virtually all relevant hits eventually refer to the work of NIOSH mining ergonomics research activities. This suggests leadership in this particular area of ergonomics research.

Review of End Outcomes

WMSD Injury Rates

In the NIOSH Mining Briefing Book section on cumulative injuries and musculoskeletal disorders, NIOSH indicated "contributing" to the 34 percent reduction in lost workdays due to these disorders from 1998 to 2004 (NIOSH, 2005). NIOSH proposes a goal of a 30 percent reduction in incidence rate by 2014. It proposes to accomplish this by continuing to integrate ergonomics process into existing health and safety programs and incorporating worker involvement in the process. If it is successful in widespread dissemination of the positive impacts of participatory ergonomics being implemented within health and safety programs, as well as widespread implementation of a number of control measures (e.g., low seam shuttle car seat), it should be able to see a 30 percent reduction in WMSD rates, doing nothing differently.

Review of Other Outcomes

There has been significant production of knowledge to be used by others to improve the mining work environment and reduce musculoskeletal disorders and disability. This has been transmitted via numerous presentations and papers in the scientific and industry communities with considerable evidence of implementation of prevention measures, as well as generation of new research ideas. An example is the Industrial Minerals Association – North America ergonomics conference in 2006 (*http://www.ima-na.org/about_ima_na/ergonomics.asp*).

Anticipated Outcomes Based on Successful Completion of Current Work and Implementation of Findings by Industry

- Better mobile equipment cab ergonomics
- Reduction in knee injuries
- Reduction in low-back disorders related to back-flexed lifting

- Industry and worker awareness of the relationship between aging, work, and injury and design work to prevent disability in older workers
- Reduction in slip and fall-related injuries

Identification of Emerging Areas of Research

To increase the likelihood of meeting the stated goal and performance measures, additional areas requiring research should be considered:

- Effects of decreasing task variety and increasing monotony on injury
- Effects of the combination of irregular heavy work and sedentary work on injury
- Exacerbation of the effects of both of the above when longer hours and more inexperienced miners are added to the equation.
- Relationship between slips-trips-falls (23 percent of injuries) and material handling injuries (36 percent of injuries)(National Safety Council Injury Facts, 2004) and aging
- Integration of ergonomics into management systems theory and practice in mining
- Impact of increased cognitive loading found in mining (use of remote controls, visual, auditory, touch, sensory cues) on musculoskeletal loading

The ergonomics group may not be able to address these important issues with existing resources.

Additional Issues

Resources

This group is doing some very interesting, important work that likely has significant impact on improving health and safety in the mining industry. It appears to have very good working relationships with a variety of stakeholders. This group is also doing a lot of case study type field research. However, intervention research methods are not strong. From the briefing materials, it appears that there were four epidemiologists and one ergonomist listed by scientific specialty in the Mining Program. It is unclear that any of the epidemiologists are working with the ergonomics group. It would be very helpful if they could collaborate either with other NIOSH groups that have epidemiological or intervention study expertise or with external collaborators in study design and analysis, which would be particularly beneficial when looking at health outcomes.

The reference documents indicate that there has been a concerted effort to document interventions, their usability, and effectiveness, but there is a considerable way to go in terms of field-based study design that can demonstrate evidence-based generalizable knowledge in this area.

Although there was an increase in funding for the cumulative injuries-ergonomics program between 1998 and 2005, it was not commensurate with the proportion of lost-time injuries in this area. In fact the discretionary budget in this area has decreased, likely due to the increase in full-time equivalents from 16 to 20.

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D

Biographical Sketches of Committee Members

Raja V. Ramani, *chair*, is emeritus George H., Jr. and Anne B. Deike Chair of Mining Engineering and professor emeritus of mining and geo-environmental engineering at The Pennsylvania State University. Dr. Ramani holds M.S. and Ph.D. degrees in mining engineering from Penn State, where he has been on the faculty since 1970. His research activities include mine health, safety, productivity, environment, and management; flow mechanisms of air, gas, and dust in mining environs; and innovative mining methods. Dr. Ramani has been a consultant to the United Nations, World Bank, and National Safety Council and has received numerous awards from academia and technical and professional societies. He was the 1995 president of the Society for Mining, Metallurgy, and Exploration. He served on the U.S. Department of Health and Human Services' Mine Health Research Advisory Committee (1991-1998). He was the chair of the National Academy of Sciences (NAS) Committee on Post Disaster Survival and Rescue (1979-1981) and a member of Health Research Panel of the NAS Committee on the Research Programs of the U.S. Bureau of Mines (1994). He was a member of the Department of Interior's Advisory Board to the Director of U.S. Bureau of Mines (1995) and a member of the Secretary of Labor's Advisory Committee on the Elimination of Coal Worker's Pneumoconiosis (1995-96). More recently, he was a member of the NAS Committee on Technologies for the Mining Industries (2000-2001) and the NAS Committee on Coal Waste Impoundments (2001-2002). In 2002, he chaired the the Pennsylvania Governor's Commission on Abandoned Mine Voids and Mine Safety that was set up immediately following the Quecreek Mine inundation incident and rescue. Dr. Ramani is a member of the National Academy of Engineering.

David Beerbower is vice president of safety at Peabody Energy Corporation, responsible for corporate-wide safety policies and programs and for compliance with federal mine safety and health laws and regulations. He has worked as a mining engineer and in various operations positions in the coal mining industry. Mr. Beerbower has served as chair of the Bituminous Coal Operators Association Health and Safety Committee, vice chair of the National Mining Association Health and Safety committee, and chair of the Society of Mining, Metallurgy, and Exploration (SME) Coal and Energy Division, and he is currently a board member of SME. Mr. Beerbower received a B.S. in mining engineering from The Pennsylvania State University and an M.B.A. in manufacturing management from Washington University in St. Louis.

Jefferey L. Burgess is director of the Division of Community, Environment and Policy at the Mel and Enid Zuckerman College of Public Health at the University of Arizona. He also serves as adjunct associate professor in the Department of Mining and Geological Engineering at the University of Arizona. Dr. Burgess's research interests include respiratory toxicology in firefighters and smoke inhalation victims, reduction of mining-related injuries and exposures, environmental arsenic exposure, and hazardous materials exposures, including methamphetamine laboratories. Dr. Burgess is the principal investigator for the National Institutes of Health Fogarty International Center-funded International Program for Mining Health and Safety as well as for research projects evaluating smoke exposure and arsenic exposure. Dr. Burgess received his M.D. and M.P.H. from the University of Washington.

James W. Dearing is senior scientist at the Colorado Clinical Research Unit of Kaiser Permanente. Until 2006, he was professor and director of graduate studies for the School of Communication Studies at Ohio University. Dr. Dearing also serves as a research scientist with the Michigan Public Health Institute. His primary area of expertise is empirical testing and application of diffusion of innovation theory to problems of moving evidence-based programs and policies into practice. He has led research projects about community-based health system reform, mass media agenda setting, community health promotion planning, interorganizational networks, and organizational change. Dr. Dearing is currently coordinating a national team of diffusion researchers to design and study the purposive acceleration of effective interventions in health promotion and education reform. He holds a Ph.D. in communication theory and research from the University of Southern

California. Dr. Dearing serves on the National Research Council (NRC) committee that developed the framework for the evaluation of the National Institute for Occupational Safety and Health's (NIOSH's) research programs and has active research grants from the National Science Foundation, the John D. and Catherine T. MacArthur Foundation, and the Robert Wood Johnson Foundation.

Francis S. Kendorski is principal and vice president of Agapito Associates, Inc. He manages the Chicago area office and is responsible for all of its activities. His work has included mining research in ventilation, blasting, ground control, rock mechanics, and mining methods; underground longwall coal mine design and subsidence engineering; underground stone mine design and ground control; cause and origin investigations of tunnel and mine failures and floods; mine explosion investigations; and ground control studies. His assignments have taken him throughout the United States and Canada, Papua New Guinea, Indonesia, New Zealand, Panama, Nicaragua, Trinidad, Chile, and India. Mr. Kendorski is a registered professional engineer in 11 states. He received his M.S. in geological engineering from the University of Arizona. His thesis was on the structural geology and rock mechanics of the rock masses at the underground Magma Copper San Manuel Mine in southern Arizona. Mr. Kendorski was the 2005 recipient of the Society for Mining, Metallurgy, and Exploration's Rock Mechanics Award for his accomplishments in that area.

Michael K. McCarter is chair and professor of the Mining Engineering Department at the University of Utah. He is also a licensed professional engineer in Utah. Dr. McCarter's interests include geotechnical engineering, explosives and rock fragmentation, mine seismicity, surface mine planning, and instrumentation. In addition to his 33 years of experience in academia, Dr. McCarter has also held several positions, from trackman to planning engineer at Kennecot Copper Corporation. Dr. McCarter holds two patents and among other activities is currently serving as a member of the SME Task Force on Mining Education and as co-chair of the Institute on Mining Health, Safety and Research. Dr. McCarter received his Ph.D. in mining engineering from the University of Utah.

David Ortlieb is assistant director for the United Steelworkers Health, Safety and Environment Department in Nashville, Tennessee. Mr. Ortlieb served as health and safety director for the International Chemical Workers Union for 13 years. He also was employed as health and safety director for the United Paperworkers International Union and for the Paper, Allied Industrial and Energy Workers International Union spanning a 10-year period. As a member of a nationwide union Emergency Response Team since 1996, Mr. Ortlieb has investigated serious and catastrophic accidents in the paper, chemical, and mining industries. He has served on various advisory and steering committees, including the Business Council of Pennsylvania Labor-Management Committee on Hazardous Waste Disposal, the John Grey Institute Steering Committee for Petrochemical Industry Safety and Health (U.S. Department of Labor, Occupational Safety and Health Administration), and the State of Ohio Governor's Commission on the Storage and Use of Hazardous and Toxic Materials. Mr. Ortlieb earned his B.S. in industrial technology from State University College at Buffalo, New York.

Susan B. Patton is vice chancellor for academic affairs and research and associate professor of mining engineering at Montana Tech. Dr. Patton has also worked as the general manager for Novak Engineering Consultants and a mining engineer for Pittsburgh and Midway Coal Mining Company. Her research interests include underground mine environment quality, mine reclamation, mine ventilation, and materials handling. Dr. Patton has taught several short courses on mine permitting, ventilation, and reclamation. She holds a Ph.D. in mining and environmental engineering from the University of Alabama.

Robert G. Peluso is a self-employed consultant. He is currently working with the Paragon Technical Services, Inc., on developing a toxic material profile for uranium miners, millers, and ore transporters. Over the past seven years he has provided expert consultation to Drager Safety, Inc. and Eagle Research Group and health and safety litigation consultation to three legal firms. Prior to private consulting, Mr. Peluso worked with the Mine Safety and Health Administration in the Department of Labor. Mr. Peluso's health and safety expertise includes the areas of respirable dust, ventilation, toxic materials physical agents, refuse handling, fires, and explosions. He received his M.S. in industrial hygiene from the University of Pittsburgh. Mr. Peluso is nominated for his expertise in disaster response and prevention.

Pramod Thakur is the manager of coal seam degasification at CONSOL Energy, Inc., and a centennial fellow at The Pennsylvania State University. He has served CONSOL for 31 years and has been mainly responsible for diversifying the company into gas operations. He is internationally recognized as an expert in coal seam degasification and coalbed methane production; in 2004, he was awarded the Howard Hartman Award, the Society of Mining Engineering's highest award for lifetime contributions to mine ventilation engineering. His lifetime endeavors have minimized the risk of coal mine explosions in the United States as well as many other countries. Dr. Thakur has conducted extensive research on coal seam degasification, respirable dust control, and diesel exhaust control. He successfully managed research projects costing a total of $90 million, leading to the development and application of four different techniques for coal seam degasification (i.e., underground horizontal drilling to a depth of 3,000 feet; vertical gob wells [with the U.S. Bureau of Mines]; massive hydraulic fracing of coal seams; horizontal hole drilling from the surface for coalbed methane production). The second major area of Dr. Thakur's efforts is to minimize the risk of coal worker's pneumoconiosis (black lung). He did extensive research on sampling and measurement of respirable dust and engineering control by water infusion, electrostatic charging of water particles, and the use of surfactants. Dr. Thakur has been a member of SME American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) since 1969 and was elected a fellow of the Mine Ventilation Society of South Africa. He holds six U.S. patents in the areas of coal seam degasification and drilling equipment designs. Dr. Thakur received his Ph.D. in mining engineering from The Pennsylvania State University.

Jeffrey S. Vipperman is associate professor of mechanical engineering, associate professor of bioengineering, and director of the Sound, Systems, and Structures Laboratory at the University of Pittsburgh. Dr. Vipperman's research spans the many related disciplines of dynamics, vibrations, controls, analog and digital signal processing, autonomous system health monitoring, smart materials and systems, acoustics, hearing loss prevention, and structural acoustics. Nearly 60 publications and almost 70 presentations have been authored by Dr. Vipperman, including many related to hearing loss prevention in the mining industry. He served in the past as a mechanical engineer at NIOSH's Pittsburgh Research Laboratory, where he conducted research in the areas of hearing loss prevention and engineering noise controls. In addition, he has collaborated with the NIOSH Alice Hamilton Laboratories to evaluate and characterize the exposure to impulse-impact noise in manufacturing settings. He has consulted for numerous corporations and private and government laboratories and chairs an American National Standards (ANSI) group in acoustics. Dr. Vipperman received his Ph.D. in mechanical engineering from Duke University.

James L. Weeks is senior scientist at Advanced Technologies and Laboratories International, Inc., a consulting firm in Germantown, Maryland, as well as an adjunct associate professor at the Bloomberg School of Public Health at Johns Hopkins University and at the School of Public Health at George Washington University. Dr. Weeks served in various roles within the Occupational Health and Safety Department of the United Mine Workers of America for more than 10 years and continues to serve as a consultant to them today. Among other activities, he has evaluated dust exposure in coal mines, fatal injuries in coal mines, quartz exposure in metal and nonmetal mines, noise exposure in construction, beryllium exposure among demolition workers, and heat exposure among workers using chemical protective clothing. He has more than 50 publications in the peer-reviewed literature. Dr. Weeks is certified in the comprehensive practice of industrial hygiene and experienced in the analysis of exposure and injury data. He has worked in the mining, construction, and manufacturing industries and is senior editor of *Preventing Occupational Disease and Injury* (Second Edition, 2004), a book widely used by occupational health professional and others. Dr. Weeks received a B.S. in engineering from the University of California, Berkeley, an M.A. in science, technology, and public policy from Case Western Reserve University, and M.A. and Sc.D. degrees from the Harvard School of Public Health.

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*The Committee on Earth Resources is a standing committee of the Board on Earth Sciences and Resources and serves as the focal point within the board for activities relevant to mineral and energy resources. This evaluation was conducted under the auspices of this standing committee.

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