COAL MINE RESCUE AND SURVIVAL SYSTEM

VOLUME IV

PROGRAM EVOLUTION AND MANAGEMENT

FINAL REPORT

September 1971

Prepared for

BUREAU OF MINES
U.S. Department of the Interior

Under Contract H0101262

By

WESTINGHOUSE ELECTRIC CORPORATION
Special Systems
Baltimore, Maryland

COAL MINE RESCUE AND SURVIVAL SYSTEM

VOLUME IV

PROGRAM EVOLUTION AND MANAGEMENT

FINAL REPORT

September 1971

Prepared for

BUREAU OF MINES
U.S. Department of the Interior

Under Contract H0101262

By

WESTINGHOUSE ELECTRIC CORPORATION
Special Systems
Baltimore, Maryland

TABLE OF CONTENTS

	Page
1. INTRODUCTION	1
1.1 NAE Concepts	1
1.1.1 Survival Subsystems	1
1.1.2 Communications Subsystem, Electromagnetic and Seismic	2
1.1.3 Mine Rescue Drilling Subsystem	3
2. COAL MINE RESCUE & SURVIVAL SYSTEM (CMR&SS) PROGRAM	5
2.1 Program Management	5
2.2 Organization and Work Breakdown Structure	6
2.3 Program Phases	6
2.4 Subject Inventions	6
3. SYSTEMS ENGINEERING	9
3.1 Introduction	9
3.2 System Requirements	9
3.2.1 Survival Subsystem Requirements	10
3.2.2 Communication/Location Subsystem Requirements	11
3.2.3 Rescue Subsystem Requirements	12
3.3 System Description	12
3.3.1 Survival Subsystem Description	12
3.3.2 Communications/Location Subsystem Description	12
3.3.3 Rescue Subsystem Description	14
3.4 Systems Engineering - Design Guidance	15
3.4.1 General	15
3.4.2 Survival Subsystem	15
3.4.3 Communications/Location Subsystem	17

	Page
3.4.4 Rescue Subsystem	17
3.5 Systems Engineering Supporting Studies	18
3.5.1 System Utility Model	18
3.5.2 Coal Mine Characterization	22
3.5.3 Mine Explosion Study	23
3.5.4 Transportation Study	24
3.5.5 Rescue Gaming Study	25
3.5.6 Behavioral Aspects of Trapped Miners	27
3.5.7 Test/Demonstration Scenario	28
4. TEST/DEMONSTRATION PHILOSOPHY	29
4.1 General	29
4.2 Purpose of the Test/Demonstration	29
4.3 Site Selection for the Test/Demonstration	30
4.4 Administration of the Test/Demonstration	31
4.4.1 Initial Preparations	31
4.4.2 Organization and Responsibilities	32
4.5 CMR&SS Test/Demonstration Performance Summary	32
5. CONCLUSIONS AND RECOMMENDATIONS	35
5.1 Mine Locations, Personnel Travel	35
Appendix - Test/Demonstration Scenario	37

LIST OF ILLUSTRATIONS

Figure		Page
2-1	CMR&SS Program Organization and Work Breakdown	7
4-1	Demonstration Rescue Organization	33

1. INTRODUCTION

This final report summarizes the effort on a very aggressively scheduled and demanding development program undertaken by Westinghouse for the U.S. Bureau of Mines under Contract No. H0101262. The objective of this program was to produce hardware and test it to determine the efficacy of certain concepts of Coal Mine Rescue and Survival as established by the request for proposal and the study performed for the U.S. Bureau of Mines by the National Academy of Engineering (NAE). (These are stated in paragraph 1.1 for reference.) In carrying out this program, Westinghouse provided specific hardware designs in consonance with the objectives of the concepts outlined in the NAE study final report.

Though this contract did not require producing final design hardware ready for introduction to the coal mining community, components of the CMR&SS — as delivered — have some value in disaster situations and are to be kept on standby alert. Additional design and production development is required and should be undertaken on most of the subsystems and components before they can be used in the competitive coal mining community.

The tests which were conducted were of two general types: 1) developmental, to fully understand the interrelationships of components being used together for the first time, or being used in a novel way, and 2) systematic evaluation in a synthesized, realistic setting to test a proffered solution to a stated problem. The conclusions drawn from such tests, and the recommendations based upon those conclusions, are arrived at in the light of the stated original concepts and, at the same time, have some overtones of, and draw upon, the experiences gained by Westinghouse in the exposure to operational situations.

A number of major steps forward were taken to increase the knowledge of certain kinds of phenomena, to produce improved means for locating and rescuing persons trapped underground, and to identify areas requiring additional development.

Each Subsystem area is addressed in a separate volume, each of which closes with the presentation of conclusions and recommendations. Summary conclusions and recommendations are presented at the end of this report volume.

1.1 NAE CONCEPTS

The following concepts as suggested by and supported in the final report of the NAE were used as a basis of the contract work. The ideas were first used by Westinghouse in the preparation of the proposal to the Bureau of Mines for consideration in the competitive evaluation. As the technical evaluation of the concepts progressed, details evolved and were briefly considered in joint Westinghouse/Bureau meetings and modified in accordance with such discussions and analyses.

1.1.1 Survival Subsystems

It was recommended that ". . . basic development work should be carried out in areas that will be essential to any survival system. . . . ways to generate oxygen under emergency conditions . . . . chlorate candles, . . . superoxides . . . stored gaseous oxygen . . . and their application to emergency individual breathing devices," and "that can be carried continuously by a coal miner . . . . ". . and underground life support systems . . . carbon dioxide removal agents, chemical light sources, food supplies and other survival shelter essentials." "An emergency life support device for underground workers 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 continuously. ". . . a device meeting the above criteria can be developed . . . to provide a one-hour oxygen supply".

It was further recommended that ". . . . research and development is needed to produce easily-installed, strong, long-life bulkheads or other types of shelters" with a "life support system capable of supporting 15 men for up to two weeks". ". . . small refuge shelters . . established near each working section and advanced or retreated as the mining advanced or retreated", without ". . . a hole from the surface to the chambers. Therefore . . . equipped with self-contained oxygen-producing and carbon dioxide removal systems. In the concept under consideration, all life support equipment — oxygen supply, carbon dioxide removal agent, chemical light sources, food, water, blankets, oxygen level detectors, methane level detectors, carbon monoxide detectors, medical supplies, and perhaps a chemical toilet — would be mounted on a wheeled cart or "red wagon". This wagon could easily be moved by a shuttle car as the refuge chamber was advanced or retreated" . . . . . "such refuge chambers . . . should provide some protection from subsequent explosions." (i.e., explosions following the first accidental explosion of an emergency situation).

1.1.2 <u>Communications Subsystem, Electromagnetic and Seismic</u>

Two sets of recommendations were made in the NAE report. In the matter of electromagnetics, ". . . the system would consist of emergency radio beacons, underground for location of and communication with trapped miners. Theoretical and experimental studies are proposed that would permit evolution of the emergency system into an operational mine radio communication system with an emergency location and communication capability". The Westinghouse proposal, based upon some in-house research efforts proposed some specific hardware ideas to carry out this general recommendation of the NAE, hence, the specific ideas of the NAE are not repeated here. It was recommended that the lower frequencies be used, and that there is some concern for properties of rock strata over typical mines which would require testing in many mines to better specify a detection program.

Secondly, the NAE recommended a seismic system which would have ". . . sufficient sensitivity that it can detect the miner-generated seismic signals at distances comparable to the dimensions of the area of possible entrapment. Another prime consideration is that the system be capable of locating the source of the signals with a precision commensurate with the requirements for safe and efficient rescue operations. Accuracy of only a few hundred feet will be required if each section of the mine is equipped with refuge chambers. The mine map can be used for exact location of the chambers, and seismic signals will be used only to determine which of the chambers are occupied. If the mine is not equipped with chambers, location accuracy of approximately ± 50 ft will be required. Although highly desirable, the ability to establish two-way communication between the miners and the surface is of secondary importance."

"The interim system is based on miner location and communication by means of seismic compressional pulses (P-waves) generated by striking the mine roof or walls with a hammer. Location is accomplished by an analysis of the relative arrival times of seismic signals at various elements of a large seismometer array. Two-way communication is achieved through a simple code based on sequences of impulses.

1.1.3 Mine Rescue Drilling Subsystem

The concepts put forth by the NAE for drilling rigs included recommendations to

1. Provide a highly mobile probe and search drill that would
   - Drill a 6- to 8-inch hole (probably 6-3/4 in. to take advantage of commercial technology in this size range) to 1,500-ft depths with a capability of being extended to 2,500-ft depths.
   - Be transported in military aircraft.
   - Drill reasonably straight holes with no more than 6-in. deviation per 100 ft depth.
   - Drill 12,000-psi rock at the rate of 100 ft per hour (or more) and strong quartzite at 20 ft per hour.
   - Have maximum traveling dimensions of 8-ft width and 10-ft height.
   - Have a hoist with a capacity of 2,500 ft of 1/4-in. wire rope. (This can be a separate unit.)
   - Drill with air circulation.
2. Provide a rescue drill capable of:
   - Drilling an 18- or 28-in. hole to 1,500-ft depth with a desired capacity of being extended to 2,500-ft depth.
   - Drilling with air circulation.
   - Setting casing for either hole size to a 500-ft depth.
   - Drilling 12,000 psi and weaker rock at the rate of 17 ft per hour and 25,000-psi quartzite at the rate of 6 ft per hour (penetration rates).
   - A hoist drum capacity of 2,500 ft of 3/8 in.

Throughout the report it is considered that these are all parts of a system which are mutually compatible. It is, also, recommended in many places that further studies during the programs of development would modify the detailed recommendations. Parallel studies were also recommended on explosion and shock wave propagation in mine workings and definition of a 20-psi shock wave.

2. COAL MINE RESCUE & SURVIVAL SYSTEM (CMR&SS) PROGRAM

2.1 PROGRAM MANAGEMENT

The program management principles and methods which had proven most successful in highly integrated system development and evaluation efforts were adapted by Westinghouse to the special needs of the CMR&SS program. As a result, the primary program objectives of evaluating the National Academy of Engineering concepts for a CMR&SS through hardware development and test were met on schedule within target costs.

Key features of the management of this program were:

(1) The centralization of management responsibility and authority for the entire program in program manager, from proposal through program completion, together with full support of the Division and senior management within Westinghouse.

(2) Extending the concept of one-man responsibility and authority to the project level and, in some cases, to more detailed items on the work breakdown structure before delegation to functional management.

(3) A system engineering function within the Program Management Office and subsystem engineering functions in project offices to identify design requirements for all elements of the system consistent with contract objectives and quantitative performance goals.

(4) Detailed initial task planning involving a work breakdown structure, critical path measurement logic, milestone scheduling, and cumulative cost projections on a consistent basis to the subtask level.

(5) A single management information system which compared technical, schedule, and cost performance with the plan on a fast-response basis to meet the requirements of managing a program to produce the three subsystems in time to test them and achieve evaluation reporting in the nine-month program. Weekly reporting included detailed cost information plus technical and schedule problems on an exception basis. Monthly reporting compared milestone progress against the milestone plan in detail and compared cost trends with the expenditure plan. This system provided the same information to the Bureau of Mines in monthly management reports as the Westinghouse Program Manager and his project managers were using to control the program.

(6) Design reviews attended by program office personnel enabled performance being achieved to be compared with goals, and permitted a further integration of technical with schedule and cost achievement to assess overall program progress against the plan, and to alter the plan to keep the program on track toward program objectives.

(7) Oral reviews with the Bureau of Mines were invaluable to Westinghouse program management in affording direct feedback from Bureau personnel on their assessment of progress and problems aired at the meetings.

(8) Technical reviews of planning documents by the Bureau of Mines Project Technical Officer based upon comments from a technical reviewing committee.

(9) Subcontractor selection was formalized to be certain that the chosen suppliers would be able to perform the desired developmental work within the expressed short-reaction time frame emphasized by the contract. Weighting analysis of various potential contractors was performed and made known to the Bureau of Mines during program review meeting.

2.2 ORGANIZATION AND WORK BREAKDOWN STRUCTURE

Figure 2-1 gives the work breakdown structure and program organization which were identical down to the major task level due to the system program management method employed on the program. The major task (or project) level is the lower level enclosed in boxes on figure 2-1 such as Systems Engineering and Survival Subsystem. Primary subtasks under the major task are listed below each box.

2.3 PROGRAM PHASES

The CMR&SS program was divided into four phases appropriate to its primary system development and concept evaluation purposes. The work of these phases was planned in detail during the initial period which followed contract "go ahead" on 17 June 1970.

(1) A predesign phase which established design requirements.

(2) A detail design phase which produced drawings and specifications for fabrication and procurement.

(3) A phase which included fabrication and assembly, plus associated procurement.

(4) A test phase which included functional testing of components and subsystems and the final demonstration testing in a system operating environment. This last phase also included preparation of the final reports and delivery of equipments and documentation drafts.

2.4 SUBJECT INVENTIONS

Throughout the period of the contract, the following were identified as possible inventions for which Westinghouse planned to make disclosures:

(1) The Surface Seismic Transmitter.

(2) The Beacon Transmitter System used for data (Seismic) Transmission.

(3) The Battery Mounted Voice Receiver.

(4) The Mine Communications Time Share and Alert System.

(5) The Seismic Location System

(October - November Monthly Technical Progress Report.)

(6) A Chlorate Candle and Lithium Hydroxide Canister combination for Use in Closed Circuit Personal Breathing Apparatus.

(7) A Nominally Constant Flow Rate Chlorate Candle of Unique Configuration for Use in Closed Circuit Breathing Apparatus.

(8) Use of a Flexible Head Hood as Man-Machine interface with a Closed Circuit Rebreather.

(9) Combination of a Large Volume Atmospheric Conditioning Unit with Individual Emergency Breathing Masks.

(10) One Hour Endurance Self-contained Closed Circuit Personal Breathing Apparatus.

(December - January Monthly Management Report)

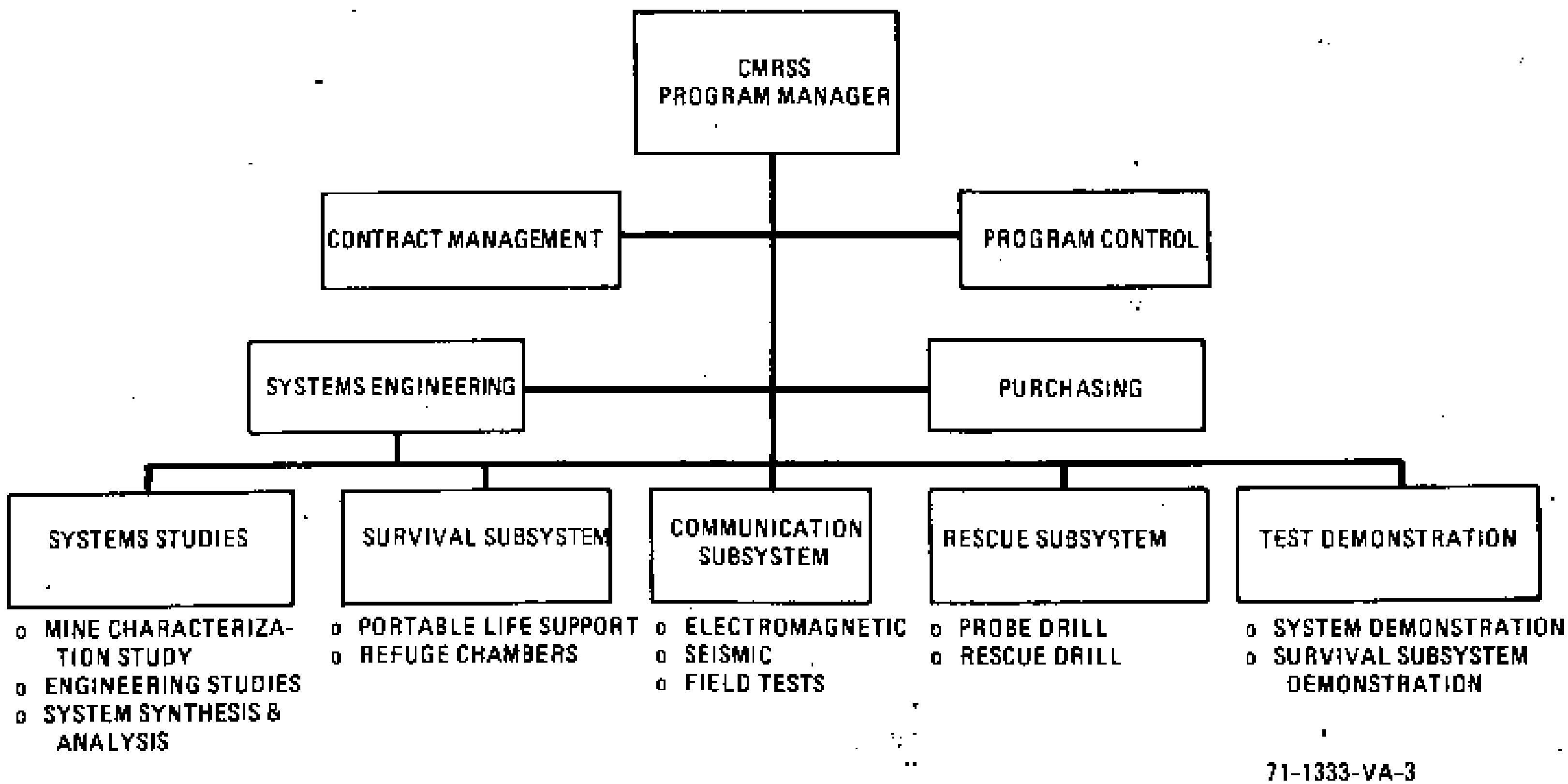


Figure 2-1. CMR&SS Program Organization and Work Breakdown

Formal disclosures have been filed and copies of the disclosures delivered to the Contracting Officer covering items (1), (3), and (4) above. Disclosures are in the process of preparation on items (6), (7), (8), and (9) which disclosures were delayed due to a subsequent analysis of these items and our evaluation that these developments were of marginal novelty and not likely to be patentable. The disclosures are, however, being submitted in order that the ultimate decision with respect to their processing may be made by the Bureau of Mines.

Originally the transmission of seismic data by means of a beacon transmitter system was thought to be a "subject invention" under the contract. Further analysis and background search revealed, however, that the transmission of this kind of data was within the scope of disclosure RES 71-262 "Through-the-Earth Communication System (Subsurface to Surface Beacon)", an invention conceived and demonstrated prior to receipt of Contract H0101262; therefore, this item is not properly reportable as an invention under the contract, but rather as a possible background patent as has been done.

With respect to the Seismic Location System, Item (5), further investigation revealed that no reasonable disclosure could be written on the system as a whole, since the whole system does not now appear to qualify as an invention. The subsurface seismic transmitter, Item (1) above, is an element of the system and was disclosed in disclosure RES 71-158 and is believed to be the only element of the system to reasonably qualify as a subject invention.

3. SYSTEMS ENGINEERING

3.1 INTRODUCTION

The Coal Mine Rescue and Survival System, CMR&SS, is a feasibility demonstration system produced and tested by Westinghouse in accordance with the contract provisions in a nine-month program bringing together state-of-the-art technological capabilities into a compatible system design. Section 3.2, below, presents System Requirements derived from contract requirements and goals, from capabilities and requirements stated by the NAE,* and from basic design considerations. Section 3.3 provides brief functional descriptions of the subsystems, while section 3.4 describes some results achieved by Systems Engineering in guiding the design, production, and testing of CMR&SS. Finally, several of the supporting studies performed by Systems Engineering are summarized in section 3.5.

3.2 SYSTEM REQUIREMENTS

Performance requirements for CMR&SS may be inferred from considerations of subsystem capabilities, providing life support alternatives (including rescue) to underground coal miners who are prevented from using normal means of escape, and the general coal mining environment. The following set of implicit system requirements has been thusly derived.

- CMR&SS shall be designed to sustain the lives of and to minimize further danger to the lives of the trapped miners whose rescue is being attempted.
- Underground elements of CMR&SS shall meet permissibility requirements of the Bureau of Mines and shall be designed to operate within nominal physical constraints found in the mine environment.
- State-of-the-art technology shall be used in the design and fabrication of CMR&SS equipment.
- The prototype CMR&SS equipment shall be delivered 39 weeks after effective contract date.
- Surface elements of the CMR&SS shall be designed for ease of transport and deployment in the event of an emergency requiring their use.
- The combined accuracies of the Communication/Location and Rescue Subsystems shall be specifically examined to be as accurate as possible, consistent with other constraints of transportability, speed of set-up, use in differing overburden, etc. Time (from occurrence of the entrapment) required to complete the "probe hole" shall be the minimum practical. For miners trapped in an ASC or LCC, the time to complete the probe hole shall not exceed 2 weeks from activation of the chamber

*National Academy of Engineering, Committee on Mine Rescue and Survival Techniques, Final Report, "Mine Rescue and Survival," March, 1970.

The foregoing system requirements are in consonance with the several subsystem design goals and with the overall objective of effecting safe, expeditious rescue of trapped miners. These general system requirements become even more important upon the realization that all trapped miners may not be able to reach a shelter where the life support capabilities exist. Under such conditions, performance requirements for seismic equipments, in locating isolated trapped miners, are stringent, and the time required to complete the probe hole to the entrapment chamber becomes critical. Specific contract requirements for these subsystems as well as those general requirements imposed by the operating environment and system goals are presented in condensed form in the following paragraphs.

3.2.1 Survival Subsystem Requirements

3.2.1.1 Personal Breathing Apparatus (PBA)

- PBA shall provide one hour emergency breathing for use in contaminated gaseous environments (smoke, carbon monoxide).
- PBA shall allow wearer to pass through a relatively high temperature flame without suffering severe burns.
- PBA shall permit wearer to pass through heavy smoke and dust.
- PBA shall permit wearer to conduct intermittent voice communications with nearby parties.
- PBA shall permit the wearer to easily don and doff the unit. (Consider personnel wearing corrective eye glasses.)
- PBA shall be conveniently stored on the miner when not in use. (Such as on the miner's belt).
- PBA shall guarantee the highest possible degree of safety.
- Hardware reflecting design and permissibility requirements shall be produced.

3.2.1.2 Auxiliary Survival Chamber (ASC)

- ASC shall be equipped with self-contained oxygen-producing and carbon dioxide and carbon monoxide removal systems.
- The ASC shall provide sufficient life support for 15 men for 14 days.
- ASC shall be capable of withstanding 20 psi blast pressure.
- ASC shall be designed for assembly, disassembly, and movement within the mine passageways.
- The ASC shall be designed to accommodate a height constraint (imposed by coal seam thickness) of between 4-1/2 and 6 feet in 6 inch increments.
- ASC shall be designed so that it may be relocated as mining advances or retreats in a given section.
- Stores of food and water for the 15 men and 14 days shall be provided. The minimum caloric intake shall be 600 calories per man per day; however, 1800 calories would be more satisfactory. The water provided per man per day shall be sufficient to provide the needs established by the diet. (Satisfactory water provision in daily life, gained in foods and by drinking liquids is 2 quarts per man per day. The needs vary depending upon the quantity of protein and carbohydrates consumed.)
- Heat generated within the chamber from the life support systems shall be considered.
- ASC shall guarantee the highest possible degree of safety.
- Hardware, reflecting design and permissibility requirements, shall be produced.

3.2.1.3 Large Central Chamber (LCC)

- The LCC shall support 50 men for 14 days.
- The LCC shall withstand 20 psi shock load and 1000 psi roof load.
- Nominal design depth for the LCC shall be 750 feet.
- A fixed location shall be selected for the LCC.
- The LCC shall be fabricated within the mine.
- A borehole opening to the surface shall be provided for LCC.
- LCC shall guarantee the highest possible degree of safety.
- The LCC shall be airtight.
- The LCC shall be fireproof.
- A paper design meeting the requirements shall be produced.

3.2.2 Communication/Location Subsystem Requirements

3.2.2.1 Electromagnetic Subsystem

Subsurface Elements

- Underground beacons shall emit signals detectable at the surface to aid in location of trapped miners.
- Range of operation through the earth shall be at least 2500 ft, depth or slant range.
- Beacons shall allow response to surface interrogations.
- Beacons are to be located in shelters, in barricade areas, or at other strategic locations in a mine.
- Receivers at these locations shall be able to receive voice signals from the surface.
- Consideration shall be given to transmission of seismic signals from in the mine via the E/M systems.
- Beacons and receivers should be low weight and low cost.
- Beacons and receivers shall be capable of 2 weeks continuous operation from a self-contained power source.
- Equipments should withstand shocks from explosions and rough handling and shall use miniaturized state-of-the-art components.
- Equipment shall meet permissibility requirements.

Surface Elements

- Equipments shall be designed for rapid transport and ease of deployment.
- Transmitter units shall transmit voice instructions and interrogations at sufficient power to be understood by in-the-mine receivers.
- Receiver units shall have sufficient sensitivity to receive and interpret responses from in-the-mine transmitters.

3.2.2.2 Seismic Subsystem

Subsurface Elements

- Underground seismic sources using readily available (in the mine) materials shall be considered. Best means of producing seismic signals shall be recommended.
- A simple set of seismic signals and coded responses shall be developed.
- Geophone(s) use to listen for signals generated by isolated trapped miners and propagating through floor or roof strata (or through the seam) shall be considered.
- Need for or utility of geophone(s) to detect seismic signals from the surface shall be investigated.
- Equipment shall meet permissibility requirements and shall remain operable under conditions of rough handling as well as long periods of nonuse.

Surface Elements

- Equipments shall be designed for rapid transport and ease of deployment.
- Sensitivity of geophone arrays shall be such as to permit detection of signals from weak sources (such as isolated miners beating on pipes or rails).
- Means of coupling geophones to the earth shall be investigated.
- Seismic sources and codes such as the use of a series of explosions at intervals to convey minimal basic instructions to isolated trapped miners shall be investigated.
- Means of bandpass filtering to reduce interference from extraneous sources shall be provided.
- Means of recording multiple sequential signals and of integrating weak signals for enhancement of detection shall be provided.
- Surface arrays shall employ self-contained power sources capable of two weeks continuous operation.
- Computations for determining locations of seismic sources shall be performed by computer (leased, purchased, or remote time-shared).

3.2.3 Rescue Subsystem Requirements

Both the Probe and Rescue Drill Rigs shall be designed to allow wide latitude in the choice of downhole drills and circulation methods. Maximum use of existing drilling technology shall be used in the design of the rigs. Table 3-1 on the following page lists target capability goals for the Probe and Rescue Drill Rigs as specified in the contract.

3.3 SYSTEM DESCRIPTION

The Coal Mine Rescue and Survival System, CMRSS, provides the elements required to effect the survival and rescue of entrapped miners.

3.3.1 Survival Subsystem Description

Following the occurrence of an emergency situation in which underground coal miners become trapped, the Survival subsystem provides life support capabilities until rescue can be effected. The subsystem consists of the following: a number of Personal Breathing Apparatuses, PBA (similar to a self-rescuer but with a self-contained oxygen supply); Auxiliary Survival Chamber, ASC; and a Large Central Chamber, LCC. Only the design of the LCC was to be delivered under terms of the contract, while the other items were to be designed, developed, demonstrated, and delivered. Individual subsystem elements are described in detail in Section 4.

3.3.2 Communications/Location Subsystem Description

The objective of the Rescue Subsystem cannot be accomplished without first establishing the existence of and location of surviving miners — the prime function of the Communications/Location Subsystem. Assuming a disaster has occurred, continuous communication with survivors can be established and maintained to determine their condition, their situation as to supplies, injuries, and number, of their location, and other information pertinent to rescue operations. Such communications can pass instructions and should provide a "psychological lift" to the trapped miners.

Electromagnetic techniques are used for beacon transmissions. The beacon transmitters and associated receiver is a simple, low cost, underground magnetic device which generates signals easily detected by sophisticated equipment on the surface. The system provides for voice communication from the surface to the underground location and precoded

TABLE 3-1

TARGET DESIGN GOALS

Item	Probe/Search Drill Requirements	Rescue Drill Requirements
Delivery	Delivery at 39 weeks	Delivery at 39 weeks
Instantaneous Penetration Rates	100 ft/hr in 12,000 psi rock 20 ft/hr in 25,000 psi rock	17 ft/hr in 12,000 psi rock 6 ft/hr in 25,000 psi rock
Overall Penetration Rate	Max. possible under geological conditions	Max. possible under geological conditions
Deviation from Scheduled Course	2^{o} in 500 ft	2^{o} in 500 ft
Range	Min 6" diam. to 1500 ft. extendable to 2500 ft.	18"-28" diam. to 1500 ft. extendable to 2500 ft.
Transportation	Transportable in military aircraft, cargo plane, and helicopter	Mounted on trailer bodies for highway or rail travel
Auxiliary Equipment	Includes all necessary auxiliary equipment for independent operation at a remote site	Includes all necessary auxiliary equipment for independent operation at a remote site

71-1333-T-1

pulsed answers from underground to the surface equipment displays. The seismic subsystem elements are intended to detect "isolated miner" generated signals for communication and location purposes. Surface explosions arranged in a simple code or pulses can pass elementary information to the miners. The location of the trapped miners may be determined by voice communications using the EM Subsystem or by computations using relative times of arrival of seismic signals at several arrays of geophones on the surface. The surface elements of this subsystem are designed for rapid transportation and easy deployment.

3.3.2.1 Electromagnetic Subsystem Description

The primary functions of the Surface EM Communications Subsystem are: 1) to transmit voice communications to trapped miners via the voice downlink; 2) to receive coded replies from trapped miners via the EM beacon uplink; 3) to receive initial beacon signals (which provide rough indication of position.) A secondary function of the beacon uplink is to aid in the calibration of the earth (overburden) propagation characteristics. Due to the probable layered character of overburden in coal mine areas it is probable that seismic disturbances originating on the surface will undergo refraction effects at layer boundaries.

The EM Communications Subsystem equipment (both uplink and downlink) use the principle of electromagnetic induction in conducting media. The transmitted signal generates a current in a horizontal wire or loop and the resulting non-radiated electromagnetic field is sensed at a remote location generally using a loop antenna. The significant characteristic of the overburden is resistivity, measured in ohm/meter. At the low frequencies involved (200 to 3000 Hz) resistivity is the DC resistance.

3.3.2.2 Seismic Subsystem

The primary objective of the seismic subsystem is to locate a single miner or a group of miners who are trapped by a mine disaster and have no means of communicating with the surface except by generating seismic signals. These signals are generated by the miner pounding on a consolidated surface such as the roof or seam bottom with whatever is available and received at the surface at multiple geophone subarrays. These geophones convert movement of the earth into electric signals. Since the travel paths from the source to each of the geophones is different, the travel time varies. It is this difference in travel time that allows location computation to facilitate knowing the location of the trapped miner(s).

Another feature of the seismic subsystem is the downlink seismic communication link. Coded sequences of explosive shots are set off at the surface. These can be detected by geophones in the mine or, if strong enough, by sound or vibration sensed by an unaided miner. Reply may be by seismic methods or by use of a beacon transmitter which has a capability of relaying seismic signals to the surface via the EM uplink.

3.3.3 <u>Rescue Subsystem Description</u>

Once trapped miners have been located, the Rescue Subsystem provides a means of providing supplies or air and, also, rescue by means of holes drilled from the surface. The Rescue Subsystem consists of two drill rigs, Probe Rig and Rescue Rig which drill 8-3/4- and 28-1/2-inch holes, respectively, and necessary ancillary equipments.

Conventional rotary drilling methods are used for both probe and rescue holes. Holes are drilled by a bit attached to the lower end of a rotating string of drill pipe. Rotary power is applied by the rig at the surface. Cuttings are cleared from the bit and transported to the surface for disposal by any of a variety of water base or air base circulation media. Weight is applied to the probe bit via heavy drill collars or to the rescue bit by a "big-hole-type" weighted assembly located in the drill string just above the drill bit. Both rigs are designed to drill straight vertical holes.

3.4 SYSTEMS ENGINEERING — DESIGN GUIDANCE

3.4.1 General

The Systems Engineering Group, together with program management, provided general engineering guidance, direction, and control to achieve overall technical integrity of CMR&SS design, procurement, assembly and testing. The compressed nine-month contract schedule precluded a comprehensive and lengthy system study which in "normal" projects would result in verification, modification, and/or expansion of the basic system concept. These findings would then be used in specifying system and subsystem requirements, submitted for formal review and customer approval and then used to guide the efforts of the subsystem design groups. The full benefits of system engineering influence on subsystem designs, therefore, could not be realized. To ameliorate this situation, each design group was required to follow a systematic approach in effecting initial design choices. Later, as data became available from systems engineering studies, the need for several subsystem design modifications became evident. Where possible these changes were reflected in the prototype subsystem designs. Below are discussed some of the more noteworthy influences of Systems Engineering. It is neither practical nor desirable to include in this report the myriad, almost daily results of design discussions held during the contract.

3.4.2 Survival Subsystem

Several design concepts had been advanced in the Westinghouse proposal for CMR&SS small shelter, or ASC. These included:

- Curved segment modular sections (rigid)
- Rigid "spherical" sections
- Box frame type metal sections
- A-frame sections (rigid)
- Inflatable structures (non-rigid)

ASC design personnel were required to use a systematic approach (tradeoff analyses and weightings) in evaluating these and other concepts to effect their design choices. Because of requirements to move the ASC from time to time so that it remained convenient to miners at the moving working face, the curved segment approach, which had appeared good from the standpoint of withstanding blast pressures and/or rooffalls, as well as the other ASC proposals concepts, were soon abandoned. A "scoring system" using a combination of subjective and quantitative evaluation factors clearly showed the advantages of a wheeled collapsible, curved-segment, modular concept during the ASC design tradeoff study.

A height of "4-1/2 feet to 6 feet in 6-inch increments" was specified for the ASC; however, an erected design height of six feet was chosen for the demonstration testing and design data accrual. Data showed that an ASC with this height could be erected without excavation in underground coal mines accounting for somewhat less than half of total U.S. production. The rationale for this choice lies in the combination of a number of factors: 1) the ASC was to be tested at the U.S. Bureau of Mines Experimental facility at Bruceton which could accommodate a 6 foot erected height; 2) basic structural materials had been advance ordered in order to meet manufacturing schedules, and changing the design to another height such as 4-1/2 feet would not introduce any different manufacturing or design problems of major importance; and 3) the prototype concept could be feasibility tested at any height; in fact, the greater height ASC would likely be more susceptible to blast damage than a lower profile ASC.

In addition to the above, Systems Engineering performed a dynamic blast effects analysis of the ASC and bulkheads; this analysis showed that the design could safely withstand pressure waves resulting from 20 psi blasts.

Interface discussions among Systems Engineering and the Survival Subsystem and Communication/Location Subsystem Groups were held on several occasions to solve interface problems. Various data were furnished to the design group during the contract. These data, partially in response to requests from the design group and partially resulting from studies conducted by Systems Engineering, were used in the study of shelter placement and movement within mines. Relaxation of the height and width constraints on ASC modules when configured for movement was allowed after study of entry dimensions and equipment design dimensions. Guidance and assistancewere also provided regarding permissibility requirements for electrical equipments.

A very brief investigation was also conducted by Systems Engineering regarding miners' attitudes toward survival shelters. Two avenues were studied:

- Whether miners would enter a shelter as opposed to attempting escape, and
- Whether the ASC should continue as a 15 man-14 day shelter or be configured in a 2-8 man or 3-5 man size with 14 day life support capability in each module.

The first of these areas was dropped as not being within the purview of Westinghouse under terms of the contract. While there is reason to feel that the larger shelter would be more acceptable to the miners, e.g., an extra man (if more than 15 are in a section at the time of the emergency) may more likely be allowed to enter a 15-man shelter than an 8-man or a 5-man shelter, this second question was never fully resolved. Using a pair of smaller shelters would allow "leap frogging" and would retain a capability for life support during repositioning. Also, it would be easier to locate or prepare a suitable position for a "smaller" shelter in many underground situations and smaller mines. Since the ASC was designed in six modular sections, it is adaptable to two three-section shelters by fabrication of two additional end bulkheads and rearrangement of some internal fittings and supplies; hence, final resolution of the question was not attempted under the CMR&SS contract.

Once design concept tradeoffs were completed for the Personal Breathing Apparatus, Systems Engineering made only minor contributions to the design process for this equipment. Background data of various types were provided to the design group for the design of the Large Central Chamber; LCC.

3.4.3 Communications/Location Subsystem

Systems Engineering participated in the design of the Communication/Location Subsystem to a limited extent. A "backup" computer routine was generated by Systems Engineering to compute seismic signal locations from data collected by the geophone arrays. This routine implements a "least squares" solution to find a single "best fitting" solution to signal source position. It was hoped that this approach would lead to more accurate solutions than a simple averaging of multiple solutions implemented by the design group. However, the simplifying expedient of using a single "average" velocity for seismic signals through the overburden in both routines apparently masks the potential advantages of the least squares solution.

Systems Engineering conducted discussions of the physical and electrical interfaces between the Communication/Location and Survival Subsystems. Interchange of data and ideas between the groups resulted in adoption of a common type of battery and provisions for cross feeding electrical power during battery replenishment or in event of failure. Handling procedures for Communication/Location Subsystem equipment during relocation and upon activation of the ASC also were derived during these discussions.

3.4.4 Rescue Subsystem

The Probe Rig and the Rescue Rig which are trailer-mounted are the largest, heaviest portions of CMR&SS. Early concern for the weight and size of these rigs led to an investigation of highway transportation capabilities. Federal highway standards data for U.S. highways listed 13 feet 6 inches as the design standard height for underpass. Systems Engineering, therefore, set a requirement that the road transport height of the rigs be less than 13 feet 6 inches which caused redesign of some of the mechanical parts of the rig towers and stabbing platform design. There was still concern, though, that the rigs might encounter difficulties enroute to an emergency. West Virginia, for example, was known to have a large number of weight-restricted bridges and low clearance underpasses. While these occur mainly within the secondary road system, many are found on the U.S. highway system in the state. For these reasons, the initial routing study showing routes and distances from C-130 jet freighter aircraft compatible airports to points in selected counties in coal producing states appeared in need of more detailed examination. The purposes of this effort were threefold:

a. To ascertain if it is possible to route the fully assembled rigs (configured for highway transport)

b. If more than one route is open, to select the closest route in terms of elapsed time, and

c. If there is a number of "inaccessible" areas, to ascertain what repackaging of the rigs would be necessary.

This study showed that low underpasses could usually be bypassed by rigs with a design height of less than 13 feet 6 inches. Weight restricted bridges, however, would pose problems especially in the northeastern counties of West Virginia, provided weight restrictions listed for the bridges are realistic and inviolable.

From consultations with trucking concerns and with the Rescue Subsystem design group several facts became evident:

a. In most cases "permit weight" trucks can and do proceed over bridges at well above posted weights

b. That it is more practical (or less costly in terms of time delays) in most cases to provide temporary reinforcement for weak bridges than to break down the loads into smaller weight packages;

c. In less mountainous areas heavy rigs are often detoured around such constraints by moving cross country, fording small streams, etc. (Such fords already exist in many cases to get heavy loads into the mine area.)

It was concluded, from this exercise, that CMR&SS could rely on commercial trucking contractors, with assistance of state and local police and highway authorities, to route the rigs to the deployment site in event of an emergency and that no major repackaging of the rigs would be necessary.

3.5 SYSTEMS ENGINEERING SUPPORTING STUDIES

To provide for the effective design and operation of the Coal Mine Rescue and Survival System, several background studies were undertaken by the Systems Engineering Group. The "Coal Mine Characterization Study" issued in preliminary form in November, 1970, as Technical Report 262-1 and a study investigating the feasibility and techniques of modeling mine explosions are examples. Products of these studies established the design height requirement for the ASC and provided guidelines used by the Survival Subsystem Design Group in the study of shelter placement within a mine. As described earlier, vertical clearance findings made during the transportation study resulted in a lowering of the design heights of the drill rigs (as configured for road transport). A System Utility Model or SUM was developed under Section 1.2 of the CMR&SS contract. This tool allows the determination of total systems performance in terms of subsystem performance. Its principal value to CMR&SS efforts lies in its ability to point out areas where future improvement would provide the greatest payoffs, i.e., it may be used as a tool for subjective improvement toward optimization of the system. The System Utility Model and other systems supporting studies efforts are discussed below.

3.5.1 System Utility Model

3.5.1.1 Problem Definition and Summary

The development of a System Utility Model, SUM, was undertaken early in the contract period under section 1.2 of the CMR&SS contract. This effort was not further pursued as it was deemed infeasible to iterate system design tradeoffs within the contract schedule beyond the first analysis which showed reasonable compatibility of the performance parameters of the Subsystems.

Problem definition began with defining the operating environment for CMR&SS and deriving expanded system and subsystem requirements. The system worth model was, as proposed, to define system worth of system performance as the weighted sum of subsystem performances:

$$SP = \sum_{i=1}^{3} w_i \; P_i,$$

where

w_i is the importance weight assigned to the i^{th} subsystem,

$\sum_{i=1}^{3} w_i = 1.0$, and P_i is the indicated performance of the i^{th} subsystem derived in terms of capabilities to meet specific requirements measured by critical parameters.

In simplest terms, the purpose of CMR&SS is to sustain the lives of trapped miners until rescue can be effected. This definition of "system utility" allows certain simplifying assumptions: (1) Rescue Subsystem performance may be measured by probe drill performance since, once the probe hole has been successfully completed, it may be presumed that trapped miners' lives can be sustained, and (2) except for size and portability the ASC and LCC perform the same functions; therefore, the ASC may serve as the predictor of Survival Subsystem performance.

3.5.1.2 Qualitative Synthesis

The second step in deriving a SUM is that of identifying critical parameters — sometimes called qualitative synthesis. Without negating the importance of drill rate — bit life derived from weight on the bit, rotary speed, etc. — in predicting the performance of the probe rig, drill rate is not the critical performance parameter contributing to system performance. The important function of the Rescue Subsystem is, in fact, to drill the probe hole in time. The critical parameter thus was identified as the total elapsed time to drill the probe hole. This time is to be measured from the time the ASC is activated (with 15 men inside).

For the ASC, three parameters were identified: transportability within mines, erectability of the ASC, and life support capability — the latter being the most critical.

The performance of the Communication/Location Subsystem, composed of both electromagnetic and seismic subsystems can be measured in terms of depth or range of capability, error of location, and time to effect location. The listing below summarizes the results of qualitative synthesis and shows the relative importance weights, w_i, assigned. Although reasonable care was exercised in choosing these weights, it may be argued that they are, at best, inexact. However, since the value of a utility model lies in its ability to enable relative comparisons of system performance rather than to provide an absolute measure of performance, meaningful comparisons may be made even though the weights are at inexact values. Note that the pervading parameter is time.

i	W_i	Subsystem	Critical Subsystem Element	Critical Measurement Parameters
1	.4	Survival	ASC	transport, erection, life support, time
2	.35	Rescue	Probe Rig	time to drill
3	.25	Comm/ Location	EM, Seismic	depth or range error, time

3.5.1.3 Quantitative Analysis

Capabilities, performance values, and other subsystem traits exhibited during the test and demonstration exercise provided needed data for the quantitative analysis as well as allowing final choice of the critical parameters identified above. Other considerations, such as the ability of man to survive without food or water for several days, however, must be taken into account. Still there are some subsystem parameters which have only yes or no or go-no-go values, e.g., the ability of the ASC to supply respirable air for 14 days for 15 men. Yet other parameters require subjective or judgmental evaluations. The means normally chosen for quantifying these is a scoring system. Results of this quantitative analysis effort were used in developing the rationale for computing performance measures.

The use of a logarithmic function to express performance in terms of requirements has an advantage over a straight ratio of capability to requirement. For example, overdesign (achieving performance better than the requirement) is rewarded at a decreasing rate, while underdesign is duly penalized. For this reason logarithmic ratios were chosen to evaluate a number of performance parameters.

3.5.1.4 Quantitative Synthesis

Where multiple performance elements were deemed important to performance evaluation, as before, weighted sums were employed. Again reasonable care was used in the choice of weights and use of subsystem performance values in relative comparisons should be valid. Table 3-2 summarizes the results of quantitative synthesis. Rationale or criteria for performance calculations are also shown in the table.

Using the notation of table 3-2 and paragraph 3.5.1.1 the System Utility Model may be reduced to a single expression

$$SP = 0.064T + 0.016E + 0.32L + 1.202 - 0.583 \log_{10} t_R +$$

$$0.175 \log_{10}\left(\frac{D_S}{R \cdot t_L}\right) + 0.075 \log_{10} D_E$$

3.5.1.5 CMR&SS Score

Let us now examine the set of input facts exhibited by the prototype CMR&SS elements to determine system performance. For the ASC there were restorable seal failure and alignment problems. From the scoring table of table 5-2 score of 0.7 for life support (1.0 less 0.2 less 0.1) would be awarded or L=0.7. The transportability, T, has a value of 0.79 while the erectability equals 0.26. Survival Subsystem score (weighted) is therefore 0.279.

For the Rescue Subsystem the elapsed time to complete the probe hole was approximately 174 hours. This value has not been adjusted for lost time due to an accident and subsequent freezeup problems at the drill site; also, activation of the ASC was assumed at about noon on 16 January. The weighted Rescue Subsystem performance score is, therefore, approximately 0.121.

TABLE 3-2

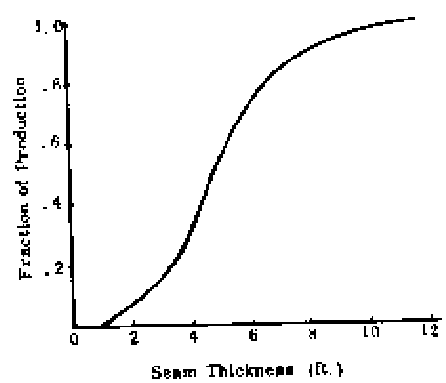
QUANTITATIVE SYNTHESIS SUMMARY AND RATIONALE

Subsystem	Measure	Symbol	Weight	Measure Function	Criteria or Rationale
Survival	Life Support	L	.8	(score)	See scoring table below. Score is 1.0 less total penalty
	Handling (transportability)	H (T)	.2 (.8)	.8T + .2E (see rationale)	Fraction of production in seams transport height of ASC (42") or .79 (see graph)
	(erectability)	(E)	(.2)	(see rationale)	Fraction of production in seams erected height of ASC (72") or .26 (see graph)
	PERFORMANCE	P_1	.4	$.2H + .8L$	
Rescue	Time	t_R (hrs)		(see rationale)	Survival time (14 days) less transport time (25 hrs) less location time (25 hrs) less rig up time (6 hrs) = 280 hrs
	PERFORMANCE	P_2	.35	$5/3 \log_{10} (\frac{280}{t_R})$	Fraction has value of 1.0 at t = 70 (man o.k. about 3 days without food and water), 0.0 at t = 280
Communication/Location Seismic	Depth	D_S(ft)		Requirement: 2000 ft	98% of mines at depth < 2000 ft.
	ERROR	R (ft)		Requirement: 20 ft	Allows differentiation between 2 parallel entries separated by 40 ft. or larger pillars
	Time	t_L(hrs)		t_D = 50 hrs.	Measure against performance capability at Test/Demonstration where t = 50
	Performance	P_{31}	.7	$1 + \log_{10} (\frac{D_S}{2000}) + \log_{10} (\frac{20}{R}) + \log_{10} (\frac{50}{t_L})$	
Electromagnetic	Depth	D_E(ft)		Requirement: 2000 ft	98% of mines at depth < 2000 ft.
	Performance	P_{32}	.3	$1 + \log_{10} (\frac{D_E}{2000})$	
	PERFORMANCE	P_3	.25	$P_3 = .7 P_{31} + .3 P_{32} = -.201 + .7 \log_{10} \left(\frac{D_S}{R \times t_L}\right) + .3 \log_{10} D_E$	

NOTE: Subscript D indicates performance achieved during the test and demonstration exercises.

Life Support Scoring

Item	Penalty Score
Structure fails < 20 psi	-.3
< 14 days respirable air	-.1 per day
Seals fail but restorable	-.2
Alignment problems	-.1
Physical/mental discomfort	-.1



3.5.2.1 General Mine Characteristics

A requirement was established to "characterize" coal mines throughout the country in terms of several parameters — type of mine, mining techniques, coal seams mined, thickness of seam, number of employees, production rate, and environmental conditions such as temperature, humidity, and gaseous concentrations.

Historical data showed that the average seam thickness, based on percent of production, was about 4-1/2 feet, with the figure growing slowly smaller with the trend toward mining thinner seams. An ASC which was 7-feet tall when erected, for example, would be useful (fit without excavation) about 7 percent of the time; whereas a 4-1/2 foot tall ASC would fit about 50 percent of the time. The ASC design height requirement of "4-1/2 to 6 feet in 6-inch increments" resulted from a compromise between seam thickness constraints and practical lengths and volume considerations; however, since the prototype implementing the ASC concept was to be tested in the experimental facilities at Bruceton, which will accommodate a 6-foot height design, it was decided to proceed with a 6-foot height design, which would provide a suitable structure for the two test series: men living in it to test internal systems and the explosion resistance tests.

3.5.2.2 Transportation Logistics

The tasks listed below were accomplished as part of the "characterization" of coal mine areas:

- Establish the criteria for an airfield capable of handling C-130 cargo aircraft and identify those air terminals in the vicinity of coal mines that meet the criteria.
- Examine the road networks from these airfields to the vicinity of the mines; specify the preferred access routes and indicate the corresponding distances.
- Note any restrictions such as low weight capacity bridges, sharp turns, and low vertical clearance overpasses. (The latter data were used in lowering the design height requirements of the drill rig trailers.)

3.5.2.3 Communication Aspects

The study determined and described the overburden in the vicinity of current mining operations. This included data on the nominal or expected range of electrical resistivity, seismic velocities, and overburden attenuation factors.

3.5.2.4 Drilling Information

The study provided information on the overburden strata composition for purposes of specifying and/or selecting drill bits for optimum penetration to the mine level. Data associated with drill selection were presented in an appendix to the study.

3.5.3 Mine Explosion Study

A separate effort, the mine explosion study, investigated elements of coal mine explosions which influence the Coal Mine Rescue and Survival System. Information contributed by this study was used in establishing design constraints for the hardware development and in providing systems guidance for dealing with problems resulting from explosions. It established methods that can aid in locating shelters or other survival escape mechanisms in coal mines. It also demonstrated some preliminary approaches to mathematical modeling of coal mine explosions.

Documented observations of the effects of coal mine explosions were obtained from sources such as: disaster reports, historical disaster write-ups, and Bureau of Mines publications such as Bulletins and Reports of Investigations. It was found that there are common characteristics that exist during mine explosions; however, the way in which an explosion propagates and affects a specific mine is unique. Some of the major factors contributing to this uniqueness are: variations in the physical characteristics from mine to mine; mining practices within the mine; changing mining methods; and safety improvements imposed by law, e.g., more stringent ventilation and rock dusting requirements.

Based on general mine characteristics and mining methods, criteria or guidelines for the deployment of ASC's were derived. The listing below summarizes these placement guidelines:

- Locate at distances from likely explosion origins such that survival is likely. ASC's should be placed at a distance greater than 450 feet but less than 3000 feet outby the face.[1] A distance of approximately 1000 feet outby seems a good compromise.
- Advantage should be taken of conditions favorable to limiting explosion effects such as, turns of 90 degrees or better, dead-ended or butt headings, etc.
- Location on established escape routes in such a position that post explosion hazards (e.g., bad air) and natural hazards (flooding, roof failure) are minimized.
- Location favorable to the drilling of probe and/or rescue holes from the surface.
- Location at points favorable to electromagnetic and seismic communication, e.g., not below gob area.
- The number of shelters in a given mine would depend on the size and dispersion of the work force as well as the location and number of other survival means such as escape ways.

3.5.4 Transportation Study

Initial highway routing information was extended to examine constraints imposed by weight-posted bridges and low overpasses with special attention to the southern portions of West Virginia to be responsive to the contract requirement to demonstrate the systems within 100 mile radius of Charleston and in a coal mine. Automation of route selection was investigated for an area consisting of 12 counties in West Virginia. The feasibility of this approach was demonstrated; however, the practicability is questionable. Since truckers can and do exceed weight limits on bridges, and, since there "usually" are means of detouring around low overpasses, no major repackaging of the drill rigs was found to be required for road transport, and the transportation study extension was concluded. As indicated by the discussion below, highway transport will probably continue to be the primary means of moving the Rescue Subsystem to a stricken mine.

[1] Distances of 3000 feet and 450 feet were selected by considering, as limiting factors, PBA endurance for a miner walking, and near certainty of kill due to explosive effects on unprotected miners, respectively.

Equipment comprising the Rescue Subsystem is designed so that it may be transported by truck, rail, or air. For air transport the rigs and other assemblages must be partially disassembled into packages compatible with the transporter. Cargo aircraft such as the C-130 or C5A may be used for long distance movements. Local moves over difficult terrain are possible with a heavy lift helicopter such as the Sikorsky "skycrane". As much as 36 hours are required to break the rigs down into air transport compatible packages and possibly another 36 hours to reassemble them at their destination.

Both the Probe Rig and the Rescue Rig are normally trailer-mounted for highway transport. Rig sizes and weights are compatible with rail transport although removal of the masts or portions thereof would be required in isolated instances over some lines.* The chief deterrents to rail transport are procedural difficulties in setting up priority rail clearances and the general lack of adequate facilities for off-loading the rigs at a point near a stricken mine, particularly to then transport the rigs to the drill site which may be some considerable distance from the rails.

3.5.5 Rescue Gaming Study

3.5.5.1 General

A part of the system engineering effort for the CMR&SS program was the development and exercise of a gaming technique to simulate and evaluate a practical rescue operations plan and to evaluate the performance of rescue team members in the execution of this plan. Gaming is extensively used by military planners for many purposes from ascertaining the number of men required in a squad to the deployment of task forces involving all three military services. The general approach involves the definition of a set of objectives, the description of snapshots or scenarios as functions of time and/or location, and the measurement and evaluation of performance, subject to obstacles or constraints faced by the performers.

3.5.5.2 CMR&SS Application

Operations plans were developed for CMR&SS for two purposes: first, a Mine Emergency Rescue Plan defining the procedures to be implemented by Westinghouse, upon request by the Bureau of Mines, to deploy the CMR&SS equipment in the event of an actual mine emergency; second, a Demonstration Test Operations Plan for the conduct of the January, 1971, field test and demonstration of the equipment in West Virginia. These plans were made as comprehensive as possible and, in the first case, as adaptable to various geographical environments as possible.

Typical questions that arose in the course of plan development were:

- Is the rescue team organization appropriate?
- Has all required equipment and material been identified?
- Are all necessary personnel skills included?
- Has all required coordination with outside agencies been specified?
- Have all "act of God" factors (e.g., extreme weather, hostile conditions in the mine, and difficult access problems to the desired drill point) been adequately considered in the planning?
- Is the team prepared to cope with a range of human errors and equipment failures?

*Based on data contained in "Railway Line Clearance including Weight Limitations of Railroads in the United States, Canada, and Mexico." ©1970, The Railway Equipment and Publication Company, N.Y., N.Y.

These questions and probes led to the idea that an effort should be expended to test the adequacy of the rescue plans, particularly the test and demonstration plan. This was accomplished by postulating hypothetical disasters, representing realistic events, and exercising the rescue team functions. Observations and measured responses served to provide a yardstick to evaluate performance. One by-product of this procedure was the recognition that it could serve as a training aid in preparation for the test and demonstration and for actual rescue operations. A gaming exercise was performed on January 7, 1971, at the Westinghouse Defense and Space Center to evaluate the readiness of the rescue crew.

The exercise was accomplished with the members of a rescue team as the participants and a control team as the administrator. The control team set the rules, specified the conditions and constraints, and observed and evaluated the performance of the participants. The participants included:

- Rescue Director
- Field Operations Manager
- Support Operations Manager
- Facility Operations Manager
- Plant Protection Guard.
- Transportation Coordinator
- Communications and Surface Survey Representative

The individuals on the control team responsible for presenting the situations to the rescue team and for controlling the conduct of the game included analysts who developed the gaming material and representatives of the CMR&SS Program Management.

The approach was designed to involve a large number of CMR&SS personnel and operating situations in a short period of time. The exercise involved start-up operations for a rescue task; this introduced a simulated emergency in a specific location and, thereby, created a setting in which system management personnel simulated the actions required to get the CMR&SS operations underway. The operations covered included:

- Alert and notification
- Movement to the staging area
- Staging area activities, and movement from staging area to mine emergency site
- Initial activities at the mine site
- Employment of the Communication/Location Subsystem
- Employment of the Rescue Subsystem
- Miscellaneous supporting services
- Demobilization and site restoration

3.5.5.3 Exercise Results

The benefits of the gaming exercise were:

- It allowed an opportunity to observe and discuss reactions to various postulated problem situations.
- Specified reactions to problems defined in the Operations Plan were re-examined in the presence of the full rescue team.
- New problems were presented requiring new responses.
- Group participation and response simulated real life conditions. Interactions between functions were identified and attacked realistically.
- Exercise of the game pointed out flaws in planning and allowed derivation of corrective measures.

3.5.5.4 Applications

The following benefits of exercise gaming are indicated:

- Gaming/simulation techniques at a simple level can be applied effectively to CMR&SS problems.
- The game exercise will result in increased readiness on the part of rescue personnel.
- The adequacy and completeness of CMR&SS Operations Plans can be evaluated by a gaming exercise so that correction of deficiencies can be planned.

3.5.6 Behavioral Aspects of Trapped Miners

The basic concept of a shelter for miners involved in an emergency situation which has not killed them and has cut off their immediate means of escape is foreign to many persons who have been underground. It was required, however, to design such a shelter. To do this, a part of the consideration of the design is the attitude and expected behavior as pertains to the shelter of men who regularly work underground. For this purpose a brief study was made of miner attitudes. Especially a better understanding of miner viewpoints toward rescue, entrapment, barricading, and altruism during and following emergencies was sought. A trained social scientist reviewed the very few documents reporting on attitudes and behavior associated with underground workers after disasters.

One of the specific considerations was whether a shelter sized for 15 men is better than say two shelters of 8-man capacity. Consideration was given to group dynamics, and to acceptance by group of an extra man or two in the event more than 15 or 16 men are in the section at the time. It was concluded that the 15-man shelter design was better than a number of smaller chambers.

Fear of not being rescued was a major concern of the trapped miners involved in three disasters studied. This was evidenced by the repetition of futile escape attempts — covering the same ground several times. Behavior of this type could be prevented by equipping the miners with communications means. If the men could be advised from the surface about what action to take, much anxiety could be prevented, and morale could be kept up. Should the men elect to wait for rescue, keeping them busy with a pre-planned routine to facilitate their location and rescue will also help relieve their anxiety and prevent confusion and conflict.

The most significant factor with regard to miner behavior lies in the concept of fatalism. The fatalist (in varying degrees) believes that there is a fixed and inevitable course to future events so that it is pointless to worry. He may, therefore, feel that nothing he can do will affect these events. Miners sometimes take unnecessary risks and have been known to resist the introduction of new safety measures. These personality characteristics undoubtedly contribute to mine accidents and disasters. The extent of these attitudes can be determined and steps taken to improve them.

According to the Disaster Research Group of the National Academy of Sciences, panic is a frequently anticipated but rarely occurring reaction to a disaster. Evidence from research on non-mining disasters indicates that being trapped or in an extreme danger situation from which escape routes are blocked or about to be cut off, rouses intense terror (and panic would be anticipated); the individuals may use poor judgment, set off in precipitate flight, or engage in non-useful or self-destructive behavior. This reaction is probably more frequent if the person is alone or feels cut off from the source of rescue.

In conclusion, it is believed from this very limited review of the few professional studies of miner attitudes at disasters, that a continued program of miner training in the best ways to survive in certain situations is the next step. This should include training in seismic noise making for use by the Communication/Location system. Following this, provision of some of the elements of the communications and life support developments of this contract could be made a required part of the stored materials in key locations in the mine for use in emergencies such as presently available barricade materials.

However, all such concepts require a better understanding than is presently published, about how miners think and are motivated.

3.5.7 Test/Demonstration Scenario

Prior to the Test/Demonstration in West Virginia, Systems Engineering prepared a scenario giving situational information with supporting "messages" which by a planned sequence of events was to "drive" the demonstration rescue operation to the desired actions. In addition a set of contingency events was prepared to provide further guidance or direction to the Rescue Director in the event that his actions led the operations away from the intended course of events. The products of this effort are presented in the Appendix.

4. TEST/DEMONSTRATION PHILOSOPHY

4.1 GENERAL

Testing of CMR&SS equipment was planned and conducted at three levels: factory tests, subsystem field tests, and system field tests. This section deals primarily with system field tests which, during the CMR&SS program, were commonly referred to as the Test/Demonstration. Field testing of a system such as CMR&SS involves making arrangements for accommodating a large number of test and operating personnel, officials, and visitors — a task which was more complicated than normal by the desired realism in the tests. To provide an "emergency" atmosphere for the operating personnel, the actual location of the tests was known by less than 10 persons outside of management of the mine — none of whom were associated with deployment, operation, or logistical support of the system — until about two weeks before the Test/Demonstration.. At that time a small advance party of test personnel moved into the field to complete arrangements for administration of the tests. The Rescue Director, his logistics team, and system operating personnel had no knowledge of the test site location until the simulated emergency was formally begun on January 16, 1971.

No elements of the Survival Subsystem were present at the Test/Demonstration in West Virginia; however, all other aspects of CMR&SS including mustering and transport of key operating and support personnel, movement of equipment from the staging base at Charleston to the field and set up and operation of subsystems were involved in the Test/Demonstration. Subsystem performance data, collected by operating as well as test personnel, have been evaluated and are incorporated in separate volumes for each subsystem. The complete description of the Survival system testing is in that volume. The remainder of this section presents further discussions of the Test/Demonstration philosophy, planning, and conduct of the exercises in West Virginia.

4.2 PURPOSE OF THE TEST/DEMONSTRATION

The Test/Demonstration had as its main purpose the field check out and evaluation of all portions of the prototype CMR&SS (except the Survival Subsystem), as well as the operating and support personnel teams, under as realistic a set of conditions as practicable. Below are described the various CMR&SS activities which were to be evaluated during the Test/Demonstration. Factors affecting the evaluation of these activities are also shown.

- Mustering of key operating and support personnel
  - a. check completeness of alert plan
  - b. check response time of team members and groups
  - c. check acceptability of non-priority travel for bulk of personnel.

- Movement of CMR&SS from staging base to deployment site
  - a. check procedure of loading subsystems and supplies onto transporters
  - b. check degree of coordination with and support from state and local authorities
  - c. check order of dispatch to the emergency site
  - d. check routing procedures and arrangements
  - e. check transport times
- Set-up and Operation of CMR&SS
  - a. check site and access preparation, adequacy of support equipments
  - b. check setup, test, operation of Communication/Location Subsystem
    - (1) Seismic subsystem
    - (2) EM subsystem
    - (3) Operational Plans
  - c. check setup, test, operation of Rescue Subsystem
    - (1) Probe Rig
    - (2) Rescue Rig
    - (3) Ancillary equipment
  - d. check adequacy of surface communication plans
  - e. check operational command/control
- Logistical Support Operations
  - a. check completemess of operation support supplies
  - b. check availability to procure additional supplies and services as required.
  - c. Verify manning levels and personnel qualification requirements

4.3 SITE SELECTION FOR THE TEST/DEMONSTRATION

The general timing and locale for the Test/Demonstration were set in mid-winter, in the mountainous portions of southern West Virginia. The exact time and location were to be set by the Westinghouse Program Manager under cognizance of the Bureau of Mines Project Officer. The Bureau of Mines reserved approval on the Program Office selection of the Test/Demonstration mine.

A number of site selection criteria were discussed among Program Management, Systems Engineering, and Field Engineering personnel responsible for the Test/Demonstration. These selection criteria were reviewed by the Bureau of Mines technical group. Factors to be evaluated prior to selection included the following:

- Geographical location, topography
- Transportation facilities and access to surface above mine (ownership)
- Mine owner/operator willingness to participate
- Costs and schedule
- Condition of the mine and safety record
- Seam thickness
- Availability of standard communications (both surface phones and in the mine)
- Depth and characteristics of overburden
- Availability of an isolated section (non-gob area distant from active faces and sources of seismic and electromagnetic noise, to simulate a mine emergency situation like a mine not operating)

In order to provide for adequate testing of CMR&SS capabilities, yet hole costs and time required for the tests to practical values, 7 mandatory and 6 desirable characteristics for site selection were set:

MANDATORY

- Overburden 800 to 1200 feet
- Owner/operator agreement to host the Demonstration
- Location in mine 1 mile from working faces, 1/4 mile from electrical noise sources (e.g., trolly wires) or arrangement for "quiet periods"
- Access to mine by highway (or rail) from Charleston
- Surface area above mine accessible by surface transportation with permission to clear, level, and use area
- Mine should have good safety record and good roof.

DESIRED

- Seam should be of medium thickness
- Large captive mine — shaft or drift
- Good in-the-mine communications, available telephone service on the surface
- One or 2 shift mine operation — closed weekends
- Overburden consists of stable, non-waterbearing or low flow rate strata; core samples available
- No worked out areas above the underground location

The procedure of selecting the Test/Demonstration mine was accomplished by the following steps:

- Identification of a number of mines, based on size and ownership, which should be suitable
- From available information eliminate those not having mandatory or desirable characteristics
- Contact one or more of the remainder candidates and determine willingness to participate
- Negotiate details of participation — cost, legal, insurance, surface access.

4.4 ADMINISTRATION OF THE TEST/DEMONSTRATION

4.4.1 Initial Preparations

Prior to the scheduled start of the Test/Demonstration several actions were taken with the goal of assuring a successful, realistic exercise. The availability in the vicinity of Charleston of support services that were known to be required was ascertained by logistic support personnel and purchase orders were issued with delivery place not specified. The Program Manager and Deputy Program Manager with the cooperation of the mine management determined the availability of supplies and services, including telephones at the site. The prototype CMR&SS equipments at the staging base were placed in as great a state of readiness as possible. The Rescue Director, his rescue team and key operating personnel had listed and studied expected sequences of events in deploying and operating CMR&SS and had participated in the gaming exercised described in Section 3. The start of the Test/Demonstration exercises was expected some time during the week of January 18, 1971, at some site within 100 miles of Charleston.

Operation and support plans for the Test/Demonstration were laid out in detail in November 1970.* Portions of the plan — dealing with the organization for conducting the exercise are summarized below.

* Plans for a real emergency were also promulgated.

4.4.2 Organization and Responsibilities

Two separate organizations were staffed to conduct the Test/Demonstration exercises — the operating team under the Rescue Director and the observer team under the Test Director — as shown in Figure 4-1. The Rescue Director was responsible for the demonstration of CMR&SS capabilities and for providing necessary supporting functions including:

- Loading and movement of CMR&SS equipment and supplies from the staging base to the mine.
- Deployment, set-up and operation of CMR&SS at the mine.
- Operation and use of Communication/Location Subsystem equipment.
- Operation and use of Rescue Subsystem equipment.
- Providing support and services to accomplish the above.

The Test Director was charged with implementing the game plan which was designed to guide the Resdue Director's decisions so that acceptable displays of subsystem capabilities would ensue (see Section 3.5.7 and Appendix). The underground team was responsible for simulating the activities of a group of "trapped miners" including operation of underground portions of the Communication/Location Subsystem.

Activities of the underground team were coordinated by the referees* whose primary function was to act as independent observers and provide subjective evaluations of operating personnel and system performance. Data collection, photographic documentation, and other similar functions were assigned to the Data Team.

4.5 CMR&SS TEST/DEMONSTRATION PERFORMANCE SUMMARY

Performance data for the Communication/Location and Rescue Subsystems may be found in their respective volumes. This section presents a summarization of performance relative to personnel actions and to the overall system.

Because of forecast snow and concern for disruption of local non-mining traffic and other congestion the Test/Demonstration was begun earlier than had been planned. The first alert for the "simulated emergency" was given at about 12:30 PM on Saturday, 16 January 1971.

The Rescue Director and his operating team arrived at the mine (at 6:30 PM) just over 6 hours after the alert was given. The "Comm Van" arrived with police escort at about 8 PM. The following morning at 6 AM, Communication/Location Subsystem personnel arrived on site from Boulder, Colo., and were briefed by the Rescue Director. They then set out to establish EM Communications with the shelter; however, according to the game plan the EM Beacon had not yet been activated to force the team to use the seismic gear. After some delay and receiving no beacon signals the team set about deploying the seismic arrays. A large area was "covered" by the arrays which were deployed so as to receive signals from panel 2 and/or 4. The commercially hired survey crew was quite slow in identifying surface features.

At 9 PM on 17 January the EM Beacon was ordered turned on. Activation of the primary battery was then initiated by the underground crew and the EM Beacon was activated at 9:36 PM. At 9:41 PM the Comm Van reported hearing strong EM Beacon signals. Seismic signals were detected and

*The referee team was composed of Bureau of Mines representatives from fields related to rescue, communications, drilling, etc., and Westinghouse personnel associated with the CMR&SS program.

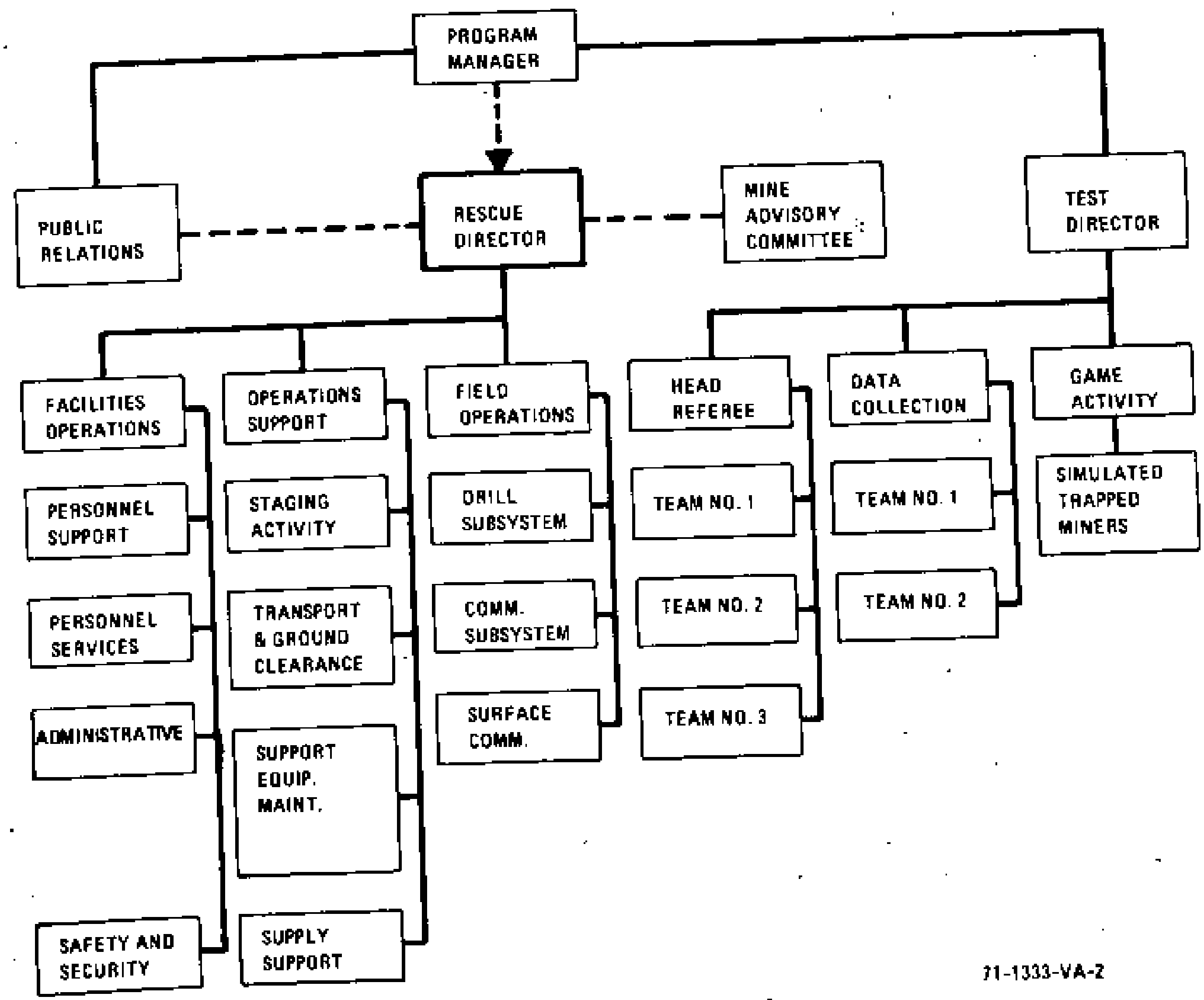


Figure 4-1. Demonstration Rescue Organization

recorded during the evening of 17 January; however, the work of "surveying in" seismic subarrays had proceeded quite slowly due to the rugged terrain. At 1 AM on the morning of 18 January the Program Manager ordered abandonment of the game plan and stated that seismic and rescue drilling experiments would proceed in parallel from that point, with the referees and data team assisting the operating teams wherever possible.

At 5 PM on 18 January a call went out for "all hands" to assist in repositioning geophone arrays. This effort involved about 10 persons for several hours during darkness on the side of the mountains. At 6 AM on the morning of 19 January the probe/search drill rig was positioned over the chosen drill point. Crews had worked all night to provide fill so that the drill rig could be placed at the drill point. The rig was erected and rotation begun by 4 PM.

At 4:25 PM one of the drillers slipped and injured himself when he fell down the side of the then snow covered mountain. He was not wearing a safety line while installing guy wires for the rig. During suspension of activities (during the rescue) portions of the circulation system froze due to extreme cold. It was early on the morning of 20 January before drilling could be rebegun. At noon that day the Rescue Rig arrived on site and was parked on the mountain. At 3:11 AM on 23 January the probe/search hole broke through the mine roof at a depth of 776.6 feet. Well log showed a hole deviation of about 1-1/2 feet. Probe/search rig removal was initiated by pulling the first joint at 11:20 AM on 23 January.

The rescue rig was spotted in, its tower was raised, and drilling the rescue hole was begun by 10:30 AM on 24 January. The hole was completed at 5:41 PM on 31 January, with a trip to change the drill bit having been made on 29 January.

The CMR&SS Test/Demonstration served well the purpose of demonstrating the capabilities and testing the unknown mobilization aspects of the prototype system in its maiden exercise. Although the Test/Demonstration could be considered successful, there were obvious shortcomings which needed correction before the system could be termed operational. The more salient of these findings are presented as conclusions and recommendations in the following section.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 MINE LOCATIONS, PERSONNEL TRAVEL

5.1.1 Conclusion

Comments from the Rescue Director's team indicate that exact locations of a stricken mine is not easily determined in the event of an emergency. This may delay CMR&SS deployment or the arrival of key operating personnel. Association of mine locations with nearby airports and major U.S. and state highway road intersections would facilitate emergency CMR&SS deployment.

5.1.2 Recommendation

That such data be collected, added to a National Mines Data Bank, and made available to CMR&SS operators. That such data be kept with regionally deployed systems for use in planning or specifying equipment routing to the vicinity of a stricken mine.

5.1.3 Recommendation

That such information be integrated into national and state disaster plans, that tentative emergency routing and escort plans be made in association with appropriate state and local officials and that emergency priority credentials be issued to key operating personnel to facilitate commercial air travel.

5.2 RESCUE SUBSYSTEM

5.2.1 Conclusion

The greatest payoff in improved system performance can be achieved through reduction in elapsed time required to complete the probe hole. (See System Utility Model, Section 3.5.1.) Improvement potential should be sought in at least two areas: improved mobility and penetration rate — especially in the first 100 feet or so.

5.2.2 Recommendation

That the Bureau of Mines pursue a program of investigation and design modification of the probe rig and its associated operating procedures to determine feasibility and methods of improving the performance of this subsystem. The possibilities of incorporating directional drilling to eliminate the necessity of positioning the rig directly over the breakthrough point in the mine and the use of pull down, down hole drill motors, etc., to increase penetration rates should be considered. Where the overburden is less than 1000 feet consideration should be given to use of faster, lighter drill rigs which may be located nearby the stricken mine.

5.2.3 Conclusion

CMR&SS operations are hampered by severe weather to an extent not anticipated for the prototype system (from referee comments).

5.2.4 Recommendation

That the Bureau of Mines authorize winterization modifications for the Rescue Subsystem.

5.2.5 Conclusion

The bit life of the rescue drill was smaller than expected.

5.2.6 Recommendation

That an investigation of the feasibility of drillability prediction from general strata characteristics be instigated. Results of such effort, if feasible, should be used for bit selection and planning the drilling program at an emergency site.

5.2.7 Conclusion

Nighttime operation of CMR&SS was hampered by insufficient lighting (from referee comments).

5.2.8 Recommendation

That additional area lighting be procured for the system.

APPENDIX
TEST/DEMONSTRATION SCENARIO

APPENDIX - TEST/DEMONSTRATION SCENARIO

1.0 GENERAL

In order that the Test/Demonstration exercise be as realistic as possible and yet result in an appropriate demonstration of CMR&SS, Systems Engineering prepared a planned sequence of events and contingencies designed to cause the Rescue Director to take desired actions.

There were 2 distinct sets of games extant for the exercise — the underground game serving as the driving function and the surface game which operated in a controlled or limited knowledge situation. The sequence of events leading up to the arrival of the Rescue Director is as presented in the following sequence of events and messages. One of the messages presents the essence of information given to the press who, having been alerted to the exercise by public relations news releases to the local populace (in order to preclude possible adverse reactions to the simulated emergency) were on hand to observe early phases of the exercise.

2.0 SEQUENCE OF EVENTS PRIOR TO ARRIVAL OF WESTINGHOUSE RESCUE DIRECTOR

Time	Event
T	Blast Occurs (simulated)
T + 0:05	a) Mine Superintendent, at site, learns of blast. b) Word passed by phone to clear mine. Some people can't be reached. c) All Electrical Equipment (except for ventilation fans) shut off.
T + 0:15	a) Mine Supt. calls Mine Rescue Team and State Mining Inspector. b) Crews working in Area X escape from mine; no word received from third crew.
T + 0:30	Escaped crew foreman reports to Mine Supt. that he has no knowledge of the location or effect of the blast except to note that it did not occur in Area Y where he was working.
T + 1:25	Mine Rescue Team and State Mining Inspector arrive at site. They hold conference with Mine Supt. and key men of the escaped crew. State Inspector then calls BuMines Official and recommends that W Rescue Team be alerted to stand by.
T + 1:30	a) BuMines Official calls W Plant Protection Guard with Message #1 (Jan. 16, 1971, 12:30). b) W Program Manager calls Press with Message #2. c) Mine Supt. and Mine Rescue Team review available disaster information, data and mine maps and plan initial rescue attempt.
T + 1:45	Mine Rescue Team proceeds underground in attempt to effect a rescue.

Time	Event
T + 2:15	Additional information becomes available to Mine Supt.: a) number, names and jobs of missing employees; b) general underground area where missing crew was working; average cover 700 feet. Note: During this period, if W calls the Mine Supt. asking advice on routes from Charleston or for general info on type of mine, mining methods, etc., the Mine Supt. is to answer the questions honestly (i.e., no simulated response) and to the best of his ability, restricting himself to info on hand at that time. Similarly for any calls to BuMines. Respond directly to questions without offering additional info.
T + 3:30	Mine Rescue Team emerges from mine after rescue attempt and presents report (Message #3) to Mine Superintendent and other officials (and press).*
T + 3:40	State Inspector calls BuMines official and recommends that W Rescue Team (Drill Rigs) be brought in.
T + 3:45	BuMines Official calls W Plant Protection Guard with Message #4. W Rescue Director arrives at the emergency site and is briefed by the Mine Superintendent. (Message #5) Contingency Events (Separate Listing).

* This event may be postponed if press has not yet arrived. In any case, it is assumed that this info is available to Mine Supt. at D:H+3:M+30 and, from then on, may be related to W Rescue Director if he calls for additional info.

Message #1

Time: T + 1:30

To: W Plant Protection Guard (301) 765-________
Subject: Standby Alert

At approximately (12:30 pm on 16 January 1971) simulated underground explosion occurred at U.S. Steel #14 near Gary, West Virginia. The mine is located on road called 15/1, 3 miles south of Route 102 Intersection. The Mine Supt. is Mr. ____________ and the telephone number is (304) 383-______.

The nature of the emergency is not exactly known yet. A total of 14 men are still missing and believed trapped.

A Mine Rescue Team has just arrived on site, is reviewing available information, and planning a rescue attempt. Please have CMR&SS equipment and personnel stand by for possible use in this emergency. My telephone number is (304) 383-2381.

Mobilize the CMR&SS Communication Gear to the mine and alert the Rescue Drill Equipment.

Project Officer
Bureau of Mines

Time: T + 1:30

Message #2

To: News Media
Subject: CMR&SS Demonstration
Call to Press at ________________ Charleston (304) 344-________

A mine disaster is being simulated in Gary, W. Virginia, for the purpose of demonstrating the Westinghouse Coal Mine Rescue and Survival System. Westinghouse has just been asked to stand by on alert — the Bureau of Mines has not yet called the CMR&SS into action. A copy of the alert message (Message #1) is appended.

It should be several hours before Westinghouse's advance crew, including their Rescue Director, ________________, arrives at the "emergency scene". In fact, at this time ________________ does not yet know of the alert nor the location of the demonstration site. Only a select few individuals were aware of the location of this site until this point. The Westinghouse Program Manager, ________________, is already on location and will hold a conference for the benefit of the news media upon their arrival at the area.

The emergency is assumed to have occurred at 12:30 pm at U.S. Steel #14 Mine at Gary, W. Virginia, on #15/1, 3 miles south of Route 102. This mine is currently being worked and all effort will be expended to ensure non-interference with ongoing mining operations. For this reason, you are asked to report to the Mine Office at the mine site. Please do not communicate with mine personnel. The Mine Superintendent will be available, together with his Mine Rescue Team, at the press conference to present the emergency scenario and a description of the initial simulated rescue attempts by the Mine Rescue Team (which is expected to emerge from the mine, completing their attempted rescue, at about 4:30 pm.)

____
CMR&SS Program Manager

Time: T + 3:30

Message #3

From: Mine Rescue Team
To: Mine Superintendent
Subject: Mine Rescue Team Attempted Rescue

"We entered the mine at the South Mains and proceeded along the North Mains in the direction of panels 2 and 4 where the missing miners were working. We encountered a number of roof falls in the North Main and were unable to proceed beyond about here (indicates area around A-A) because of a roof fall completely blocking the North Mains. Near this area, we heard weak tapping sounds (by listening to the rails). We banged on the rails near the roof fall and got a response. We think the guys are alive but are trapped in panel no. 2.

"We then made our way back through the North Mains to No. 1 Haulage Left to see if we could get into panel no. 2 by way of the entry here (indicates B-B). We encountered water in No. 1 Haulage Left, however, and could not reach the cross cut so returned here after again hearing tappings apparently coming from Panel 2 right.

Message #4

Time: T + 3:45

To: W Plant Protection Guard (301) 765-__________
Subject: CMR&SS Activation

The report brought back by the Mine Rescue Team after its initial foray into the mine indicates that there are trapped miners, still alive, buried behind massive roof fall which could take at least a month to clear away. A decision has been made to use the Coal Mine Rescue and Survival System Drills. Notify the Westinghouse Rescue Director of this decision. Please have them proceed to the mine immediately with all CMR&SS personnel and equipment.

Project Officer
Bureau of Mines

3.0 EVENTS SUBSEQUENT TO RESCUE DIRECTOR TEAM ARRIVAL

3.1 RESCUE DIRECTOR BRIEFING

Upon his arrival at the mine office the Westinghouse Rescue Director was given a briefing on the status of events. The substance of this information is presented below.

3.2 GAME SITUATION – SURFACE

At approximately 12:30 pm on the 16th of January 1971, an underground explosion occurred at the U.S. Steel #14 mine located at Gary, W. Virginia. This mine is located on secondary road #15/1, and is approximately 3 miles south from the intersection of Route 102, about 7 miles south of the town of Gary.

The mine superintendent, ______________________, was informed of the explosion over normal mine communications facilities within a few minutes of the explosion. The mine superintendent immediately gave word to clear the mine of all personnel and, with the exception of ventilation fans, all electrical power within the mine was shut down. Although the exact nature of the emergency is still not known at this time (immediately after hours) the mine superintendent, immediately after calling for the evacuation of personnel from the mine, notified the nearest inspector at large in the State Department of Mines in W. Va. His arrival is expected momentarily.

The mine superintendent also alerted the company rescue team; however, since some of the rescue team were on shift within the mine, and since others of the rescue team were off shift and not immediately available, it took approximately one hour to assemble the rescue team. The last member of the rescue team arrived a few minutes before the state inspector.

The Rescue Director was provided with a mine map which was specially constructed for the exercise. One panel (corresponding to the actual mine workings shown as "Pump Headings") designated as panel 4 and 2 other (non-existent) panels labeled 3 and 2 were indicated on the "dummy" mine map. Information given to the Rescue Director regarding the emergency was constructed to agree with the dummy mine map. In addition, a topographic map overlay showing the surface features was available to the Rescue Director.

At the time of the explosion, there were three crews working within the mine. Two of the crews were able to escape from the mine by way of the South Mains within the first half hour of the explosion. Both of the crews that came out of the South Mains stated that they did not know the source or magnitude of the explosion; however, they had encountered a number of minor roof falls on their way out. At this time, the fourteen miners in the third crew are unaccounted for. This crew was assigned to work in panels 2 and 4 off the north mains. It is known that pump trouble reported earlier in the day in panel 2 was being worked on by a maintenance crew. And some equipment was being moved from panel 2 into panel 4 to continue mining operations there due to interference of the work in panel 2 from the seepage of water into the panel.

Shortly after the arrival of the last member of the rescue team and upon consultation with the State Department of Mines Inspector, the mine superintendent sent his rescue team in through the south mains portal to assist the situation and to determine if survivors could be found in the working areas in panels 2 and 4. The rescue team made its way down the North Mains to a point in the general direction of panels 2 and 4 where the missing miners were working. They encountered a number of roof falls in the north main and were unable to proceed about beyond here (indicating an area along A-A') because roof falls were completely blocking the North Mains at that point. Near this area the rescue team reported that they heard weak tapping sounds (by listening to the water pipes). They banged on the pipes near the roof fall and got what seemed like a response. Their statement on returning to the mine portal was "We think the guys are alive but are trapped".

The rescue team then made their way back through the North Mains to the number 1 haulage left to see if they could get into panel 2 through the cross-cut here (indicates the B-B'). They encountered water, however, in the number 1 haulage left and could not reach the crosscut and so returned to the portal after again hearing tappings apparently coming from panel 2.

3.3 GAME SITUATION UNDERGROUND

Under the control of the referees, at the general direction of the program manager, the "underground situation" was presented to the team participants in the mine in a planned sequence.

The underground team were provided a copy of the "dummy" mine map and situational information from which answers to questions asked by the surface rescue forces could be determined. The underground situation and instructions were phased with the intent of exercising most of the features of the Communications/Location Subsystem. Seismic signals simulating an isolated trapped miner or barricaded miners were first attempted (envelope No. 1). Later the seismic thumper at the shelter position was to be activated (envelope No. 2). This plan was followed initially, in spite of the fact that it was known that the Communications/Location Subsystem personnel were expecting to first detect the EM beacon. After some delay with marginal results from seismic detection, the program manager had the EM Beacon (envelope No. 3) activated. Within 5 minutes of its activation the communications van reported receiving "strong signals" from the beacon. (This part of the exercise pointed out the value of the EM Beacon in providing rough locational information). The final underground envelope (No. 4) cited secondary roof falls which cut off the barricaded personnel from the shelter.

This event was to provide final situational guidance to cause the probe hole to be drilled in the vicinity of the barricade. Contents of the envelopes, the situational data at the barricade and at the shelter, and some responses to specific questions were as shown below. Intended questions were also supplied to the underground teams.

MISSING PERSONNEL

Miners	Age	Dependents	Job
Bob Johnson	37	3	Foreman
Steve Ableman	28	1	Roof Bolter
Alan Kowalski	46	1	Loading Machine Operator
Bob Waters	35	4	Roof Bolter
Howard (Lefty) Perry	47	2	Shuttle Car Operator
Dick Shaw	50	2	Electrician
Bradley Brown	48	3	Loading Machine Operator
Al McWhite	52	2	Shuttle Car Operator
Ralph Brady	25	0	Driller
Jim Manners	44	2	Timberman
Bill Clark	39	5	Shuttle Car Operator
Sam Brady	58	2	Blaster
Ray Williams	45	1	Mechanic
George Knight	28	2	Utility/Rock Duster

Envelope No. 1

Underground Scenario to Barricade Personnel

At approximately 12:30 pm on 16 January 1971 an explosion accompanied by roof falls occurred somewhere underground in the No. 14 U.S. Steel Mine at Gary, West Virginia. There were 14 miners working near the face in panel 4. About 30 miners on this shift were working in other parts of the mine. Several of the 14 miners in your crew were injured by flying debris and/or falling rock immediately after the blast. (For specifics of injuries, consult accompanying "situation sheets.") At 1:00 pm, you noted that the ventilation was poor; however, the air was still good. It would be best, all agreed, if you were to move to the recently installed Auxiliary Survival Chamber; however, due to injuries, one man (Bradley Brown), was unconscious from a head injury and couldn't be moved. It was decided, then, to split into 2 groups. Steve Ableman volunteered to stay with Brown and 4 others who also sustained injuries to construct a barricade. The remaining 8 miners were to attempt to escape and bring back rescue personnel to carry out the injured.

After the barricade is finished, (now) you start banging on rails and/or water pipes to signal your presence to the surface.

UNDERGROUND SITUATION AT BARRICADE

Miners	Age	Dependents	Job	Physical Condition	Cause
1. Bob Johnson	37	3	Foreman	Broken leg	Falling timber (was working with timberman, Jim Manners)
2. Steve Ableman	28	1	Roof Bolter	OK	------
3. Bradley Brown	48	3	Loading Machine Operator	Head injury (shock)	Blast threw him against loading machine
4. Al McWhite	52	2	Shuttle Car Operator	Broken arm	Loaded shuttle car tipped over onto his arm. Others helped him get free.
5. Ralph Brady	25	0	Driller	Cuts	Cuts incurred by flying debris
6. Jim Manners	44	2	Timberman	Ankle injury	Injury incurred by falling timber

Equipment

1 sledge, 2 shovels, 1 pick-mattock
rail to beat on
EM manpack receiver
first aid kit
6 PBA's
6 miners lamps (used 5 hrs on shift)
1 gallon of water (from lunch pails)
food — 2 oranges, 3 apples, 2 sandwiches
1 Davies miner's lamp

Environment

Barricaded with normal kit (wood, nails, hammer brattice cloth)
Size: 17' x 51'
Air — ok
Temperature — 60°F
Humidity — 90%
No electric power

Envelope No. 2

Underground Scenario to ASC Personnel

After leaving Steve Ableman with the seriously injured miners (list attached), you chose Alan Kowalski as your leader. Your group walked toward North Mains By-Pass but encountered roof falls blocking this exit (c - c[1]). You attempted to dig through but gave up after several hours. You then started down North Mains but again were blocked by roof falls at (A-A[1]). Again you were not able to dig through. You then returned to panel 4, entered the ASC, treated the minor injuries, and attempted to set up communications with the surface.

At this time, you are to activate the seismic transmitter (thumper). Set the thumper for about 1 thump every 10 seconds and run continuously for 15 minutes followed by 10 minutes of silence. Repeat this on-off cycle until (1) instructions from surface are received, or (2) exhausting of gas supply or (3) further instructions by Referee.

Envelope No. 3

Additional ASC Personnel Instructions

You are now to activate the EM Beacon. Place switch in "NORMAL" mode. Operate continuously for 24 hours unless instructed otherwise by the Referee or by instructions received from the surface.

(Answers to any questions are to be consistent with situation sheet data. If doubt arises as to how to answer any question consult with your Referee.)

Envelope No. 4

Steve Ableman came to the shelter about an hour ago. He took food and water back to the men at the barricade -- enough for several days. After he had been gone about 20 minutes, additional roof falls were heard outside the ASC. On investigating you have found the barricade is now cut off from you. You have heard nothing from Steve or the others. This is an emergency situation. You must get word to the surface.

UNDERGROUND SITUATION AT AUXILIARY SURVIVAL CHAMBER (ASC)

Miners	Age	Dependents	Job	Physical Condition
1. Alan Kowalski	46	1	Loading Machine Operator	OK
2. Bob Waters	35	4	Roof Bolter	Sprained wrist
3. Howard (Lefty) Perry	47	2	Shuttle Car Operator	Cuts and bruises
4. Dick Shaw	50	2	Electrician	Minor Burn on hand
5. Bill Clark	39	5	Shuttle Car Operator	Stunned but recovered
6. Sam Brady	58	2	Blaster	Minor Burns on hand and arm
7. Ray Williams	45	1	Mechanic	Hurt knee in fall
8. George Knight	28	2	Utility/Rock Duster	OK

Environment	
Temperature	77°F
Humidity	90%
Methane Level	.12%
Carbon Monoxide	.005%
Oxygen	19.8%
Carbon Dioxide	.03%

3.4 CONTINGENCY EVENT PLAN

Contingency Number C-1

Situation: Electromagnetic Communications have been established; however, no seismic signals have been recorded.

Your situation is as stated in the title, and this situation exists now at a period some ________ hours after the arrival and set up of the communications gear. It is important that you use whatever intelligence you have received from the mining company's rescue team and from your use of the electromagnetic communications gear to fix a location for drilling the probe search hole. It is assumed that any further delays in initiating drilling with the probe search rig may have detrimental effect on the trapped miners.

Contingency Number C-2

No seismic or electromagnetic communications have been established.

The elapsed time of ________ hours without establishment of communication with trapped miners has become critical. For purposes of this exercise it is assumed that momentary telephone communications have been established with a group of trapped miners who have barricaded themselves in at a point near the active place. The acting mine superintendent will deliver the following message to the rescue director.

Mine Superintendent, "We have succeeded in establishing some very poor communications with a group of trapped miners who report their position somewhere near this point. (Indicates point on mine map) The air was reported to be ok in the barricade; however, very little ventilation near the barricade position was observed by the miners. I suggest that we try one more time to establish seismic or electromagnetic communications with this group of miners, but that if this is not possible that we act on the information already received."

Contingency C-3

Seismic signal is recorded, but location fix impossible.

Due to a breakdown in telephone communications with the remote computer or to a computer breakdown or other cause of inability to use the remote computer to fix location of sources of the recorded seismic signals it is at present impossible to fix a location. This is the situation which exists at a time approximately ________ hours after the receipt of the first seismic signals.

At this time the mine superintendent will be instructed to encourage the rescue director to select the sight for the probe search hole on the basis of available information. This information may include responses to questions asked over the electromagnetic communication equipments or may be merely the initial intelligence from the mine owner's rescue team including the mine map.

Contingency C-4

Seismic signal is recorded, but location fix incorrect.

There is no fixed time presented for this contingency. Both the rescue team and the program management office will have a knowledge of the actual positions of the "trapped" miners. Should this situation occur, the mine superintendent will be instructed to present information to the rescue director as in Contingency C-2. The program manager may, however, first attempt to guide this situation by having the mine superintendent indicate ventilation pattern or other clues.

Contingency C-5

Location fix obtained but survey incorrect.

No fixed time for this contingency is set forth. Should the situation occur the head referee will alert the program manager to the occurrence.

The program manager will step in and by verbal override or verbal directions cause the location surveyed to be rechecked.

If after rechecking position, the surveyed position is still incorrect, the program manager will cause the mine superintendent to point out the approximate positions of auxiliary survival chambers in the mine and will indicate the face at which men were supposed to be working at the time of the incident.

Contingency C-6

Bad site for the rescue or probe search rig.

It is likely that the "correct position" (position over the location of the trapped miners) will be in such a position that quick placement of the rigs will be impossible.

If the rescue subsystem manager and the rescue director have selected an alternate location for the drilling, the referees and/or program manager will ascertain if the selected drilling location is within the acceptable regions. If not, the program manager will, by verbal override direct the rescue director's attention to the mine map and will attempt to guide him into choosing an appropriate (acceptable) region for locating the probe search hole.

Contingency C-6A

Alternate location for drilling outside of acceptable area.

Should contingency C-6 occur, and should the program manager not be able to guide the rescue director into choice of an acceptable drilling position, the following artificial event will be injected into the test and demonstration: Program Manager will hand the rescue director an envelope which indicates the performance of a seismic survey in the vicinity of the mine. Such seismic survey will be reported to have indicated extensive roof falls in the area which has been selected for the drilling. Relocation of the rig into the acceptable region will be directed by verbal override of the program manager.

Contingency C-7

No appreciable surface water encountered.

In the event that no appreciable surface water flow has been encountered by the time either the probe search drill or the rescue drill have reached a depth of approximately 500 feet, the rescue subsystem referee will alert the program manager. Upon such an event the program manager will hand to the rescue subsystem director an envelope containing a statement saying that surface water has been encountered with an indication of flow rates which would cause the necessity for installing casing.

Contingency C-8

Probe hole (or rescue hole) ends inside a pillar.

In the event of such an occurrence and if such condition should prevail for a period of ________ minutes after the probe drill has passed through the coal seam, the program manager will suggest that the rescue director cause the "trapped miners" to be questioned as to whether they can hear the drill and if so, to determine by response to questions the approximate location of the drill.

Contingency C-9

Early finish.

In the event that all intended test and demonstration items have been completed, several days before the end of the two-week period, the program manager may declare an early conclusion of the field exercise. At this point, and prior to dismantling all equipments, the communication/location subsystem director may be instructed to complete any additional measurements, i.e., resistivity, which he deems necessary for the proper documentation of the operating environment. These tests and post demonstration exercises shall have been preplanned.

Contingency C-10

Serious injury or death.

In the event of a serious injury or death associated with personnel engaged in the test and demonstration, the program manager shall cause an immediate suspension of demonstration activities. Such activities shall be resumed only upon advice of the Advisory Committee.

Contingency C-11

Unsafe rescue hole.

In the event that the material surrounding the rescue hole upon completion of the drilling is considered unsafe for the simulated rescue of personnel, the planned "rescue" of actual personnel shall not be carried out. Instead, a simulated weight or dummy load consisting of approximately 200 lbs. of sand in bags shall be substituted for the actual person. The authority for making such a decision shall lie with the program manger upon advice of his advisory committee.

Contingency C-12

Transportation.

This contingency is general and involves several possibilities.

a. If movement to the drilling site is impossible due to weather, the program manager may direct either suspension or cancellation of the intended exercise.

b. If there are road accidents which cause loss or damage of essential CMR&SS elements, then test and demonstration events shall be suspended during which time salvage operations are attempted. Such salvage operations may require the use of the Sikorsky Heavy Lift Helicopter.

c. In the event of an early finish of all planned test and demonstration events it may be deemed desirable by the program manager to demonstrate the use of helicopter lift and the transport of rescue subsystem equipments. Authority for such decision lies with program manager, who may, in conjunction with the rescue director's transportation coordinator, implement such a decision.