COAL MINE RESCUE AND SURVIVAL SYSTEM

VOLUME V

EXECUTIVE SUMMARY

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

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1. COAL MINE RESCUE AND SURVIVAL SYSTEM

This volume summarizes the contract work performed over a nine-month period by Westinghouse Electric Corporation on a Cost Plus Fixed Fee Contract for the Department of Interior's Bureau of Mines. The contract has been extended primarily to carry out improvements recommended for equipment produced under the contract for communicating with and locating trapped miners. These improvements will enhance the performance and utility of this equipment for operational use in actual mine emergencies. An additional complete set of the equipment will also be furnished to the Bureau under this extension.

The work of the basic contract was to design, produce and test hardware in accordance with the Westinghouse response to a Bureau of Mines Request for Proposal which was based technically on recommendations of a study performed for the Bureau by the National Academy of Engineering (NAE). The NAE study made suggestions for new equipment in three areas of need:

a. Survival Equipment - both a small, readily available, oxygen-producing breathing apparatus of one-hour duration to replace the present carbon-monoxide filtering self-rescuer and a shelter with a built-in life support for 15 men for up to two weeks of entrappment which could be installed in the vicinity of working faces and relocated as a mine is developed. A larger, permanently located central survival chamber was to be designed but not produced;

b. Communications Equipment - through-the-earth wireless systems, both electromagnetic (radio-like) and seismic with the expectation that these sets of equipment as designed and produced might, also, have the capability to use such signals for locating men who are not able to tell where they are; and

c. Rescue Drilling Equipment - highly mobile, rapid drilling systems, based upon Atomic Energy Commission sponsored big hole drilling techniques and the oil well drilling industry. These systems are to be deployable over rough terrain and in typical coal mining regions.

Both the NAE study and this contract are steps in a continuing program of the Bureau of Mines to carry out the mandate of Congress in the Coal Mine Health & Safety Act of 1969 (P. L. 91-173) to develop improved means for effecting the rescue of trapped miners. Consequently, in addition to its hardware aspects, work under the contract was to include recommendations for future effort under this continuing program.

The specific objectives for this contract as part of a continuing mine rescue research and development program were several. One was to evaluate the NAE concepts for a coal mine rescue and survival system through actual testing of hardware built to these concepts. A second was to give the hardware developed to this R&D objective as much utility as possible for subsequent operational employment in mine emergencies. Also, a mandatory bidders requirement called for all work to be completed in less than a year. These objectives and the schedule constraint strongly influenced the Westinghouse proposal, subsequent decisions regarding the configuration of items of equipment, and the planning and management of program effort. In particular the Westinghouse proposal featured a simulated emergency demonstration and test at a working coal mine to evaluate the emergency applicability of the developed hardware designs and their mutual compatibility under simultaneous use. As offered by Westinghouse, the contract was scheduled for a nine-month period. Program management techniques applied in the defense industry were adapted to the planning and control of performance, schedule, and cost. Five periodic oral reports to the Bureau of Mines and monthly progress reports on both technical and management aspects were required.

Final Report Arrangement

The first four volumes of this report present the essential information derived from the program. The first three volumes are structured for use as reference texts on the state of the art in the equipment areas of survival, communications, and rescue identified by the NAE for hardware evaluation on a compressed time scale. Development of subsystems for this evaluation comprised three major tasks under the program. The fourth volume covers the subject matter of the remaining major tasks — program management, systems engineering and the philosophy for system evaluation testing under conditions simulating actual mine emergencies. This summary, Volume V, completes the final report documentation. Volume numbers and titles are as follows:

Volume I	Survival Subsystem
Volume II	Communications/Location Subsystem
Volume III	Rescue Subsystem
Volume IV	Program Evolution and Management
Volume V	Executive Summary

Description of Major Tasks

Detailed descriptions are contained in Volumes I through IV. Summary descriptions only are provided in this volume.

1.1 SURVIVAL SUBSYSTEM

The NAE study noted that a breathing device was needed, which could "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. The Committee believes that a device meeting the above criteria can be developed from existing technology to provide a one-hour oxygen supply. . . sold for under \$50. . ." The PBA developed under the contract was designed to be responsive to these criteria to the extent possible within the time frame of the contract. Figure 1 shows the PBA in its case and being worn. The project established the feasibility of a low cost production apparatus meeting the duration, protection, oxygen-production and communications parameters stipulated by the NAE. It also provided cool (compared to a self-rescuer) inspired gas and a universal fit. However, it was too bulky and heavy for miners to wear continuously. The Westinghouse-proposed and contract-required 9-month schedule constraint proved particularly limiting in pursuing weight and size goals. Within the time available, Westinghouse was unable to establish a development program which could be counted on to produce an acceptable single chemical bed for all chemical functions which, potentially, will permit a lighter, more compact apparatus than the chlorate candle-chemical filter combination used for the PBA under this contract. Additional development based on the concepts of a single chemical bed in combination with the hood and other parts of the PBA offers a prospect for an apparatus combining acceptable physical characteristics with adequate performance as part of an integrated mine survival system.

The shelter, designed to provide for 15 men for two weeks, is called the Auxiliary Survival Chamber (ASC). It is designed to be capable of disassembly and reassembly after being moved up closer to the working face as the face advances. The ASC, featuring a sectionalized structure, was built to a design selected by trade-off analysis from four radically different structural concepts. The chamber is shown in figure 2. The prototype was tested at the Bureau of Mines test mine at Bruceton, Pennsylvania, both for habitability (by 15 men selected partially from Bureau of Mines personnel and partially from the contractor's staff) over a 48-hour testing period sufficient to establish temperature and humidity equilibrium and later, subjected to a series of explosion tests of increasing severity up to the design level of about 20 psi. over-pressure. Although the structure withstood the shocks, the intersection sealing scheme failed. It required longer times for transport and assembly than is desired for a completely acceptable concept or design. The feasibility tests resulted in a great deal of data, and specific recommendations for improvements should the moveable shelter concept receive further consideration in the efforts of the Bureau of Mines to develop improved survival systems. Also, the ASC internal systems (for food, water, gas sampling, waste disposal, lighting, CO and CO_2 scrubbing and oxygen supply system, communications storage, arrangements, electrical supply and miscellaneous other supplies) all appear to be both complete and suitable with some modification for any emergency cache or barricading concept, independent of the moveable shelter concept.

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Figure 1. Personal Breathing Apparatus In Case (top) and In Use

Figure 2. Auxiliary Survival Chamber in Bruceton Test Mine

The permanent, centrally-located shelter designed under the contract to accommodate 50 men for two weeks is called the Large Central Chamber (LCC). The internal systems employed in the LCC were derived from those developed for the ASC by applying proper scaling of equipment and supplies to the larger volume and number of men and taking into account the completely-built-in concept which has a major effect on the heat transfer properties of the structure. The design provided under the contract appears a feasible basis for a large central chamber installation should shelters of this type be warranted in particular mines.

1.2 COMMUNICATIONS/LOCATION SUBSYSTEM

This subsystem has two major elements, an electromagnetic through-the-earth communications element, and a seismic element which is primarily for locating trapped miners but which has an auxiliary communications function.

An electromagnetic concept developed by Westinghouse prior to the contract was further tested and modified to provide a simple, inherently safe system with adequate performance for two-way (voice down, code only up) emergency communications between the surface and miners trapped underground. Major underground equipment includes a permissible* receiver for use in the Auxiliary Survival Chamber or as a man-pack receiver for carry by miners as a part of their miners' lamp battery assembly. Figure 3 provides a view of this receiver. This arrangement was selected so that the receiver would be owned and would, thus, be maintained by the engine rather than have a transistor radio-like unit that could either fall into disuse or disrepair or which would not have active battery power when needed. The receiver uses such a small amount of power that after use of the lamp for an 8-hour shift, the receiver would still have enough battery power to work for more than two-weeks if the battery was fully charged at the beginning of the shift. The underground equipment for communication up to the surface, called a beacon transmitter, is also permissible.* Figure 4 shows the beacon transmitter as it is packaged for carrying along with the chamber receiver. It is powered by a battery similar to an automobile battery which is stored completely inert and dry, requiring only water for activation. Replacement of the anodes produces another full charge. Called a zinc-air battery, it was fully examined for toxic by-products and for proper containment as a permissible* unit. The beacon transmitter has six answer keys to send pre-selected discriminable pulses of differing low frequencies to the surface receiver giving coded answers to questions and answering instructions received by the miners in full voice over the man-pack or chamber receivers. Typical answers are: Yes, No, Don't know, Repeat, Good, Bad or a number. A tone key is provided for sending more complex messages in Morse code. The code is posted inside the beacon transmitter

* Experimental permits obtained only.

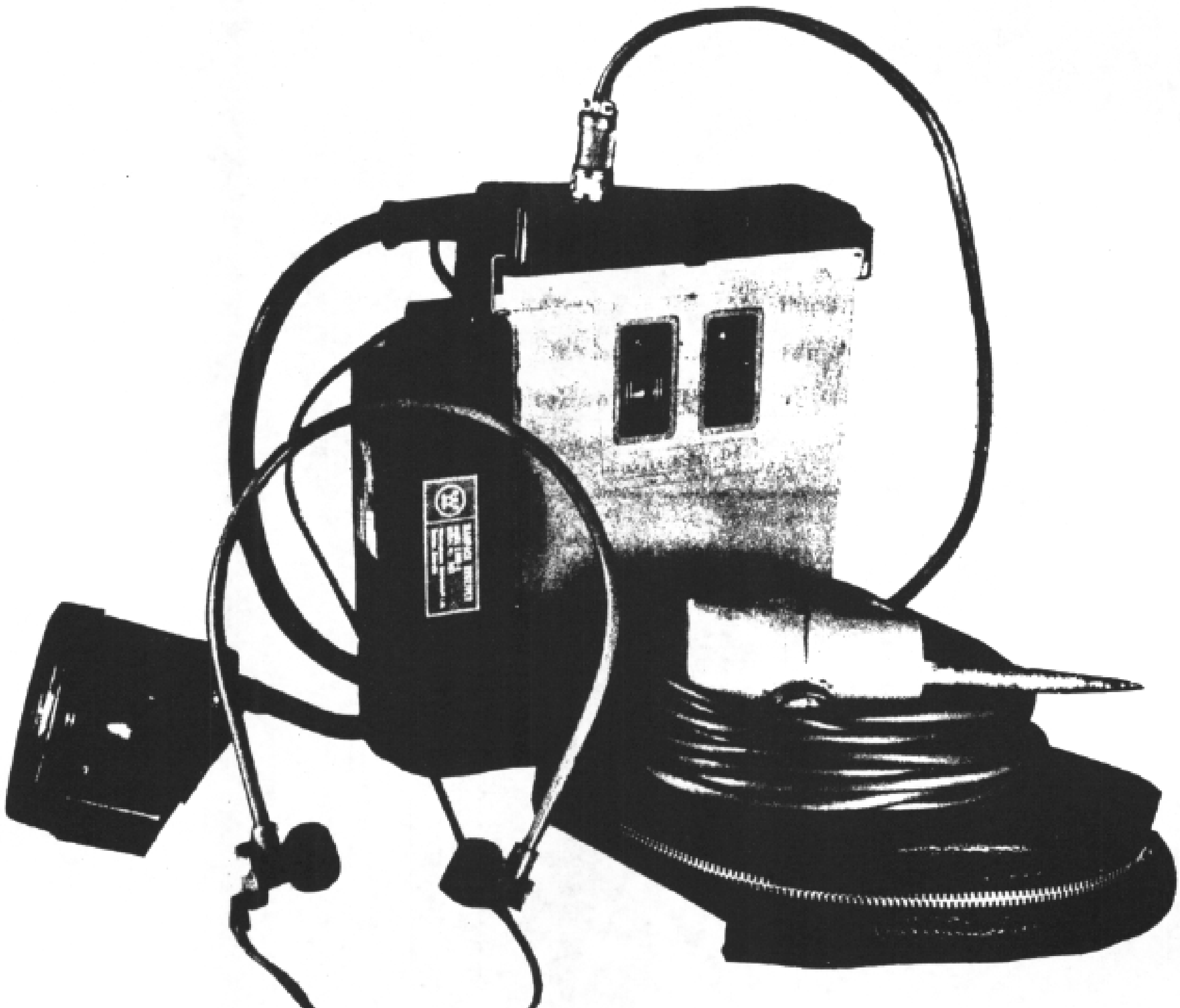

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Figure 3. Man-Pack Receiver With Geophone

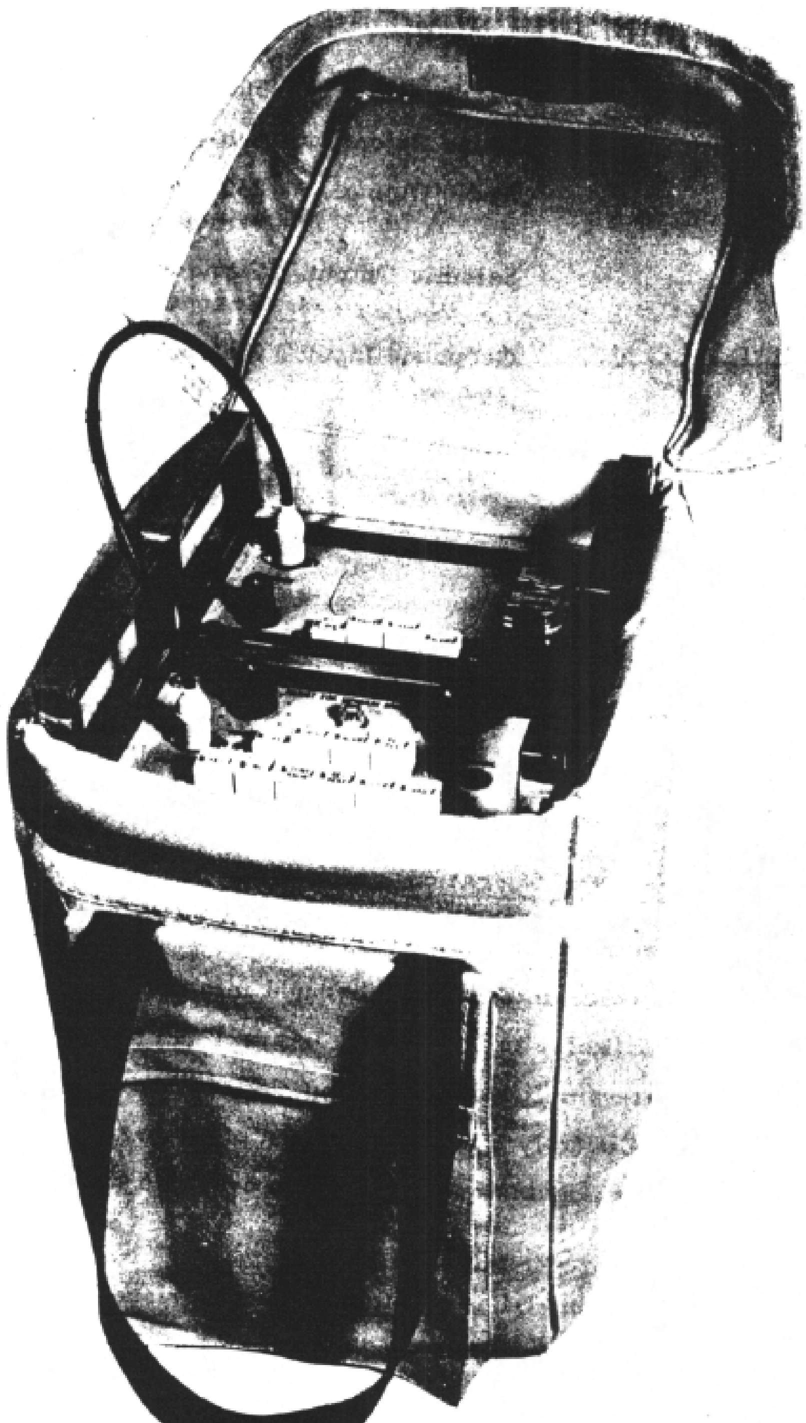

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Figure 4. Habitat Voice Receiver and Beacon Transmitter in Canvas Carrying Bag

housing. The beacon transmitter can also transmit geophone signals to the surface electromagnetically. (This permits the stronger, in-the-seam seismic signal to be, in effect, amplified by the electromagnetic equipment and sent to the surface to be used as additional information to solve the seismic location problem.) The beacon transmitting antenna is a multiple coil laid out of the mine floor.

The seismic portion of the communications subsystem was based upon very preliminary investigations performed for the NAE study. Review of this and other prior work in the seismic field revealed no fund of advanced knowledge specific to the miner location problem. Thus the Westinghouse Georesearch Laboratory in Boulder, Colorado, which was responsible for the Communications/Location Subsystem, developed the seismic system and integrated it with the EM system they had previously developed, using existing seismic components and basic knowledge of geophysics supplemented by extensive development testing and consultants in specific areas. Experimenting with explosives in holes drilled in the surface strata and using reasonably well understood seismic information processing techniques, data was taken on noise, signal levels, transmissivities, frequency attenuation, etc. Then, a system was developed to produce a consistent seismic signal for test purposes using compressed gas, lead weights and a valve and extension cylinder to mechanically lift the weight and drop it. Called the "thumper" it permitted detailed evaluation of signals because of the mechanical consistency of its output energy. A computer, on site, permits signal processing and, additionally, remote time-share programs are set up using a telephone access and a portable teletypewriter for input of the arrival times gleaned from analysis of signals received by various deployed geophones. A simple code was developed to provide "thumps" from explosive charges set off in sequence on the surface which could be heard by men underground. A means of connecting an amplified geophone into the EM manpack receiver was also devised to evaluate the feasibility of permitting men to hear surface-generated or underground "thumps" as an added possible crossrelationship of the EM and seismic systems.

Development tests of the Communications/Location Subsystem in several mines in Colorado, Pennsylvania, and West Virginia, and the demonstration conducted under simulated emergency conditions in West Virginia confirmed the performance and operational suitability of the Electromagnetic System. Seismic system tests appear to have achieved location errors as low as 20 feet under the most favorable conditions. These tests also revealed the limitations of present components and systems state of the art as regards detection range and signal location under less favorable conditions and provided data on which to base system improvements and additional field testing.

Pounding on roof bolts is not the best way to produce seismic signals for location or communication purposes. In tests conducted at three mines visible signals were obtained on 50% of the recording channels in two mines and in the single test of roof-bolt signals in the third mine, not at all. No conclusion can be drawn from this data that depth or other specific factors were the reason for lack of signal pick-up.

1.3 RESCUE DRILLING SUBSYSTEM

As required by the contract, two drilling rigs were produced, both capable of drilling (in terms of size and hook load, cable length, and power plant capacities) to 2500' but supplied on this contract with drill pipe for only 1500'. The smaller of the two, called the probe rig, drills an 8-3/4-inch diameter hole to provide emergency aid to trapped miners as soon as possible after entrappment. The rescue rig drills a 28-1/2-inch diameter hole through which the men can be brought to the surface. Both rigs can be disassembled for airlift by C130 prop-jet military transport aircraft and by Sikorsky Skycrane helicopters. The designs, accomplished by Rowan Drilling Co. and its subcontractors to specifications approved by Westinghouse, were based on Rowan's extensive experience in large and deep hole drilling for the AEC and for the oil industry both in the USA and overseas, and in large helicopter lift designs. Rowan was selected over other contractors with AEC experience and reputations for good performance in the oil industry after extensive review of proposals to accomplish the desired work (both design and demonstration test drilling) and review of their organizational ability to control cost and schedule which were acknowledged contract requirements. Some parts were readily available in the industry as standard assemblies requiring only integration into a properly sized system, while others had to be field modified in the Rowan yard to suit the special requirements of mobility, including dimensional constraints for various transport modes.

The rigs and their ancillary equipments, to provide the many options in drilling techniques and circulation fluids, were tested for interaction and general performance in December prior to shipment by Rowan to the storage facility rented in Charleston, W. Va., in preparation for the simulated emergency test in January. Crews were identified and plans to respond to emergency call were worked out and tested. Figure 5 shows the system under demonstration at U.S. Steel Mine No. 14 in West Virginia during January.

The simulated emergency test confirmed the mobility of the systems for truck deployment under typical mid-winter conditions in the hilly mining country of West Virginia. Drilling accuracy surpassed contract goals and the demonstration confirmed the practicability of sending emergency supplies to trapped miners through the completed probe hole. Rates of penetration fell short of contractual goals, especially near the surface.

Drilling rate performance, instantaneous penetration rate, or overall elapsed time for complete hole depth achieved is fully addressed in Volume III. The 777 feet deep probe hole was stopped twice during the Gary district tests to obtain quiet periods for seismic tests. Such stops in turn cause additional drilling delays for shutdown and start-up procedures in the cold

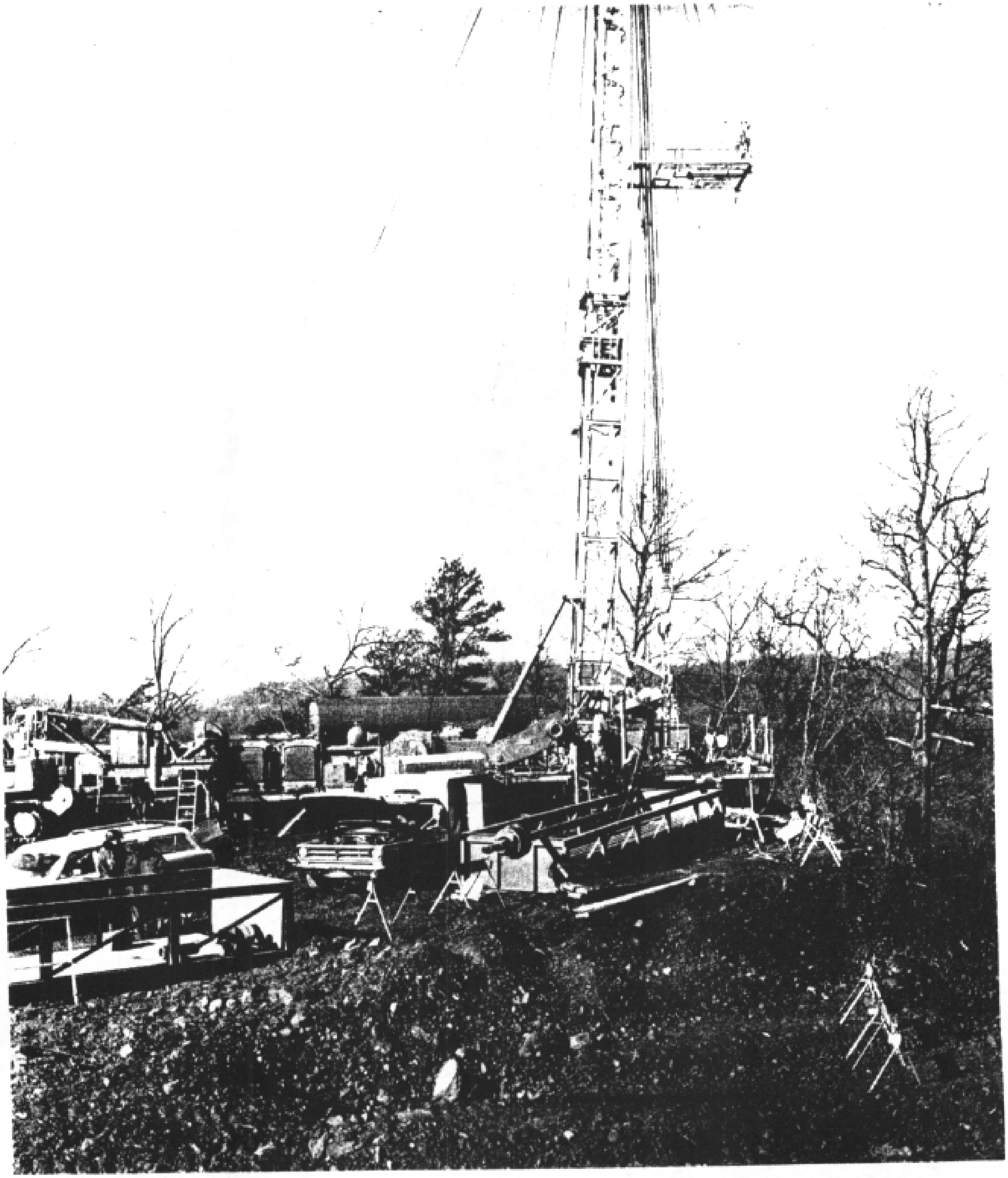

Figure 5. Probe Rig on Demonstration Site at Charleston

weather. Also, for underground roof safety reasons prior to breakthrough, the U.S. Steel safety personnel requested slowdown for the last 20 feet. A surveying elevation error, indicating 738 feet as expected hole depth compounded the effect of the slowing on overall time. The total time to complete the probe hole was four days and 1 hour with a total rotating or drilling time of 54.1 hours. Thus, drill penetration rate was 8.0 ft/hr or 14.3 ft/hr, depending on the base of calculation. Instantaneous drilling rate (for short periods) achieved 60 ft/hr.

1.4 PROGRAM EVOLUTION AND MANAGEMENT

System Program Management principles and methods were employed in the management of the contract program. A single program manager and subsystem project managers were assigned with full authority to accomplish this aggressively scheduled program within the time and dollar estimates of the contract. Responding to a Bureau of Mines management structure which included the Program Manager, the contracting officer and his technical representative, the contractor provided monthly technical progress and management reports. These reports were distilled from information generated for internal contractor control of the program by a highly responsive management information system. This system included weekly cost reports which compared estimated actual costs with planned costs on an accrual basis and forecasted changes in cost at completion. Changes in technical performance and schedule milestones were predicted and reported weekly on an exception basis. Design and monthly program reviews examined technical and schedule progress in detail with the aid of milestone charts and Critical Path Measurement (CPM) diagrams at the subtask, major task and program levels. Frequent informal communications supplemented the formal process.

In addition to monthly reporting, periodic oral reviews and informal communications kept the Bureau of Mines informed of progress on a continuous basis. In the first few weeks of the contract, systematic review was made of potential suppliers of major components of the Survival and Communications Subsystems and of potential contractors for the Rescue Drilling Subsystem drilling equipment. Selection criteria were established and after ranking of potential suppliers, negotiations were conducted to obtain contracts which met the prime contract requirements.

Similarly, within Westinghouse, negotiations were conducted with other divisions by the Special Systems Department, which had overall responsibility for the program. Agreements were obtained on assignment of management personnel, reporting techniques compatible with existing divisional systems, dollar levels, and performance criteria including schedule and lower tier subcontractors.

System engineering effort, conducted at the system and subsystem levels, was responsible for integration and optimization of design, and for the planning and review of technical work. System engineering work included methodical tradeoff studies to select the subsystem configurations which represented best choices in view of contract requirements, program objectives, limitations of technology and component availability, and interface compatibility. System engineering also conducted several contractually required studies. A study conducted early in the program identified the characteristics of coal mines and mining areas which would influence design and planning for both the simulated emergency test and demonstration, and for operational employment of system elements in actual emergencies. This study examined such factors as mine dimensions, production, proximity to roads and airfields, and overburden characteristics including conductivity, ground water content and rock hardness. This work was summarized in a report, primarily used by the contractor organizations as a basis for general design background information, called "Mine Characterization Study." Also, a small effort was expended to examine a computerization of the functional performance aspects of the CMRSS called the "System Utility Model." It was not needed in the intersystems engineering. Examination was also made of the published information on underground explosion forces, pressure levels and rise times, and propagation aspects including geometrical effects, to provide a better understanding and definition of the requirements for explosive resistance of shelters and the possible assistance which location or geometrical arrangement of cross-cuts might have on structural and manned survivability. As an assist to survival system evaluation and further program planning, a psychologist trained in socio-economics examined the problems of group dynamics of small groups in stressful situations. The study determined that a 15-man shelter is preferred to, say, two eight-man shelters to provide for a section crew of 15 or so men.

Two quite different test and demonstration programs were dictated by differences among subsystem functions and characteristics, and by the limitations which safety, time and cost imposed on the mine emergency conditions which it was practical and meaningful to simulate. As a result of these factors, the Communications/Location Subsystem and the Rescue Drilling Subsystem were demonstrated together in January at U.S. Steel Mine No. 14 near Gary, West Virginia, under conditions which closely simulated the most critical operating and logistics aspects of deployment as well as system operation. On the other hand, the Survival Subsystem concepts and equipment were evaluated in a series of tests in the laboratory and in the Bureau of Mines test mine at Bruceton, Pennsylvania, where the equipment and man-equipment interfaces critical to the concepts embodied in this equipment, such as performance of the PBA and explosion tolerance of the ASC, could be tested safely. This test and demonstration philosophy accomplished its purposes. Both test programs produced data which enabled the NAE concepts to be assessed with higher confidence than had been possible with paper analyses, revealed the capabilities and limitations of the equipment and procedures provided under the contract for operational use in mine emergencies, and enabled specific equipment and procedural improvements and future research, development and field test to be recommended with assurance. Details of these tests and demonstrations and results attained are provided in Volumes I through IV.

Based on planning for the simulated emergency tests of the combined Communications/Location and Rescue Drilling subsystems, plans were made and submitted to the Bureau of Mines by the contractor to maintain this prototype equipment in ready storage at Charleston, W. Va., and deploy it for mine emergencies when directed by the Bureau. At the request of the Bureau of Mines, the contractor's program manager and logistic support manager traveled to the emergency at Hyden, Kentucky, on December 30, 1970, with no deployment of equipment. The contractor's full team responded, on request, to the Nemacolin, Pennsylvania, emergency of March 26, 1971. On both cases, experience gained was applied to improve deployment and logistics plans and make recommendations for equipment improvements.

1.5 SUMMARY AND CONCLUSIONS

The plans, approved by the Bureau of Mines contract monitors, were carried out by the contractor to demonstrate and evaluate the concepts suggested by the NAE study. The original contract was completed on time and within planned funding. As the systems were developed and tested much was learned about detailed operations, new possibilities were identified and weaknesses in performance were uncovered. The detailed reports of the subsystems report these and make detailed recommendations. In general, the electromagnetic communications system works well. The seismic system has shown some promise as a communications technique of very elementary capability. Its use as a location system has not been sufficiently developed but seems to have some capability to be used in an emergency prior to more sophisticated means which require production of hardware, distribution to all underground personnel, and training in use of such equipment. Both systems require additional testing for optimizing performance in differing geological areas and situational uses (mine arrangement) and in non-coal mine areas. Improvements in the way it is installed in mobile vans, how it is deployed, and how it is made known to the underground mining community for maximum effectiveness in emergencies needs additional work.

The survival equipment is less immediately useable as it was only demonstrated as feasible. No plans for production of shelters or breathing apparatuses resulted from the contract.

The drilling equipment is ready for and has been used in emergency drilling operations. It is "big-hole", deep equipment and thus must be augmented by other equipment to provide very rapid set-up, and to improve penetration times, especially to make initial contact with men trapped at relatively shallow depths of a few hundred feet. Some additional provisions for winterizing of the equipment and the provision of shelters for the drilling crews is being accomplished as a result of this contract.