Underground Mine Disaster Survival and Rescue: An Evaluation of Research Accomplishments and Needs

Report of the

Committee on Underground Mine
Disaster Survival and Rescue
Commission on Sociotechnical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1981

Do Not Circulate
[illegible] Report 79-2

Underground Mine Disaster Survival and Rescue: An Evaluation of Research Accomplishments and Needs

Report of the

Committee on Underground Mine
Disaster Survival and Rescue
Commission on Sociotechnical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1981

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Commission on Sociotechnical Systems is one of the major components of the National Research Council and has general responsibility for and cognizance over those program areas concerned with physical, technological, and industrial systems that are or may be deployed in the public or private sector to serve societal needs.

This study by the Commission on Sociotechnical Systems was conducted under Contract No. J0100014 with the Bureau of Mines, U.S. Department of the Interior.

Printed in the United States of America

COMMITTEE ON UNDERGROUND MINE DISASTER SURVIVAL AND RESCUE

R. V. RAMANI, *Chairman*, Professor of Mining Engineering, Pennsylvania State University, University Park, Pennsylvania

M. DAYNE ALDRIDGE, Director, Energy Research Center, West Virginia University, Morgantown, West Virginia

PATRICK R. HARVEY, Health and Safety Coordinator, Western Operations, Climax Molybdenum Company, Golden, Colorado

KENNETH F. KIMBALL, Physician, Medical Arts Surgical Group, Kearney, Nebraska

J. P. MOONEY, Safety and Health Coordinator, United Steelworkers of America (retired), Canon City, Colorado

LOUIS J. PIGNATARO, Professor of Transportation Engineering, Polytechnic Institute of New York, Brooklyn, New York

WOODS G. TALMAN, Mining Consultant, Pittsburgh, Pennsylvania, and Chief Inspector, Health and Safety, Coal Operations, U.S. Steel Corporation (retired)

GEORGE L. WILHELM, Manager, United States Operations, Exxon Minerals Company, New York, New York

Liaison Representative

H. KENNETH SACKS, U.S. Bureau of Mines, Pittsburgh, Pennsylvania

Staff Officer

ABRAM B. BERNSTEIN, National Research Council, Washington, D.C.

PREFACE

Post-disaster survival and rescue research is a small component of the U.S. Bureau of Mines (USBM) health and safety research program. During the period 1970-1979, post-disaster research received approximately 5.5 percent of the total USBM health and safety research funds.

The objectives of this study were to evaluate the USBM post-disaster research program and to recommend future efforts in this area. In conducting the study, the Committee on Underground Mine Disaster Survival and Rescue received extensive data from the Bureau of Mines on its program. The committee also obtained input from other federal agencies, state officials, mine operators, equipment manufacturers, and miners' representatives, and visited two operating mines, a training center, the USBM research center in Pittsburgh, Pennsylvania, and the Mine Safety and Health Administration's (MSHA) Mine Emergency Operations (MEO) facility in Hopewell, Pennsylvania. The committee reviewed reports of all the mine disasters, as well as a number of accidents, that occurred in the United States during the period 1970-1979. The committee also reviewed the laws, regulations, and procedures bearing on disasters, disaster response, and post-disaster audits. An important source document for the committee was the report "Mine Rescue and Survival," prepared by the National Academy of Engineering in 1970.

The committee has developed a definition of a disaster survival and rescue system that provides a frame of reference for the evaluation of research accomplishments and the assessment of future needs (Chapter 1). On the basis of its review of the past decade's disasters (Chapter 2) and research accomplishments (Chapter 3), the committee has briefly outlined the essential components of an R&D program in the post-disaster area (Chapter 3). The committee has then looked to the future and addressed two topics that the mining community must consider if it is to develop a more effective capability for post-disaster survival and rescue. These are: the need for a systems approach to preparing for disaster response (Chapter 4), and the special considerations that apply to government-sponsored research and development leading to the design of escape, survival, and rescue equipment (Chapter 5).

The disaster survival and rescue system identified in this report encompasses research institutions, government at all levels, mine management, unions, and miners, all within the framework of a total systems approach. Without such an approach, the total system may not perform as well as possible with respect to the objectives of post-disaster survival and rescue.

The report has therefore touched on areas that are not exclusively research and that are not entirely under the control of the Bureau of Mines. The call for an evaluation of MSHA's post-disaster audit process and mine emergency operations is a case in point. The recommendations concerning assessments of the standards set for oxygen self-rescuers and of the rulemaking process is another. Examination of these areas may be useful to legislative and administrative bodies that must determine whether there are better methods for achieving the desired objectives and whether funding levels are adequate. The approaches to training called for in this report can be pursued by the mining industry, independent of government. For the individual miner, the role he or she can play in discovering hazards, in ensuring the safety of fellow workers, and in escape and evacuation are emphasized.

The record of the mineral industry over the years reveals continuous endeavors by management, miners, and federal and state governments to eliminate the dangers involved in the extraction of minerals from underground. The significance of the progress that has been made to ensure a safer and more productive work environment should neither be overlooked nor minimized. Yet it is clear from the continued occurrence of disasters and accidents that attainment of the objective of a totally safe mine remains elusive. Pursuit of this objective is continuing. This study, directed toward evaluating the Bureau's survival and rescue research during the past decade, is a part of that endeavor.

The bulk of the recommendations in this report concern research and are directed to the U.S. Bureau of Mines. However, mine management, unions, miners, enforcement agencies, legislative bodies, and research organizations have important roles to play in ensuring that research efforts are effectively directed toward productive ends. In that sense, the report findings should be of interest to everyone in the mining community in the United States and abroad.

R. V. Ramani
Chairman

TABLE OF CONTENTS

Page

OVERVIEW

An underground mine disaster is an accident of major proportions that takes a significant toll in human lives. A disaster usually disrupts the normal functioning of a mine and may result in entrapment of miners whose normal egress from the mine is cut off. A disaster often necessitates a rescue operation and a means of keeping the trapped miners alive while they await rescue.

Explosion, fire, inundation of water or toxic gases, and collapse of a major portion of a mine are among the causes of mine disasters. Miners threatened by such an occurence must either bring the situation under control (e.g., by extinguishing a fire) or remove themselves from the danger. If control is unsuccessful, they must retreat to a place of safety.

Four different activities may be involved: evacuation, escape, survival, and rescue. Evacuation is the orderly exit of people from the mine using previously identified escapeways and following a previously determined evacuation plan. Miners whose normal evacuation routes are blocked may be able to find alternative exit routes and escape by their own efforts. For those who cannot, the issue becomes survival while waiting to be rescued. The survival period may last for many days while rescue efforts are mounted from outside the mine.

Development and enforcement of mine safety regulations is the province of the Mine Safety and Health Administration (MSHA) in the Department of Labor. That agency also has responsibility for responding to mine disasters and taking charge of rescue operations if necessary. Research and development relating to mine safety is the responsibility of the U.S. Bureau of Mines (USBM) in the Department of the Interior. In both MSHA and USBM, the major effort is directed toward accident and disaster prevention. As a result of these agencies' efforts and those of the mining industry and the labor unions, the frequency of mine disasters has diminished in recent years. Yet disasters do continue to happen, and measures to enhance the miners' prospects for surviving a disaster continue to be necessary.

The present study was undertaken by the National Research Council to advise the Bureau of Mines on the effectiveness of its post-disaster R&D program and to suggest future directions for that program. The program was begun in 1970 and has been primarily equipment-oriented. While many of the projects carried out have been technologically sound, disappointingly few results have found their way into operational practice. The committee finds that this has been caused in part by insufficient attention to the integration of individual projects into a coherent effort to achieve broad program goals, and in part by failure to draw sufficiently on the experience, perceptions, and expertise of prospective users in planning and continually reassessing research programs.

From its review of the underground mine disasters of the past decade and its examination of present disaster-response capabilities, the committee has concluded that what is needed is not only new survival and rescue equipment, but also more effective planning and training so that miners, mine managers, and government officials are better prepared to cope with disasters. Of particular importance are the first few minutes of a disaster, when crucial decisions must be made--often with incomplete information about what has happened or is happening. Modern simulation techniques could be of great value in developing and evaluating disaster plans and in training personnel.

There is one piece of equipment that the committee believes would have great life-saving potential: an oxygen-providing escape breathing apparatus small enough and light enough to be carried on the miner's person. The device in present use--the "filter self-rescuer"--does not provide oxygen and is effective only against carbon monoxide. The "oxygen self-rescuers" developed thus far are too large and heavy to be continuously carried or worn by miners and would have to be cached at strategic places in the mine. Development of a light, compact "oxygen self-rescuer" was urged by the National Academy of Engineering in 1970 but has not yet been accomplished--in part because of rigid adherence to a statutory requirement that such a device provide enough oxygen to keep a miner alive for an hour. No analytic determination of the necessary time requirement for an escape breathing apparatus or of the rate of oxygen consumption typical of escape activities has been carried out.

The committee believes that a systems approach integrating specific equipment and procedures with disaster plans, disaster training programs, and evaluations of the effectiveness of the response to each disaster and potential disaster, would lead to improved prospects for miners surviving a catastrophic accident. The committee believes this approach should be reflected in the R&D program addressing post-disaster survival and rescue, and the majority of the recommendations offered in this report are directed toward that end.

MAJOR RECOMMENDATIONS

The committee places utmost importance on the following recommendations, which concern (1) the need for a systems approach in post-disaster research and development, (2) the importance of planning for effective response to mine emergencies, (3) the development of an oxygen-providing escape breathing apparatus, (4) the design of escape, survival, and rescue equipment and the training of miners in its use, and (5) the development of an improved data base for decisions concerning post-disaster R&D. These recommendations are summarized here with parenthetical references indicating the chapters in which they are discussed. Other recommendations are found in the text of the report and are summarized at the end of each chapter.

A Systems Approach for Post-Disaster R&D

1. In managing its post-disaster R&D program, the Bureau of Mines should adopt a systems approach. The entire post-disaster response system--encompassing research, design, planning, operations, training, regulation, and enforcement--should be viewed as a whole. In every phase of the R&D program, the Bureau should involve all parties who will ultimately be involved in implementing the R&D results. These include government agencies, mine operators, unions, and mine equipment manufacturers. The Bureau must actively solicit this input, not just invite it. The mining companies and unions must actively participate in the process. (Chapter 5)
2. The Bureau should institute management procedures that ensure continual evaluation of the interrelations between different research projects and that ensure assessment of their combined effectiveness in achieving program goals. (Chapter 3)
3. In evaluating both proposed and ongoing research projects, the Bureau should utilize outside review by research scientists and engineers, manufacturers and users, and experts from related areas in other programs and industries. In particular, input should be sought from those with actual experience in the area under study (e.g., mine rescue team captains, miners who have successfully barricaded, etc.), and those who are likely to use the R&D results. (Chapter 3)

4. In developing new systems, the Bureau should provide for adequate R&D, demonstration, and testing of key components of the system before proceeding with development of the integrated system. (Chapter 3)
5. The Bureau, MSHA, NIOSH, state regulatory agencies, mining companies, unions, and manufacturers should cooperate in the development and implementation of new devices and procedures. Ideally, rulemaking should evolve only after the new technology has been adequately tested and proven, using devices constructed as they would be in mass commercial manufacture. Companies should be offered incentives to participate in product development and testing of early designs. For this cooperative interaction to work it must begin at the research initiation phase and continue through research, product development, demonstration, testing, approval, and marketing. (Chapter 3)
6. The joint USBM-MSHA procedure for assigning priorities to suggested research projects should be examined to ascertain whether it actually meets industry's safety needs. In particular, the bias in favor of short-term, low cost projects should be critically evaluated. (Chapter 3)

Planning for Effective Emergency Response

7. Guidelines and criteria should be established for use by mine operators in developing disaster plans and training programs, and by MSHA in evaluating those plans and programs. While this clearly is an MSHA responsibility, the Bureau of Mines should provide the necessary foundation by conducting research aimed at developing methodologies for testing and evaluating mine emergency plans using simulation or other appropriate techniques. The Bureau should also undertake R&D to develop specific techniques for applying system safety analysis to mine disasters. This should include the development of systematic methods for identifying and investigating potential disaster situations. These methods should be made available to MSHA and to the mining industry. (Chapter 4)
8. Guidelines and standards should be developed for integration of a mine's emergency medical care system and emergency communication system into the emergency medical care and emergency communication systems serving the local community. (Chapter 4)
9. Emergency medical care training for miners should be developed and evaluated in light of realistic assessments of need and utilization. Ongoing refresher training must be a part of this system. (Chapter 4)
10. A careful and systematic assessment should be undertaken of the risks involved in non-routine underground mining activities. All such activities should be backed up with well-defined disaster response procedures. All personnel involved in the activity should be familiar with, and trained in, evacuation and disaster response procedures. (Chapter 2)
11. The federal government's mine emergency response capability, and specifically MSHA's Mine Emergency Operations (MEO) group,

should be evaluated in the context of the complete emergency response system. The feasibility and effectiveness of mechanisms other than the present MEO structure should be examined. (Chapter 4)

An Oxygen-Providing Escape Breathing Apparatus

12. R&D on an oxygen-providing escape breathing apparatus should be continued, with major emphasis on a system that is designed for escape and can be carried on the miner's person. (Chapter 3)
13. Physiological and metabolic research, combined with simulation of mine emergencies requiring escape efforts, should be undertaken to establish realistic oxygen rate and time duration requirements for an escape breathing apparatus. This should include a reexamination of the validity of the one-hour requirement, and if the one-hour duration is found to be unnecessary, it should include determination of the appropriate time requirement. (Chapter 3)
14. A systems study should be undertaken to identify the design requirements and optimum strategies associated with the various options for meeting the necessary time duration requirement for an escape breathing apparatus, including cached devices and "piggy-back" systems. This will provide a rational basis for tradeoffs leading to a system with which the miner's prospects for survival are maximized. (Chapter 3)

Design of Escape, Survival and Rescue Equipment and Training of Miners in its Use

15. Realistic design criteria for escape, survival and rescue equipment should be established early in the R&D process, and should take into account the nature of mine emergencies, the conditions under which the equipment will be used, and the human element in its use. R&D progress should continually be assessed in light of these criteria. (Chapter 5)
16. Among the considerations in the design and evaluation of emergency equipment should be the need to train miners in its use in actual or simulated emergency conditions. This may require simulation techniques analogous in principle to use of the Link Trainer in aviation. (Chapter 5)
17. More attention should be given to developing equipment for communication among rescue team members. (Chapter 3)
18. Continued research on oxygen sources for breathing apparatus should be carried out. (Chapter 3)
19. Continued research on rescue breathing apparatus is needed, with emphasis on an apparatus that provides greater comfort over longer working periods and on a mine rescue team helmet-breathing apparatus configuration that promotes both comfort and utility. (Chapter 3)
20. The applicability of the refuge chamber concept should be examined in detail, with emphasis on the relative utility of refuge chambers and other kinds of survival system elements such as better barricading techniques and improved mine layouts with a multiplicity of escapeways. (Chapter 3)

21. The Bureau should undertake R&D to develop improved capabilities for rescue work in deep and hot mines. (Chapter 2)
22. The Bureau should make a more active effort to study technology developed in other industries and other countries that might be applicable or adaptable to mine disaster survival and rescue efforts in the United States. (Chapter 3)

An Improved Data Base for Post-Disaster R&D

23. Present reporting and investigating procedures should be examined to see if they adequately serve their purpose, or whether an alternative approach--such as investigation of mine disasters by an independent body analogous to the National Transportation Safety Board--would be more effective. (Chapter 2)
24. It is essential to collect and analyze data on the medical causes of death or disability in mine disasters in order to determine the adequacy of the medical training, equipment, and procedures in the mine emergency response system, and to identify research needed to enhance the likelihood of survival for those injured in disasters. (Chapter 4)
25. In compiling data on past accidents and disasters, it would be useful to include information on situations that had the potential to develop into major disasters but didn't. Such "near misses" are likely to occur more frequently than actual disasters. A provision for granting immunity from punitive action to those who report such incidents should be considered as an element of the reporting system. (Chapter 2)

CHAPTER 1. INTRODUCTION

In 1979, in response to a request from the Bureau of Mines in the U.S. Department of the Interior, the National Research Council appointed the Committee on Underground Mine Disaster Survival and Rescue to review the Bureau's post-disaster survival and rescue program. The objectives of this review were the following:

1. Provide a critical evaluation of the current U.S. Bureau of Mines post-disaster survival and rescue program in the light of current technology and the present needs of the mining industry.
2. Suggest future research and development efforts in the post-disaster survival and rescue area.
3. Suggest ways to foster the integration of new effective technology and procedures into operational safety programs for the mining industry.

This chapter discusses the following: the events leading to this review; the scope of the review; the definitions of mine hazards, accidents, and disasters; the elements of a survival and rescue system; the underground mining industry; and the role of government in mine safety.

1.1 BACKGROUND

In 1969, at the request of the Bureau of Mines, the National Academy of Engineering (NAE) appointed a Committee on Mine Rescue and Survival Techniques to assess survival and rescue techniques for use in mine disasters. That committee was concerned with:

- The degree to which miners' prospects of survival might be improved in the event of circumstances preventing their normal withdrawal from a mine.
- The prospects of improving rescue procedures, improving the effectiveness of existing devices, and developing new devices or equipment that might make it possible to improve significantly miners' chances of survival in the environments that prevail following disasters.

- o Technological advances in related fields, such as space exploration, deep submergence, and civil defense, that might lead to significant improvements in mine rescue techniques and equipment.*

The NAE committee's report, "Mine Rescue and Survival,"** hereafter called "the 1970 NAE Report," consisted of two major parts. Part I described an interim mine rescue and survival system that the committee believed could be made available within a year using well-developed technology whose application was straightforward. The committee felt that such a system could have saved almost all of the coal miners who had died in recent years from carbon monoxide poisoning following explosions or fires. The interim system described in that report consisted of three subsystems: a survival subsystem using improved emergency breathing devices and refuge chambers, a communications subsystem using seismic or electromagnetic devices to locate and communicate with survivors, and a rescue subsystem using large- and small-hole drilling equipment and rescue teams. Some of the equipment recommended for the interim system was deemed applicable to survival and rescue of miners trapped by inundations or cave-ins. However the primary purpose of this system was to be rescuing survivors of fires or explosions.

Part II of the 1970 NAE report dealt with recommendations for a research and development program which could lead to an advanced survival and rescue system. The recommendations included acquisition of basic data relating to mine rescue and survival so that newer and state-of-the-art technology could be incorporated in the advanced system. Part II also contained several recommendations on needed R&D in survival, communication and rescue subsystems.

The 1970 NAE report became the basis of the USBM post-disaster survival and rescue program. The discussion and recommendations found in that report are, for the most part, still relevant today, although in some instances technology and operational capabilities have advanced to a point where modifications in that report's discussion of disaster response and management are warranted.

In 1979, the Bureau of Mines asked the National Academy of Sciences to review the accomplishments of its post-disaster survival and rescue program in the light of current technology and needs, and to recommend future research directions and ways of effectively implementing research results. In undertaking this task, the Committee on Underground Mine Disaster Survival and Rescue has examined not only the Bureau's program, but also the nation's experience with mine disasters since 1970 and the present capabilities and practices of mining companies and government agencies as they relate to disaster planning and emergency operations. Many of the committee's findings relate to organizational and planning matters

---

*See the "Scope of Work" statement in Contract No. S0190606 between the United States of America and the National Academy of Sciences, February 26, 1969

**"Mine Rescue and Survival," National Academy of Engineering, Washington, D.C., 1970 that are the responsibility of the mine operators and of the Mine Safety and Health Administration, rather than of the Bureau of Mines. While these are discussed in this report, the primary focus is on improvements that require research and development.

1.2 SCOPE OF THIS STUDY

In conducting this study, the Committee on Underground Mine Disaster Survival and Rescue has

- Reviewed all underground mine disasters that have occurred in this country since 1968 to identify kinds of equipment or procedures that could have saved lives had they been available. The committee has also reviewed the reports of investigations of these disasters to assess their value in guiding decisions concerning research, regulations, and mine operations.
- Evaluated the survival, rescue, and recovery procedures and equipment currently in use and under development to determine their potential for reducing the number of fatalities in mine disasters.
- Examined the research and development program carried out by the Bureau of Mines since 1970 in the post-disaster survival and rescue area.
- Made recommendations based on the above reviews.

The committee has not examined the economics of post-disaster survival and rescue in any detail. It did examine the budgets of the Bureau of Mines and MSHA post-disaster programs, but did not attempt to assess the adequacy of funding levels. The committee believes it would be useful for the Bureau of Mines and MSHA to contract for studies of cost-effectiveness of specific technological developments and operational procedures, but it did not attempt to carry out any such analyses. Nor did it attempt to analyze the economics of individual projects. It was more concerned with the overall pattern of post-disaster operations, related research, and implementation of research results, and the integration of these into a coherent and effective post-disaster survival and rescue system. Clearly, cost is an important criterion in such a system, but one that should be considered against a background of national policy and objectives concerning mine safety.

While the committee has, for the most part, directed its recommendations toward the Bureau of Mines, its feeling is that to be effective, post-disaster survival and rescue must be viewed as a system in which research, planning, management, training, and design and manufacture of equipment are all essential elements. Consequently, the report as a whole is addressed to the mine safety community--the Bureau of Mines, MSHA, NIOSH, the state mine inspection agencies, the mine operators, the unions, the equipment manufacturers, the research community, and the counterparts of all of these in other countries.

1.3 HAZARDS, ACCIDENTS, AND DISASTERS

Unless there is a common understanding of terms, there can be considerable confusion in transmitting information and knowledge.

This can be particularly vexing to the understanding of safety literature in which terms such as "injury" and "accident" are often (and mistakenly) used interchangeably, and the definitions of accidents and hazards adopted for classification purposes may not be adequate for interpretation and control.

The term "hazard" is used here to describe a dangerous situation in a mine. Perception of the hazard is essential because if the hazard is not perceived, no action can be taken. A "hazard source" is the background condition which, while not posing a danger in itself, may give rise to a hazard. An "accident" is the realization of a hazard. An accident of major proportions representing a substantial threat to human life may be said to have "disaster potential." If a large number of people are in fact killed, it is deemed a "disaster." For some time the Mine Safety and Health Administration defined as a "disaster" any accident resulting in the deaths of five or more miners. This definition no longer has official status, but is still used informally and will be used in this report.

To illustrate: The presence of methane in a mine is a hazard source. Concentrations of methane below 5% are not in themselves dangerous, but there must be continual alertness to the possibility of dangerous concentrations of methane, and awareness of the steps to be taken should the concentration reach dangerous levels. Certain actions are required at specified concentrations of methane. In the working face area, when the concentration exceeds 1% operations must cease and the ventilation system must be adjusted to lower the concentration; when the concentration exceeds 1.5% the miners must withdraw from the area.* When the concentration reaches 5% a hazard exists. If an ignition source is present a methane ignition can occur. This ignition is an accident that has disaster potential. The appropriate actions now are evacuation, first aid, etc. If the ignition develops into a methane explosion that claims a substantial number of lives, it is a disaster.

Many mine accidents that have "disaster potential" do not become disasters, either because the accident occurs at a time when no or few workers are in the mine, or because the response is effective and all the threatened miners are evacuated safely. For those involved in safety management and research, the distinction between accidents and disasters is not important, and the aim is to identify and control the hazard. However, disasters command tremendous attention, because of their infrequent occurrence and the extent of human suffering involved, even though the number of deaths from non-disaster accidents has been many times higher.

During the period 1970-79, 195 people died in underground mine disasters, while 1438 died in other accidents, as shown in Table 1.1.

Survival and rescue of miners following an accident depends upon (1) the state of the mine communication system, (2) the ability of the accident to propagate and lead to more serious events, (3) the extent of injuries from the physical violence associated with the accident (4) the threat to life due to toxicity of the mine atmosphere, (5) the

---

*30 CFR 75.308

Table 1.1 Number of underground mine fatalities resulting from disasters (defined as accidents in which five or more people died) and other accidents, 1970–1979. Disaster figures are in italics. (Data provided by the Mine Safety and Health Administration.)

Type of Mine		1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	TOTAL
Coal	*Disaster*	*38*[a]	-	*14*[b]	-	-	-	*26*[c]	*9*[d]	*5*[e]	-	*92*
	Other	166	133	108	99	90	99	81	82	72	115	1045
Metal	*Disaster*		-	*91*[f]		-	-	-	-	-	-	*91*
	Other	35	34	31	37	34	25	24	35	29	16	300
Non metal	*Disaster*	-	*7*[g]		-	-	-	-	-	-	*5*[h]	*12*
	Other	10	5	5	6	9	3	9	3	7	8	65
Stone	*Disaster*		-		-	-	-	-	-	-	-	-
	Other	1	6	2	3	4	3	2	2	3	2	28
TOTAL		250	185	251	145	137	130	142	131	116	146	1633

a Finley Coal Company explosion, Hyden, Kentucky, December 30, 1970

b Consolidation Coal Company fire, Blacksville, West Virginia, July 22, 1972 (9 deaths) and Itmann Coal Company explosion, Itmann, West Virginia, December 16, 1972 (5 deaths).

c Scotia Coal Company explosions, Oventork, Kentucky, March 9 and 11, 1976 (23 miners and 3 non-miners died)

d Kocher and Leon Coal Company inundation, Wilkes Barre, Pennsylvania, March 1, 1977

e Clinchfield Coal Company inundation, Duty, Virginia, April 4, 1978 (4 miners and 1 non-miner died)

f Sunshine Mine fire, Kellogg, Idaho, May 2, 1972

g Barnett Complex Fluorspar Mine hydrogen sulfide poisoning, Rosiclare, Illinois, April 12, 1971

h Belle Isle Salt Mine explosion, Belle Isle, Louisiana, June 8, 1979 difficulty in sustaining life due to inadequate oxygen, (6) the number of miners trapped in the mine, (7) the impaired accessibility to the entrapped miners due to damage to hoists, etc., and (8) the availability of evacuation, escape, survival, rescue and recovery equipment and procedures, and of workers trained in their use.

1.4 A MINE DISASTER SURVIVAL AND RESCUE SYSTEM

The four essential elements of an underground mine disaster survival and rescue system are illustrated schematically in Figure 1.1. The elements are: hazard identification, mine design, disaster response, and post-disaster audit.

Hazard Identification: The first element is a rigorous and continuous search to identify sources of hazards and to move towards designing mining systems that will eliminate or reduce the likelihood of hazards.

Mine design: The second element is the design of the mine itself to (1) eliminate as many hazards as possible; (2) reduce the chances of occurrence of hazards that cannot be eliminated; (3) localize the effects of accidents having disaster potential, and (4) enhance prospects for evacuation, escape, and survival in the event of a major accident.

Disaster response: Six stages of response may be called for when a hazard is realized. These are hazard control, evacuation, escape, survival, rescue, and recovery.

Hazard control refers to immediate action to eliminate the hazard or limit its scope--e.g., action to extinguish a fire. If successful, this may be all that is called for. If the hazard cannot be controlled, then personnel must move to a place of safety.

Evacuation refers to the orderly exit of people from the mine using predetermined escapeways and following a predetermined plan for exit.

Escape refers to safe exit by individual miners whose normal evacuation route is blocked. These miners may try a number of alternate routes but do finally manage to escape. In both evacuation and escape, miners may use an emergency breathing apparatus such as the "filter self-rescuer," a belt-worn device that, when in use, filters carbon monoxide out of the air the miner breathes.

For those who are unable to evacuate or escape, the issue becomes survival while waiting to be rescued. Some miners may be immobilized and some may be injured. The trapped miners may erect barricades to isolate themselves from life-threatening gases or may take shelter in refuge chambers where these are available. The survival period may last for many days. This may be a period of considerable physiological and psychological stress.

Rescue efforts are mounted from outside the mine, and are directed toward locating, communicating with, reaching, and removing the trapped miners. If the rescue effort proves too difficult, or takes too long, or if the atmosphere in the mine is too hostile or the miners' injuries too severe, some or all of the trapped miners may succumb. Rescue

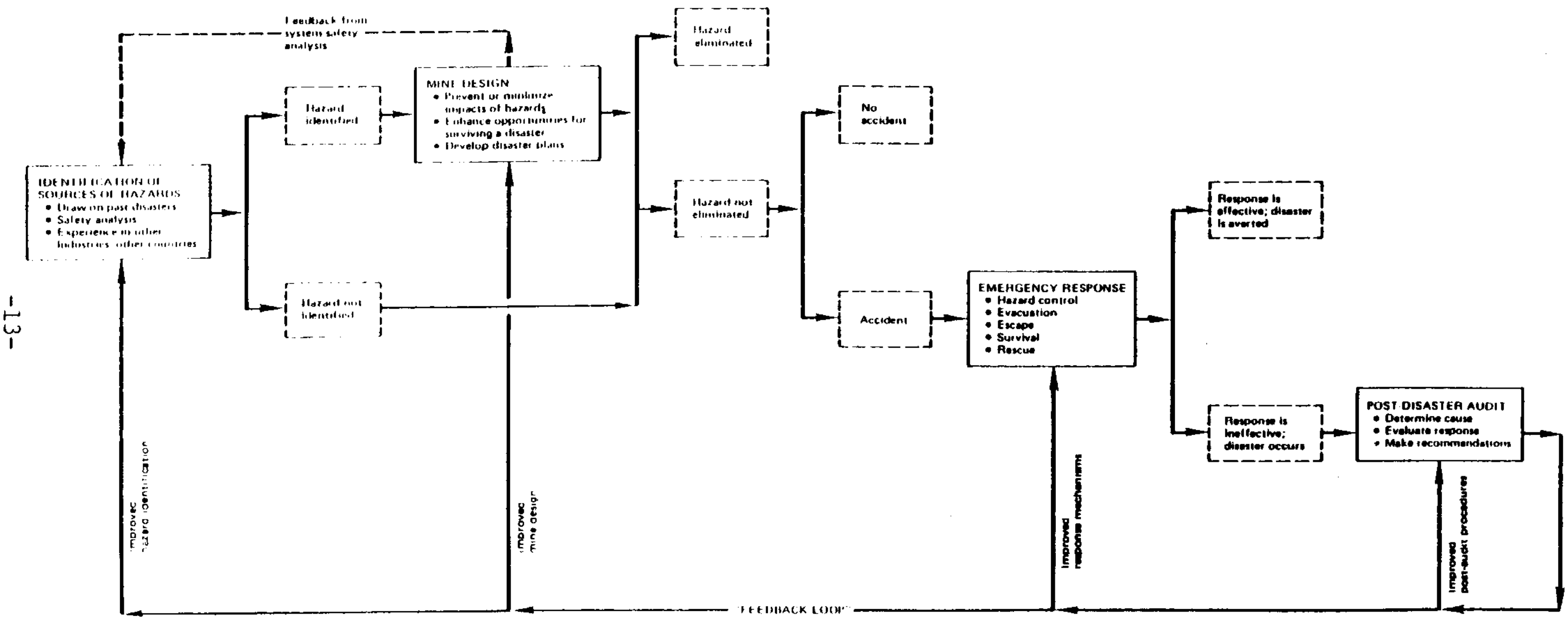

Figure 1.1 The elements of an underground mine disaster survival and rescue system.

efforts are continued to the point at which additional effort is deemed fruitless or likely to endanger the lives of the rescue personnel.

Recovery of the bodies of the victims and restoration of normal operations in the mine follow once conditions inside the mine permit this.

Post-disaster audit: A thorough post-disaster audit should determine the cause of the disaster, evaluate the functioning of the emergency procedures, and recommend, as needed, (1) development of new equipment, new approaches to mine design, and new emergency procedures and plans; (2) better training; and (3) changes in legislation, regulation, and enforcement. The findings of the audit must be made available to the affected mine and to all other mines, so that out of each disaster comes an increased awareness of the steps that can be taken to prevent future disasters or to respond to them effectively.

An effective survival and rescue system depends upon the development of technology and procedures for mine alarm, emergency communications, mobilization of personnel, emergency medical assistance, and surface organization to manage rescue operations, as well as the equipment and procedures needed for evacuation, escape, survival, rescue, and recovery.

1.5 THE UNDERGROUND MINING INDUSTRY

Mining is the process of extracting materials from the earth. Mining methods can be broadly classified as surface or underground, depending on whether the ore body is recovered from operations on the surface of the earth, or from operations in underground openings. In a sense, mining includes the removal of gas and oil from underground chambers and the recovery of subterranean water as well as the extraction of coal, mineral ores, and stone. This report is limited to the study of rescue and survival activities that are associated with underground mining of solid resources.

There is considerable variety in the physical structure of underground mines. Some are cavernous stone mines with roofs 25 to 50 feet high and huge portals capable of accommodating heavy motorized vehicles. Some are shallow mines in coal seams two or three feet high in which miners must crawl or "duckwalk." There are gassy and nongassy mines, mines with elevators and mines with ladders, mines with truck or rail transportation systems and mines with none. Some mines employ hundreds of underground workers and some employ fewer than five.

This report follows the usual practice of considering the mining industry as consisting of two distinct segments: (1) coal; and (2) metallic and non-metallic minerals and stone (usually abbreviated as "metal-nonmetal"). There are approximately 2,500 underground coal mines in the United States, accounting for roughly 40% of the nation's coal production, and approximately 500 underground metal mines, 100 underground non-metallic mineral mines, and 100 underground stone mines, which together account for 6% of the nation's ore production. All of the nation's more than 7,000 sand and gravel mines are surface operations, and they will not be considered.

Table 1.2 shows the total number of underground mines, the total number of miners, and the distribution of mines by number of employees for the coal, metallic, non-metallic and stone operations. In 1978, underground coal mining accounted for 81% of the total underground workforce in the mineral industry and for 79% of the total number of underground mines. Only 13% of the mines employed more than 100 miners, while 60% of the mines employed fewer than 20 miners.

Underground coal mines tend to be concentrated in Appalachia, Illinois, and western Kentucky. Metal and nonmetal mines are found throughout the country. The mine designs and mining methods differ, and appropriate post-disaster survival and rescue equipment and procedures must be uniquely determined for each operation.

1.6 THE ROLE OF GOVERNMENT

Initially, state governments regulated mining. The Bureau of Mines was established in the U.S. Department of the Interior in 1910, and was charged with conducting research in mining methods and mine safety but had no inspection or enforcement authority.* Inspection and enforcement were left to the states, and state laws reflected the nature and extent of mining in that state--such as deep or surface mining--and the type of ore mined (e.g., coal, metal, non-metal). Pennsylvania's regulations date back to 1869, and the Illinois law dates back to 1872.

Enactment of significant health and safety legislation at both the federal and state levels has closely followed major mine disasters

---

*The Bureau of Mines Organic Act, P.L. 179, May 16, 1910 (36 Stat. 369) states that the Bureau shall conduct

> "...diligent investigation of the methods of mining, especially in relation to the safety of miners, and the appliances best adapated to prevent accidents, the possible improvement of conditions under which mining operations are carried on, the treatment of ores and other mineral substances, the use of explosives and electricity, the prevention of accidents, and other inquiries and technologic investigations pertinent to said industries, and from time to time make such public reports of the work, investigations, and information obtained as the Secretary of said department may direct, with the recommendation of such bureau..." (Sec. 2)

and specifies that

> "...nothing in this Act shall be construed as in any way granting to any officer or employee of the Bureau of Mines any right or authority in connection with the inspection or supervision of mines or metallurgical plants in any State." (Sec. 5)

Table 1.2 Number of underground mines by type and employee size group in 1978[1]

Type of Mine	Total Number of Miners	Number of Mines Having Given Numbers of Employees									Total Number of Mines
		1-4	5-9	10-19	20-34	35-49	50-99	100-149	150-249	250+	
Coal	143,993	234	532	797	373	169	218	104	115	150	2,692
Metal	24,138	162	88	50	27	16	33	20	25	15	436
Non metal	7,314	27	19	26	15	6	9	8	10	6	126
Stone	2,410	25	31	47	22	7	6	0	1	0	139
TOTAL	177,855	448	670	920	437	198	266	132	151	171	3,393

[1] Data from:
"Injury Experience in Coal Mining, 1978." Mine Safety and Health Administration Informational Report IR 1112, 1979, p. 19.
"Injury Experience in Metallic Mineral Mining, 1978." Mine Safety and Health Administration Informational Report IR 1116, 1979, p. 13.
"Injury Experience in Nonmetallic Mineral Mining (Except Stone and Coal), 1978." Mine Safety and Health Administration Informational Report IR 1114, 1979, p. 13.
"Injury Experience in Stone Mining, 1978." Mine Safety and Health Administration Informational Report IR 1113, 1979, p. 13.

(see Table 1.3). However the federal government was, prior to 1969, extremely reluctant to intrude into the areas of mine health and safety and particularly the enforcement of standards, which was viewed as a state responsibility.

1.6.1 The Federal Role

Changes in the federal government's responsibility for mine safety have developed through the series of legislative actions shown in Table 1.3, culminating with passage of the Federal Metal and Non-metallic Mine Safety Act of 1966 (the 1966 Metal Mine Act), the Federal Coal Mine Health and Safety Act of 1969 (the 1969 Coal Mine Act), and the Federal Mine Safety and Health Amendments Act of 1977 (the 1977 Mine Safety and Health Act).

Although the 1966 Metal Mine Act* did not make specific reference to research, it did authorize the Secretary of the Interior to develop, revise as necessary, and promulgate health and safety standards for the purposes of protection of life, the promotion of health and safety, and the prevention of accidents in mines. The 1969 Coal Mine Act went much further. The purpose of that Act was

> (1) to establish interim mandatory health and safety standards and to direct the Secretary of Health, Education, and Welfare and the Secretary of the Interior to develop and promulgate improved mandatory health or safety standards to protect the health and safety of the Nation's coal miners; (2) to require that each operator of a coal mine and every miner in such mine comply with such standards; (3) to cooperate with, and provide assistance to, the States in the development and enforcement of effective State coal mine health and safety programs; and (4) to improve and expand, in cooperation with the States and the coal mining industry, research and development and training programs aimed at preventing coal mine accidents and occupationally caused diseases in the industry.*

Section 301(b) of Title III elaborated on the application of mandatory safety standards:

> The purpose of this title is to provide for the immediate application of mandatory safety standards developed on the basis of experience and advances in technology and to prevent newly created hazards resulting from new technology in coal mining. The Secretary (of the Interior) shall immediately initiate studies, investigations, and research to further upgrade such standards and to develop and promulgate new and improved standards promptly that will provide increased protection to the miners, particularly in connection with hazards

---

*Federal Metal and Nonmetallic Mine Safety Act, P.L. 89-577, 80 Stat. 772

**Federal Coal Mine Health and Safety Act of 1969, P.L. 91-173 (83 Stat. 742), Sec. 2(g)

Table 1.3 Development of Federal and State Mine Safety Laws in the United States.*

DATE	DISASTER	SIGNIFICANT STATE AND FEDERAL LEGISLATION	PROPOSALS FOR OR ENACTMENT OF OTHER LEGISLATION
1842			Pennsylvania Mine Safety Act PROPOSED
1865			Federal Bureau of Mines PROPOSED
14.3.1866			Schuylkill County, Pennsylvania (Anthracite) Mine Inspection Act PROPOSED
12.4.1869			Schuylkill County, Pennsylvania (Anthracite) Mine Inspection Act
6.9.1869	Avondale, Pennsylvania (108 killed)		
3.3.1870		Pennsylvania (Anthracite) Mine Inspection Act	
22.4.1870			Mercer County, Pennsylvania (Bituminous) Mine Inspection Act
27.3.1872			Illinois Mine Inspection Act
21.3.1874			Ohio Mine Inspection Act
18.4.1877		Pennsylvania (Bituminous) Mine Inspection Act	
11.3.1879			West Virginia Mine Inspection Act
10.5.1884			Kentucky Mine Inspection Act
25.2.1886			Federal Inspection of all mines where more than 10 men work--Wyoming Territory
3.3.1891			Federal Inspection of all Mines in Territories with greater than 1000 tons production--New Mexico, Oklahoma, and Utah
7.1907			Federal Inspection of mines in the Territories transferred to the U.S. Geological Survey
6.12.1907	Monongah, West Virginia (361 killed)		
19.12.1907	Darr, Pennsylvania (239 killed)		
5.1908		U.S. Geological Survey funded to investigate mine accidents and explosions	
28.11.1908	Marianna, Pennsylvania (154 killed)		
13.11.1909	Cherry, Illinois (259 killed)		
10.7.1910		U.S. Bureau of Mines established, no mine inspection rights	
13.3.1912			Virginia Mine Inspection Act
7.5.1941		PL 49: Federal Coal Mine Inspection Act	
24.7.1946		Federal Mine Safety Code	
25.3.1947	Centralia, Illinois (111 killed)		
4.8.1947		Mandatory compliance with the Federal Mine Safety Code for 12 months	
4.8.1947		PL 328: Survey of mines to determine compliance with the FMSC of 1946 (33% compliance found)	
21.12.1951	West Frankfort, Illinois (119 killed)		
16.7.1952		PL 552: Federal Coal Mine Safety Act	
1960			Senate Bill: S. 743 Eliminate Small Mines Exemption of PL 552 PROPOSED
26.3.1966		PL 376: Elimination of the small mines exemption of PL 552	
16.9.1966		PL 89-577 Federal Metal and Non-Metal Safety Act	
9.1968			Federal Coal Mine Health and Safety Act PROPOSED
20.11.1968	Farmington, West Virginia (78 killed)		
30.12.1969		PL 91-173: Federal Coal Mine Health and Safety Act of 1969	
9.11.1977		PL 95-164: Federal Mine Safety and Health Act of 1977	

*From "An International Review of Regulations for Diesel-Powered Equipment in Underground Mines" by G. W. Kenzy and R. V. Ramani, in Proceedings of the Second International Mine Ventilation Congress, Reno, Nevada, November 4-8, 1979, published by the Society of Mining Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineers, New York, 1980, pp. 175-190.

from trolley wires, trolley feeder wires, and signal wires, the splicing and use of trailing cables, and in connection with improvements in vulcanizing of electric conductors, improvement in roof control measures, methane drainage in advance of mining, improved methods of measuring methane and other explosive gases and oxygen concentrations, and the use of improved underground equipment and other sources of power for such equipment.*

Title V of the Act set important requirements for and authorized the appropriation of funding for health and safety research:

> The Secretary (of the Interior) and the Secretary of Health, Education, and Welfare, as appropriate, shall conduct such studies, research, experiments, and demonstrations as may be appropriate--(1) to improve working conditions and practices in coal mines, and to prevent accidents and occupational diseases originating in the coal-mining industry; (2) to develop new or improved methods of recovering persons in coal mines after an accident; (3) to develop new or improved means and methods of communication from the surface to the underground area of a coal mine; (4) to develop new or improved means and methods of reducing concentrations of respirable dust in the mine atmosphere of active workings of the coal mine; (5) to develop epidemiological information to (A) identify and define positive factors involved in occupational diseases of miners, (B) provide information on the incidence and prevalence of pneumoconiosis and other respiratory ailments of miners, and (C) improve mandatory health standards; (6) to develop techniques for the prevention and control of occupational diseases of miners, including tests for hypersusceptibility and early detection; (7) to evaluate the effect on bodily impairment and occupational disability of miners afflicted with an occupational disease;(8) to prepare and publish from time to time, reports on all significant aspects of occupational disease of miners as well as on the medical aspects of injuries, other than diseases, which are revealed by the research carried on pursuant to this subsection; (9) to study the relationship between coal mine environments and occupational diseases of miners; (10) to develop new and improved underground equipment and other sources of power for such equipment which will provide greater safety; and (11) for such other purposes as they deem necessary to carry out the purposes of this Act.
>
> (b) Activities under this section in the field of coal mine health shall be carried out by the Secretary of Health, Education, and Welfare, and activities under this section in the field of coal mine safety shall be carried out by the Secretary (of the Interior).**

---

*Op cit, Sec. 301(b)

**Op cit, Sec. 501(a,b)

While the 1969 Act applied only to coal mines, it was amended by the Mine Safety and Health Act of 1977* to include non-coal mines as well.

The 1966 and 1969 Acts represented a significant departure from tradition in that health and safety standards were to be enforced by an agency of the federal government. Enforcement of the 1966 Metal Mine Act and the 1969 Coal Mine Act originally rested with the Bureau of Mines in the Department of the Interior. In 1973, the enforcement of both of these laws was entrusted to a new agency, the Mine Enforcement and Safety Administration (MESA), created within the Department of the Interior. The 1977 Act established in the Department of Labor a Mine Safety and Health Administration (MSHA) to be headed by an Assistant Secretary of Labor for Mine Safety and Health, and transferred the enforcement responsiblity to this new agency. The 1969 and 1977 acts also gave certain responsibilities to the National Institute for Occupational Safety and Health (NIOSH) in the Department of Health, Education, and Welfare (now the Department of Health and Human Services).

The result is that today the federal government's responsibilities for mine safety and health are divided among three agencies: MSHA, the Bureau of Mines, and NIOSH. MSHA is responsible for issuing and enforcing mine safety and health regulations, for training miners, and for responding to mine emergencies. The Bureau of Mines is responsible for conducting research on mine safety and on technological means for reducing health hazards in mines. NIOSH is responsible for conducting research relating to miner health, and together with MSHA for testing and certifying devices used to detect hazardous materials in mines and protective equipment used by miners.

MSHA and the Bureau of Mines work cooperatively to identify areas in which research and development have the potential to contribute significantly to an improved survival and rescue capability. The Bureau has the major responsibility for conducting the R&D, while MSHA shares with the Bureau the responsibility for integrating R&D results into operational practice. MSHA implements R&D results either by incorporating them into its own operations or by rulemaking that requires new practices or equipment to be adopted by the mining industry.**

The Interagency Memoranda of Understanding clarifying the responsibilities of MSHA, the Bureau of Mines, and NIOSH are reproduced in Appendix I.

---

*Federal Mine Safety and Health Amendments Act of 1977, P.L. 95-164

**While there have been many instances in which the Bureau's R&D results have been adopted by the mining industry without rulemaking, these have generally occurred in areas other than post-disaster survival and rescue.

1.6.2. The Mine Safety and Health Administration: Regulations, Enforcement, Training, and Emergency Operations

The Mine Safety and Health Administration (MSHA) is responsible for promulgating and enforcing regulations to implement federal mine safety and health laws.* Regular mine inspections are conducted under the supervision of district managers (there are distinct organizational elements addressing coal and metal-nonmetal mines) to ensure compliance with regulations. The district managers are also the officials with primary responibility for responding to serious mine emergencies, assessing their nature, and determining the course of action to be followed. MSHA also maintains a training academy that provides health and safety related training to its employees and to mine personnel.

Sections 103(j) and 103(k) of Title II of the 1977 Mine Safety and Health Act provide that:

> j) In the event of any accident occurring in any coal or other mine, the operator shall notify the Secretary (of Labor) thereof and shall take appropriate measures to prevent the destruction of any evidence which would assist in investigating the cause or causes thereof. In the event of any accident occurring in a coal or other mine, where rescue and recovery work is necessary, the Secretary or an authorized representative of the Secretary shall take whatever action he deems appropriate to protect the life of any person, and he may, if he deems it appropriate, supervise and direct the rescue and recovery activities in such mine.
>
> (k) In the event of any accident occurring in a coal or other mine, an authorized representative of the Secretary (of Labor), when present, may issue such orders as he deems appropriate to insure the safety of any person in the coal or other mine, and the operator of such mine shall obtain the approval of such representative, in consultation with appropriate State representatives, when feasible, of any plan to recover any person in such a mine or to recover the coal or any other mine or return affected areas of such mine to normal.**

These provisions grant the MSHA representative broad authority to take whatever action is appropriate to protect lives. The MSHA representative's role in an emergency operation may be limited to support and advice, or it may extend to taking partial or total command of the rescue and recovery activities.

---

*In addition to mines, MSHA's responsibility includes all underground excavations, encompassing, for example, tunnels and caves.

**Federal Mine Safety and Health Amendments Act of 1977, P.L. 95-164, Title II, Sec. 103 (j,k)

Part 50 of the Code of Federal Regulations requires mine operators to immediately notify MSHA of accidents. As used in this regulation, "accident" means:

1. A death of an individual at a mine
2. An injury to an individual at a mine which has a reasonable potential to cause damage
3. An entrapment of an individual for more than 30 minutes
4. An unplanned inundation of a mine by a liquid or gas
5. An unplanned ignition or explosion of gas or dust
6. An unplanned mine fire not extinguished within 30 minutes of discovery
7. An unplanned ignition or explosion of a blasting agent or an explosive
8. An unplanned roof fall at or above the anchorage zone in active workings where roof bolts are in use; or, an unplanned roof or rib fall in active workings that impairs ventilation or impedes passage
9. A coal or rock outburst that causes withdrawal of miners or which disrupts regular mining activity for more than one hour
10. An unstable condition at an impoundment, refuse pile, or culm bank which requires emergency action in order to prevent failure, or which causes individuals to evacuate an area; or, failure of an impoundment, refuse pile, or culm bank
11. Damage to hoisting equipment in a shaft or slope which endangers an individual or which interferes with use of the equipment for more than 30 minutes
12. An event at a mine which causes death or bodily injury to an individual not at the mine at the time the event occurs.*

If such an accident occurs, the mine operator must immediately notify the MSHA district or subdistrict office having jurisdiction over the mine. If the operator cannot contact the appropriate MSHA district or subdistrict office, then MSHA headquarters in Arlington, Virginia, must be notified.

Accidents resulting in two or more deaths, fires that are not extinguished within 30 minutes, explosions, inundations, entrapments, and any other accidents requiring mine rescue and recovery procedures are immediately reported by the district or subdistrict manager to MSHA headquarters in Arlington, Virginia. The district or subdistrict manager is authorized to take whatever actions may be necessary to protect lives pending the receipt of instructions from Arlington.

MSHA's Mine Emergency Operations (MEO) facility maintains rescue and recovery equipment consisting of a rescue drilling rig, communications equipment, and supporting mine emergency services, personnel, and equipment (provided in large part through contracts with private firms and other governmental agencies) that are held in readiness for rapid mobilization. MEO supports on-site communications, logistics, gas sampling and analysis, and, where needed, seismic locating of trapped miners and exploratory and rescue drilling. During the past decade

*30 CFR 50.2(h)

there were no emergency escape holes drilled utilizing MEO's heavy drill rig. Small-diameter probe and test holes were drilled in several situations, using locally available drills.

Table 1.4 lists the 18 situations during the period 1970-1979 when MEO facilities were deployed, and in each case shows the elapsed time between occurrence of the accident, the MEO alert, the MEO deployment, and the arrival of the MEO team at the accident site. The time spans between the MEO alert and the order to deploy, and between deployment and arrival on site, have been quite variable, with the latter occasionally taking as long as 36 hours. It has sometimes been as long as 12 to 48 hours after MEO personnel arrive at the accident site before the seismic locating equipment is put into operation and drilling is begun if needed.

MEO is only one part of MSHA's response to an emergency. Other appropriate steps may be taken, such as establishment of a ventilation evaluation office at the mine, staffed with ventilation experts from the district office and MSHA's technical support personnel.

The MSHA rescue and recovery operation is conducted in coordination with any operations conducted by state officials and agencies. Representatives of the company and the mine workers are also given an opportunity to participate in and be informed of these operations, provided that this does not interfere with the rescue and recovery work.

MSHA also conducts investigations of accidents. The depth of the investigation and the detail of the investigation report are determined by the nature and severity of the accident. Unless granted permission by an MSHA district or subdistrict manager, no operator may alter an accident site or an accident-related area until completion of all investigations pertaining to the accident, except to the extent necessary to rescue or recover an individual, prevent or eliminate an imminent danger, or prevent destruction of mining equipment.

1.6.3 The Bureau of Mines: Mine Health and Safety Research

The legislative actions of 1969 and 1977 led to increased funding for the Bureau's health and safety research program and set several new objectives for Bureau research. Research and development activities were to be undertaken to reduce or eliminate hazards potentially injurious to the health or safety of miners and to provide a technological basis for industry compliance with existing health and safety regulations and for the development of new regulations.* Some of the Bureau's research is conducted in-house at its 10 research centers, but the major portion is conducted under contract by private organizations.

From 1970 to 1979, the Bureau spent approximately $326 million on health and safety research. Of this, post-disaster research has received $17.9 million (See Table 1.5). Other major areas of concern have been ground control ($71.6 million), industrial hazards ($69.7

*Five Year Plan, Bureau of Mines, U.S. Department of the Interior, February 1980.

Table 3-4 Situations in which MSHA's MEO facilities were deployed,[a] 1970-1979. (Data provided by MSHA)

Date of Incident	Location of Incident	Type of Incident	Time of Occurrence	MEO Alerted	MEO Deployed	MEO On-Site	MEO Secured	Nature of MEO Involvement
March 26, 1971	Nemacolin Mine Buckeye Coal Company Nemacolin, Pennsylvania	coal mine fire	March 26 10:20 a.m.	March 26 4:55 p.m.	March 26 5:11 p.m.	March 27 12:11 a.m.	April 6	Logistics, communications, drilling, seismic location
May 2, 1972	Sunshine Mine Sunshine Mining Company Kellogg, Idaho	silver mine fire	May 2 11:40 a.m.	May 3 11:30 a.m.	May 3 9:00 p.m.	May 4 12:30 a.m.	May 18	Logistics, communications, TV probe
July 22, 1972	Blacksville No. 1 Mine Consolidation Coal Company, Blacksville, West Virginia	coal mine fire	July 22 7:30 p.m.	July 23 10:30 a.m.	July 23 10:30 a.m.	July 23 6:30 p.m.	July 28	Logistics, communications, communications probe, seismic location, gas sampling
August 17, 1973	Lakeshore Mine Hecla Mine Company Casa Grande, Arizona	Copper mine fire	August 17	August 17 6:30 p.m.	August 18 2:00 p.m.	August 18 6:00 p.m.	August 26 9:00 a.m.	Logistics, communications probe, TV probe, drilling consultation
September 25, 1973	Oakwood Red Ash Mine Oakwood Red Ash Corporation Vansant, Virginia	coal mine fire	September 25 -	September 25 1:10 p.m.	September 25 6:00 p.m.	September 25 8:30 p.m.	September 26 8:50 a.m.	Transported rescue team
September 30, 1973	Pyro No. 2 Mine Pyro Mining Company Sturgis, Kentucky	coal mine fire	September 30 -	September 30 1:30 p.m.	September 30 5:30 p.m.	October 1 3:05 a.m.	October 3 2:00 p.m.	Logistics, communications probe, seismic location, gas analysis, drilling consultation
June 4, 1974	Mars Hill Mine Reynolds Metals Corporation Bauxite, Arkansas	Bauxite mine fire	June 4 -	June 4 10:50 a.m.	June 4 3:00 p.m.	June 5 3:30 p.m.	June 5 10:00 p.m.	communications support
March 9, 1976	Scotia Mine Scotia Mine Company Ovenfork, Kentucky	coal mine explosion	March 9 -	March 9 1:25 p.m.	March 9 6:00 p.m.	March 9 7:10 p.m.	March 10 12:00 p.m.	Transported rescue team
March 11, 1976	Scotia Mine Scotia Coal Company Ovenfork, Kentucky	coal mine explosion and fire	March 11	March 11 1:10 a.m.	March 11 2:00 a.m.	March 11 9:00 a.m.	March 15 1977 1:00 p.m.	Transported rescue team, communications, communications probe, TV probe, gas sampling
February 7, 1977	Kerlin No. 32 Mine Bethlehem Mines Corporation Ebensburg, Pennsylvania	coal mine fire	February 7	February 7 6:00 a.m.	February 7 8:00 a.m.	February 7 11:00 a.m.	February 28[b] 5:00 p.m.	Logistics, communications, drilling, gas sampling and analysis

March 1, 1977	Portal Tunnel Fochet and Leon Coal Company, Tower City, Pennsylvania	coal mine inundation	March 1	March 1 3:20 p.m.	March 2 12:05 p.m.	March 2 5:30 p.m.	March 19 1:00 p.m.	Logistics, communications, seismic probe, TV probe, drilling, rescue
April 10, 1977	Vesta No. 5 Mine Jones and Laughlin Steel Corporation California, Pennsylvania	coal mine fire	April 10	April 10 3:00 a.m.	April 10 6:00 a.m.	April 10 7:30 a.m.	April 14 6:00 p.m.	Logistics, communications, gas sampling and analysis
July 7, 1977	P&P Coal Company St. Charles, Virginia	coal mine entrapment	July 7	July 7 10:45 a.m.	July 7 12:00 p.m.	July 7 3:00 p.m.	July 8 8:30 a.m.	Airlift of MSHA personnel
September 21, 1977	Big Yank Abandoned Mine Shaft Baxter Springs, Kansas	abandoned mine possible entrapment	September 21	September 21 10:27 a.m.	September 21 11:32 a.m.	September 21 3:00 p.m.	September 22 5:00 p.m.	Communications, TV probe
October 15, 1977	Twigg Cave Cumberland, Md.	cave entrapment	October 15 4:45 p.m.	October 15 6:45 p.m.	October 15 8:45 p.m.	October 15 2:00 p.m.	October 16 2:00 p.m.	Logistics, communications, gas sampling
September 14, 1978	Oil Shale Mine Occidental Petroleum Corporation	oil shale mine fire	September 14	September 14 3:40 p.m.	September 14 4:00 p.m.	September 14 6:00 p.m.	September 17 8:00 p.m.	Communications, TV probe, temperature probe
November 11, 1978	Connors Hotel Joplin, Missouri	hotel collapse	November 11 10:00 a.m.	November 11 12:00 p.m.	November 11 3:00 p.m.	November 11 5:00 p.m.	November 17 5:00 p.m.	Seismic location
June 9, 1979	Belle Isle Salt Mine Cargill, Inc. Belle Isle, Louisiana	salt mine explosion	June 9	June 9 3:30 a.m.	June 9 6:00 a.m.	June 9 11:00 a.m.	June 23 6:00 p.m.	Transported rescue team, logistics, communications, gas sampling and analysis, airlifts.

* In addition to the 18 situations listed here, when MEO was deployed, there were 9 other occasions during this period when MEO was alerted but not deployed.

[1] MEO remained involved for more than a year until March 17, 1978, primarily in communications and gas sampling.

Table 1.5 Funding history of Bureau of Mines post-disaster research programs, 1970-1979. (Amounts in millions of dollars; discrepancies in the "total" column result from numerical round-off).

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	TOTAL
Bureau of Mines, total	61.4	91.4	125.9	82.5	75.3	109.6	134.9	92.8	98.2	121.1	993.1
Health and Safety, total	12.1	9.5	33.1	31.4	31.4	32.1	34.7	35.1	51.0	55.6	326.0
Coal	*12.1*	*9.5*	*30.2*	*28.1*	*27.4*	*27.5*	*29.0*	*29.2*	*41.7*	*45.0*	*280.0*
Metal and Non-Metal	[illegible]	*0*	*2.9*	*3.0*	*4.0*	*4.6*	*5.7*	*5.9*	*9.3*	*10.6*	*46.0*
Post Disaster Survival and Rescue, total	3.6	0.1	2.2	1.3	1.1	1.7	1.6	1.6	2.2	1.5	17.9
Coal	*3.6*	*0.1*	*2.0*	*1.2*	*1.0*	*1.4*	*1.4*	*1.6*	*2.2*	*1.5*	*17.0*
Metal and Non-Metal	*0*	[illegible]	*0.2*	*0.1*	*0.1*	*0.2*	*0.2*	*0*	*0*	*0*	*0.9*

million), fires and explosions ($42.4 million), respirable dust ($28.9 million), methane control ($23.1 million), industrial hygiene ($16.3 million), noise ($9.5 million), radiation hazards ($8.5 million), ventilation ($2.4 million), and explosives ($2.4 million).

In each of these areas there is a joint MSHA-Bureau of Mines research review committee. These committees serve to guide the Bureau's research priorities and research funding decisions, and help to ensure that these decisions incorporate MSHA's assessments of the research and development activities it needs in order to fulfill its regulatory and enforcement role.

The Bureau's post-disaster research program is discussed in detail in Chapter 3.

1.6.4 NIOSH and State Agencies

The National Institute for Occupational Safety and Health (NIOSH) and the mine inspection agencies of the various states also have roles relating to post-disaster survival and rescue.

NIOSH conducts research relating to the occupational health of miners. Its research draws upon expertise in medicine, epidemiology, toxicology, and industrial hygiene, as well as engineering, physical science, and other health fields. NIOSH does not have a direct role in survival and rescue operations, but is involved, with MSHA, in approval of equipment that may be used in those operations.

NIOSH also provides MSHA with technical information concerning toxic materials and harmful physical agents in mines and works with MSHA in developing regulatory standards for such materials. It provides assistance to MSHA in field investigations and training. NIOSH and MSHA are jointly responsible for testing and certifying devices for measuring harmful physical agents in mines and for testing and certifying personal protective equipment. NIOSH is responsible for certifying that such devices perform as required, MSHA for certifying that they are intrinsically safe. NIOSH also conducts research on worker fatigue in relation to design features of breathing apparatus.

NIOSH plays a public health role in addition to its research role. Its activities in mining include health hazard evaluations, general mining surveillance as mandated by law, and medical surveillance including coal miner x-ray and autopsy programs. When appropriate, NIOSH performs or assists in performing autopsies on miners killed in accidents and disasters.

Many states in which mining is significant have mine inspection agencies, whose budgets reflect the extent and nature of the mining industry in that state. Some states also maintain rescue and recovery equipment and personnel that can be mobilized to respond to a disaster. The states do not generally provide funds for mine disaster survival and rescue research.

State officials are likely to be among the first on the scene of a disaster, and their technical expertise and knowledge of local conditions are of great value.

CHAPTER 2. UNDERGROUND MINE DISASTERS OF THE PAST DECADE

During the decade from 1970 through 1979 nine underground mine disasters occurred in the United States (See Table 2.1.) Six were in coal mines and three were in metal and non-metal mines. Four were caused by explosions,* two by fires, and two by inundations; one involved poisoning by hydrogen sulfide gas. A total of 195 lives were lost in these disasters. During the same period, 1438 lives were lost in lesser accidents in underground mines.

Investigative reports on two of the decade's disasters, Scotia and Porter Tunnel, have not yet been publicly released because of pending litigation. Reports of the investigations into the other seven disasters were examined by the committee to identify aspects of disaster management that have been affected by the Bureau of Mines post-disaster research program or that could be addressed by that program. The committee sought to determine which survival and rescue procedures have been particularly effective and which have presented problems. The committee also sought to determine what the potential lifesaving impact might have been of techniques and equipment that were not available at the time but that are available today. In addition to these disasters, the committee looked into 56 accidents--47 in coal mines and 9 in metal and non-metal mines--that had disaster potential and were thus relevant to its examination of post-disaster survival and rescue.

In this chapter coal mine disasters and metal-nonmetal mine disasters are discussed separately. Although it might appear more logical to group disasters by cause (e.g., fire, explosion, inundation) than by commodity, there are significant differences between coal and metal and nonmetal mines. These differences are reflected in the organization of the mining industry and the federal agency responsible for mine safety and health, and also in the relevant federal laws and regulations, which treat coal and metal-nonmetal mines differently.

---

*The Scotia disaster involved two separate explosions two days apart.

Table 2.1 Underground mine disasters in the United States, 1970-1979. (Information provided by the Mine Safety and Health Administration)

	Date	Location	Kind of Mine	Kind of Disaster	Number of Miners Underground	Number Killed	Number Injured
COAL:	December 30, 1970	Nos. 15 and 16 Mines Finley Coal Company Hyden, Kentucky	Coal	Explosion	39	38	1
	July 22, 1972	Blacksville No. 1 Mine Consolidation Coal Company Blacksville, West Virginia	Coal	Fire	43	9	0
	December 16, 1972	Itmann No. 3 Mine Itmann Coal Company Itmann, West Virginia	Coal	Explosion	121	5	3
	March 9 and 11, 1976	Scotia Mine Scotia Coal Company Ovenfork, Kentucky	Coal	Explosions	*	26	*
	March 1, 1977	Porter Tunnel Kocher and Leon Coal Company Wilkes Barre, Pennsylvania	Coal	Inundation of water	19	9	*
	April 4, 1978	Moss No. 3 Portal A Mine Clinchfield Coal Company Duty, Virginia	Coal	Inundation of blackdamp	4	5**	2
METAL AND NONMETAL:	April 12, 1971	Barnett Complex Mine Ozark Mahoning Company Rosiclare, Illinois	Fluorspar-lead-zinc	Hydrogen sulfide poisoning	22	7	0
	May 2, 1972	Sunshine Mine Sunshine Mining Company Kellogg, Idaho	Silver	Fire	172	91	0
	June 8, 1979	Belle Isle Salt Mine Cargill, Inc. St. Mary Parish, Louisiana	Salt	Explosion	22	5	*

*Information not available to the committee.

**The 5 victims included 2 of the 4 miners working underground and 3 of the 10 personnel on the surface who participated in rescue attempts.

2.1 DISASTER INVESTIGATION REPORTS

Disaster investigation reports can help determine legal liability and can provide information that will help avoid future disasters through enactment of new laws and regulations, changes in inspection or enforcement procedures, modifications in equipment design, development of new training procedures, institution of improved emergency plans, and conduct of new research.

Prior to May 1973, all mine disasters were investigated by the Bureau of Mines. The Bureau's reports had a reputation for being complete and comprehensive, and were often published as Information Circulars and widely circulated.

When MESA was created in 1973, all mine safety inspection and investigation responsibilities were transferred to that agency. With that change, greater emphasis was placed on findings related to noncompliance with federal health and safety regulations. This new emphasis continued when, after enactment of the Federal Mine Safety and Health Amendments Act of 1977, responsibility for disaster investigation reports passed to the newly created MSHA in the Department of Labor. This appears to be associated with a growing tendency toward litigation after disasters, and a concern within mining companies, unions, and government agencies about the possible legal implications of statements made during disaster investigations. One consequence is that reports are often delayed for legal review, and important findings that could be applied in other mines are not as quickly and widely available as they should be.

2.2 COAL MINE DISASTERS

The number of coal mining disasters and associated fatalities decreased from 13 disasters with 239 victims during 1960-1969 to 7 disasters with 92 victims during 1970-1979. This extended a trend that had begun some years prior to 1960. Similar favorable trends were noted in the number of accidents having disaster potential. Much of this progress may be attributed to

- Improvements in mine design
- Improved escapeways and other mine egress facilities
- Improved disaster prevention techniques and equipment
- Improved training programs for miners
- Better mine emergency plans and evacuation drill programs
- More effective coordination between mine operators and miners' safety committees
- Improved mine rescue apparatus
- Better geographical distribution of trained mine rescue teams

These improvements notwithstanding, the committee's review indicates that further efforts are needed, both in disaster prevention and disaster response.

Brief descriptions of the decade's disasters, drawn from the official investigation reports, follow.

Finley Coal Company Explosion (Hyden, Kentucky; December 30, 1970):

A coal dust explosion was caused by improper use of explosives, and exacerbated by inadequate application of rock dust. Thirty-nine miners were in the mine. Thirty-three were killed instantly; five who appeared to have moved a short distance after the explosion presumably died of asphyxiation or carbon monoxide poisoning.

Mine employees did not carry self-rescuers, although filter self-rescuers were available and stored in set locations. It is unlikely that the miners who survived the explosion could have donned self-rescuers in time to save their lives had they been on their persons, or if oxygen self-rescuers would have been effective had they been available.

Consolidation Coal Company Fire (Blacksville, West Virginia; July 22, 1972):

The fire broke out during a Saturday operation that was not for production but was for the purpose of relocating equipment within the mine. The fire apparently was caused by an electrical short circuit when a continuous mining machine being hauled along a track contacted the energized trolley wires. Forty-three miners were in the mine at the time. Thirty-four evacuated safely. Nine miners were trapped in the mine and ultimately died. They were wearing filter self-rescuers when overcome. Delay in communicating with these miners and evacuating them proved critical. More timely evacuation would probably have enabled them to survive. Delay nothwithstanding, availability of oxygen self-rescuers would probably have enabled them to make their way out of the mine.

Itmann Coal Company Explosion (Itmann, West Virginia; December 15, 1972):

Methane was ignited by an electric arc that occurred when the trolley pole of a portal bus lost contact with the trolley wire. The explosion occurred during a regular change of shifts on a scheduled production day. Five miners were killed outright and three severely burned miners were rescued by a mine rescue team.

Scotia Coal Company Explosions (Ovenfork, Kentucky; March 9 and 11, 1976):

Two methane explosions, two days apart, claimed a total of 26 victims. No official report on this disaster has yet been released because of pending litigation.

Seven of the 15 victims of the first explosion survived the initial explosion. It was found during the recovery operation that they had started to evacuate, donned filter self-rescuers, and then decided to return to the working place and barricade, where they ultimately died. The 11 victims of the second explosion were killed instantly. Two survivors donned filter self-rescuers and guided themselves out of the mine by following a telephone cable.

Porter Tunnel, Kocher and Leon Coal Company Water Inundation (Wilkes-Barre, Pennsylvania; March 1, 1977):

This was an inundation of water from earlier abandoned workings. Nine miners were killed instantly. Eight miners escaped unaided, one was carried out, and one was rescued by search parties the next day. No official report has yet been released because of pending litigation.

Clinchfield Coal Company Blackdamp Inundation (Duty, Virginia; April 4, 1978):

An entry being advanced by a continuous mining machine cut into a mined-out and abandoned area of the same mine, and was inundated by a rapid inrush of blackdamp (air deficient in oxygen and high in carbon dioxide). Five miners died and four escaped by their own efforts or with the aid of others. The five victims all lacked life-support equipment. Two of them might have survived had they withdrawn immediately; the other three died while attempting to rescue the affected miners without appropriate equipment.

In its review the committee also examined a number of accidents that had disaster potential. The committee concentrated on ignitions and mine fires inasmuch as the great majority of recent coal mining disasters have stemmed from such incidents. The committee did not confine its study to domestic occurrences. It also reviewed disaster reports and follow-up studies of several foreign mine fires and explosions. These studies confirmed the conclusions drawn from the review of domestic disasters, listed below.

Conclusions

Review of coal mine disasters of the past decade suggests that the most significant gains in post-disaster survival and rescue would result from

- Providing miners with an oxygen-supplying escape breathing apparatus ("oxygen self-rescuer") to be carried on their persons. Such a device would be for the purpose of keeping miners alive while they escape through regions of oxygen-deficient or toxic atmosphere. It would not need to support the level of respiration needed for rescue work. Nor would it need to be as rugged as a rescue apparatus.

- More effective training of miners in the immediate actions to be taken when a fire or other emergency is detected or suspected.
- More effective training of managers, supervisors, and dispachers in the development and implementation of disaster plans, so that in the event of an emergency proper instructions are given in timely fashion and are promptly and properly carried out.

There has also been some indication* that rescue teams could work more effectively in conditions of high temperature and humidity if they were provided with liquid-oxygen rescue breathing apparatus. This is of particular importance in deep, hot, humid mines such as are found in the western United States.

Two of the decade's disasters, the Blacksville fire and the Clinchfield inundation, occurred during periods of irregular operation rather than during regular production shifts. Experience in other industries suggests that often weekends and other non-regular periods are times when the usual chain of top management personnel are not on duty, and when subordinates may hesitate to make prompt decisions that are likely to cause major disruptions in the mine. The committee could not determine whether this has been a problem in mines. If it has, management should take steps to ensure that appropriate decisions are made quickly if an emergency arises at such a time.

Other measures that might have considerable impact include: improvements in mine design to permit rapid isolation of areas affected by fire; improvements in mine communication systems for emergency use; prompt dissemination, throughout the industry, of investigative reports of disasters and accidents having disaster potential; emphasis in disaster reports on technological and operational remedies in addition to the present emphasis on noncompliance with regulations; and better understanding of human reactions and behavior in emergency situations as a basis for more realistic disaster plans and disaster training.

2.3 METAL AND NON-METAL MINE DISASTERS

There were three disasters in metal and non-metal mines during the 1970-1979 decade (see Table 2.2). The Sunshine Mine fire in 1972, with 91 fatalities, caused the industry and government agencies to reexamine all elements of mine rescue and disaster response. Even as enhanced disaster prevention and rescue capabilities were put in place, the industry continued to experience serious accidents that could have resulted in greater loss of life than was actually experienced.

During the decade there were three fatal fires in underground metal and non-metal mines. In addition to the 1972 Sunshine Mine fire, fires at the Star Mine in 1971 and the Lakeshore Mine in 1973 claimed two lives each. There were also two methane explosions that resulted in fatalities. Both were in salt mines. The Sterling Shaft explosion in 1975 took four lives. The Belle Isle explosion in 1979

---

*See "Recovery; Somerset Mine," U.S. Steel Corporation, Western District-Coal, undated.

Table 2.2 Disasters and potential disasters in underground metal and non-metal mines, 1970-1979. (Information drawn from MSHA reports.)

Location	Kind of Mine	Date	Incident	Number of workers who were Exposed	Evacuated	Trapped	Rescued	Killed	Injured
Disasters									
Barnett Complex Rosiclare, Illinois	Fluorspar-lead-zinc	April 12, 1971	Gas Inundation	22	15	-	-	7	-
Sunshine Mine Kellogg, Idaho	Silver	May 2, 1972	Fire	172	79	93	2	91	-
Belle Isle Mine Belle Isle, Louisiana	Salt	June 8, 1979	Methane explosion	22	-	17	17	5	*
Potential Disasters									
Star Mine Burke, Idaho	Lead-zinc-silver	January 20, 1971	Fire	*	*	2	-	2	-
Lakeshore Mine Casa Grande, Arizona	Copper	August 17, 1973	Entrapment and fire	112	110	2	-	2	-
Mars Hill Mine Bauxite, Arkansas	Bauxite	June 3, 1974	Material run	44	42	1	1	1	1
Sterling Shaft Retsof, New York	Salt	April 18-19, 1975	Gas explosion	13	*	-	-	4	4
Homestake Mine Lead, South Dakota	Gold	May 9, 1975	Fire	610	610	-	-	-	-
American Tunnel Silverton, Colorado	Base metals	June 4, 1978	Inundation of water and mud	-	-	-	-	-	-
Crescent Mine Kellog, Idaho	Silver	June 28, 1978	Fire	35	35	-	-	-	-
Logan Wash Debeque, Colorado	Oil shale	September 12, 1978	Fire	*	*	-	-	-	-
Long Dave Lode Lockwood Valley, California	*	November 2, 1979	Entrapment by material run	3	-	3	3	-	-
TOTAL				1033+	891+	118	23	112	5+

*Not discernable from official report.

resulted in five deaths. A hydrogen sulfide gas invasion at the Barnett Complex mine in 1971 took seven lives.

The Belle Isle explosion and the Star, Sunshine, and Lakeshore fires all resulted in entrapment of miners. In the Belle Isle disaster, the 17 trapped miners were successfully rescued. In the Sunshine fire, only two of the 93 trapped miners were rescued, and in both the Star and Lakeshore fires, the trapped miners, two in each case, perished. The Lakeshore fire was also characterized by materials entrapment. There were two other incidents of entrapment by materials: Mars Hill in 1974 and Long Dave Lode in 1979, in which one and three miners respectively were trapped; all were rescued.

Fires at the Homestake Mine in 1975 and at the Crescent and Logan Wash Mines in 1978 had disaster potential but did not result in entrapment, injury, or death, either because no miners were in the affected area or because all were evacuated safely. The same is true of the inundation of water and mud at the American Tunnel Mine in 1978.

The three disasters of the decade (Barnett Complex, Sunshine, and Belle Isle) involved about 216 of the industry's approximately 36,000 employed personnel; 103 of these were killed. In two of these disasters, all miners underground were involved in life-threatening circumstances. The nine potential disasters that the committee looked into involved more than 1,000 additional underground employees in possible life-threatening circumstances, and resulted in nine deaths. Seven of these incidents affected the total mine area and required evacuation of all underground personnel. (See Table 2.2.)

Underground fires, liberation of toxic formation gases, and inundation continue to be major causes of metal and non-metal mine disasters and potential disasters. Frequently these occurrences are associated with a non-routine activity, which complicates control of the situation and makes evacuation and rescue difficult.

Although it is evident that new practices developed over the decade are contributing to an improved emergency response, shortcomings are still present, as discussed below.

Fires

In addition to the three fires that resulted in loss of life to miners, there were 105 other reportable fires (i.e., fires of more than 30 minutes duration) during the decade. Most of these fires were handled with pre-planned procedures providing for prompt evacuation of personnel from the mine followed by appropriate fire fighting actions.

A normally small fire, compounded by other unusual circumstances, can rapidly grow to disaster dimensions. The Sunshine Mine fire in 1972 is a case in point. A small fire in the exhaust airway of the mine complex breached the separating bulkheads to contaminate the fresh air intake. The fire increased in intensity more rapidly, spread more quickly, and produced more toxic gas than is considered normal for underground mine fires. Knowledge of mine fire chemistry was not sufficiently understood at that time to have predicted the concentrations of combustion products that did in fact occur. Moreover, a systematic study of the Sunshine Mine design would have revealed that rescue efforts in response to a fire of this nature would be difficult.

An underground mine fire at the Star Mine in 1971, resulting in two deaths, was also unusual in that the fuel was a new product made of chemical resin-based materials. Two employees accidently ignited a fiberglass ventilation duct pipe. The combination of resin-based fuels and moving air in the duct created a chemical fire with dense and toxic combustion products. Both workers were overcome while attempting to retreat from the fire location. Neither of the two exposed employees had filter self-rescuers. The follow-up investigation did not determine whether protection from the fumes and smoke would have been possible had filter self-rescuers been available. This accident resulted from the use of a new product in mine operations without fully testing it for combustion qualities. The product is now manufactured with a flame retardant to prevent a reoccurrence of the Star Mine fire.

A large variety of diesel-powered loaders, transporters, concrete pumps, and other machinery is used in modern mining, and several mine fires have involved this mobile diesel-powered equipment. Of these, only the Lakeshore Mine fire in 1973 resulted in fatalities. In this unusual circumstance, a large diesel loader was covered by drill cuttings flowing uncontrolled out of a large diameter borehole. The sudden slide of drill cuttings trapped two miners in a dead-end tunnel and covered the loader with its motor running. The buried loader overheated and started burning. If not for the fire, the trapped personnel probably would have been freed.

Many of the 108 metal and non-metal mine fires resulted in orderly evacuation of mine personnel without incident or injury. The use of the filter self-rescuer in these evacuations is not always detailed in the reports of these incidents. However, enough cases describe the use of the filter self-rescuer to demonstrate its value while evacuating through smoke-contaminated mine entries.

Entrapment

Entrapment of personnel, either by toxic smoke or by material runs that blocked exits, characterized six accidents in which a total of 118 people were trapped or prevented from making a normal exit from the mine. Ninety-three of these were the 91 victims and two survivors of the Sunshine Mine fire. Including the latter two, 23 people were rescued from entrapment by mine rescue personnel. Both the Belle Isle Mine and Sunshine Mine evacuations were complicated by inoperative shaft facilities, in the first case due to damaged equipment and in the latter due to the operator of an underground hoist being overcome by the fire combustion products. These rescue efforts are notable for the organization and achievement by mine rescue personnel under difficult and unfamiliar conditions.

Methane explosions

Methane ignitions and explosions in non-metallic mines resulted in nine deaths during the decade. The Sterling Shaft explosion in 1975 involved ignition of gas in an abandoned salt mine shaft which was being backfilled. The explosion resulted in the deaths of three miners at the shaft collar, with another missing, having probably fallen down the shaft. This is an example of a non-routine activity resulting in a disaster.

The Belle Isle Mine methane explosion and high pressure gas blowout in 1979 illustrates how the normal evacuation of personnel not directly involved in the explosion can be hampered by damaged man-hoisting facilities.

Disaster Response and Rescue Operations

Metal and non-metal mine disasters and rescue operations differ from those in coal mines primarily in the wide variety of situations the metal and non-metal rescue team is confronted with. Nearly all the disaster situations differ in mine design and operating methods. The shaft access is about the only facility common to most metal and non-metal mines.

Metal and non-metal mines of all sizes have been involved in disaster recovery and rescue operations. More than half of the decade's disasters and potential disasters involved the exposure of fewer than 50 people working underground at the time of occurrence. The other half of the incidents occurred in large metal mines. Disasters do not usually directly involve the total mine complex of the larger mines; the Sunshine Mine fire was an exception. Usually all personnel except those directly affected by the disaster are evacuated successfully. This has been particularly true in recent years following implementation of new safety standards for evacuation and emergency exit provisions.

Entrapment or isolation from fresh air exits is an important concern in metal and non-metal mine disasters. During the past decade twenty-seven miners, not including the victims of the Sunshine Mine fire, have been trapped. All but five were rescued through the efforts of mine rescue teams. The two survivors of the Sunshine Mine fire had been trapped in a branch of the fresh air ventilation circuit that had not been invaded by contamined air, with no exit except through an unlined 48-inch diameter vertical borehole. They were rescued through the efforts of Bureau of Mines personnel supported by various other government agencies.

Prior to the present practice of having trained mine rescue personnel readily available at the mine site, a number of rescue operations were frustrated by late arrival of mine rescue personnel. Some of the seven lives lost in the 1971 Barnett Complex disaster might have been saved if mine rescue teams and support equipment had been available on a timely basis. Recent experience indicates that to a large extent, mining companies have established mine rescue teams capable of responding on short notice.

Most deep metal and non-metal mines are accessed through a hoisting facility which is often the rock hoist and material and man-hoist combined. A major concern in most metal and non-metal mine disasters is whether or not the vertical shaft entrance is affected or damaged. At the very least, the shaft presents a difficult path for mine rescue teams striving to gain access to deep mine levels. Seventeen miners were rescued after the Belle Isle explosion in 1979 by heroic efforts of mine rescue personnel who entered the mine through a damaged hoist facility.

No safe and expedient method of entering a damaged shaft has been developed. In deep mines, drilled boreholes are not reasonable alternatives to a damaged shaft.

Other Aspects of Survival and Rescue

Many metal mines are vertically oriented and are relatively deep, compared to horizontally oriented, relatively shallow coal mines. For these reasons, presently available trapped-miner location devices and borehole-drilling rescue techniques have not been used in metal mine rescue operations.

Filter self-rescuers have been used in evacuation of personnel through smoke in mine fires since the Sunshine Mine fire in 1972. Except in the case of a fuel-rich fire or other chemical-fueled fire, where large quantities of combustion products are produced, the filter self-rescuer appears to have provided adequate protection to personnel traveling through smoke. Several large diesel loaders have caught fire, but either have been allowed to burn out or were so situated that workers and fire fighters were not in the heavy smoke produced by the fire. With the wider use of chemically formulated materials and diesel equipment with rubber tires, the potential for fires consuming diesel fuel, rubber, and other materials and producing dense smoke and high concentrations of carbon monoxide and other toxic combustion products will increase. The filter self-rescuer, which only protects against carbon monoxide, is probably not adequate in such an atmosphere of smoke and chemical combustion products.

Rescue operations in the Sunshine Mine fire and at the Lakeshore Mine demonstrated the extreme difficulty facing a mine rescue team in advancing their fresh air base in deep, hot underground mines. Single-heading advance of the fresh air base is difficult and requires considerable ingenuity by the mine rescue team. If the mine is hot, the work involved in building bulkheads is extremely fatiguing and time consuming.

Conclusions

Greatest loss of life in underground metal and non-metal mine disasters has been associated with those instances in which the fire or explosion affects all or most of the underground mine complex. This further complicates rescue and recovery operations and adds to the time required for mine rescue teams to reach and help survivors.

In many cases, a systematic evaluation of mine design for hazards could have revealed the possibility of a disaster. Appropriate preventive measures might then have been taken, and appropriate disaster response plans provided. Such plans, carefully developed and installed, and supported by proper training, would substantially enhance the survival prospects of miners. Existing technology can provide a great deal of support to these plans.

Oxygen self-rescuers, or even filter self-rescuers had they been available and used, might have saved some of the Sunshine fire victims. With the increasing likelihood of toxic combustion products in mine fires, oxygen self-rescuers will assume greater importance in disaster survival. Because of the variety of mine conditions, an evaluation of each mine may be necessary to determine whether oxygen self-rescuers should be carried on the miners' persons or whether they can be cached.

The present capability of mine rescue teams for advancing quickly in the mine and for working in hot environments has not been adequate to assure timely rescue.

Improved emergency communications are vital to efficient evacuation and rescue operations. Operating communications have often been destroyed or damaged extensively in major fires or explosions, and emergency systems that can withstand such events are needed.

Thorough training and continued practice in disaster response procedures would enhance the miner's capability for proper use of emergency procedures and equipment.

Seismic techniques for locating trapped miners, rescue drilling capabilities, and refuge chambers have made little or no contribution to the rescue of survivors of underground metal and non-metal mine disasters.

There is evidence to suggest that non-routine activities, especially on weekends, are times of high vulnerability to disaster. Better preparation for the eventuality of disaster in such circumstances could result in saving lives.

In the committee's judgment, the improvements that would have been most effective in saving lives in the past decade's underground metal and non-metal mine disasters are

- An oxygen-supplying escape breathing device ("oxygen self-rescuer") available to all miners.
- More thorough training of miners in emergency response procedures.
- Improved capabilities for rescue teams working in deep, hot mines.
- Improved communications systems for use in emergency and rescue operations.

Other improvements having very limited potential for saving lives are

- Refuge chambers suitable for use in metal and non-metal mines.
- Procedures for locating trapped miners in deep mines.
- A rescue drilling capability for deep mines.

2.4 RECOMMENDATIONS

On the basis of a review of the decade's disasters--both in coal and in metal and non-metal mines--the committee believes that the single piece of equipment most likely to reduce loss of life in mine disasters is the oxygen self-rescuer. The next most effective means of reducing the number of fatalities is better training to prepare miners to take appropriate action when a fire or other emergency occurs. Better planning for emergencies is needed to make such training effective. Improved capabilities for rescue work in deep or hot mines is needed to expedite rescue operations in such environments.

A careful and systematic assessment of the risks involved in non-routine activities should be undertaken. All such activities should be backed up with well-defined disaster response procedures. All personnel involved in the activity should be familiar with and trained in evacuation and disaster response procedures.

Present reporting and investigating procedures should be examined to see if they serve their purpose adequately or whether an alternative approach--such as investigation by an independent body analogous to the National Transportation Safety Board--would be more effective. The problems associated with self-incrimination should be addressed, as it is of critical importance to be able to conduct a post-audit in a manner that encourages honest evaluation without fear of legal repercussions associated with litigation or prosecution.

In compiling data on past accidents and disasters, it would be useful to include information on situations that had the potential to develop into disasters but didn't. Such potential disasters are likely to occur more frequently than actual disasters, but may not be reported, either because there is no requirement to report them or out of fear of punitive action. Yet it is as important to know what worked in responding to potential disasters as it is to know what didn't. It would be useful to develop a mechanism for reporting and analyzing such incidents and for disseminating the resulting information in a form that might assist others in averting disaster. A provision for granting immunity from punitive action to those who report such incidents might increase the effectiveness of the reporting system.

CHAPTER 3. THE BUREAU OF MINES POST-DISASTER RESEARCH PROGRAM

Within the USBM Health and Safety program, research directed specifically to the survival and rescue of miners following potentially disasterous events is classed as "post-disaster research." This program was initiated for coal mines in 1970 as a result of the Coal Mine Health and Safety Act of 1969. Similar efforts were initiated for metal and non-metal mines in 1972. In both areas, research efforts were stimulated by disasters in which the lives of miners might have been saved if different technology and procedures had been available.

Post-disaster research has accounted for $18 million out of the total of $326 million spent in the last decade for health and safety research. There have also been research efforts aimed at detecting or mitigating conditions which might lead to disasters which were not funded under the aegis of the post-disaster program, but which could conceivably lead to technology that would be applicable in disasters as well.

3.1 INTRODUCTION

The USBM post-disaster research program during the past decade has focused on developing technology for the following:

1. Communicating with and locating trapped miners.
2. Supporting the lives of miners trapped underground and of those involved in rescue and recovery work.
3. Rescuing trapped miners.*

The program was shaped to a great extent by the recommendations of the 1970 NAE report.** That report suggested a number of specific areas of research as early objectives of the new program, and to a large extent these recommendations were followed. Progress was hampered by a number of factors outside the Bureau's control, among them

- o The shortage in the early 1970s of R&D-oriented scientists and engineers with knowledge of underground mining.

*A list of the research projects undertaken in the past decade is given in Appendix III.

**"Mine Rescue and Surval," National Academy of Engineering, Washington, D.C., 1970.

- Organizational changes within the federal government with regard to mine safety and health, e.g., the creation of the Mine Enforcement and Safety Administration in 1972 and its conversion to the Mine Safety and Health Administration in 1977.
- The growing role of the National Institute for Occupational Safety and Health in setting design standards and conducting approval testing of such safety equipment as dust samplers and breathing apparatus.
- Pressure on the federal R&D program to produce visible and useful results, which in this case led to emphasis on the design and construction of equipment and its demonstration in operating mines, sometimes at the expense of continued development that might have proved more useful in the long run.
- The selection of research projects because of statutory or regulatory requirements rather than because of their appropriateness for achieving overall program goals.

Despite initial difficulties, the program got off to a good start. The decision was made to initiate Phase I (the interim system) of the 1970 NAE report through a single major contract, while building a long-term research capability through a combination of in-house and contract activities. This was a realistic response to the pressure for results, the level of funding, and the shortage of necessary expertise.

However, as time went on, management of the program became project-oriented rather than program-area-oriented. While it is evident that detailed planning and evaluation have taken place on an annual basis, there seems to have been a lack of sufficiently well-defined objectives, covering broad program areas, to adequately maintain the longer-term coherence that is necessary. This does not mean that individual contracts and in-house projects have not had well-stated objectives, but rather that the broader objectives that tie several projects together do not appear to have been a strong component in the routine planning and evaluation process. As a consequence, there have been research projects that, while technically successful, have not found their way into operational practice because they were not perceived by the mine safety community as meeting a real need.

The evaluation of the USBM post-disaster research program set forth in this report is based on the committee's examination of the major program sub-areas--communications, life support, and rescue operations--and on the research progress or lack of it within each sub-area. The committee made no attempt to evaluate in depth all projects and did not consider it to be its responsibility to resolve scientific or engineering issues. The primary criterion has been whether the progress made has contributed to enhancing the survival and rescue capability represented by that sub-area. A secondary criterion has been whether research in the sub-area has been responsive to the goals set forth in the 1970 NAE report, many of which are still valid today.

3.2 COMMUNICATIONS

"Post-disaster communications" in the 1970 NAE report means "locating and communicating with workers trapped underground either behind barricades, in refuge chambers, or attempting to escape."* That report discussed telephone, electromagnetic, and seismic communications. Telephone communications were dicussed primarily in terms of short-term improvements; electromagnetic and seismic communications were identified as areas in need of longer-term R&D.

3.2.1 Electromagnetic Communications

The 1970 NAE report noted that "Electromagnetic communications techniques have the advantage that in the long term, they might evolve as a means of operational communications within the coal mine. If properly designed, enough of the operational system could survive an explosion to provide emergency communications. Moreover, electromagnetic or radio communications is the only technique that would permit emergency voice contact between men on the surface and those underground."** Further, "Rescue team operations could probably be enhanced by the development of radio systems for communications between team members..."***

The USBM responded with a program aimed at developing devices to permit communication between persons inside a mine or between persons inside and outside the mine, and to make it possible to locate persons trapped inside the mine using electromagnetic waves as the propagation medium. These devices were to be capable of performing reliably in most mines under normal mining conditions, as well as in disasters, and were to be manufacturable at a reasonable cost. To satisfy this objective several alternatives were pursued:

1. Direct through-the-earth propagation
2. Guided wave propagation through the mine entries
3. Leaky feeder propagation
4. Inductive coupling to wires and metallic objects
5. Wire propagation

All of these options were given consideration as part of several systems-oriented studies. Greater emphasis was placed on option 1, and options 4 and 5 received less attention for post-disaster situations.

The program evolved with a combination of simultaneous equipment development, field experiments, and theoretical and analytical efforts being pursued. Efforts were made to fully characterize the propagation media through advanced analytical techniques, measurement of conductivities and noise, and consideration of design options. A review of the various efforts suggests that analytical and theoretical work were neglected at times in favor of equipment construction for demonstration purposes. In the later 1970s, however, the second phase of equipment and systems development appears to have relied more heavily on the analytical work.

---

*Mine Rescue and Survival, p. 12

**Mine Rescue and Survival, p. 13

***Mine Rescue and Survival, p. 23

The work in this area has clearly shown the practicality of electromagnetic techniques for communicating with and locating trapped miners. The value of inductive coupling to existing wires and metallic objects for mine rescue teams has been demonstrated in South African mines, and experiments suggest this technique will be of value in the United States as well. The Bureau made significant advances in establishing the theoretical, analytical, experimental, and hardware design aspects of electromagnetic communications for meeting post-disaster needs. Options have been considered for the possibility of meeting both routine and post-disaster needs with one system. The concept of a "hardened" or "explosion proof" telephone system was studied, with the conclusion that such a system could not be constructed, installed and maintained at a reasonable cost. However, the use of multipath telephone circuits has been recommended and various approaches have been devised. Battery-powered carrier current radios for trolley haulage systems came into use during the decade and provided another communication path. Techniques for coupling electromagnetic communication signals to steel hoist rope were developed. This method is now being used in conjunction with battery-powered carrier radios to permit voice communication with the cage even when all electrical circuits between the cage and the surface are lost.

During the 1970s advances in electronic communication technology were driven primarily by the rapid development of highly dense packaging techniques for integrated circuits. The concomitant development of the microprocessor made it possible to realize the benefits of digital communication and circuit control techniques that had been developed during the previous two decades.

The higher packaging densities and wider array of practical design alternatives (e.g., digital vs analog) made system realizations more adaptable to the specific needs of mines and made costs more acceptable to low margin companies.

The availability of low cost digital circuits now makes possible sophisticated signal processing techniques for minimizing the effects of noise and compensating for peculiar system characteristics such as those experienced with "through-the-earth" systems. Such applications are now practical for hand-held devices, as well as for portable field equipment.

Solid state switching technology is revolutionizing the design of telephone systems. New design options now exist both for in-mine systems and for inside-to-outside systems, which make it possible to accommodate to specific rescue and survival needs. Telephone systems can be designed with features that are activated during emergency conditions, so that, for example, when any underground phone is taken "off hook" it automatically "rings" the emergency communication center.

Knowledge of "through-the-earth" propagation of electromagnetic waves has greatly advanced during the decade, primarily because of contract work sponsored by the Bureau of Mines. With adequate information about the earth's resistivity profile near mine workings, accurate predictions of signal propagation patterns can now be made for a wide variety of system configurations. Availablity of adequate resistivity data is now the major limiting factor in analyzing a given situation.

The extensive body of data that has been gathered and is now being analyzed and processed should meet the major needs of the next few years.

The development of integrated-circuit technology during the past decade has contributed greatly to reducing battery requirements for in-mine applications. This has many advantages, including lighter weight, longer operating times, and easier compliance with "intrinsic safety" requirements of MSHA.

The development of electronic devices during the past decade has generally led toward better reliability and the practicality of trading off important factors such as weight, packaging, costs, and environmental considerations (such as temperature).

Evaluation:

USBM research in electromagnetic propagation for use in post-disaster communication and location techiques has more than met the recommendations of the 1970 NAE report. Development of a direct through-the-earth beacon for location and communication has been followed through to the logical point of producing prototypes that can be manufactured and placed in use in several operating mines. This program may represent the greatest single contribution to evolve from the 1970 NAE recommendations. Electromagnetic through-the-earth experiments have shown that a maximum propagation distance of about 1000 feet is possible in most mines.

However, development of medium-frequency (i.e., in the vicinity of 1 MHz) two-way communication units for rescue teams and possible routine applications was not initiated as early in the research program as would have been desirable. Also, inordinate attention was given to overly sophisticated "integrated systems" for demonstration purposes before many of the system components had been adequately developed or tested.

The rapid development of electronic technology during the 1970s has made equipment development easy, but has made it difficult to decide at what point to adopt a basic design for extensive testing and possible operational deployment. This problem was and still is compounded by the lack of a clear policy or methodology for the transition from basic research to applied research, development, demonstration, testing, and ultimately, implementation. It is not clear how much of this transition is considered to be a USBM responsibility.

The more recent emphasis on establishing equipment reliability and exploring new hardware, system and signal processing techiques are clearly steps in the right direction for this program. Because of the limitations imposed by earth conductivity and ambient noise and the prospects for deeper mines, it is important that these new methodologies be pursued. This effort needs to place more emphasis on exploratory research, and less on equipment development and demonstration.

All of the effort related to locating and communicating with trapped miners has centered on communication between a station on the surface and miners trapped underground. No attention has been given to communication between two underground stations--e.g., between trapped miners and advancing rescue teams. This concept merits some attention.

3.2.2 Seismic Communications

Because of the wealth of knowledge existing in 1969 on seismic techniques, their application to locating and communicating with trapped miners was discussed in great detail in the 1970 NAE report. It was recognized that all of the required receiving and signal processing equipment was available "off the shelf," and that the miner might need no more than a hammer with which to pound on rails or roof bolts. Thus the use of seismic waves was viewed as the most promising short-term method for locating a trapped miner.

The early analytical and theoretical work resulted in a portable receiving system mounted on the back of a pick-up truck with an array of geophones to be deployed on the surface. The miner transmitted signals by pounding with a sledge hammer. A weight-dropping device was also used in some experiments. Down-link communications were achieved by firing shots on the surface.

Early results indicated that electromagnetic communication was more promising than seismic communication for this purpose and the program emphasis was therefore shifted to electromagnetics. Nevertheless there was a continuing commitment to maintaining a seismic communication capability because the miner would not need a special transmitting apparatus. Standard seismic procedures were developed and are now taught to miners as part of their mandatory training.

Among the longer term research objectives identified in the 1970 NAE report were the gathering of data on seismic transmission through various geologic structures, the use of accelerometers to detect high-frequency seismic pulses, the development of automatic seismic signalling devices, and the study of transmission paths of seismic energy in mining areas. Work has gone on in a number of these areas. Some of the studies indicate techniques that could be useful for monitoring geological conditions in mines daily, quite apart from their potential value for locating and communicating with miners during disasters.

Evaluation:

Early plans for the seismic approach were altered when the first electromagnetic experiments demonstrated that in most locations where seismic techniques could work, experimental electromagnetic devices performed better in most cases. Even though the miner had to carry an "active" transmitting device, the electromagnetic receiving apparatus had the advantage of being smaller, portable and much easier to deploy than seismic devices. As a result, the overall developmental effort shifted toward electromagnetics.

Nevertheless, there is still a need for theoretical and experimental seismic work, not only to support post-disaster applications, but also as part of a continuing effort to explore ways in which permanently installed seismic systems could be used on a day-to-day basis, and thus be available during disasters for miner location. Location of transducers inside mines should be considered, in conjunction with distribution of microcomputers.

3.2.3 Borehole Probes

The objective of this effort was to develop probes that could be lowered through a borehole and used in emergency mine rescue operations. Probes for two-way voice communication with trapped miners, continuous mine atmosphere monitoring, temperature indication, and television searching have been developed, and have been deployed by MSHA's Mine Emergency Operations facility. Methods for using infrared imaging to "see" through smoke have been studied but have not yet proven to be practical.

Another effort in this area was the development of a portable gas analyzer to permit rapid measurement of gases present in a coal mine fire. A useful device was developed and several units are available for deployment.

Evaluation:

The borehole-probe work has primarily been development based on existing technology rather than research. Useful and practical equipment has been developed and deployed.

3.3 LIFE SUPPORT SYSTEMS

Breathing apparatus falls into two categories. The escape breathing apparatus (EBA), also called personal breathing apparatus, emergency breathing device, or "self-rescuer," enables the individual miner to continue breathing while passing through regions of hostile atmosphere when escaping from the mine. The rescue breathing apparatus (RBA) is used by volunteer rescue teams in the processs of searching for and rescuing trapped miners and reestablishing fresh air ventilation in the mine. The requirements for the two differ. The escape apparatus must be available to every person in the mine, must be simple to use, and need only keep the miner alive for the time it is likely to take to reach a safe location or a stockpile of additional breathing devices. The rescue apparatus is used only by specially trained volunteer rescue teams and must keep them alive for a longer period of time while they engage in strenuous rescue work.

The escape breathing apparatus in current use is the "filter self-rescuer." It essentially filters carbon monoxide out of the air the miner breathes; it does this by means of the catalyst hopcalite which converts carbon monoxide to carbon dioxide as the air passes through the device. The filter self-rescuer offers no protection against toxic gases other than carbon monoxide and does not provide oxygen; therefore it is useful only in an atmosphere that contains sufficient oxygen to support life and that is contaminated solely by carbon monoxide. Moreover, when it is used in a carbon monoxide environment, the mouthpiece heats up to blistering temperatures (in excess of 300° F at a 2% concentration of carbon monoxide). The filter self-rescuer is light weight (about 2 pounds) and compact (the size of a small water canteen) and is worn by all miners on their belts.

All the rescue breathing apparatus in current use are self-contained oxygen-providing units. They tend to be heavy (about 30 pounds) and bulky (the size of a backpack). An oxygen-providing breathing device can contain either a supply of compressed oxygen gas or cryogenic liquid oxygen or a chemical source for oxygen generation.

To improve the design of any breathing apparatus it is necessary to know (1) the environment in which the apparatus will be used, (2) the physical condition of the miners who will use the apparatus, (3) the physical activity in which they will be engaged and the physiological and metabolic requirements arising from that activity, (4) the length of time that protection must be provided, and (5) the "human factors" considerations that determine what features the apparatus must have if it is to be accepted and used properly by those it is intended to protect. These last considerations are more of a problem with the EBA, which must be accepted and used by all miners, than with the RBA, which is used only by select volunteers.

3.3.1 Escape Breathing Apparatus

The 1970 NAE report identified the requirements for an EBA, or escape breathing apparatus. It "should provide a respirable atmosphere, regardless of the environment; should permit intermittent voice communication; should provide eye and face protection in areas of high dust and smoke concentrations; should be of the longest possible duration; and should be light and compact enough that miners will not object to carrying them continously."* That report went on to point out that, for such a device, "...safety is related not only to the reliability of the device, but to its availability and the willingness and ability of the miner to use it. Minimum weight, volume, and comfort when in use may be more important than very strict requirements for operating time, permissible carbon dioxide levels, and inspired gas temperatures. No matter how reliable the device, safety is not provided if it is so bulky and heavy that it is 'inadvertently' stashed some place in the mine."** The report urged the same approval schedule not be used for EBAs and RBAs, and specifically recommended for EBAs "that a new approval schedule reflecting the philosophy of maximum probability of survival should be adopted," and that this schedule "should not establish inflexible requirements, but should permit tradeoffs to achieve a better total design."***

To provide a respirable atmosphere regardless of the environment, an EBA must contain a source of oxygen. The 1970 NAE report discussed possible sources: compressed oxygen, cryogenic liquid oxygen, and chemically generated oxygen using potassium or other superoxides or chlorate candles. Most of the R&D supported by the Bureau of Mines during the past decade involved chemically generated oxygen; only toward the end of the decade was work begun on compressed oxygen systems, and no effort has been devoted to cryogenic systems (see

---

*Mine Rescue and Survival, p. 9

**Mine Rescue and Survival, p. 33

***Ibid

Table 3.1). There was clear evidence as early as late 1970 to indicate that the weight and dimension recommendations of the 1970 NAE report were not being met. This led to USBM research that developed a lightweight, compact 10-minute unit and also a "piggy-back" combination of a belt-wearable 10-minute device and a cached 60-minute device (the MSA 10/60 system). That system did not require the miner to remove the mouthpiece, as the 60 minute unit could be plugged directly into the 10 minute unit. Neither of these systems was marketed.

The EBAs that ultimately emerged from this program to be marketed are sufficiently heavy (8-9 pounds) and bulky (the size of a small knapsack) to raise questions about the willingness and ability of miners to wear them. Consideration has been given to regulations specifying that when these devices are introduced they may be cached rather than carried on the miners' persons, in which case miners would continue to carry filter self-rescuers to provide protection until they reach a cache of oxygen-providing EBAs (oxygen self-rescuers).

Evaluation:

The examination of mine disasters and rescue efforts during the past decade reaffirms the 1970 NAE conclusion that an escape breathing device that is continuously carried on the miner's person and that provides sufficient oxygen to support life for the time it takes to get to a place of safety would be the most important piece of lifesaving equipment that could be developed. The committee believes that while individual R&D projects in this area were sound, the program as a whole failed to provide the needed focus on an effective escape breathing device.

The R&D carried on in the past decade indicates significant engineering problems in developing an oxygen EBA, particularly with regard to size and weight. If being light enough and compact enough that miners will wear them continuously is given high priority, as the committee believes it should, then other avenues should be explored to reduce weight and bulk.

The 1969 Act calls for a one-hour device, and this has been considered a rigid requirement thus far. The one-hour requirement should be reexamined on the basis of a realistic assessment of the physical condition of the miners, the physical activity involved in escape and survival, and the associated physiological and metabolic requirements. Further R&D should be conducted in the chemistry of oxygen generation and in the use of oxygen sources other than chemical generation. Systems like the "piggyback" device, that combine wearability with caching, should be explored further.

Caching is a legitimate option to be considered, but one that should have been taken into account early in the R&D process in determining appropriate tradeoffs among the requirements and in developing design specifications. It is also necessary to develop a strategy for caching. This should include location of the cache, number of units to be cached, shelf life and maintenance requirements, etc. There is a real concern that cached devices may not be as effective as devices that are belt-wearable and tragedies may result from caching bulky devices. Therefore, this committee reaffirms the importance that the 1970 NAE report placed on tradeoffs among requirements leading to

Table 3.1 The status of oxygen-providing escape breathing apparatus in the United States in 1980; the "filter self-rescuer" is included for comparison. (Information provided by the Bureau of Mines)

Unit (Mfr. model	Duration (min.)	Weight (lbs.)	Size (in.^{3})	Year Completed	Remarks
MSA, W-65 Draeger, 810	60	2.2	70	1970	Filter type (does not supply O_2); listed for comparison.
Westinghouse, PBA (Chlorate Candle)	60	8.7	525	1971	No NIOSH approval; not marketed.
Lockheed, PBA (KO_2)	60	4.5	200	1970(sic)	NIOSH-approved; not marketed.
MSA, PBA (KO_2)	10	2.4	100	1974	10-minute, belt-worn device; NIOSH-approved; not marketed.
MSA, 10/60 System (KO_2)	10	4.2 (worn)	170 (worn)	1978	Plug-in system; NIOSH approved won't be marketed.
	60	8.5 (both deployed)			
Drager, SR-60	60	8.5	545	1979	Available by 1979; NIOSH approved; planned for U.S. marketing 1980-81; smaller version in use in Europe.
MSA (KO_2)	60	9.1	425	1979	Available by 1979, NIOSH-approved; planned for marketing 1980-81.
CSE, AU-9 (compressed O_2)	60	8.1	265	1979	Used in Europe; modified unit submitted to NIOSH for approval in 1979; planned for marketing 1980-81.
US Divers (compressed O_2)	60	6.5	250	1979	Presently in prototype evaluation stage; was planned for marketing 1980-81.

creative design and a better total system--i.e., one in which the miner's probability of survival is maximized--and for R&D to develop methods for evaluating tradeoffs.

Whatever device is developed should be subjected to extensive field testing in different kinds of mines, with careful observation of the way miners actually use it, and feedback and suggestions should be sought from those who participate in such field tests, before consideration is given to mandating its use. Initiation by MESA in 1976 of rulemaking to require use of an oxygen EBA preceded any extensive field testing and was accompanied by a reduced level of funding for R&D in this area.

3.3.2 Rescue Breathing Apparatus

While the 1970 NAE report did not identify improvement in rescue breathing apparatus as a high priority item, it did point to the need for long-term research that could contribute to improvements in the then existing equipment, which it described as heavy, cumbersome, costly, and uncomfortable if used for long periods. The Bureau has conducted some research in this area, and has just recently begun a limited effort in the design of a light-weight, low-profile rescue breathing apparatus suitable for use in thin coal seams and other confined spaces for which the present equipment is too bulky.

The committee is concerned that in the RBA work that has been done, decisions to require positive pressure in the facepiece throughout the respiratory cycle, and to effectively discourage "buddy valves" (which would allow a second person to breathe temporarily from another's breathing apparatus), have been made somewhat arbitrarily and do not reflect the most essential needs of rescue work. Moreover, insufficient attention has been paid to the value of cryogenic (liquid oxygen) devices, especially for use in hot mines. This may be the result of inadequate solicitation of guidance from individuals with rescue team experience.

Evaluation:

Improved rescue breathing apparatus was not given high priority by the USBM. What work has been done has not been sufficiently subjected to review by those who have used or will in the future use such apparatus.

3.3.3 Physiological and Metabolic Research

Physiological and metabolic studies are required both to establish the requirements for an emergency breathing apparatus and to design procedures for testing and approving such apparatus. Although the requirements for escape and rescue apparatus differ, the approach is the same. It involves (1) distinguishing between the different kinds of activity likely to be engaged in by miners using the equipment (e.g., walking to a place of safety vs. engaging in arduous rescue work), (2) relating this to the physical and medical conditions likely to be found among miners and rescue team members, and (3) developing requirements and techniques for human tests and automated breathing simulators that can be used in the development of breathing apparatus. The 1970 NAE report says of such studies:

> "The metabolic requirements of the miners must be determined more accurately for design of improved emergency breathing devices. Under conditions following an explosion, a miner's oxygen consumption, tidal volume, and respiratory frequency are likely to increase. Each of these parameters affects the emergency breathing device design requirements. A research program should attempt to develop, in the laboratory or in the field, experimental stresses that are similar to those actually experienced during emergency conditions. Because of the difficulty in simulating hazardous conditions in a laboratory environment, considerable care and thought will be required to design meaningful experiments. The subjects should be drawn from the population at risk--the miners themselves. Additional training should not be given to those participating in the experiments, and every possible effort should be made to impose realistic stresses on the subjects."*

The report goes on to state that while the missions of escape and rescue apparatus differ, they are covered by the same approval schedule. While this schedule is appropriate for rescue apparatus, for escape apparatus "...a new approval schedule...should be adopted. The schedule should not establish inflexible requirements but should permit trade-offs to achieve a better total design."**

Part of the Bureau's program during the past decade was directed toward development of an automated breathing metabolic simulator for testing breathing apparatus under development prior to human testing. The program has also supported physiological research on people in stress situations similar to those miners might experience during a disaster, and these results have been applied to the development of escape breathing apparatus. However both of these activities have been hampered by inadequate early attention to design criteria, experimental protocols, and sampling procedures, so that progress has been slow. The work has proceeded independently, rather than having the pace set and the priorities determined by the ultimate goal--development of an escape breathing device for miners.

A revised human subject test for approval of breathing apparatus that does distinguish between escape and rescue has now been developed and is being evaluated before it is proposed as a revised MSHA/NIOSH regulation.

Evaluation:

The Bureau of Mines has supported studies of physiological response and metabolism under stress conditions and development of an

---

*Mine Rescue and Survival, pp 32-33

**Mine Rescue and Survival, p. 33

automated breathing metabolic simulator. For too long, however, the characteristics of the actual miner population were not sufficiently taken into account. Moreover, the distinction between escape and rescue activities has remained blurred, and the development of test schedules appropriate to escape has been slow. This is particularly unfortunate since new rescue breathing apparatus was not as badly needed as an oxygen-generating escape breathing apparatus (and in fact little R&D in rescue breathing apparatus was undertaken).

Because the weight and bulk of an escape apparatus increase with the length of time it must keep a miner alive, which in turn is related to the miner's physical state and activity, to develop a truly light-weight, belt-wearable device the Bureau must realistically assess the effort required of a miner attempting to escape. The Bureau's physiological and metabolic research has not provided sufficient support for development of a lightweight escape breathing apparatus.

3.3.4 Refuge Chambers

The 1970 NAE report proposed refuge chambers that "...would provide protection from poisonous gases and some protection from subsequent explosions until the men could be rescued. The chambers could also serve as a temporary haven for men to replace or replenish emergency breathing devices or wait for the air to clear before resuming escape attempts."* The report pointed out that

> "When it appears to be impossible to escape or imprudent to attempt escape following a fire or explosion, miners are trained to isolate themselves from toxic gases and smoke by erecting barricades of brattice cloth on wood framing. From 1909 to 1961, more than 1,000 coal miners were rescued from behind barricades. In the period under consideration, the past two decades, 62 miners were rescued from behind barricades and 27 died behind inadequately constructed barricades."**

The report discussed the pros and cons of refuge chambers:

> "Some have strongly argued that in case of emergencies miners should proceed immediately to a refuge chamber and await rescue. While this would provide almost absolute protection from poisonous gases, there is always the possibility that a subsequent explosion or a roof fall might destroy the chamber and kill its occupants. If an emergency two-way voice commmunication capability can be developed, a good approach would be for miners to proceed

*Mine Rescue and Survival, p. 7

**Mine Rescue and Survival, p. 10

to the chamber to receive information on the extent of damage and whether escape is feasible or they should wait until rescue. In the final analysis, the decision will have to be made by the men underground at the time, and the mine rescue and survival system should maximize their chances for either escape or survival underground."*

The report further stated:

"...When escape is not possible or the risk is considered to be too high, chambers may also serve as waystations for miners escaping from the mine to rest, replace or replenish emergency breathing devices, and communicate with the surface...If possible, without creating the hazardous situation inherent in any major underground construction project, some protection should be provided against secondary explosions. Two potential concepts have been identified. A preliminary design has been made of a metal bulkhead and door, two of which could be used to enclose a shock wave. The bulkhead could be anchored by roof bolts into the roof and floor. It would be made in sections that could be easily moved as mining sections are opened and closed. The other concept is an inflatable structure that, if inflation is rapid enough, can be left deflated until actually needed... A combination of sectional and central underground shelters may be the most economical method of providing protection. Analysis of the hazards of individual mines should be conducted to aid in selection of types of underground protection."**

The Bureau has conducted some technical research on bulkheads and on guidelines for refuge chamber design and construction. However, the applicability of the refuge chamber concept as part of the total survival and rescue system has not really been examined in depth.

Evaluation:

This area has received little attention from the Bureau. What work has been done has been narrow in scope. It has failed to distinguish between the usefulness of refuge chambers in different kinds of disasters (e.g., explosion, fire) or in different kinds of mines (including their usefulness for thermal protection in deep, hot mines). Nor has there been any in-depth analysis of the requirements for refuge chambers or of the distinction between self-contained refuge chambers and those connected to the surface by drill holes.

In light of the considerable concern that has been expressed about the implications of the refuge chamber concept, and the querries that

---

*Mine Rescue and Survival, p. 7

**Mine Rescue and Survival, pp. 10-11

have been raised about the deployment of these chambers, the Bureau has been appropriately cautious. What work has been done clearly indicates a host of engineering difficulties with the refuge chamber concept. However not enough has been done to provide a basis for judging whether further pursuit of this approach is likely to be fruitful, particularly in view of the regulations that now exist with regard to mine design, escapeways, emergency drills, and communications.

3.3.5 Oxygen Sources for Breathing Apparatus and Refuge Chambers

The 1970 NAE report discussed the need to develop appropriate oxygen sources, both for breathing apparatus and for refuge chambers. This does not appear to have been recognized by the Bureau as an identified area for R&D until 1974. Since then, there have been projects on improved oxygen sources but these have concentrated exclusively on metal superoxides. There has been no effort to develop new oxygen sources for refuge chambers, as existing sources that were considered too heavy and bulky for breathing apparatus were considered adequate for refuge chambers.

Evaluation:

The development of new sources of oxygen for breathing apparatus and refuge chambers has not been recognized and funded as a major area of R&D, despite the significance that such development could have for an improved escape breathing apparatus.

3.4 RESCUE OPERATIONS

The improvements in rescue operations called for in the 1970 NAE report center on (1) rescue drilling and (2) equipment to assist rescue teams. The latter category includes rescue breathing apparatus (See Sec. 3.3.2), rescue team communications (See Sec. 3.2), and such other approaches as infrared and other spectral detectors to search for fires or hot spots within the mine, new types of rigid foam for construction of temporary stoppings, the possible use of remote control vehicles to complement rescue team operations by sampling the atmosphere and searching for hot spots, and development of bubble-type helmets to provide better visibility and greater comfort for the wearers of rescue breathing apparatus.*

3.4.1 Rescue Drilling Technology

The 1970 NAE report went into great detail concerning the requirements for rescue drilling. That report envisaged the combination of a highly mobile, air-transportable search and probe drill and a wider diameter rescue drill. Although 6- to 8-inch diameter drills for sinking probe holes were recognized to be commercially available, larger rigs capable of sinking 18- to 28-inch diameter holes were considered to be too slow and cumbersome for rescue work. Therefore

*See Mine Rescue and Survival, p. 23

research was recommended for improving the mobility and drilling rates of the larger rigs. Moreover, the report pointed out that considerable drilling research that might be applicable to mine rescue was already in progress. Therefore, it was recommended that the Bureau monitor and evaluate such research activity. It was recognized that additional work might have to be sponsored by other laboratories under USBM guidance and leadership. The report implied that the Bureau should not develop an in-house research capability in this area.

Work in the drilling area was primarily dedicated to development and testing of the two drills now assigned to MSHA's Mine Emergency Operations. These drills were later modified as a result of testing and deployment during actual emergencies.

Research related to drilling during the past decade was limited to two projects. A study of the state of the art for down-the-hole percussion devices in 1972 led to the conclusion that privately sponsored research was more than adequate and that Bureau support was not necessary. In another project, a guidance system was developed for field-testing the probe drill developed for the mine rescue system.

Evaluation:

Although the Bureau did not mount a major research effort in post-disaster drilling technology, the program it conducted was responsive to the 1970 NAE recommendations. In light of funding constraints in the post-disaster area and in view of drilling research being conducted outside the Bureau, the magnitude of the Bureau's post-disaster drilling research seems appropriate.

3.4.2 Mine Survey and Rescue Vehicle

The 1970 NAE report envisaged a remotely controlled probe vehicle that "...might be equipped with manipulator arms...and could have closed circuit television that would be transmitted to the surface through the mine opening by repeater stations dropped from the vehicle at suitable intervals. A vehicle of this type...must be powered by a self contained system. Novel power sources such as fuel cells and sophisticated methods of making diesel, natural gas, and other internal combustion engines acceptably permissible should be investigated."*

The Bureau undertook to design and build a remotely controlled vehicle to operate in a hostile mine environment. Provisions for measuring methane and carbon monoxide concentrations and ambient air temperature were to be included.

The feasibility of using a remotely controlled vehicle in a mine environment was demonstrated. Many factors and limitations affecting the general usefulness of such a machine were discovered. It was determined that the vehicle had limited mobility and was easily stranded by tracks, ruts and large rocks. The system was judged to be at best a prototype and not sufficiently reliable to be used in emergencies.

---

*Mine Rescue and Survival, p. 24

It is apparent that minimal funds were expended to develop this vehicle. The Bureau's review of the contractor's final report concluded that the original scope of work was too ambitious for the time allowed and the resources available.

In another effort, the National Aeronautics and Space Administration was engaged to adapt a lunar rover inertial reference system for use on the vehicle described above. A number of problems were identified in trying to adapt the reference system to the vehicle and the tests appeared to be incomplete and inconclusive.

(A related effort involved development of a manually operated rescue team vehicle, sufficiently large to carry people and supplies in and out of dangerous areas and thus hopefully extend the useful range of activity for a rescue team. This device is basically a battery powered rough-terrain rubber-tired vehicle operated by an onboard driver and provided with gas sensors and wireless communication equipment.)

Evaluation:

The 1970 NAE report recommended that remotely controlled surveillance vehicles should be investigated by the Bureau. There was virtually no elaboration on this recommendation.

It appears there was never a concerted effort to fully explore the potential value of such vehicles and to set forth a development effort for meeting the most important needs. The experience gained by the initial effort was never exploited in later developments.

The research performed leads to the conclusion that remotely controlled surveillance vehicles would have only limited utility during mine rescue oprations. This utility probably exists only when mine conditions make it impossible or unusually risky for a rescue team to operate, e.g., in areas where there is risk of a secondary explosion or a roof cave-in.

3.4.3 Rescue Team Helmet and Cooling Garment

The 1970 NAE report noted that "Rescue team operations could probaly be enchanced by...development of bubble-type helmets to provide better visibility and greater comfort for the wearers of breathing devices."* Until 1975 the Bureau undertook no research in this area. Since 1975 the Bureau has developed, under contract, a bubble rescue helmet, and, through a combination of contract and in-house reseach, cooling garments for rescue work in hot environments. These items are now available for rescue use.

Evaluation:

This area was not given high priority in the 1970 NAE report, and the USBM response has been appropriate. However, more attention should be paid to the conditions under which rescue work is carried on, and an effort should be made to develop equipment that increases the rescue team members' comfort and visibility.

---

*Mine Rescue and Survival, p. 23

3.5 RELATED RESEARCH

Although mine monitoring was not specifically addressed in the 1970 NAE report, in the early 1970s two projects involving the monitoring of airflows and undesirable gasses in mine airways were funded by the post-disaster research program. Both projects were aimed primarily at disaster mitigation; however, the post-disaster value of having detailed data on conditions before and during the disaster was recognized. The possibility of the monitoring equipment surviving the disaster was recognized but not made part of the design requirements. Both projects led to construction, installation and demonstration of monitoring equipment in coal mines.

A third research project addressed the possibility of using low-data-rate through-the-earth transmission techniques for monitoring conditions in a mine following a disaster. The feasibility of having permanent or semipermanent beacons which could be activated by a signal from above ground was considered. Although this is possible in principle, the overall value of such devices is questionable.

Research efforts aimed at detecting or mitigating conditions that might lead to disasters can sometimes lead to technology or knowledge that would aid during post-disaster conditions. Several projects conducted by the Bureau fell into this category but were not funded under the post-disaster program. These projects related mostly to controlling mine fires and included efforts aimed at improved temporary stoppings which could have post-disaster applications. There were also several projects involving sensors and monitoring systems which could aid in evaluating pre- and post-disaster conditions. Also, several projects funded by the Bureau have led to new communication equipment for everyday use which has some capability of responding during disaster situations.

Evaluation:

There have been various R&D areas related to post-disaster survival and rescue that have not been carried out as part of any one of the identified post-disaster subprogram areas. This in itself is unobjectionable; however there does not appear to be any systematic procedure within the USBM for integrating such R&D results into the major programs.

3.6 SURVIVAL AND RESCUE PLANNING AND MANAGEMENT

While the 1970 NAE report did not explicitly speak of a mine disaster planning and management system, a number of the elements of such a system were specifically addressed. Thus the report states:

> "There is strong evidence that in addition to proper equipment, proper training is essential to survival and rescue. Each mining crew should be organized for and drilled in behavior that would maximize their chances for survival. They should be taught the specific hazards associated with different types of emergencies and the

best way to meet them. The records of coal mine disasters show very clearly that many more miners would have survived had they known the proper course of action to follow.

Two possible training aids for long-term development are an explosion model to demonstrate the effects of explosions and a simulator in which miners could be exposed to simulated conditions of a fire or explosion. A simulator could be equipped with a refuge chamber, smoke generator, and other devices to realistically simulate emergency conditions."*

The report goes on to clarify the notion of an explosion model:

"The model could be a physical and/or mathematical analog capable of indicating: (1) the progression and magnitude of shock waves traveling through a mine; (2) gaseous constituents of the atmosphere after ignition of primary and subsequent explosions; and (3) the effects of mine configuration (e.g., tunnel size, crosscut and spur location, etc.) on shock wave attenution, refuge chamber location, etc. An experimental program should be conducted to improve and verify the model."**

The report points out that in mine disasters, information on exact medical cause of death is usually not available, and concludes that "The information that could be gained by autopsies on fire and explosion victims would aid materially in the design of future rescue and survival systems."*** It further recommends that "Previous mine disasters should be simulated to gain additional insight into the causes of death. This knowledge could then be used to develop more effective procedures to search for survivors."**** Moreover, "...an operations research type of analysis of rescue team techniques should be conducted to determine if a more efficient method of team operation is possible."***** In an overall sense, the report pointed out, "The success of the program is dependent upon the integration of the components into a total system. This systems integration or systems engineering effort will make the difference between having a smooth-functioning mine rescue

---

*Mine Rescue and Survival, p. 8

**Mine Rescue and Survival, p. 32

***Mine Rescue and Survival, p. 6

****Mine Rescue and Survival, p. 32

*****Mine Rescue and Survival, p. 24

and survival system and having only improved equipment still used in the limited manner of the past."*

The only efforts undertaken by the Bureau in this area were three studies involving ventilation systems and guidelines for emergency escape systems. Some computer simulation was involved. (Further discussion of the value of a systems approach to post-disaster survival and rescue is found in Chapter 4.)

Evaluation:

The Bureau could have used the 1970 NAE recommendations quoted above as a foundation for a true systems approach to post-disaster survival and rescue. It did not. Instead it approached various components piecemeal. The concept of a survival and rescue system, incorporating accident analysis, operations research, training, design, and post-disaster investigation, all leading to improved response planning and management, is not evident in the Bureau's post-disaster R&D program.

3.7 PROJECT SELECTION

A crucial element in management of a program such as this is the selection of projects to be undertaken. This selection must reflect the concerns of the agencies responsible for regulating mine safety and responding to mine emergencies, the mine operators, the miners themselves (through their unions), and the manufacturers of mine safety equipment, as well as those undertaking the R&D. It must be based on considerations of need, practicality, effectiveness, acceptability, and cost of implementation, as well as considerations concerning the technological capability for the R&D.

A mechanism has evolved in which a joint USBM-MSHA committee evaluates all suggested research projects and ranks them in order of priority. Available funds are then allocated to the highest priority projects. (See Table 3.2 and Appendix II.) The ranking scheme considers three major areas: need, technical soundness, and cost of research and implementation. Each proposed project is evaluated with regard to four criteria in each of these areas, and the 12 ratings combined to give an overall ranking. However the criteria are not all independent. For example, criteria 1, 2, 3, 4, and 10 all involve the expected impact of the research on mine health and safety; it is likely that a project that rates highly in any one of these criteria will rate highly in all of them. Similarly, there is likely to be a correlation between the ratings for criteria 5 and 8, which have to do with probability of success, and between the ratings for criteria 9 and 12, which have to do with the expected cost to industry of implementing the results. The net effect of the inter-dependence of the criteria is that "need" is given more weight than "technical soundness," which in turn receives more weight than "cost."

---

*Mine Rescue and Survival, p. 19

Table 3.2 Synopsis of MSHA-USBM project rating procedure. Each proposed project is given a rating of "1" (low), "2" (medium), or "3" (high) for each of the 12 criteria. Within each area the ratings are summed; these three sums are then multiplied together to give an overall rating. This procedure was used in Fiscal Years 1979, 1980, 1981. (Based on information provided by the Bureau of Mines; see Appendix V)

Area	Criterion	High Rating	Low Rating
Need:	1. Urgency	Application needed immediately, or project will terminate a multi-year program.	Project addresses a long-term, future need.
	2. Hazard potential	Problem addressed involves a common illness with many miners exposed, or an injury of great frequency or severity.	Problem addressed involves an infrequent illness with few miners exposed, or an injury of low frequency and severity.
	3. Disaster/health risk	Problem addressed can potentially affect more than 20% of the work force.	Problem addressed can potentially affect less than 5% of the work force.
	4. Health and safety contribution	Project make make a major contribution to mine health and safety.	Possible contributions to mine health and safety are small.
Technical Soundness:	5. Pomise of success	High likelihood of success	Low likelihood of success
	6. Industry practice and alternatives	Novel idea, sound approach, few or no alternatives exist or are under development	Proposed approach is already in use in industry, or at an advanced stage of development
	7. Impact on research program	Project will make a major contribution to this area of research	Project will contribute little to this area of research
	8. Technical adequacy	Technology and approach are sound and within the state of the art.	Technology and approach have been tried previously without success or are beyond the state of the art.
Implementation and Cost:	9. Implementation potential	Industry likely to judge results of project to be cost-effective and to adopt them voluntarily.	Industry likely to opposed implementation of results as unjustified.
	10. Implementation desirability	Results of project are necessary to eliminate hazards and establish standards	Results will have little impact in eliminating hazards and establishing standards
	11. Project duration	Less than two years	More than four years
	12. Cost of implementation	Total cost of R&D and implementation will be less than $1 million	Total cost of R&D and implementation will be more than $10 million

There is another approach to technology transfer in which the prospective user becomes a partner in the enterprise at the outset. Cost-shared research conducted jointly by government and industry is one way to do this. Such an approach, the committee believes, would be far more effective in inducing user acceptance of R&D results, as it would permit shaping and reshaping the R&D program to match user-perceived needs. This approach is discussed further in Chapter 5.

In addition to the concern with outward technology transfer, there is also a need for inward transfer of technology that has been developed in other areas and that may be adaptable to mining. While mine disasters are different from most other kinds of disasters, many of the elements of coping with a mine disaster--e.g., emergency communications, firefighting, breathing apparatus--have much in common with their counterparts in other kinds of disasters, and an R&D program bearing on mine survival and rescue might be expected to look to military, space, firefighting, and undersea rescue programs for technology and procedures that might be transferable to mining. The 1970 NAE report identified several such areas of technology that could conceivably be adapted to meet mine disaster needs.* While the Bureau of Mines has at times contracted with defense agencies and with NASA for specific R&D projects, it has not established "systematized" means for transferring technology from other areas into its post-disaster R&D program.

Mine safety and health research is conducted in other countries as well. Although there are no formal agreements between the Bureau and foreign governments for post-disaster research, general agreements providing for information exchange with the United Kingdom, South Africa, and India include specific post-disaster areas.

Evaluation:

Although the Bureau of Mines has a "technology transfer" program, it focuses almost exclusively on disseminating information about completed R&D. No special emphasis is given to post-disaster R&D. No extensive attempts have been made to transfer post-disaster technology by engaging prospective users as partners in the enterprise.

There is no formal program for transferring into the Bureau information and technology from R&D programs in other government agencies. While some information exchange takes place, the Bureau has not developed creative and effective means for identifying and adapting technological developments in other areas for application to mine disasters.

3.9 EVALUATION OF THE TOTAL PROGRAM

Figure 3.1 illustrates the committee's conception of what an R&D program in post-disaster survival and rescue should look like. Note that it includes both equipment development ("hardware") and development of plans and procedures ("software") and that in addition to depicting areas of research (e.g., location and communication), it

*Mine Rescue and Survival, pp. 22, 28

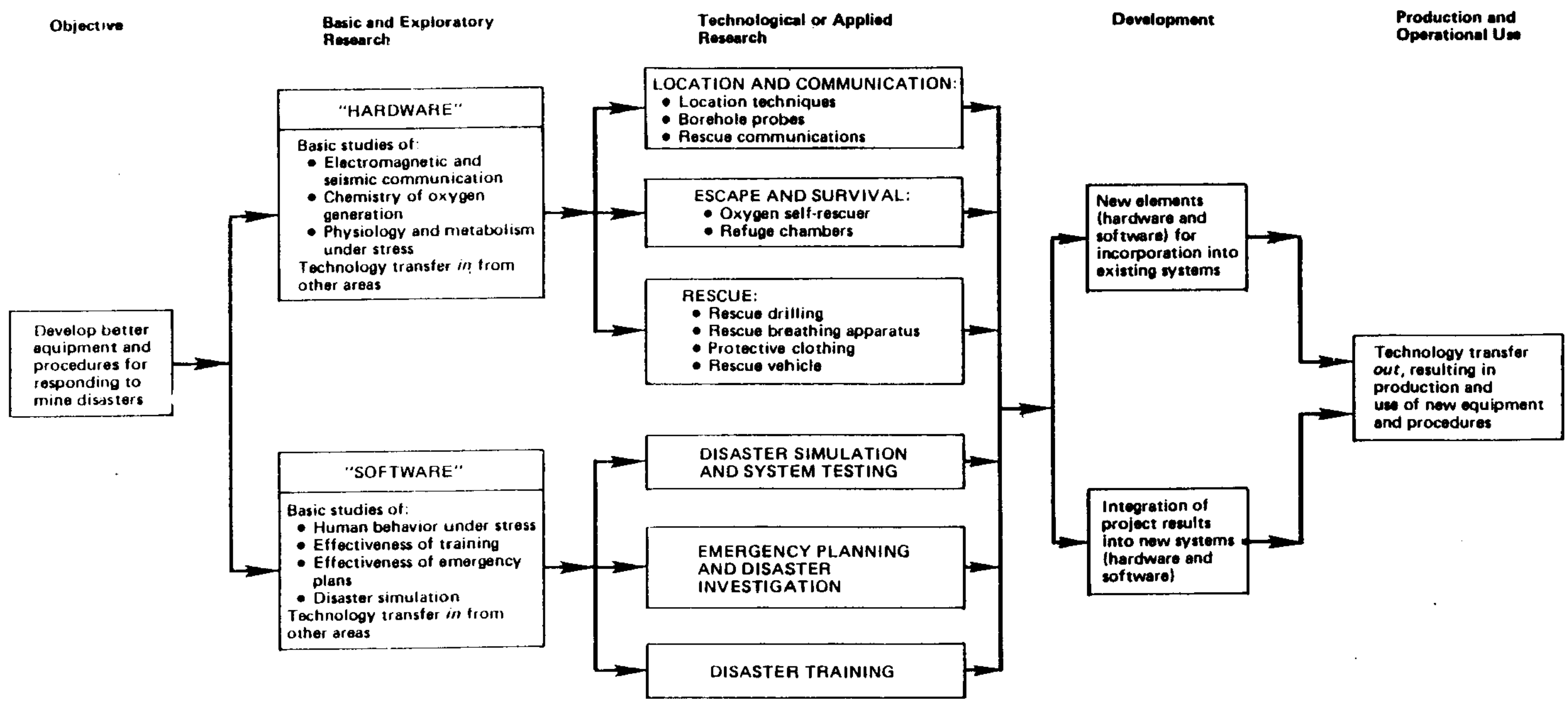

Figure 3.1 Schematic illustration of the committee's conception of an R&D program in post-disaster survival and rescue.

indicates a flow from basic research through applied research development and, finally, production and operational use of ne ment and procedures. It also depicts integration of the vario of research to lead to development of new systems, or of new e to be incorporated into existing systems, based on a number of different research projects.

As an example, the development of a new escape breathing rests on basic and exploratory research in chemical and other of oxygen and in the physiological and metabolic demands associ with escape, and draws on information about breathing apparatus in applications other than mining.

From this base, applied research is conducted, aimed at so some of the problems associated with an escape breathing appara This in turn leads to development of improved apparatus or of a new approach. The development stage must incorporate

- Conceptual development to meet identified objective
- Development of technical means for attaining objecti
- Human factors considerations in setting design speci tions.

This last item involves consideration of such questions as:

- How and in what circumstances will the equipment be
- What degree of training (or retraining) will be requ
- What confusion may arise in use?
- What fail-safe or redundant features will be require

The development phase also involves considerations of cost and co effectiveness and of problems associated with commercial scale manufacture. Development usually culminates in the construction prototype.

The prototype is then tested, evaluated, and modified if necessary. If it is a laboratory prototype, there may be several iterations leading to a commercial prototype--i.e., one built as t commercially manufactured product would be. The next steps are de stration and finally tests leading to approval. Some number of de are built, laboratory-tested, and field-tested, and whatever appro is required by law is either granted or withheld. Once approved, device is ready to be manufactured commercially and put in to use.

The same sequence of phases is required in development of a "software" system.

Figure 3.2 shows, using the same conceptual scheme, what the program actually looks like. Conspiciously absent are the inward technology transfer, all of the "software," the integration of different projects (instead, development follows projects lines), a the outward technology transfer.

Figures 3.1 and 3.2 are greatly oversimplified, but they serve illustrate the committee's perception that the Bureau's post-disast research activity is an assemblage of projects rather than an inte- grated program geared to ultimate implementation, and that insuffici attention has been paid to "software."

The committee's conclusions about the program as a whole are:

1. The Bureau of Mines post-disaster research program during t past decade addressed most of the recommendations of the 19 NAE report. However the program did not go very far beyond these recommendations. In particular, it did not undertake

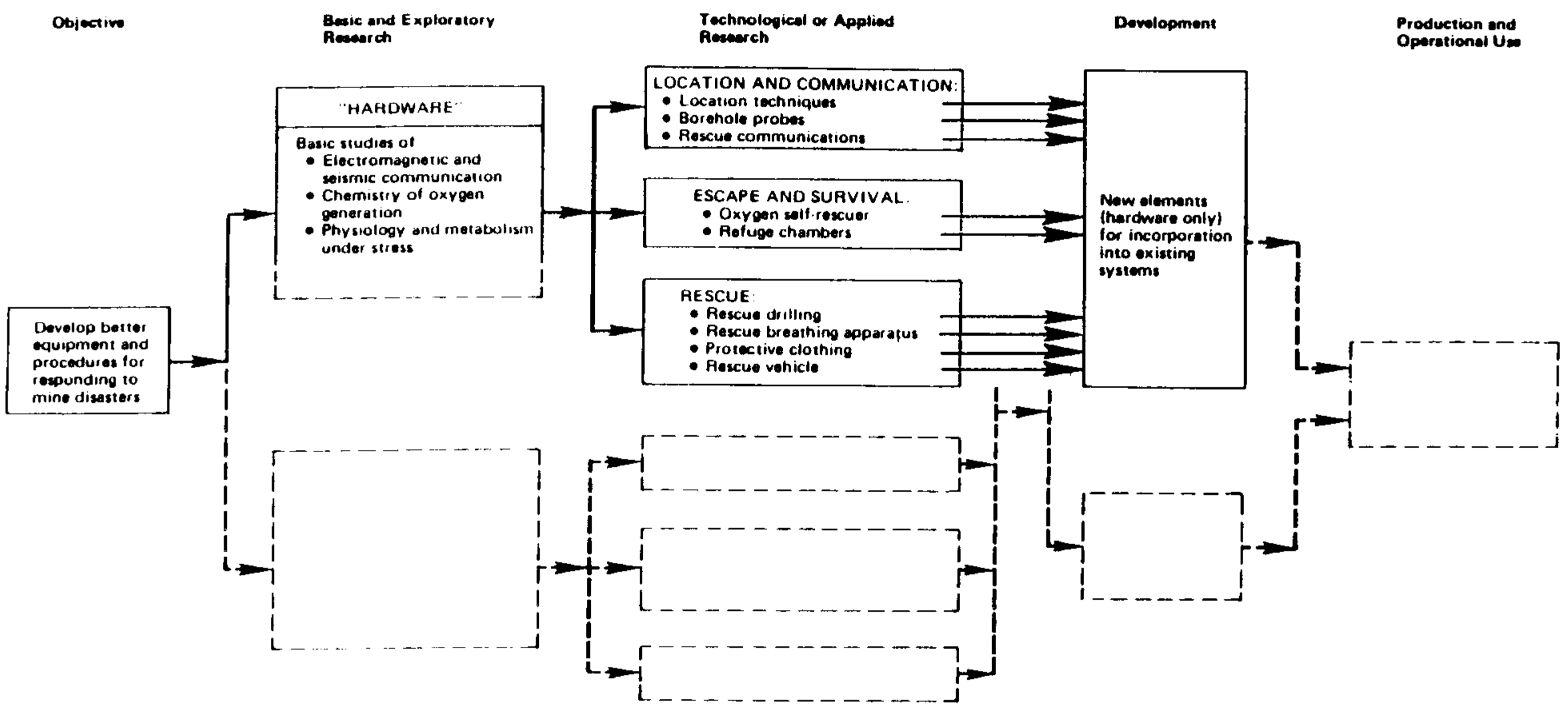

Figure 3.2 Schematic illustration of the Bureau of Mines post-disaster survival and rescue program, shown in the same conceptual scheme as Figure 3.1.

research in such areas as disaster training, disaster planning, and management, and analytical techniques for pre- and post-disaster analysis. In addition, some items in the 1970 NAE report were not addressed.

2. The USBM post-disaster research program was handicapped, especially during the early years of the decade, by a shortage of scientists and engineers with both the necessary expertise and extensive mine experience bearing on post-disaster survival and rescue.
3. The program has tended to favor technological development aimed at developing equipment, in contrast to more fundamental research endeavors. Even where fundamental work was conducted (e.g., electromagnetic through-the-earth propagation), timely integration of the results with more applied efforts has not generally been achieved. There has been no systematic effort to maintain the long-term continuity of expertise on which progress in fundamental research depends.
4. Although annual planning and evaluation procedures for individual projects improved over the years, there is no evidence of management procedures for integrating individual projects into a coherent effort leading toward achievement of broad program goals. Management has been project-oriented rather than program-oriented. This has slowed progress toward ultimate program goals. There is no systematic procedure for carrying a research problem from concept development through to final implementation. This is of particular importance as projects enter the transition from research to product development and field testing.
5. The procedure currently used to determine research priorities is biased in favor of short-term, inexpensive projects addressing near-term needs, that are deemed likely to lead to results acceptable to the mining industry.

The planning and management aspects of post-disaster survival and rescue will be discussed in detail in Chapter 4. Steps that would improve the flow of the entire R&D system from conception to implementation will be covered in Chapter 5. The recommendations offered in this chapter pertain largely to the content and management of the activities that the Bureau is now undertaking.

3.10 RECOMMENDATIONS

The committee believes that the Bureau of Mines post-disaster research program is important and should be continued. The committee's recommendations for changes in approach or emphasis fall into four major areas: program management, communications, life support and rescue operations, and technology transfer.

Program Management

1. The Bureau of Mines should institute management procedures that ensure continual evaluation of the interrelations between different projects and that ensure assessment of their combined effectiveness in achieving program goals.

2. The Bureau should institute a program for maintaining fundamental research efforts on a continuing basis.
3. The joint USBM-MSHA procedure for ranking proposed research projects should be examined to ascertain whether it meets industry needs. In particular, the bias in favor of short-term, low-cost projects should be critically evaluated.
4. In evaluating both proposed and ongoing research projects, the Bureau should use outside review by research scientists and engineers, manufacturers and users, and experts from related areas in other programs and industries. In particular, input should be sought from those with experience in the area under study (e.g., mine rescue team captains, miners who have successfuly barricaded, etc.), and from those who are likely to use the R&D results.
5. In developing new systems, the Bureau should allow time for adequate R&D, demonstration, and testing of key components of the system before proceeding with development of the integrated system.

Communications

6. Projects concerned with location and communication in disasters should place more emphasis on development of systems in which both transmitting and receiving equipment can be used underground.
7. More attention should be given to developing equipment for communication among rescue team members.

Life Support and Rescue Operations

8. R&D on an oxygen-providing escape breathing apparatus (EBA) should be continued, with major emphasis on a system that is designed for escape and can be carried on the miner's person.
9. Physiological and metabolic research, combined with simulation of mine emergencies requiring escape efforts, should be undertaken to establish realistic oxygen rate and time duration requirements for an EBA. This should include a reexamination of the validity of the one-hour requirement and, if the one-hour duration is found to be unnecessary, it should include determination of the appropriate time requirement.
10. A systems study should be undertaken to identify the differing design requirements and optimum strategies associated with the various options for meeting the necessary time duration requirement for an EBA, including cached devices and "piggy-back" systems. This will provide a rational basis for trade-offs leading to a system with which the miner's prospects for survival are maximized.
11. Continued research on oxygen sources for breathing apparatus should be carried out.
12. Continued research on rescue breathing apparatus is needed, with emphasis on an apparatus that provides greater comfort over longer working periods and on a helmet-breathing apparatus that promotes both comfort and utility.

13. The applicability of the refuge chamber concept should be examined in detail, with an examination of the relative utility of refuge chambers and other survival system elements (e.g., barricading techniques and mine layouts with a multiplicity of escapeways).

Technology Transfer

14. It is essential to have close cooperation between the Bureau, MSHA, NIOSH, state regulatory agencies, mining companies, unions, and manufacturers in the development and implementation of new devices and procedures. Ideally, rulemaking should evolve only after the new technology has been adequately tested and proven, using devices constructed as they would be in mass commercial manufacture. Companies should be offered incentives to participate in product development and testing of early designs. For this cooperative interaction to work it must begin at the research initiation phase and continue through research, product development, demonstration, testing, approval, and marketing.
15. The Bureau should make a more active effort to study technology developed in other industries and other countries that might be applicable or adaptable to mine disaster survival and rescue efforts in the United States.

CHAPTER 4. CONTINGENCY PLANNING AND MANAGEMENT

Anticipating emergencies and planning to meet them are vital steps in the development of procedures that will lead to quick, orderly, effective and efficient post-disaster response. Therefore, this chapter will address such topics as disaster planning, system safety analysis, emergency medical services, and emergency response mechanisms of the Federal government.

Whereas special precautions, preparations, and procedures may be necessary to reduce the threat to life and increase the chances of evacuation, escape, and survival in the event of a disaster, it is necessary to understand that there is no sharp line between disasters and accidents, particularly in planning for control. Much of the material in this chapter is therefore applicable not only to post-disaster survival and rescue operations, but also to general hazard control activities as well. In addition, most of the methodology discussed is already available but needs to be adapted to the mining industry.

4.1 DISASTER PLANS

As long as hazard sources such as methane, coal dust, water pools, electrical equipment, etc., exist in mines, there is always a possibility that accidents will occur. Good mine planning and operating practices, greater choice in equipment, increasing mandatory and advisory regulatory standards, and vigilance by management and labor have greatly reduced, but not eliminated, the likelihood of hazards and of loss of control during an accident. Loss of control--and the time frame within which this loss takes place--depends on the type of accident. Explosions, inundations, fires, and massive roof falls vary greatly in their potential for damage and the opportunities for re-establishing control.

Successful response to a hazard or accident depends upon many factors. Among the more critical ones are: (1) the existence of emergency plans with which the mine personnel are thoroughly familiar as a result of regular training, (2) the time available to make judgments and (3) the mental ability and preparedness of the individuals on the scene. The appropriate actions to take during the first few moments after an accident depend on the type of accident. Quick and correct response is vital. It is necessary to explore the source, identify corrective actions, and then take the best action to bring the incident under control. Sometimes it is necessary to abandon efforts at control and to redirect resources to safeguarding personnel.

Review of past disasters indicates that at times even a well thought-out disaster plan is not well implemented. This happens most frequently when the disaster occurs at odd hours, on weekends, or over holidays when the usual or more experienced management personnel are not available. Such instances may result in an assistant delaying evacuation of the mine in order to "see for himself" or to personally attempt to "fight the fire" or "save the lives." When the hazard is not immediately brought under control, the delay in evacuation or other appropriate action may result in loss of life, lengthy rescue efforts, and loss of mine operation for a prolonged period because of disaster damage.

While the first few moments after discovery of a hazard are crucial, the total plan for response to a hazard must be broader in scope, encompassing a number of steps from hazard recognition to final restoration of normal operations. These steps must be described in writing without ambiguity, and instilled in the mine personnel through rigorous education, training, disaster simulations, and drills. The instructions and training must clearly explain when to abandon the control effort and to initiate the evacuation procedure. Among the steps that may be required are: (1) development of a competent integrated organizational structure that will function even if key members are absent; (2) development of an emergency communication procedure that clearly identifies the essential information that must be noted and communicated upon discovery of a hazard; (3) hazard recognition and control procedures; (4) evacuation, escape, and survival procedures and equipment; (5) rescue procedures and equipment; and (6) surface organization, facilities, outside sources of technical assistance, etc., to support the emergency operations.

The lack of suitable emergency procedures and equipment can be tragic, as can a lack of familiarity with these. Review of past disasters suggest that in some cases escaping miners may not have been familiar with the escape equipment's operating characteristics, and this may have materially impeded their escape efforts.

When a disaster has occurred and rescue and recovery work is necessary, federal and state officials must be informed. An advisory body consisting of the mine management, federal and state mine officials, and union representatives should be formed as early as possible. The purpose of the advisory body should be to assist in planning rescue and recovery work, and to provide support and advice to the person in charge of the rescue. A review of past disasters does not reveal that the multi-jurisdictional and legal issues involved have affected the conduct of the rescue and recovery work. However, the committee has received the impression that, at least in the initial stages, there is some confusion. There is apparently no clearcut procedure defining the division of responsibility and accountability between federal, state, and local agencies, mine operators, labor unions, and others, in the event of a mine disaster.

There is no question that there is a great need to exercise extreme care in making decisions and taking actions that can cost lives, and all inputs to the decision-making process are useful and must be welcomed. However, there must be a single person in overall control of the rescue and recovery operation, with full responsibility for execution of the actions decided upon. This individual should be identified at the earliest possible time, and should be knowledgeable in rescue and recovery work and in the management of emergency operations. In the event of a dispute as to what decision should be made, it is essential that someone have clear-cut responsibility; otherwise, not only will confusion result but valuable time will be lost. Because of the heavy responsibility that the person in charge of the rescue operation bears, and the need for quick and decisive action, means should be sought to protect that individual from being hampered in execution of the job by undue concerns about legal liability or about the less crucial "housekeeping" aspects of the emergency operation.

It is important to ensure that in time of disaster the usual operating methodology is changed as little as possible. For example, communications will be more reliable if mine personnel can use the regular communication system (if it is operational) than if they must deploy a new system and hope that everyone will be able to properly use the equipment.

Plans must take into account the need for crowd control. Families and on-lookers can be expected to be on site in a short time. Disaster plans must not only address prevention of unauthorized personnel from obstructing or even entering the mine, but must also identify areas where they can wait, and must make provisions for local clergy, food, and perhaps even housing during prolonged operations in inclement weather. Ties to local community services such as law enforcement and medical support should be provided. Equally important is the need to issue clear and detailed reports to the news media and briefings to families of the affected. Important though these aspects are, they should not be permitted to distract the individual in charge of directing the actual rescue operation.

No one can totally plan for a major disaster with all of its unexpected emergencies. However, a good disaster plan, understood by all and practiced on a regular basis, will help to insure an orderly and efficient transition from routine operations to effective disaster response.

4.2 THE SYSTEM SAFETY APPROACH

Current approaches to hazard identification in mining rely heavily upon the study of past accident experience. Whereas this has provided valuable information to aid safety performance, an inherent limitation is that the hazard must occur to reveal a failure in the system or the program. What is needed is an approach by which existing systems, and systems under design, can be analyzed for potential hazards. There is no reason to believe that a reliable measure of safety exists unless necessary controls have been applied to ensure that preventable hazards do not occur, and unless an emergency procedure has been established to provide for unpreventable hazards.

During the early 1960s, a new conceptual approach to safety known as "system safety" evolved. This approach, developed specifically for the space program, made it possible to generate safety statistics before the deployment of new products and systems--i.e., to ensure safety on the basis of analysis of the system rather than on the basis of past history. In the space program this involved (1) making products of unexcelled quality and reliability, (2) identifying the failure characteristics of each unit and the impact of the unit's failure on the total system, (3) increasing system reliability by providing alternatives to permit safe functioning of the system in the face of failures of individual units, and (4) developing emergency procedures for contingencies. While the objectives of the space program permitted incurring larger costs in the interest of safety than may be practical in other programs, much of the system safety approach is applicable in other areas, mining among them.

The system safety approach is a composite of elements from a number of diverse disciplines such as systems engineering, statistics, reliability theory, information theory, control theory, management, and behavioral psychology. The "system approach" to the safety problem focuses on the system taken as a whole, and not on its parts separately. It involves the interaction of people, machines, and environment within procedural constraints. It does not imply that the system must be risk-free, but rather that risk can be identified, managed and controlled.

This systematic approach as applied to mine safety should include all phases from conceptual formulation of the system through design, testing, evaluation, construction, training, approval, operation, and maintenance. It requires (1) a logical examination of all the elements of the system and their interactions, (2) identification of all sources of hazards, (3) calculation of the probability of hazard occurrence, (4) a search for the available options for hazard elimination or minimization, and in the extreme case, provisions for evacuation, escape, survival, and rescue, and (5) an analysis of costs and of problems associated with implementation and other procedural aspects of the various alternatives.

Appropriate management and organizational structure are essential because overlapping tasks with unclear limits of responsibilities can lead to confusion and system failure. Development of data to support managerial decision-making is of great importance. The data and information should come from both external and internal sources. The external sources include the general public, government at different levels, other organizations involved in similar activities, and professional bodies which share an interest in the system in question. Internal sources include field reports, design reviews, periodic audits, hazard analyses, and accident and disaster investigations.

There are several aspects of mining in which the system safety approach can be applied. It can be used by regulatory agencies to evaluate mine plans and procedures before approval, and to conduct "post-audits" of disasters and accidents. It can be used by research organizations to unearth new sources of hazards in existing systems, to conduct "pre-design" audits for developing specifications and standards, and, through "post-design" audits, to evaluate the developed product or system for effectiveness. It can be used by mine operators to evaluate existing systems, suggest modifications to operations or equipment or both, and develop training programs.

Hazard analyses, both "pre" and "post," can be qualitative or quantitative. A qualitative analysis is a non-mathematical but logical analysis of all the factors that affect the safety of the system and its elements. It is a prerequisite for quantitative analysis. Quantitative analyses are necessary to establish such things as frequencies of occurrence and magnitude of risks. Without distracting from the value of qualitative analysis, quantification of hazard potential must have a high priority. Unless hazards can be quantified and funds for safety research and development justified in terms of potential hazard reduction, there can be considerable outlay of time and money with no way of knowing its effectiveness and with no guidelines for future investment.

4.3 EMERGENCY MEDICAL SERVICES

The federal mine regulations* require that selected persons be trained in first aid, and that such training be made available to all miners. First-aid training programs are also mandated for rescue teams, and the regulations require refresher first-aid training for all of the aove. Arrangements must be made by each mine for a licensed physician, clinic, or hospital to provide 24-hour emergency medical assistance for any injured person at the mine. Likewise, arrangements must be made for an ambulance or other means for transporting the injured to a medical facility, and for the establishment of communication services between the mine and the nearest point of medical assistance. Other requirements for emergency medical training are in the proposal and evaluation stages.

Emergency medical services in mines have two major functions: (1) day-to-day response to non-disaster illnesses and injuries; and (2) disaster response where there may be a number of injured personnel and their removal from the mine is hindered by fire, roof fall, explosion, or other hazardous situation.

The injuries sustained in non-disaster situations appear to be of the same general type and severity as seen in non-mine medical services. Most of the larger mines have "emergency room" facilities staffed by trained Emergency Medical Technicians (EMTs). Routine injuries and illnesses are seen here, treated, and the miners are either returned to work or transferred to the local hospital. The time between injury and treatment is not prolonged. Very small mines, on the other hand, are not capable of maintaining such facilities, and must rely on the first aid training of their supervisory personnel. They may also utilize community ambulance services and emergency rooms. Treatment is still generally prompt.

In a disaster, on the other hand, there may be delays of hours or even days before the injured reach the hands of a medical professional, and survival may well depend on the emergency medical care capabilities

*30 CFR Chapter 1, Parts 57.18 and 75.1713 of those who happen to be nearby. Therefore making adequate provisions for emergency medical care in the absence of a health professional is an essential part of disaster planning.

Unavailability of properly trained emergency medical personnel does not appear to have been a problem in past mine disasters. Nevertheless it is worthwhile to take a close look at what is involved in providing emergency medical care in mine disasters.

Efforts by the federal government to upgrade the level of pre-hospital emergency care has led to the evolution throughout much of the country of an integrated emergency response system with excellent coordination, not only among emergency medical programs, but also with fire, police, public works and disaster response systems. Coordinated communication systems are evolving across the country that require only one radio in an emergency vehicle but allow it to communicate directly with all other agencies by interfacing frequencies at the radio communication center. Likewise, intercommunication with the telephone system is becoming commonplace via the communication center link. A mine disaster response system that does not take this modern program into account and use its component parts will inevitably be a system with an inferior capability for coordination and response.

There are four major phases of pre-hospital care.

First Aid: Ideally, each miner should know American Red Cross First Aid and Advanced First Aid and cardiopulmonary resuscitation (CPR). Such a capability on the part of each miner would mean that everyone in the mine would have an elementary knowledge of how to prevent further injury while awaiting the arrival of trained personnel.

First Responder: This is the minimum level of emergency care training for people who are not involved in day-to-day care of emergency patients but who, because of their proximity to potential injury, may have occasion to stabilize patients until more definitive care is available. The nationally standardized course consists of about 40 hours of instruction. First responder training is appropriate for employees such as mine foremen who are in positions of authority and who may be immediately available to the ill and injured.

Ambulance Attendant: The ambulance attendant should be an Emergency Medical Technician (EMT) and should have completed the nationally recognized 81-hour course and should have had at least 10 hours of in-hospital experience. The EMT is knowledgeable in the primary care and transport of the patient. This level of training requires the knowledge of specific skills, and these skills must be used or practiced frequently to be sure that they are maintained. Some smaller mines may find the use of miners trained as ambulance attendants so infrequent that consideration may be given to the use of EMT personnel from the surrounding community. Modern day communications make such a system feasible.

Advanced EMT and Paramedic: The final step in pre-hospital care is provided by the advanced EMT and the EMT-paramedic. The paramedic has a broader base of training. The advanced EMT is trained in one or a few of such specialized areas as intravenous (IV) techniques and cardiac care. These people are normally allowed by state law to perform, under the supervision of a physician, such invasive procedures as starting IV's, placing chest tubes, cardiac defibrillation, etc.

The availability of such personnel will be limited to very large mines or communities. In most instances, their services would be obtained from the EMS community of a nearby metropolitan area.

There is currently an effort to identify other categories of EMT personnel with more limited training for specific functions in a specific setting. One such proposal is for the EMT-M for mining. The 81-hour EMT-A course curriculum would be reduced to around 40 hours by elimination of sections such as obstetrics, and by reductions in other areas with little impact on mine emergencies. There is currently no nationally or medically accepted standard for such a course, but several groups such as West Virginia University and NIOSH have proposed suggestions for an EMT-M curriculum. Should such a level of training be accepted nationally, these people might well become an important part of the third level of pre-hospital care in the mining industry and, in at least some mines, serve in place of the EMT-A, or between the First Responder and the EMT-A.

Several problems arise in defining the specific levels of training needed for pre-hospital emergency medical care in mines.

1. Statistics for type of injury do not appear to be available. Most of the statistics collected relate to prevention of injury, not to cause of death or disability. Thus, a report will indicate that a miner was injured or killed by a roof fall. Whether the cause of death was a crushed chest, a hemorrhage, or a head injury is usually not recorded.

2. A very well trained person who does not use the skills that have been learned may end up being unable to properly provide the needed services--or even worse, may provide the wrong services in a given set of circumstances. Large mines employing many people may be able to provide (1) at least EMT level of training for some of their personnel; and (2) an opportunity for frequent use of their skills in a nearby community. Smaller mines may need to be satisfied with first aid training, and may have to rely on the surrounding community for the EMT type of care and transport.

3. Pre-hospital service must be economically feasible on the basis of proven need. Having paramedics trained and on hand in every mine would be an inefficient use of resources. Moreover, most of them would be of little or no use in time of need, due to lack of utilization of their skills on a day-to-day basis.

Most mines will not be able to train and maintain paramedics. However, first aid training and training of first responders and ambulance attendants is reasonable and possible. Coordination of the emergency medical facilities in the community with facilities at the mine will insure the availability of well-trained people, will prevent duplication, and will avoid reliance on people who were trained to a given level but, because of lack of practice, are no longer able to provide the excellence of care that is expected.

4.4 EMERGENCY COMMUNICATIONS

An adequate communication system, like the nervous system of the body, makes possible the coordination of all other systems. It can be the key to rapid detection of the emergency, early notification of essential personnel, and coordinated response. Wherever possible the communication system should be used on a day-to-day basis, not only to insure its reliability in operation, but also to insure familiarity with the equipment in times of disaster.

Many communities have evolved consolidated emergency communication centers for both day-to-day operations and disaster response. Such communication coordination allows each system (law enforcement, fire-fighting, emergency medical services, National Guard, etc.) to operate on its own communication channels for day-to-day operations, but provides the capability for interconnects between the various systems, including telephone lines, in times of disaster. This obviates the need for multiple radio systems to insure cross-channel communications --for example, between police and EMS, police and firefighters, etc. By tying the mine safety system into such a center (whether by telephone line or radio), rapid response by off-mine disaster organizations in the event of a mine emergency can be greatly enhanced.

4.5 THE FEDERAL GOVERNMENT'S MECHANISMS FOR RESPONDING TO MINE EMERGENCIES

While there are a number of Federal government mechanisms for responding to emergencies generally (e.g., the Federal Emergency Management Agency, the Civil Defense Program, the Emergency Broadcast System, etc.), the Mine Safety and Health Administration has specific responsibility for responding to mine emergencies. One element of MSHA's response is its Mine Emergency Operations group, discussed earlier, which provides facilities and equipment for communications, logistics, probe and rescue drilling, gas sampling, etc. Other elements of MSHA's response are assembled, ad hoc, from the ranks of MSHA's inspectors and district managers, and from MSHA's Technical Support division.

The four topics discussed earlier in this chapter--disaster planning, system safety analysis, emergency medical services, and emergency communications--all have a bearing on MSHA's response mechanisms. Ideally, if disaster response were treated as a complete system, all four would interact: emergency medical services, along with emergency communications and other aspects of disaster planning, would be developed by mine operators under federal guidelines; plans would be approved by a federal agency; and the techniques of system safety analysis would be applied both to the operators' plans and to the federal agency's response mechanisms.

The groundwork for such a systems approach to mine disasters does not yet exist, and will not exist until a foundation is laid through research in disaster simulation, disaster plan assessment, training techniques, and the like. However, the techniques of systems analysis could be applied, today, to MSHA's disaster response mechanisms.

Two aspects of MSHA's emergency response system are of concern to the committee. First is the adequacy of the present arrangement, and particularly the ability of MEO and other elements of MSHA to provide the services needed in the event of a disaster. Second is the need for investigating alternative emergency response mechanisms that might be more effective or more economical than the current MEO. The two are obviously interrelated. The infrequency of disasters makes it necessary to approach them both from a systems, rather than a historical or statistical, point of view.

It is clearly essential to have a capability for mobilizing and deploying the equipment and facilities necessary to aid in the rescue of miners who may be trapped underground. In this respect, all the components of MEO--the location devices, communication equipment, TV probes, gas sampling systems, etc.--are important and can contribute to the conduct of rescue and recovery operations. However, a systems approach should be taken in examining such factors as (1) the condition of the equipment, (2) the experience of the crew with the equipment, (3) the time required to mobilize the equipment and the crew, (4) the travel time to the deployment site, and (5) the set-up time for the equipment. This will aid in developing optimum procedures, optimum locations for storage of equipment and supplies, and optimum means for transporting equipment and personnel to the disaster site. In addition, to ensure that MEO does not run into unanticipated problems during an actual emergency, deployment of the system under simulated disaster conditions must be carried out. Further, the equipment must be constantly updated with improved versions as they become available, if they are more reliable or more quickly deployable. Financial and manpower requirements for all this, in terms of both capital investment and operating costs, can be substantial.

It would be tragic, in the event of a disaster, not to have available a facility like MEO--particularly when it is technologically feasible to have one. Because of the rarity and potential severity of disasters, justification of the cost of such a facility should not be based solely on statistical considerations such as the number of lives likely to be saved, or on purely financial considerations. On the other hand, development of disaster response facilities optimally suited to meet the needs of mine emergencies around the country must be subject to rigorous assessment of need and cost.

The committee notes that MSHA's present facilities and organization may not be the most ideal, particularly when viewed in the context of the geographical distribution of mines and the geological diversity of mining conditions. Timely mobilization of the massive rescue drilling equipment may not always be possible if such equipment is stored at only a few locations. Some other kinds of equipment--such as communications and sampling systems--are more mobile than the rescue drills, and are more easily transported (by air, for example) and quickly deployed.

Duplicating all emergency response facilities in mining districts around the country may not be feasible under realistic budgetary and manpower constraints. Even if such facilities could be duplicated, the requirements for upgrading the equipment and maintaining skills through simulated disaster drills could probably not be carried out as expeditiously as is necessary to keep the facilities and personnel in satisfactory operating condition. And operating such a facility without adequate maintenance and frequent drills may not serve the intended purpose, which is to respond to a "deploy" order with the most reliable equipment and personnel in the shortest possible time.

Another alternative would be to have available, at suitable locations in all mining districts, the sampling, communications, and other kinds of emergency equipment that can be readily and quickly deployed. These could be provided and maintained by MSHA itself, or by state and local governments with technical and financial assistance from MSHA. (With regard to drilling capability, MSHA maintains a list of available drilling capabilities in each mining district, and can mobilize these facilities if the need arises. This makes it generally unnecessary to deploy MEO's small drill.) Several such decentralized regional facilities, established in cooperation with state, local and regional emergency response agencies, may be a more effective response system than a limited number of centralized MEOs.

4.6 RECOMMENDATIONS

The committee's recommendations fall into four main areas: disaster planning, the system safety approach, emergency medical services, and mine emergency operations.

Disaster Planning

Adequate disaster plans, appropriate training of personnel, and continual assessment of plans and training through drills and disaster simulations are essential elements of disaster preparedness.

Guidelines should be established for use by mine operators in developing disaster plans and training programs and by MSHA in evaluating those plans and programs. Among the critical elements of disaster planning are provisions for identifying, immediately after a disaster occurs, the individual who will "take charge" and be responsible for the disaster response operation, and provisions for the division of responsibility and accountability among the federal, state, and local agencies, the mine operator, the union, and other groups participating in the disaster operation.

While this is clearly an MSHA responsibility, the Bureau of Mines should provide the necessary foundation by conducting research aimed at developing methodologies for testing and evaluating mine emergency plans using simulation and other appropriate techniques. These methodologies should be made available to MSHA and to the mining industry. Similarly, methodologies should be developed both for using simulation and other techniques to train miners, mine managers, and government personnel in disaster operations, and for testing the effectiveness of such training.

The System Safety Approach

There should be widespread application of the techniques of system safety analysis to mine disasters. This will require considerable research and development to develop specific techniques appropriate for use in mines.

The system safety approach should be applied by the Bureau of Mines throughout its R&D program and in its determination of research priorities. It should be applied by MSHA to its post-disaster audits, its rule-making, its emergency plan approval procedures, and its mine emergency operations. It should be applied by mining companies to the determination of appropriate organizational structure for disaster response. And it should be applied, more generally, to all aspects of mine safety.

System safety analysis should also be applied to the development of systematic methods for identifying and investigating potential disaster situations. It is as important to know why some of these <u>do</u> <u>not</u> develop into full-scale disasters as it is to know why others <u>do</u>. Procedures for identifying and acquiring data on such situations, analogous to the aviation safety procedures for reporting "near misses" of aircraft, would be helpful.

Emergency Medical Services

A mine's emergency medical care system should be integrated with that of the local community in whatever manner promotes greatest effectiveness. No one approach will be appropriate to all mines or all communities, but guidelines and standards should be provided, and the plan developed should be evaluated as part of the mine's emergency plan. Similarly, the mine's emergency communication system should be integrated with the local emergency medical communication system, and with other appropriate local communication systems (e.g., the local civil defense system).

Emergency medical care training for miners should be developed and evaluated in light of realistic assessments of need and utilization. Ongoing refresher training must be a part of this system.

In order to accomplish this, and to identify other means of protecting miners from the consequences of serious injury during disasters, it is essential to collect and analyze data on the <u>medical</u> causes of death or disability in mine disasters, as well as on the incidents that lead to death and disability. This will make it possible to determine the adequacy of the medical training, equipment, and procedures in the mine emergency response system, and to identify research needed to enhance the likelihood of survival for those injured in disasters.

Mine Emergency Operations

The federal government's mine emergency response capability, and specifically MSHA's Mine Emergency Operations (MEO) group, should be evaluated in the context of the complete emergency response system, and with particular regard to requirements for the maintenance and drills needed to ensure that response is rapid and effective.

The feasibility and effectiveness of mechanisms other than the present MEO structure should be examined to see whether other strategies for storing and deploying the most potentially useful equipment (e.g., seismic locators and borehole probes) would be more responsive to the need or more cost-effective.

CHAPTER 5. CONSIDERATIONS PERTAINING TO GOVERNMENT SPONSORED RESEARCH AND DEVELOPMENT

Research and development relating to escape, survival and rescue equipment is probably more demanding than research for almost any other mine health and safety equipment, because while the equipment may be used only rarely, when it is used lives will depend on it. Failure of escape, survival, or rescue equipment is worse than the absence of any equipment, as its presence provides a sense of security and may deter the miner from seeking other means of egress. The highest degree of reliability must be demanded of this equipment.

In mining, much of the R&D in escape, survival and rescue equipment is done by government agencies, either in-house or under contract. The limited size of the market, the uncertainties associated with rule-making, and the requirement for testing and approval by governmental agencies all serve as barriers to investment in such R&D within the private sector. Consequently, government finds itself in the role of proposing and underwriting the development of new technology. Market analysis may not play a dominant role in these decisions. Moreover, the private sector may not share government's perception of the problem (and the solution) and government may have to underwrite not only the R&D, but implementation of the results as well, either by regulatory mandate or by economic means such as tax incentives or subsidies. Nonetheless, mining companies, unions, equipment manufacturers, and others in the mining community have important roles in ensuring that research programs are effectively directed toward useful purposes.

In assessing the contribution that research and development can make to post-disaster survival and rescue, a number of concepts must be defined and clarified. First is the nature of the R&D path from initial identification of a need, a problem, or an opportunity, through the somewhat overlapping activities of broad-ranging <u>basic research</u>, objective-oriented <u>exploratory research</u>, project-oriented <u>technological or applied research</u>, specific <u>product development</u>, and finally, <u>implementation</u> of R&D results. Second is the difference between R&D conducted by the private sector where success is measurable in terms of sales, profits, or other economic considerations, and R&D conducted by government to benefit the public welfare, where the object is improved health and safety, environmental protection, or other similar goals that are not readily measured in economic terms. Finally, there is the different nature of the demands on escape, survival, and rescue equipment and the impact of these differences on R&D programs in those areas.

5.1 The Idealized R&D Process

The R&D process is often conceived of as consisting of a number of loosely defined elements such as "basic research" and "applied research,""research" and "development," or "research" and "implementation of research results." There have been many attempts to define these components of R&D: for the purpose of this report, the discussion by White* is particularly appropriate.

White considers four broad bands of research activity that are different in nature, although they do overlap and merge into each other. First, in the sense that it is likely to precede the others in time, is basic research. Basic research can be completely free or it can be directed toward some broad underlying mission, but it is not bound by the time schedule of a particular project and it is open-ended, in the sense that the researcher is not striving toward some specific goal but is willing to go in whatever direction the research leads. Second, and closely allied to this, is exploratory research—research that is oriented toward a specific objective, but is nevertheless open-ended and not tied to specific project objectives.

Third is technological research, also called applied research, objective-oriented research, or product-oriented research. Here the previous research has led to an innovative idea, and further research is necessary to determine its feasibility and in fact to take the concept from an idea to the point where its likely viability as a marketable product, or a solution to a technical or social problem, can be ascertained. This stage often includes assessment of costs and markets and assembly of the information needed by top management in order to decide whether or not to go ahead with development. Development is the final stage. Here research methods are used to take a process or product that is conceptually understood to the point where it can be put to practical use.

These four phases of research activity do not necessarily follow each other in recognizable sequence. A fundamental idea may be sufficiently complete in itself that it can be applied directly to a practical operation. On the other hand, development may be well under way before it is realized that there is a need for some fundamental research.

The decision to commit resources to development is perhaps the most important decision in the R&D sequence. Before this decision is made, the amount of money spent is often relatively small, as is the involvement of staff and facilities outside the research department. Results often are not and cannot be hurried. With the decision to proceed with development the pace steps up. The development engineer

---

*The discussion in this section follows that in White, P.A.F., "Effective Management of Research and Development," John Wiley & Sons, New York, 1975, pp. 5-9.

enters the picture alongside the research scientist whom he will eventually replace in the management of the project. Market research and market development, along with other considerations concerning implementation of the final result, begin to receive attention, and the amount of money spent increases. In fact, development costs may be as much as 10 times greater than research costs.

Successful development is followed by a final <u>production</u> stage, in which R&D is no longer involved. Here the R&D result is produced and sold or incorporated into operations or in some other way put into practical use.

From a managerial point of view, it is helpful to consider the following sequence.

- <u>Stimulus</u>: A company or organization is provoked by some need into expressing the requirement for a new idea, and a member of the organization gives expression to a new idea potentially capable of meeting the need.
- <u>Conception</u>: A plan of action to give form to the new idea is conceived.
- <u>Proposal</u>: A formal proposal to adopt this plan is developed and presented to management.
- <u>Adoption</u>: After assessment by appropriate specialists, the proposal is accepted as something for the organization to make its business.
- <u>Implementation</u>: All the steps necessary to bring the new idea to the point of being a marketable product, or to put it into operational use, are undertaken.

From this perspective, basic and exploratory research usually play a major role in "stimulus," while technological research and development, along with such non-research processes as market development, production, quality control, advertising, sales, and service, all fall under "implementation."

The sequence, along with the relative emphasis of the roles of the research scientist, development engineer, and production manager, is illustrated schematically in Figure 5.1. In its early stages, the process is subject primarily to "scientific or technological push." Beginnning with the decision to start development, it becomes increasingly subject to "managerial pull" and "market" considerations.

5.2 R&D in the Private and Public Sectors

In the private sector, where the ultimate goal is manufacture of a new product, the success of the R&D effort can be measured in sales. Where the goal is improved efficiency in an operation, success may be measurable in reduced operating costs. As long as there is some economic measure of the result, "success" can be quantified. Even measures relating to health and safety, environmental protection, and other public welfare goals may be amenable at least in part to economic assessment in terms of time lost from work, costs of early retirement for health reasons and of training new workers, and costs for legal defense in regulatory proceedings, costs of paying fines, costs of lawsuits, etc.

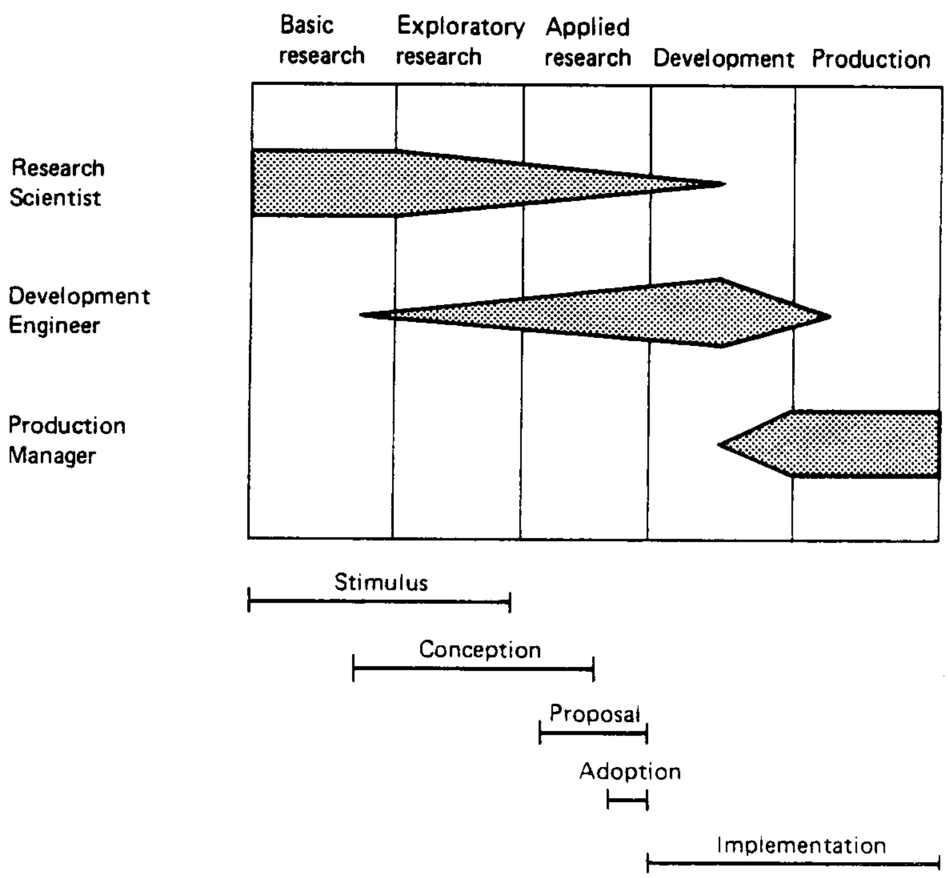

Figure 5.1 Schematic illustration of the R&D process and the relative roles of the scientist, engineer and production manager

In the government sector the picture is much less clear. While in principle social welfare programs involving health and safety and the environment can be measured by the cost to society of mitigating or compensating for the effects of problems that are not corrected, these are often long term costs and are not generally calculated as part of the "cost of doing business." Moreover, while the ultimate purpose of such government programs is the public well-being, the way in which government achieves this purpose is usually by enacting and implementing laws and regulations. In allocating resources for the R&D needed to implement these laws and regulations, a legislative or administrative decision is made concerning the level of funding that will be devoted to a particular program and this, rather than market considerations, dictates the economics of the effort.

Moreover, whereas in industry R&D and production are often internal to one organization, government R&D addressing health and safety usually involves government doing the research, private manufacturers producing the equipment, and mine operators purchasing and using the equipment. Thus there are many actors, all with different motives. This gives the "implementation" part of the R&D process a distinctly different flavor from what it has in private industry. In particular, funding priorities are usually determined by the importance of the goals, rather than by economic considerations.

A further distinction that is useful to keep in mind is that between relatively well-bounded, single-discipline research and more loosely bounded, multi-disciplinary research. Development of a new method for radio transmission may involve only electronic engineering; development of a new rescue breathing apparatus may involve chemistry, materials, human factors, mechanical engineering, etc. Complex safety systems are certain to require a systems analysis approach. The greater the complexity of the task, and the more disciplines or areas of expertise likely to be involved, the greater the challenge to management.

There are three essential elements in the ultimate success of an R&D venture: proper identification of a need; successful research and development to meet that need; and successful implementation of the research results. The last of these is crucial, for without it the previous effort will be wasted. Successful implementation requires user acceptance, which in turn depends on cost, appropriateness of design, human factors considerations, quality control in manufacture, and effective marketing. Recognition of the various participants in the process and their differing perceptions must be explicitly addressed. For example, if the research managers in the Bureau of Mines, the regulatory officials in MSHA, the mining companies, the unions, and the mine equipment manufacturers do not agree on (1) the existence of the need and (2) the degree to which the R&D addresses this need, there will be a great deal of resistance to implementing the R&D results.

The steps necessary for successful transfer of R&D results into operational practice must be developed specifically for each R&D project. Some general comments can, however, be made. No product can be successful if it does not have user acceptance. The likelihood of acceptance will be enhanced if those who ultimately will be involved in implementation--for example, equipment manufacturers, operators, unions, etc.--are involved from the beginning. Unless their views and their economic considerations are taken into account, the necessary ingredients for a successful R&D effort may be missing.

In a sense, the concern for production and implementation must begin at the stage of problem identification, and be active throughout the R&D process, rather than being a final step that starts when development is complete. It is not enough for government to <u>invite</u> input from industry and labor. It is government's responsibility to reach out and actively solicit this input, and it is the responsibility of the mining companies and unions to actively participate in the process.

There are a number of ways in which this can be done, and there is no one "correct" way. A specialist in implementation of R&D results could be assigned to each proposed project from the start, before projects are ranked and funding priorities assigned. This specialist can contribute an assessment of ultimate user acceptance, and can maintain liaison with potential users throughout the project's life, seeking reactions, suggestions, and evaluations. Other approaches include advisory bodies, boards of consultants, ad hoc meetings of mine safety directors, industrial applications committees in professional societies, etc., so long as these groups function at the "nuts and bolts" level rather than at the policy level.

In seeking input from the "industry," it is important to recognize that the mining industry is not monolithic. There are a number of organizations representing, in different ways, the different points of view that arise due to the diverse nature of the mining industry. These organizations include the American Mining Congress, Bituminous Coal Operators Association, National Coal Association, National Independent Coal Operators Association, and National Crushed Stone Association. All of this puts still more of a responsibility on government to establish means of drawing on the expertise and perceptions of the industry as research is going on.

Within government too the picture is not as simple as it might appear. Where different parts of the R&D sequence are the responsibilities of different agencies, it is particularly important to be clear about the areas of overlap so that decisionmaking by management is not impaired. In the case of mine disaster survival and rescue, the Bureau of Mines has much of the responsibility for research and development, while MSHA and NIOSH have much of the responsibility for initial identification of needs and, ultimately, for testing, approval, and implementation. NIOSH also has some responsibility for research. The joint MSHA-USBM project ranking procedure discussed earlier is a formal mechanism for effective management at the research funding stage although, as indicated in Chapter 3, it could be improved. Mechanisms are also needed to foster appropriate decisionmaking at the development-implementation end of the process.

5.3 <u>Design Considerations for Escape, Survival, and Rescue Equipment</u>

There are important distinctions between the equipment used for escape and survival and that used in rescue operations. <u>Escape</u>

equipment must be available to all miners in an emergency, and is used to survive for a short time in a hostile environment while moving to safer areas of the mine. Adeptness at using the equipment is not readily developed as it is not regularly used. Furthermore, when the time for its use arises, the miner may be under considerable stress, and time may be a serious limiting factor. Therefore, the equipment must be simple to operate, must have clearly understandable instructions, and should be deployable with considerable ease.

From a human factors aspect, the equipment must be totally unobjectionable to the miner. Frequent inputs from industry, unions, manufacturers, and life support R&D efforts in other agencies must be sought and incorporated in the development effort to ensure that these design criteria are met and that the resulting product is accepted. More important, the design specifications must be correctly established for the activities involved in escape. Several designs should be evaluated, and the selected design should be studied in detail through pre-design tests, employing such techniques as failure mode and effects analysis and fault-tree analysis to ensure that the product will work under expected conditions, that it will meet requirements, and that operating procedures are in fact simple and understandable.

Frequent demonstration and briefing meetings should be held with all concerned parties to discuss developmental problems and any need that may arise for changes in research objectives and goals. Evaluation tests similar to pre-design tests should be performed on the designed product. This should be followed by extensive tests to ensure that the product will perform as required under worst-case conditions. After this phase, there should be field tests, trials and demonstrations. Before full scale deployment, the deterioration in performance characteristics over time (particularly in the underground mine environment of dust, moisture, and vibrations) must be established, and on the basis of this maintenance and replacement schedules must be developed.

Survival equipment must enable the survivors to isolate themselves from the hazards posed by the surrounding environment. These hazards depend on the type of emergency, and can be life threatening due to toxic gases, generation of explosive atmospheres, excessive heat, lack of oxygen, collapse of workings, etc. Therefore the requirements and applicability of survival capability and equipment may be quite variable. Improved mine design considerations, such as the provision of two escapeways from any work location (one of which will be in the fresh air intake), greatly reduce the likelihood of a situation in which evacuation or escape becomes impossible. Also, providing miners with oxygen self-rescuers should aid in evacuating and escaping through airways that may contain irrespirable atmospheres, further dimininshing the likelihood of entrapment. However, being trapped is a contingency that must be anticipated and provided for by careful evaluation of the alternatives for survival. Much of what has been said above with regard to the development of escape equipment applies to survival equipment as well. However, there are some important implications and differences.

Refuge chambers have been suggested as a means of enabling trapped miners to survive. The dangers of promoting a refuge chamber as anything other than a "last resort" capability should be stressed. When it has been decided that a point of no return has been reached with regard to the control of the emerging disaster, evacuation and escape should be the first alternative. It is important that miners not try to use prematurely a refuge chamber when there may be means to escape. Once inside a refuge chamber it may mean staying there until rescued due to the hostility of the environment outside the facility. It is also important to ensure that the refuge chamber will in fact protect the miners in it against the anticipated hazards for the designated period, and that the miner inside the facility can and will be rescued before the end of that period. Nothing can be more disastrous than to find the facility not to have performed as designed in an actual emergency, or to find that the facility cannot be approached or serviced as planned.

The number of miners, their distribution in terms of work locations, and the maximum anticipated duration of entrapment must be established. The facilities, equipment and instructions can be more complex than is the case for escape equipment. Some of the considerations with regard to the equipment itself will be such things as the quantity, location, construction, ventilation, communications, provision of food and other supplies, etc., all of which depend on the refuge chamber's specific purpose.

Given the diversity of mining conditions, the types of additional hazards posed during an emergency, the areal and vertical extent of the mine, and the number of miners who may be affected in an emergency, the need for refuge chambers and the kind of equipment with which they must be supplied can be quite variable. These needs should be established by contingency analysis. It is essential to solicit input and feedback from the miners who will use the equipment, from those who have used similar and different equipment in the past, from equipment designers and manufacturers, and others with relevant expertise.

Equipment for use by rescue personnel differs from that intended for escape and survival. Rescue equipment is used only by specially trained persons who undergo rigorous and frequent training. Therefore, considerable flexibility can be exercised in research and development. Several different designs and different pieces of equipment can be developed as it is always possible to match equipment with personnel or vice-versa through training. The equipment can be designed to be as complex as needed to fulfill the requirements of rescue operations.

The most important piece of rescue equipment is the rescue breathing apparatus. This apparatus must not only be extremely reliable but must be generally acceptable to rescue workers. The important design considerations are the physiological needs of persons working in an extremely hostile environment. Primary areas of concern are system weight, system bulk, operating time, human factors and system performance.

R&D efforts aimed at aiding rescue teams underground must solicit input from those who have actually participated in rescue efforts in mines and who have an appreciation of the needs. Inputs from personnel who have rescue experience in other fields can be very useful; however, such inputs must be carefully sorted out for applications to mining. Other government agencies having R&D efforts in rescue equipment and procedures and related psychological and physiological research, as well as manufacturers of rescue equipment, should have significant input. Since the research outcomes have applications to rescue and recovery efforts in all parts of the world, and there are centers of research in many countries, information exchange to and from such centers will facilitate coordinated efforts. However, it is worthy of special note here that different countries have different societal demands, and these are usually reflected in their mine safety regulations. Thus, foreign experience and development must be considered in the context of the applicable rules and regulations.

5.4 Recommendations

In managing research and development for post-disaster survival and rescue, it is essential to adopt a systems analysis point of view. The entire post-disaster response system--encompasssing the roles of mine management, workers, equipment manufacturers, and federal agencies, and the functions of research, design, planning, operations, training, regulation, and enforcment--should be viewed as a whole. Specifically, within this context:

1. It is essential, in managing the R&D program, to draw from the start of each project upon the expertise, viewpoints, and economic considerations of all parties who will ultimately be involved in the implementation of the R&D results. This includes federal agencies, mine operators, unions, and mine equipment manufacturers. It is not enough for the R&D agency to merely invite such input; it must be actively solicited, and the mining companies and unions must actively participate in the process. Concern for problems associated wtih production and implementation must begin at the stage of problem identification and continue throughout the R&D process.
2. Mechanisms should be developed for effective managerial decisionmaking at those points in the R&D process where responsibility passes between the Bureau of Mines and MSHA. Research without an eye to implementation, or vice versa, cannot be effective.
3. With regard to escape, survival and rescue equipment, realistic design criteria should be established early in the R&D process, taking into account the nature of mine emergencies, the conditions under which the equipment will be used, and the human element in its use. R&D progress should continually be assessed in light of these criteria.
4. Among the considerations in the design and evaluation of emergency equipment should be the need to train miners in its use in actual or simulated emergency conditions. This may require simulation techniques (analogous in principle to use of the Link Trainer in aviation). The filter self-rescuer, for example, which heats up to mouth-blistering temperatures

in actual use in a carbon monoxide environment, requires development of a training simulator that at least approaches the temperatures achieved in emergency use.

GENERAL REFERENCES

"Disasters: The Anatomy of Environmental Hazards" by John Whittow, University of Georgia Press, 1979.

"Safety Management" by John V. Grimaldi and Rollin H. Simonds, Richard D. Irwin, Inc., 3rd Edition, 1975.

"Handbook of System and Product Safety" by Willie Hammer, Prentice Hall, Inc., 1972.

"Principles of R&D Management" by Philip H. Francis, American Management Association, 1977.

"Effective Management of Research and Development" by P.A.F. White, John Wiley & Sons, 1975.

"Underground Coal Mining: An Assessment of Technology" Prepared by Hittman Associates, Inc., for the Electric Power Research Institute, 1976.

"The Direct Use of Coal," Office of Technology Assessment, U.S. Congress, undated.

"Coal Data Book," President's Commission on Coal, 1980.

"Analysis of Large-Scale Non-Coal Underground Mining Methods," prepared by Dravo Corporation for the U.S. Bureau of Mines, 1974.

APPENDIX I. INTERAGENCY MEMORANDA OF UNDERSTANDING BETWEEN USBM, MSHA, AND NIOSH

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
BUREAU OF MINES
AND THE
MINE SAFETY AND HEALTH ADMINISTRATION

1. Background and Purpose

(a) On February 6, 1976, the Bureau of Mines (BOM), Department of the Interior and the Mining Enforcement and Safety Administration (MESA), Department of the Interior entered into a Memorandum of Understanding to insure full and effective use of the capabilities and resources of BOM in managing and conducting research and of the capabilities and resources of MESA to assist in planning research and to assure maximum utilization of technologic developments resulting from mine health and safety research. The Federal Mine Safety and Health Act of 1977 (Mine Act), Pub. L. 91-173 as amended by Pub. L. 95-164, effective on March 9, 1978, combines the protection of the health and safety of all of the Nation's miners under a single law, transfers MESA to the Department of Labor, and changes the name of MESA to the Mine Safety and Health Administration (MSHA), Department of Labor. The purpose of this revision is to substitute MSHA for MESA and to execute the Memorandum between BOM and MSHA.

(b) The Mine Act requires the Secretaries of the Interior and Labor to coordinate activities in the field of research.

(c) The Secretary of the Interior through BOM is responsible for the management and conduct of mine health and safety research programs under the Mine Act, and the Secretary of Labor through MSHA is responsible for mine safety and health, assessment, and compliance, technical support, and education and training functions under the Mine Act.

(d) Both BOM and MSHA desire to strengthen their cooperation in achieving the goal of improving the safety and health of the Nation's miners.

2. Management, Coordination, and Conduct of Research

BOM shall manage and conduct the mine safety and health research programs described in this Memorandum of Understanding and shall provide overall coordination for the mine safety and health research programs including the assessment and prioritization of all research needs and the formulation of a balanced overall program at projected budgetary levels in a standard format. This activity shall be approved by the Director, BOM. BOM shall coordinate such activities with MSHA. Such coordination shall include:

(a) Establishment of explicit methodology and criteria for defining and selecting research needed to solve problems identified from analysis of mine accidents, safety and health hazards, and standards compliance experience;

(b) Joint use of the methodology to formulate research programs from information received from all sources including that solicited from the mining industry, labor organizations, other governmental organizations, and the academic community;

(c) Joint review and evaluation of ongoing programs;

(d) Assurance that research contractors follow MSHA procedures for obtaining any required approvals of equipment, materials, or procedures to be used;

(e) Joint development of strategies for the use of research results by delineating requirements for field testing and demonstration to validate new technology; disseminating potential use information to the mining community and/or developing rules and regulations for its use;

(f) MSHA representation, at the request of the BOM or MSHA, in preparing RFP's and on technical evaluation committees for mine health and safety research contracts; and

(g) MSHA review, at the request of BOM or MSHA of draft final reports on mine health and safety research contracts.

3. Advice and Assistance From MSHA

MSHA shall provide advice and assistance to BOM in BOM's management and conduct of the mine health and safety research program referred to in this Memorandum of Understanding. Such advice and assistance shall include:

(a) Information on health and safety hazards, accidents, injuries, fatality investigations, compliance, and training as necessary for the purposes of research planning and evaluations;

(b) Advice on both an as-identified basis and on an annual budget cycle planning basis of health and safety problems requiring research. Research input will be provided to BOM in a mutually agreed upon format;

(c) Participation with BOM through the life cycle of research projects that impact MSHA responsibilities in developing and enforcing standards, solving compliance problems, and training. Such participation may include advising, monitoring and review functions for purposes of assuring adequacy and proper timing control;

(d) Coordination of activities of MSHA's research review committees with BOM's standards input committees;

(e) Advice, at the request of BOM, on health and safety aspects of mining research projects conducted under programs other than health and safety research; and

(f) Maintenance within MSHA of a coordination staff for the purpose of carrying out the functions agreed to by MSHA herein (such staff to be fixed and adjusted from time to time by MSHA in accordance with budgetary and personnel requirements).

4. Coordination in Standards Development

MSHA shall advise BOM of its plans for developing and revising standards for the purposes of allowing sufficient opportunity for technical consultation between MSHA and BOM prior to publication of such standards as proposed rulemaking. BOM shall advise MSHA of research results which can impact existing or proposed standards through input from BOM standards committees.

5. Cooperative Assistance

BOM shall assist MSHA in executing its regulatory responsibility by continuing such laboratory investigations and studies on explosive products as are needed by MSHA in its Approval and Certification activities. MSHA shall assist BOM in its research programs by performing Approval and Certification procedures on BOM-developed hardware. Costs for cooperative assistance efforts, such as are identified above but not limited to these two items, shall be paid by the receiving agency to the requesting agency on the basis of published fee schedules or on an actual cost-reimbursable basis as appropriate.

6. Implementation

To effectively implement this Memorandum of Understanding, BOM and MSHA shall:

(a) Conduct their responsibilities pursuant to this Memorandum jointly and in a manner to minimize cost and time to meet budget and program deadlines;

(b) Develop joint research strategy on the solution of mine health and safety problems. Program thrusts will be established jointly for short, intermediate, and long-term (5 years or more) objectives with program balance to be established by BOM;

(c) Utilize a jointly developed methodology and criteria for selecting and evaluating programs and projects;

(d) Exchange annual and long-range, as well as general program plans and supportive appropriations requests;

(e) Utilize, to the extent possible, meetings of peer groups from both BOM and MSHA, but in any event carry out research evaluations on an annual basis by such peer groups in accordance with the established "methodology and criteria"; and,

(f) Identify a percentage of available funds in each fiscal year for preemption in the event of contingencies, including, but not limited to, research of opportunity identified by MSHA, cost overruns, and research necessary to aid during mine rescue emergencies;

(g) Identify key personnel responsible for coordination of information exchanged between BOM and MSHA relative to research and/or standards. Coordinators for research input to BOM will be named by MSHA, including research coordinators for coal, metal and nonmetal, and the special areas of education and training and technical support. Coordinators for standards input to MSHA will be named by BOM including standards coordinators for coal and metal and nonmetal mining.

(h) Hold formal meetings between BOM and MSHA coordinators at least 12 months in advance of the start of BOM's budget cycle to prepare strategy papers and update long-term plans;

(i) Develop joint issue papers, congressional testimony, and other documents whenever appropriate.

(j) BOM shall advise MSHA of determinations made pursuant to a written request by any operator or authorized representative of miners as to whether any physical agent or equipment found or used in a mine has potentially hazardous safety effects at the same time and in the same manner as submitted to the operators and miners.

7. Applicability, Modification, and Termination

(a) This Memorandum of Understanding and the specific provisions contained herein shall govern the activities of BOM and MSHA pertaining to mine health and safety research and standards formulation affected by that research.

(b) The Memorandum of Understanding dated February 6, 1976, shall terminate as of March 9, 1978, at which time it is replaced by this Memorandum.

(c) This Memorandum of Understanding shall remain in effect until modified or terminated by mutual consent of Department of Interior and Department of Labor or by operation of law.

Assistant Secretary of Labor for Mine Safety and Health
Department of Labor
ROBERT B. LAGATHER
Assistant Secretary—Energy and Minerals
Department of the Interior
JOAN M. DAVENPORT

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
BUREAU OF MINES
AND THE
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

I. Background

The Bureau of Mines (BOM) has conducted mining safety and health-related research since 1910 under authority of the Organic Act of the Bureau of Mines, the Federal Metal and Nonmetallic Mine Safety Act of 1966 (P.L. 89–577), and the Federal Coal Mine Health and Safety Act of 1969 (P.L. 91–173) (the Coal Act). The National Institute for Occupational Safety and Health (NIOSH) has conducted health research for mines under authority of the Coal Act and the Public Health Service Act (P.L. 78–410).

The Federal Mine Safety and Health Amendments Act of 1977 (P.L. 95–164) (the Act) gives responsibility for mine health research to NIOSH, through the Secretary of Health, Education, and Welfare and responsibility for mine safety research to the Secretary of Interior, who has delegated this responsibility to BOM.

BOM conducts a mining technology research program and NIOSH conducts a health research program both to protect the health of miners. BOM and NIOSH have cooperated since passage of the Coal Act in conducting this research while avoiding unnecessary duplication of effort.

BOM and NIOSH desire to continue to cooperate, within the guidance and congressional mandate of the Act, to improve the Federal research effort for the protection of the safety and health of the nation's miners.

II. Points of Agreement

BOM and NIOSH agree on the following:

(1) General Guidelines on Research Responsibilities

BOM shall conduct mining research designed to improve mine safety and to improve the environmental conditions in mines. BOM shall conduct safety and health-related research requiring expertise in engineering and the physical sciences and knowledge of mining methods, equipment and conditions. In this context, health-related research consists of studies to identify technological alternatives which reduce the health hazards encountered by miners, such as designing health hazards out of the mining system, machine modifications to reduce worker exposure to health hazards, and control technology related to mining problems. BOM research shall be concerned with improving mining methods and equipment and work practices. Such research shall address both assessment of existing and development of improved control technology to improve health and safety in mines.

NIOSH shall conduct occupational health research designed to prevent occupational diseases originating in the mining industry. NIOSH shall conduct such research as requires expertise in medicine, industrial hygiene, toxicology, epidemiology, engineering, physical sciences and other health fields. NIOSH research shall be concerned with the examination of and protection of the health of miners, evaluation of their exposure to health hazards and the development of improved industrial hygiene, environmental health methodology. NIOSH shall be concerned with assessment of existing control technology as required to make recommendations for improved health regulations.

(2) Activities Under the Act

BOM shall conduct directly or by grants or contracts, such studies, research, experiments, and demonstrations as may be appropriate.

(a) to improve working conditions and practices, to prevent injurious accidents, and to improve environmental conditions in mines;
(b) to develop new and improved devices and technology to measure environmental conditions in mines;
(c) to develop new or improved methods for recovering persons in mines after accidents;
(d) to develop new or improved means and methods of communication from the surface to the underground area of a mine;
(e) to develop new or improved means and methods of reducing concentrations of respirable dust in the mine atmosphere of active workings of mines;
(f) to develop new and improved underground equipment and other sources of power for such equipment which will provide greater safety;
(g) to determine upon the written request by any operator or authorized representative of miners, specifying with reasonable particularity the grounds upon which such request is made, whether any agent or equipment found or used in a mine presents a potential safety hazard, and shall submit such determinations to both the operators and miners as soon as possible; and
(h) for such other purposes as necessary to carry out the intent of the Act.

NIOSH shall conduct directly or by grants or contracts, such studies, research, experiments, and demonstrations as may be appropriate.

(a) to improve working conditions and practices to prevent occupational diseases in the mining industry;

(b) to develop epidemiologic information to identify and define positive factors involved in occupational diseases of miners, provide information on the incidence and prevalence of pneumoconiosis and other occupational diseases of miners, and improve mandatory health standards;

(c) to develop techniques and devices for the prevention and control of occupational diseases of miners, including, but not limited to, respiratory protection, tests for hypersusceptibility and for early detection;

(d) to evaluate bodily impairment and occupational disability in miners afflicted with an occupational disease;

(e) to develop new or improved measurement methods for the determination of levels of physical and chemical agents in mines;

(f) to prepare and publish from time to time reports on all significant aspects of occupational diseases of miners as well as on the medical aspects of injuries;

(g) to study the relationship between mine environments, recommended changes in work practices and occupational diseases of miners;

(h) to determine upon the written request by an operator or authorized representative of miners, specifying with reasonable particularity the ground upon which such request is made, whether any substance normally found in a mine has potentially toxic effects in the concentrations normally found in the mine, or whether any physical agent found or used in mines has potentially hazardous health effects, and shall submit such determinations to both the operators and miners as soon as possible; and

(i) for such other purposes as necessary to carry out the intent of the Act.

(3) Implementation

To effectively implement this agreement, BOM and NIOSH shall:

(a) Identify personnel responsible for coordination, information exchange and addressing issues of immediate concern.

(b) Hold meetings at approximate 6 month intervals, but not less than annually, for exchange of research plans and results, identification and discussion of research in mine health and safety that may impact the responsibility of the other agency, identification of any potential duplication of research effort, and discussion of any other matters of concern to both agencies.

(c) Coordinate in development of plans for activity related to mine health and safety. Coordination on research, hazard evaluation and other issues of immediate concern may be through one or several persons, as appropriate.

(d) Exchange annual and long range plans for mine health and safety research.

(e) Coordinate research projects in special areas where the responsibilities of each agency partially overlap. These areas include:

(1) Development of devices and techniques for measurement of environmental conditions in mines;

(2) Characterization of the mine environment;

(3) Ergonomics;

(4) Assessment of existing control technology;

(5) Other areas which may be identified later.

Research personnel in each of these special areas will be identified and efforts will be made to develop improved direct communication between them. Assistance may be given in preparation of work statements, evaluation of proposals and monitoring of contracts in these special research areas and joint funding may also be considered. Such assistance will be given at the request of the other agency, contingent upon the availability of personnel and funds.

(f) Coordinate in performing hazard evaluation by:

(1) Exchanging information and assistance as appropriate to provide effective response to hazard evaluation requests.

(2) Forwarding hazard evaluation requests that fall within the other organization's scope of concern.

(3) Coordinating response and designating the lead organization for hazard evaluation requests containing both safety and health aspects.

(4) Making requests for assistance in hazard evaluations in writing except in emergencies, when an oral request will be followed by a written request. Requests will provide specific background, details, and purpose of assistance requested.

(5) Providing copies of all completed hazard evaluation reports to a designated person on the other organization.

(4) Applicability, Modification and Termination

The intent of this agreement and the specific provisions contained herein shall govern the activities of BOM and NIOSH pertaining to mine health and safety research. This agreement shall become effective upon signature by both parties, and may be modified or terminated by mutual consent, or by either party upon 30 days written notice to the other.

J. MICHAEL LANE, M.D.
Acting Director, National Institute for Occupational Health and Safety

John D. Morgan, Jr.
Acting Director, Bureau of Mines

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
MINE SAFETY AND HEALTH ADMINISTRATION
AND THE
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

This Memorandum of Understanding is entered into the 4th day of May 1978, between the Mine Safety and Health Administration, Department of Labor (MSHA), and the National Institute for Occupational Safety and Health, Department of Health, Education, and Welfare (NIOSH).

The purpose of this memorandum is to set forth an understanding between MSHA and NIOSH for consultation, coordination, and cooperation in effectively and efficiently carrying out their respective safety and health functions under the Mine Safety and Health Act of 1977, P. L. 91-173 as amended by P. L. 95-164. MSHA and NIOSH, therefore, agree to the following:

A. Identification of Toxic Materials and Agents Found in Mines

1. NIOSH, with the assistance of MSHA, shall identify toxic materials and harmful physical agents used or found in mines and develop a program for determining if these materials or agents are potentially toxic or harmful at the concentrations or levels at which they are used or found in mines.

2. MSHA shall make available to NIOSH any MSHA reliable data on concentrations or levels of toxic materials and harmful physical agents used or found in mines for use with other information NIOSH may obtain or evolve during its identification program described in (1) above.

B. Development of Mine Health Criteria

1. NIOSH shall consult with MSHA to establish the priorities for criteria development for toxic materials and physical agents.

2. NIOSH shall consult with MSHA on all parameters to be considered in the development of criteria for each toxic material and physical agent.

3. NIOSH shall submit determinations with respect to toxic materials or substances and physical agents to MSHA. NIOSH also shall submit all pertinent criteria regarding any material or substance determined to be toxic or harmful agents as the criteria are developed.

C. <u>Development of Mine Health Standards</u>

1. MSHA shall advise NIOSH, as far in advance as possible, of the schedule of the rulemarking process for developing standards for toxic materials and harmful physical agents.

2. NIOSH shall appoint one or more coordinators to serve as liaison for NIOSH technical assistance to MSHA in the preparation and review of standards prior to and during the rulemaking process. The coordinator shall be available to address technical health-related issues raised during the rulemaking process.

3. NIOSH shall provide, where possible, expert technical witnesses in support of MSHA in public meetings, administrative hearings, court litigations and other legal actions involving toxic materials and harmful physical agents.

D. <u>Testing and Certification</u>

1. Devices for the measurement of respirable dust, toxic materials and harmful physical agents, as well as personal protective equipment for use in the mining industry, shall be certified jointly by NIOSH and MSHA. Examination, inspection and testing for performance of such devices and equipment shall be conducted by NIOSH, and examination, inspection and testing for permissibility shall be performed by MSHA.

2. NIOSH shall provide technical assistance to MSHA in identifying toxic substances and the degree of hazard of products submitted to MSHA for acceptance for use in mines. MSHA shall provide NIOSH with the necessary technical information and chemical identification of the products and the ingredients of the products.

E. <u>Health Hazard Evaluation and Interaction with Compliance</u>

NIOSH shall respond to Health Hazard Evaluation (HHE) requests under the authority of Section 501(a)(11) of the Act. Any HHE requests received by MSHA personnel shall be sent by MSHA to a NIOSH representative designated by the Director, NIOSH. To obtain details regarding any request, NIOSH shall contact MSHA, the representative of the miner and the mine operator, as appropriate, when initiating an HHE. NIOSH shall coordinate field activities with MSHA in each mine for which a NIOSH HHE has been requested. A copy of the draft HHE report shall be transmitted to MSHA for timely comment on conflict between NIOSH recommendations and MSHA regulations. One or more copies of the final report shall be sent to a designated person in MSHA.

F. Field Technical Assistance

NIOSH shall provide, where possible, technical assistance and supportive field investigations to MSHA. Requests shall be made in writing in all cases, except oral requests in an emergency shall immediately be acted upon by NIOSH and followed up by a written request from MSHA. Each request shall contain sufficient information for NIOSH to develop a study protocol which includes the basis for the request; the details and results of the MSHA investigation the request is based on; the specific nature and extent of assistance requested; the purpose of the assistance; any constraints imposed by pending or contemplated legal or quasi-legal actions; any other information which might aid NIOSH in developing its response to the request. Coordination of requests shall be made through the Assistant Secretary of Labor for Mine Safety and Health, and the Director, NIOSH, or their designees.

G. Training

NIOSH shall, depending upon the availability of resources, provide assistance to MSHA in performing MSHA's training and education responsibilities under the Act. MSHA shall provide assistance to NIOSH in training NIOSH personnel for work in mines. The procedures for and form of such mutual assistance shall be specifically agreed to in each instance.

H. Research - Health Effects

1. NIOSH shall conduct long-term field studies embracing retrospective and prospective epidemiology necessary for evaluating suspected causes of occupationally-related diseases in the mining industry. Such epidemiologic studies may include medical examination, mortality and morbidity statistical surveys and evaluations of applicable working environments. Depending upon the availability or resources, MSHA shall provide assistance to NIOSH in the performance of these studies.

2. NIOSH shall conduct laboratory studies on the toxicity or physiological effects of physical agents, minerals, mineral products, or substances encountered in the mining industries.

I. Meetings

Meetings of NIOSH and MSHA personnel designated by the Assistant Secretary for Mine Safety and Health, and the Director, NIOSH, will be held bi-monthly, or more often as needed, to discuss progress and direction of work related to the technical work groups and surveys.

Policy level meetings will be convened on a quarterly basis or more often as needed.

The Assistant Secretary of Labor for Mine Safety and Health or his designee will attend and participate in all meetings of the Mine Health Research Advisory Committee established under Section 102(b) of the Act.

The Director of NIOSH or his designee will attend and participate in all meetings of mine health advisory committees established under Section 102(c) of the Act.

ROBERT B. LAGATHER
Assistant Secretary
for Mine Safety and Health
Department of Labor

JULIUS B. RICHMOND
Assistant Secretary for Health
Department of Health, Education,
and Welfare

APPENDIX II. THE USBM-MSHA PROCEDURE FOR RANKING PROPOSED RESEARCH PROJECTS.

The following material has been extracted from a memorandum sent by the Director, Minerals Health and Safety Technology, Bureau of Mines, to the Directors of the Bureau's 10 research centers, on January 4, 1980.

United States Department of the Interior

BUREAU OF MINES
2401 E STREET, NW.
WASHINGTON, D.C. 20241

IN REPLY REFER TO:

Memorandum for Record

Subject: FY 1981 Project Proposal Evaluation

The criteria and methodology used for joint ranking of FY 1980 health and safety project proposals has been reviewed. The majority of the MSHA research chairmen and Bureau coordinators were satisfied with the FY 1980 procedures, and only a very few comments requesting changes were offered. These were minor in nature and did not represent a consensus view. Thus, the criteria and methodology to be used for FY 1981 will be identical to that used for FY 1979 and 1980. This document, dated January 1980, will be used for evaluating and ranking the FY 1981 health and safety project proposals.

Robert L. Marovelli
Bureau of Mines

Edwin M. Thomasson
MSHA

January 1980

FY 81 Procedure for Ranking Project Proposals

1. BOM & MSHA will exchange project descriptions as far in advance of evaluation meetings as possible.

2. Meetings of evaluation committees will take place during March and April. The Bureau Coordinator and MSHA Chairman will establish the dates of the meetings. General meeting agenda is as follows:

   a. Committee discusses projects, combines any remaining duplicative projects, and arrives at a master project list for evaluation.

   b. The committee reach mutually acceptable definitions for the meaning of rating levels (such as low, medium, high) that are applied to each of the 12 rating factors.

   c. Using the rating for A, the members of the committee either individually rate each project, or arrive at a group consensus rating for each project.

   d. When evaluations are completed, summary form B will be completed to reflect the committee's rating of each proposal. If the committee members individually rated each proposal, the final rating is determined by averaging the individual project ratings. If the committee rated each proposal on a group consensus basis, this arrived at rating is the proposals final rating.

   e. The committee develops a priority ranked project list (in decreasing priority) from the group rating using form C . From budget guidelines for Fy 81, the cutoff point on the ranked list will be established. Committee members may comment on differences between the group ranking and their individual ranking of projects (limited to 1 page per member). Particular attention should be paid to those projects within $\pm$ 10 percent of the budget cutoff line.

   f. The committee will deliver to the committee coordinator the following items:

      (1) all evaluation forms A containing raw evaluation data.

      (2) summary for B containing group ratings.

      (3) ranked list of projects on form C

      (4) any written comments provided by committee members.

3. It is anticipated the above described evaluation meetings will occupy one to three days per research area.

4. The evaluation committee is constituted with equal representation from MSHA and the Bureau. Should members be absent, separate averages of the MSHA representatives and the Bureau representatives will be used to derive a final project score.

5. A reminder: when rating projects, examine each rating factor as it applies only to the research area under evaluation, e.g. Ground Control; do not attempt to relate factors between areas, e.g. Respirable Dust versus Radiation.

6. The Bureau Program Manager responsible for programming a research area, or MSHA representative, may attend the evaluation meetings if he chooses. His active participation would be in the discussion of projects; he will not rate the projects.

7. While differences will always exist in personal opinions as expressed in project ranking, objectivity remains an important criteria for all evaluators. At the conclusion of the FY 81 ranking, the individual scores in areas of continuing concern will be standardized using a technique similar to the one used during evaluation of RFP proposals. This "after the fact" review of the ranking procedures will be provided to the members of evaluation committees (and to Bureau and MSHA management) and should serve as a measure of their members individual objectivity.

8. The ranked list of projects resulting from the ranking meetings is used as a guide in developing a balanced overall research program. In those instances where the projects selected for funding follow a prioritization other than that shown on the ranked list of projects, a detailed rationale for such changes will be submitted to Bureau management, MSHA research liaison, and the Bureau and MSHA chairmen of the evaluation committee.

January 1980

Instructions to Evaluators
of
H&S R&D Project Proposals
FY 81

First, each project proposal within a program and subprogram area will be evaluated by one group of evaluators.

Second, each proposal will be evaluated with a number of criteria. The proposal will be measured against those criteria and a value of 1,2, or 3 given to each factor by the evaluating team. Each value will represent a stated range or value of the factor, e.g. Project duration 1: = 4 years of more; 2: = 2-4 years; and 3: = less than 2 years.

Third, the project value will be determined by adding the 4 individual factors within each of the 3 areas evaluated, e.g. Need for R&D, to obtain a summed value for each area. These summed values for each group are multiplied together to obtain a value for the project proposal. This number is the value to be used in ranking The R&D proposal. The higher numbered proposals are the more attractive.

Fourth, the committee will complete forms A, B and C according to the FY 81 Procedures for Ranking Project Proposals dated January 1981.

FY 81 Rating Criteria

Criterion	Question	Range and Rating
A: Need for R&D		
1. Urgency Coefficient	What is the sense of urgency imposed either by enforcement activities, injury experience, or health and safety requirements?	1. Future, long term significance. 2. Needed within next three years. 3. Application needed immediately, or proposal represents termination of multi-year program.
2. Hazard Potential		
a. Occupational illness risk potential	What is the potential to cause occupational illness to miners?	1. Low possibility-infrequent illness with very few miners exposed to hazard. 2. Medium possibility. 3. High possibility-common illness with relatively large portion of miners exposed to hazard.
OR		
b. Injury/severity experience	What is the relative frequency and severity of the injury/experience based on total injuries in coal or metal and nonmetal mines?	1. Below average frequency and below average severity. 2. Average frequency or severity or both. 3. Above average frequency or severity or both.

FY 81 Rating Criteria (Continued)

Criterion	Question	Range and Rating
A. <u>Need for R&D</u> (Contd.)		
3. Disaster/Health Risk a. Health Deterioration Potential	What potential is there for causing or aggrevating bad health for several miners in a portion or complete working areas of many mines from this hazard?	1. Involves exposure of less than 5 percent of workforce. 2. Involves less than 20 percent of workforce. 3. Involves more than 20 percent of workforce.
OR		
b. Disaster Potential	What is the potential for causing multiple fatalities, injuries or a disaster involving collectively lives of several miners in a portion or complete working area of the mine?	1. Involves exposure of less than 5 percent of workforce. 2. Involves less than 20 percent of workforce. 3. Involves more than 20 percent of workforce.
4. Health and Safety Contribution	What are possible contributions of the proposed work to either provide new and improved health and safety procedures or standards, to clarify critical aspects of technical uncertainty in this research area, or to provide guidance for health and safety training for management and miners?	1. Low, very little significance. 2. Medium. 3. High, major thrust area.

FY 81 Rating Criteria (Continued)

Criterion	Question	Range and Rating
B. **Technical Soundness**		
5. **Promise of Success**	What is your estimate of the probable success of the project in achieving its goals?	1. Low. 2. Medium. 3. High.
6. **Industry Practice and Alternatives**	Are there other alternate approaches being developed or used to solve the project problem more effectively than as proposed?	1. Approach/practice already exists and being used by industry. 2. Fairly good alternate approach being developed but not reduced in industry practice as yet. 3. Novel idea with a sound approach; few or no alternate approaches exist or are being developed.
7. **Impact on Research Program**	To what degree will the proposed work contribute to the achievement of the objectives and goals of this research area?	1. Low. 2. Medium. 3. High.
8. **Technical Adequacy**	To what extent does the proposed work represent a new or technically acceptable approach to solving its identified problem as opposed to a frequently tried and unsuccessful-to-date approach?	1. Low-previously unsuccessful or outside state-of-the-art technology. 2. Medium-reasonable approach. 3. High-technology and approach sound and within state-of the art.

FY 81 Rating Criteria (Continued)

Criterion	Question	Range and Rating
C: <u>Implementation Considerations and Cost Factors</u>		
9. Implementation Potential	What will be industry's reaction to the results—will legislation be voluntary or regulatory?	1. Implementation and legislation cannot be justified. 2. Industry in opposition to implementation and legislation of results. 3. Results viewed as cost effective and voluntary implementation by most mines anticipated.
10. Implementation Desirability	To what extent do the results contribute to hazard elimination and standards promulgation?	1. Little effect on reducing hazards or establishing standards. 2. Desirable but not necessary to eliminate or minimize hazard and to establish standards. 3. Necessary to eliminate hazard and to establish standards.

FY 81 Rating Criteria (Continued)

	Criterion	Question	Range and Rating
11.	Project Duration	At the expected level of funding, how long will it take to complete the project including in-mine demonstrations and verification?	1. Greater than 4 years. 2. Two to 4 years. 3. Less than 2 years.
12.	Cost of Implementation	What will be the total project cost including cost to complete the research effort and the cost to the mining industry to adopt the results. Research effort costs include in-mine demonstrations and verification. Industry costs include costs to equipment manufacturers.	1. Greater than 10 million. 2. Between 1 and 10 million. 3. Less than 1 million.

Contract No.: H0101691
Title: Research on the transmission of acoustic and electromagnetic signals between mine workings and surface
Contractor: Colorado School of Mines

Contract No.: H011838
Title: Investigation in the use of seismic transducers for mine communications
Contractor: U.S. Dept. of the Air Force

Contract No.: H0112033
Title: Research and development on lithium-nickel fluoride batteries for mine life support equipment
Contractor: Gulton Industries, Inc.

Contract No.: H0112209
Title: Design, fabricate and demonstrate an automated breathing metabolic simulator
Contractor: IBM Corp.

Contract No.: H012207
Title: Probe drill guidance system
Contractor: Telcom, Inc.

Contract No.: H0122026
Title: Electromagnetic and seismic noise survey related to coal mine rescue communications
Contractor: Arthur D. Little, Inc.

Contract No.: H0122061
Title: Analytical study of electromagnetic location of trapped miners
Contractor: Office of Telecommunicatins

Contract No.: H0122063
Title: Development of a manually operated rescue team vehicle
Contractor: Mine Safety Appliances Co.

Contract No.: H0133020
Title: Mine escape hoist standards
Contractor: Foster-Miller Assoc., Inc.

Contract No.: H0133045
Title: Minature waveform generator for electromagnetic (EM) location of trapped miners
Contractor: Collins Radio Group

Contract No.: H0133050
Title: Design of a portable bulkhead for a cross-cut refuge chamber
Contractor: Foster-Miller Assoc., Inc.

Contract No.: H0133112
Title: Experimental mine surveillance system with applicatoin to the location of trapped miners
Contractor: Continental Oil Co.

Contract No.: H0155008
Title: Analytical investigation of electromagnetic fields in mine environments
Contractor: Office of Telecommunications

Contract No.: H0155094
Title: Design of a portable gas analyzer for monitoring during mine fires - Phase I
Contractor: Mine Safety Appliances Co.

Contract No.: H0166015
Title: Explosion proof reusable bulkheads
Contractor: Foster-Miller Assoc., In.c

Contract No.: H0166083
Title: Communication system for refuge shelters
Contractor: Collins Radio Group

Contract No.: H0177098
Title: Through-the-earth monitoring of mine envrironments
Contractor: Arthur D. Little, Inc.

Contract No.: H0188071
Title: Electromagnetic retransmission system for locating trapped mine workers
Contractor: Polhemus Navigation Sciences

Contract No.: H0220040
Title: One-hour self-rescue breathing apparatus
Contractor: Lockheed Missiles & Space Co.

Contract No.: H0220045
Title: Design and development of an improved mine rescue breathing apparatus
Contractor: Kinergetics, Inc.

Contract No.: H0220071
Title: Short-duration self-rescue breathing apparatus
Contractor: Mine Safety Appliances Co.

Contract No.: H0220073
Title: Trapped miner locaton and communication system
Contractor: Westinghouse Electric Corp.

Contract No.: H0220081
Title: Report on the state-of-the-art of down the-hole percussion devices
Contractor: Reico Industries

Contract No.: H0230034
Title: Hoist radio system for deep shafts
Contractor: Collins Radio Corp.

Contract No.: H0232049
Title: Locatin system prototype development and test and communication station modification and demonstration at Bruceton Experimental mine
Contractor: Westinghouse Electric Corp.

Contract No.: H0242006
Title: EM location system modification and test in a hardrock mine
Contractor: Westinghouse Electric Corp.

Contract No.: H0242010
Title: Waveform generator-package and receiver
Contractor: Collins Radio Group

Contract No.: H0242047
Title: Improved oxygen sources for breathing apparatus
Contractor: NASA

Contract No.: H0252050
Title: Multipurpose rescue team helmet
Contractor: Gentex Corp.

Contract No.: H0252051
Title: Rescue team liquid-cooled garment
Contractor: NASA

Contract No.: H0252079
Title: Combined short and long duration self-rescue breathing apparatus
Contractor: Mine Safety Appliances Co.

Contract No.: H0262041
Title: Lightweight rescue breathing apparatus
Contractor: Mine Safety Appliances Co.

Contract No.: H0308041
Title: Closed circuit T.V. borehole probe
Contractor: Design Engineering Labs.

Contract No.: H0308042
Title: System to prevent clogging of gas sampling tubes
Contractor: Charlton Assoc., Inc.

Contract No.: H0377009
Title: Infrared borehole imaging probe
Contractor: Xerox Electro-optical Systems

Contract No.: J0100043
Title: Development of an ultra lightweight oxygen container
Contractor: Grumman Aerospace Corp.

Contract No.: J0100057
Title: Methodology development for mine life safet y system evaluation
Contractor: West Virginia University

Contract No.: J0166060
Title: Reliability and effectiveness analysis of EM location system
Contractor: Westinghouse Electric Corp.

Contract No.: J0166100
Title: Modify and test an electromagnetic locatin system in metal/nonmetallic mines
Contractor: Westinghouse Electric Corp.

Contract No.: J0177043
Title: Mine emergency operations
Contractor: MSHA

Contract No.: J0188026
Title: Low temperature testing of rescue breathing apparatus
Contractor: U.S. Department of the Army

Contract No.: J0188037
Title: Technical support of through-the-earth EM transmission measurement program
Contractor: Arthur D. Little, Inc.

Contract No.: J0199009
Title: Emergency rescue system for deep mines
Contractor: Develco, Inc.

Contract No.: J0199109
Title: Post disaster communication techniques
Contractor: University of Michigan

Contract No.: J0199118
Title: Guidelines for oxygen self-rescuers
Contractor: Foster-Miller Assoc., Inc.

Contract No.: J0255017
Title: Development of emergency escape systems guidelines for underground metal and nonmetal mines
Contractor: Foster-Miller Assoc., Inc.

Contract No.: J0387210
Title: Develepent of guidelines for rescue chambers
Contractor: Foster-Miller Assoc., Inc.

Contract No.: J0387214
Title: Assessment of guided wave technology
Contractor: Arthur D. Little, Inc.

Contract No.: J0395017
Title: Design to specification and fabrication of VF transmitters and baseband receivers
Contractor: General Instrument Corp.

Contract No.: J0395064
Title: Auto detection algorithm for MSHA's seismic location system
Contractor: Sonic Sciences, Inc.

Contract No.: M9330187
Title: Development of mine surveillance vehicle guidance system using NASA Lunar Rover Inertial Reference System
Contractor: NASA

Contract No.: S0177117
Title: UHF equipment for the mine rescue vehicle team
Contractor: Motorola Comm. Elec., Inc.

Contract No.: S0199136
Title: 02 Self rescuer - 60 minutes - Draeger Model OXY-SR-60
Contractor: National Mine Service Co.

Contract No.: 00503181
Title: Borehole television probe
Contractor: Equitable Gas Co.

Contract No.: 005003182
Title: Advanced communications
Contractor: Hecla Mining Co.

Contract No.: 00700514
Title: Carbon monoxide monitoring devices
Contractor: Sunshine Mining Co.