CLEAN WATER

WATER POLLUTION CONTROL RESEARCH SERIES • 14010 DZM 08/70

Feasibility Study of Mining Coal in an Oxygen Free Atmosphere

U.S. DEPARTMENT OF THE INTERIOR • FEDERAL WATER QUALITY ADMINISTRATION

Feasibility Study of Mining Coal in an Oxygen Free Atmosphere

A DEMONSTRATION OF A NEW MINING TECHNIQUE TO PREVENT THE FORMATION OF MINE ACID IN AN ACTIVE DEEP MINE
PHASE I

BY

ISLAND CREEK COAL COMPANY
ISLAND CREEK DIVISION
HOLDEN, WEST VIRGINIA 25625

AND

CYRUS WM. RICE DIVISION
NUS CORPORATION
PITTSBURGH, PENNSYLVANIA 15220

FOR THE

FEDERAL WATER QUALITY ADMINISTRATION
DEPARTMENT OF THE INTERIOR

PROGRAM NO. 14010 DZM

AUGUST, 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1.50

FWQA REVIEW NOTICE

ABSTRACT

A systems evaluation was made to determine the engineering feasibility and probable economics of mining coal in an active deep mine in an oxygen free atmosphere using current technology in the application of life support systems to conventional coal mining techniques. The project was Phase I of a four phase program to demonstrate that mining coal in an oxygen free atmosphere will prevent the formation of acid mine water. Other major benefits include improved working conditions from a health and safety standpoint.

A detailed investigation was conducted into the application and suitability of commercially available inert gas generators, life support clothing and equipment, and personnel communications systems. Three sites were investigated for a demonstration mine.

The investigation revealed it is feasible from an engineering standpoint to mine coal in an oxygen free atmosphere. Life support and associated equipment are available essentially off-the-shelf. A deep mine using conventional mining equipment can be designed to operate in an oxygen free atmosphere. The comparative economics are extremely favorable when methane gas is recovered and sold.

This report was submitted in fulfillment of Program Grant No. 14010 DZM between the Federal Water Quality Administration and Island Creek Coal Company.

Key Words: Acid Mine Water, Inert Gas Blanketing, Mining, Life Support Systems, Mining Engineering, Health, Safety, Communication Systems, Data Acquisition.

CONTENTS

FIGURES

TABLES

SECTION I

CONCLUSIONS

The feasibility study conducted on the application of an oxygen free atmosphere to the mining of coal has developed the following conclusions:

1. It will be possible with today's technology to mine coal in a deep mine in an oxygen free atmosphere and that at least in the instance of gassy mines, the economics of such operation will be highly favorable.

2. Modification of existing conventional mining equipment will be minimal for such operation.

3. Present day miners skilled in operating conventional as well as continuous and long wall mining equipment have the necessary skills to operate in an oxygen free atmosphere.

4. The outside air ventilated refuge station located near the working section will allow the miners to take regular breaks from operation of equipment in addition to providing a safe haven in the event of an accident or emergency.

5. The miner's life support suits and helmets (undergarment, gas tight suit and helmet, coverall) are available essentially off-the-shelf.

6. The two-piece miner's life support rebreather unit (portable O_2 module, fixed chiller module) must be constructed for the particular application but employs standard off-the-shelf components and makes use of a large reservoir of existing technology in design and fabrication.

7. Miner's emergency rebreathing and rescue equipment is available off-the-shelf.

8. Communications employ standard FM transceivers and systems demonstrated workable in subway stations. Such units are completely off-the-shelf and are widely used in industrial applications.

9. Natural gas burning inert gas generators are off-the-shelf items in the desired sizes, reliable and economic to operate.

10. Removal of heat generated by the mining equipment can be handled in a straightforward fashion by recycling the oxygen free mine atmosphere using the external ventilation fan provided for emergency air ventilation along with requisite duct work.

11. The amount of heat to be removed from recycle gas requires only modestly sized mechanical refrigeration equipment (50 tons per day per active section) and no new technology.

12. Dust control at 12,000 CFM circulation rate at the face in each section should not present either greater nor less a problem from a visibility viewpoint than is currently encountered with conventional equipment operation. The recycling of the mine atmosphere offers the possibility of complete dust control through the installation of external dust removal equipment.

13. The gas lock design is straightforward and employs established principles of gas curtain designs for such purposes and requires no new developments.

14. Preliminary estimates of the costs of equipping a 5,000 ton per day deep coal mine show that the added cost for inert gas blanketing would probably not exceed 12% of the installed cost of the mine. In a non-gassy mine, the operating costs of inert gas operation may increase the operating costs of the mine by a few percent. In the case of a gassy deep coal mine, operation in an inert gas atmosphere may actually decrease the cost of the mine operation by as much as 20% when credit is applied for the methane gas that is trapped and sold.

15. Sufficient data could be gathered in a single section demonstration mine operated in an oxygen free atmosphere that sound projections to full scale deep mining operation with either nitrogen or methane blanketing could be made. Such a demonstration would be necessary before any full scale application could occur.

16. If a demonstration mine were to be constructed, the Pond Fork site of Island Creek Coal Company in Boone County, West Virginia would allow the use of the adjacent active mine's external coal preparation facilities and utilities and would be suitable from geologic considerations for a demonstration project. There is a good chance that the site would produce mildly acid mine drainage in the absence of blanketing.

SECTION II

RECOMMENDATIONS

The feasibility study on the application of an oxygen free atmosphere to deep coal mining has developed a series of conclusions regarding the key factors involved. Based upon those conclusions, the following recommendations are extended:

1. The important life support components of the proposed mining system should be tested in a Phase II program in an active air ventilated deep coal mine using conventional mining equipment. Specifically, the miner's life support suit, the miner's life support rebreather unit with tether hoses, the miner's emergency rebreather unit and the miner's communication system should be purchased from available suppliers, tested, modified as required, and retested. The purpose of the testing is to develop a final design and specifications as well as operations and maintenance manuals for these systems suitable for the miner's use in an oxygen free atmosphere when operating standard mining equipment. The initial specifications for the components to be tested should be those developed in the Phase I feasibility study.

2. At least one of each piece of conventional rubber tired coal mining equipment required for operation of a single section should be obtained for a Phase II test program. The required modifications to the life support systems should be developed based on operation of this equipment as well as any modifications of the mining equipment itself required to accommodate the life support systems. Sufficient life support and communication components should be obtained to equip two miners for the test program.

3. Detailed plans, specifications and estimated costs should be prepared in the Phase II program for construction and operation of a demonstration mine to be constructed if the results of the Phase II program warrant a Phase III program. The mine consisting of a single active section should be operated in an oxygen free, nitrogen-carbon dioxide atmosphere by a mining crew of approximately ten men. The plans should be based upon the use of the coal preparation and support facilities of an active mine adjacent but unconnected with the demonstration mine. Such plans should

include those for the mine proper and for external support buildings special to the project as well as those for the gas locks, inert gas system, heat and dust control, gas and water quality instruments, communications, refuge station, and coal handling. The bases for the designs should be those developed by the feasibility study.

4. Provision should be made in the foregoing design of the demonstration mine to accommodate installation of a room to contain a supply of a known acid producing pyritic material through which a portion of the mine drainage may be diverted so as to augment the data obtained on the normal drainage characteristics of the selected mine. The demonstration mine should contain only one air ventilated refuge station. The extent of mining anticipated for a demonstration program would be sufficiently limited that one refuge station will be within easy walking distance of the working faces. The oxygen free atmosphere to be employed in the demonstration mine should be achieved by use of exhaust gas from combustion of natural gas in standard industrial inert gas generators of this type.

SECTION III

SUMMARY

Miner's Life Support System

The miner in the proposed process must work in an atmosphere that will have less than 0.1% oxygen and will be at 100% relative humidity. The life support system thus must not only supply breathing oxygen but must remove carbon dioxide all without contributing significantly to the oxygen content in the mine. The life support system must be comfortable for eight hours per day, five days per week. It cannot unduly hinder the miner in his operation of conventional mining equipment.

Face masks, helmets with neck seals, helmets with torso seals, liquid cooled undergarments, full suits with cuff seals and suits with pressure tight gloves and boots were considered.

It is concluded that each miner should wear a full suit and helmet. The helmet can be equipped with a fitting to attach a standard miner's lamp. A voicemitter diaphragm can be located over one ear enabling the miner to hear directly sounds outside the suit and surrounding him. The other earpiece in the helmet should be equipped with a communications earphone. A mouthpiece connected to an emergency breathing apparatus should be installed in the helmet in a position easily accessible to the miner. The helmet can be attached to the suit with a sealed clamping ring, and should be readily removable and replaceable by the miner.

A gas impervious middle garment should be used, constructed of lightweight rubberized cloth. The garment can be fitted with gloves and boots detachable via ring seals at the ankles and wrists. The suit can be designed to operate at one-half inch water pressure relative to the outside atmosphere. A maximum leakage rate of 1 cubic foot per hour at 7" H_2O pressure should be specified. An outer wear resistant garment should be worn over the gas impervious middle garment.

The 100% relative humidity in the mine atmosphere plus the heat generated by the mining equipment requires that the metabolic heat and perspiration in the suit of the miner be removed by external means. The oxygen requirements of the miner must be supplied both during operation and during movement to and from the equipment. The components of the life support system must be reliable and off-the-shelf. The weight of the oxygen supply and carbon dioxide absorber must be low enough to permit twelve hours supply in a portable unit of modest weight able to be carried by the miner to and from his work.

In approaching the life support problem, consideration was given to cryogenic oxygen, pressure cylinder oxygen, potassium superoxide, chlorate candles, and Baralyme absorbers for breathing requirements. Cryogenic gas and mechanical refrigeration were considered for removing heat. Single units as well as dual units were examined. Multiple, crew type systems were also considered. The relative merits of replacing oxygen and CO_2 units inside the mine versus outside the mine were studied.

It is concluded that one complete rebreather system should be used for each miner. Such a rebreather system can consist of three components: (1) An umbilical hose for conveying breathing and ventilating air to and from the miner; (2) A portable oxygen module; and (3) A fixed chiller module. The umbilical hose should be flexible with quick, self-closing disconnects on each end. Hose lengths can be variable up to 20 feet depending upon the anticipated activity of the miner.

The portable oxygen module can contain the oxygen supply, the CO_2 absorber, the circulating blower, and the battery for blower operation during such times that the module is disconnected from an outside power supply. The module can be compact in size, weighing approximately 30 pounds. The oxygen supply can be via a demand regulator from a 2,200 psi cylinder of pressurized gaseous oxygen sufficient to supply 12 hour requirement based upon a 0.2 pounds of oxygen per hour consumption. The CO_2 absorber can be a Baralyme unit of sufficient capacity for 12 hours operation.

The miner should carry the portable oxygen module with him whenever he leaves his piece of operating equipment to go to the refuge station or to exit the mine. During such times, the portable oxygen module can supply the necessary oxygen requirements and CO_2 removal, but cannot remove any heat or perspiration. The battery should have sufficient capacity for two hours of blower operation and can be recharged each time the portable oxygen module is reconnected to the power supply associated with a fixed chiller module.

The fixed chiller module can contain the mechanical refrigeration unit capable of removing 2,000 BTU's per hour from the recirculating air to the miner. The recycled air should be controlled at 72°F and 40% relative humidity as it is supplied to the suit. The fixed chiller module estimated to weigh approximately 100 pounds should be mounted on the mining equipment or transport equipment and should be powered from it.

Failure of the rebreather system for any reason, or failure of the miner's suit by tearing or by fracturing the face plate requires that an emergency back up system be provided that will operate independently of either the normal rebreather system or the suit. Sufficient capacity must exist in the emergency unit that it will allow the miner safe passage to a refuge station or out of the mine. The unit must be small enough and light enough to allow the miner to carry it with him at all times without unduly hindering his activity. The unit must also have a long shelf life or have a ready means of assuring its serviceability. No provision for body heat removal need be made.

Chemical oxygen rebreathers as well as pressure cylinder oxygen rebreathers were considered with capacity up to one hour. It is concluded that a satisfactory system can consist of a potassium superoxide canister that is the source of oxygen as well as being the CO_2 and moisture absorber. The canister can contain a chlorate candle for rapid ignition and quick supply of oxygen for one hour. A rebreather bag should be used and the assembly connected to the helmet with quick disconnect hoses which, in turn, lead to the mouthpiece previously described. The miner, by breathing in and out through his mouthpiece, will be able to sustain himself.

Communications

With the miner completely enclosed in a life support suit, communication between miners as well as communication to a refuge station and to a control point outside the mine must be provided. The system employed should be rugged, highly reliable, lightweight and not hinder the activity of the miner. It should not require that he manipulate the device whenever he wishes to talk. Communication between miners must include those riding on shuttle cars as well as working out of sight in separate rooms or passageways.

Hard wire connection through cables on equipment and junction boxes, passageways, inductive wireless transmission, low and high frequency radio communication were considered. Availability and reliability of equipment or system to operations underground was a requisite. Direct communication by loudspeakers and microphones was also studied.

It is concluded that individual high frequency FM transmitter receivers should be used. The units can be carried by the miner and connected to the headset within the helmet. A voice operated microphone can be used which will enable the miner to communicate without having to activate any switches. Communication should be by transmission line of sight to an antenna cable which will pick up the signal and carry it to an external remote base station. The base station receives the individual signals and rebroadcasts same at much higher power back on to the antenna cable. The antenna cable, which can be strung along the ceiling in active crosscuts and down one entry, can rebroadcast the signal from the base station to be picked up by the individual miner receivers. The previously described voicemitters on each helmet should enable the miner to hear sounds made by his equipment in operation as well as to listen to sounds made by the roof so as to detect unsafe conditions.

Gas Blanketing System

A non-combustible oxygen free inert gas must be provided to interface between the outside air atmosphere and the pressurized oxygen free atmosphere in a sealed mine. In the instance of a non-gassy mine, the inert gas used for the interface would also be used as the gas within the mine proper. The interface occurs in the gas locks for personnel, for equipment, and for the coal removed. The inert gas employed for purging the gas locks must be inexpensive and readily available at the mine site. The source must provide for short duration high demand flow rates.

Consideration was given to carbon dioxide, liquid nitrogen, locally cryogenically produced nitrogen, and to combustion exhaust gas, a mixture of nitrogen, carbon dioxide, and water vapor.

It is concluded that the inert gas for purging the gas locks and for blanketing and sealing a non-gassy mine should be obtained as the product combustion gas from natural gas and air burned in a standard industrial inert gas generator. The effluent from the generators should go to a gas holder tank (100,000 cubic foot capacity in the case of the demonstration example).

The gas holder can smooth out the demand which reaches peaks during periods of maximum personnel and equipment locking. Inert gas can be maintained in the holder at one to two inches of water pressure, the same pressure as the mine proper.

The inert gas within the mine should be recycled continuously at 12,000 CFM per section using the ventilation fan provided for initial air development. This same fan can serve for emergency purposes when it might become necessary to abort the gas blanket in the mine and to ventilate the mine with air. In gassy mine operations, the circulating inert gas can be natural gas from the coal formation. Pressurization of the mine would thus come from the natural gas generated within and be maintained by proper pressure control devices. Natural gas released from the mine can be recovered and pressurized for discharge into a natural gas pipeline system.

It is necessary that personnel and equipment be able to routinely enter and leave the oxygen free atmosphere in a sealed mine. During such transit, air cannot be allowed to enter the mine, nor can the mine atmosphere, particularly a methane atmosphere, be allowed to enter the outside air indiscriminately. The amount of inert nitrogen gas used for the interface between inside and outside the mine must be minimized.

Completely purged gas locks were studied as well as gas curtain designs where the primary effect is to prevent mixtures of air or mine atmosphere in the lock. A double bin design and a water seal design were investigated for conveying the coal from a mine while maintaining the mine in a sealed condition.

It is concluded that the gas locks provided for personnel entry into the refuge stations and for personnel and equipment entry and egress from the mine proper should be designed with two doors interlocked so that only one door will open at a time, and that exhaust from the gas locks should be from plenums surrounding each door on the inside of the gas lock producing a gas curtain which will prevent the atmosphere within the gas lock and that within the mine or outside the mine from mixing.

The conveyor belt emerging from the mine should be contained in a duct which can extend from the entry to the top of the coal bin. The coal bin should be a two section bin with a gate valve between each and at the exit from the lower bin. Coal can discharge into the upper bin under the atmosphere of the mine, which atmosphere would be maintained within the duct and in the top of the bin. Inert gas can be supplied to the lower bin to purge it during such time as coal is transferred from the upper bin to the lower bin. Inert gas can also be supplied to the lower bin when coal is being discharged from it into the truck for transport to the preparation plant. Gas curtains exhausting to fans can be used around the exit of each of the gates in the coal bin to minimize mixture of the outside atmosphere or mine atmosphere with the lower bin. It is estimated, for example, that the total inert gas demands for the proposed single section demonstration mine could be as much as 600,000 cubic feet per day for a one shift per day operation.

Dust and Heat Control

The electrical power required to operate the pieces of equipment used in mining coal results in the generation of heat in the working face area. Normal air ventilation used for control of methane or dust removes this heat conveying part to walls of the mine and rejecting the remainder in the exhaust to the outside atmosphere. Dust generated by the mining equipment is controlled to a large degree by water sprays but remaining dust is conveyed from the working area by air ventilation. This residual dust is deposited in passage through the mine with some small unknown fraction finally rejected to the outside in the exhaust. In a sealed mine, the moisture in the ground produces a 100% relative humidity in the mine atmosphere at whatever the temperature of the mine finally results.

The steady state rejection of heat to mine walls was considered. Liquid cooling of equipment, local recirculation through chiller coils, as well as general recirculation were studied. Local dust filters were also considered. The effect of miner suit temperature was taken into account. The use of external dust removal processes was investigated.

It is concluded that the heat generated by the mining equipment, estimated at 600,000 BTU's per hour per operating section, can be removed from the working face by recirculation of the mine atmosphere at 12,000 CFM per section using the external mine fan properly ducted. Some heat will be removed by conduction to the walls of the mine and some by the coal removed. Most of the heat must be removed however by mechanical refrigeration provided outside the mine. Chiller coils can be located in the duct work at the inlet to the circulating fan. Water sprays can be provided to wash off any dust depositing on the chiller coils. Fifty tons of mechanical refrigeration capacity are estimated as sufficient to provide the required cooling for a single section. Stoppings can be used to convey the cooled discharge from the ventilating fan to the working crosscut. With 12,000 CFM gas flow rates supplied at the working face per section, it is anticipated that the dust problems will be no more nor no less than those encountered in equivalent standard open air ventilated operation. The recycling gas temperature should be controlled between 55 and 74°F at 100% relative humidity in order to avoid condensation of the mine atmosphere on the suit.

In-Mine Systems

A mine using the oxygen free blanketing process should be constructed in a fashion normal for the conventional mining equipment procedures chosen. The development of the desired single section in the case of the proposed demonstration mine should be away from an adjacent active mine but constructed in a way not to preclude eventual operation in an air ventilated status to recover the remaining coal if the inert process is abandoned.

In opening a new mine to use the inert process only, three entries need be driven. Once inside, development of the five headings for the first section can be on 60 foot centers, for example in the case of the demonstration mine. Later, after initial development, the breakthroughs can be driven on 80 foot centers. The width of the mine entries and headings can be 20 feet. During initial development, a ventilation fan can be used to drive in several hundred feet under conventional ventilation to construct the first three breakthroughs before placing the mine in an oxygen free status. Five parallel headings can be used to form the single section desired.

It is necessary that a place be provided in a sealed mine that will be air ventilated at all times and uncontaminated by the oxygen free mine atmosphere. Such a refuge station must serve to house safely an entire section crew and provide them with sanitary facilities as well as emergency supplies. The refuge should be within several minutes walking distance of the working face so that any required breaks in work activity may be taken conveniently. Since the 30-60" height of seams of general interest does not allow the stand-up required for suit servicing, opening up to 84" is required for the refuges and thus portable shelters with self-contained air were only briefly considered.

A refuge station of desired design should be located in the proposed demonstration mine, for example, just beyond the entries after the start of the breakthroughs. A convenient size is approximately 20 feet wide, 40 feet deep, with the roof opened to a 7 foot height. It is practical to seal with concrete block and to plaster the block with cement and bituminous-based material to insure its being gas tight. A single gas lock will provide sufficient access and it can be sized to accommodate a man on a stretcher. The gas lock will serve as the entry from the mine into the refuge station. Two 10 inch diameter boreholes should be drilled from the surface into the refuge for ventilation. These boreholes can also be used to supply power and communications separate from the mine proper. One of the boreholes can also serve to exhaust the atmosphere in the gas lock during passage of personnel to and from the refuge. The refuge should be supplied with sanitary facilities, emergency maintenance facilities for the life support suits, spare life support system units, emergency rescue units, as well as first aid equipment.

The necessity of maintaining the mine in a tightly sealed condition dictates the use of conveyor belts rather than tracks for coal movement out of the mine. The gas locking of individual coal cars would be time consuming and require very large quantities of inert gas. Coal movement within a large mine could be either by tracked equipment or by belt with discharge from the mine to the outside atmosphere always by belt.

The proposed demonstration mine being only a single section should thus be all rubber-tired without tracks or tracked equipment. In this case, the coal removal would be by a single conveyor to a bin outside the mine from which the coal would be hauled by truck to the coal preparation plant.

Modifications will have to be made to the standard mining equipment for the installation of power converters and racks to support the individual life support systems required for the equipment operators.

Routine maintenance of mining equipment can be conducted within the oxygen free atmosphere in the mine. Major maintenance on equipment can be performed outside the mine in the shop. Passage of the equipment in and out of the mine for maintenance can be through a gas lock in one of the entries; this gas lock must be constructed of sufficient size to take the largest piece of equipment involved.

Miner Training Program

Miners by their own selection and pursuit of a mining career demonstrate that they do not experience claustrophobia; they have not however had experience in the special problems associated with a life support suit. Discussion with NASA was held on their experience with skilled labor at Cape Kennedy operating in such suits. Island Creek's experience with miner training was considered also. It is concluded that present job specifications can be employed for each of the men involved, supplemented with thorough physical exams and only sufficient psychological testing to determine that the individual will be able to operate in a life support suit.

Training of experienced miners in the functioning of their suit, their life support and emergency breathing apparatus will be necessary for their safety. While each miner will be familiar with normal operation of mining equipment, further familiarization with such operation while wearing a suit is advisable before going under an oxygen free atmosphere.

A training facility should be located outside the sealed mine. This facility should contain a classroom, a small gas lock chamber in which men can be accustomed to the safety of their suits and apparatus, and a garage in which individual pieces of mining equipment can be operated by the men while wearing the life support suits so that they can become accustomed to such operation before having to perform it within the confines of the mine proper. Approximately one month is anticipated for training a ten man section crew before they would begin operation in an oxygen free atmosphere.

Data Collection

One of the primary purposes of the inert gas program is to effectively prevent the formation of acid mine drainage. How drainage quality will vary with time from transition from air to inert gas status is thus of great interest. Comparison with a reference condition is desirable. Manual as well as automatic recording analysis of drainage quality was studied for a sealed mine.

It is concluded that continuous instrumental monitors should be provided to measure the quantity and quality of the effluent from the sealed mine. In addition, in the proposed demonstration mine, the flow and quality should be measured in the stream above and below the mine site. The continuous monitoring program should be supplemented with automatic sampling and laboratory analyses for the remaining components of interest. In the case of the proposed demonstration program, provision can be made for the insertion of heavily pyritic material within the demonstration mine and for measurement of the drainage that would ensue from it as an additional control.

Monitoring of the mine atmosphere as well as the atmosphere in the gas locks and refuges should be continuous for each of the gases of interest. Such instrumentation is available and reliable. It can be located either in refuge stations or external to the mine, whichever is most convenient. All results can be displayed in a central control room.

Safety

A personnel accident in an oxygen free mine requires that first consideration be given to rescue apparatus that will provide breathing atmosphere for an unconscious and possibly stunned individual completely separate from any of the breathing apparatus carried by the individual. The apparatus must be portable, reliable and have a high shelf life. It is concluded that the rescue breathing apparatus used should be the automatic resuscitator type with provision for demand breathing. Such equipment is self-contained and operates from a pressure cylinder of oxygen. Such apparatus is not the recycle-rebreathing type but is the full purge type. The helmet can be removed from an injured miner and the face mask of the rescue apparatus placed on the miner.

The initial development of any mine as well as that of the proposed demonstration mine would be in an air atmosphere under at least temporary ventilation sufficient to meet all normal safety regulations. The transition from air ventilation to an oxygen free pressurized status must be performed safely and at reasonable speed. Likewise, there may arise certain conditions, particularly in any demonstration mine, when it will be necessary to abandon the oxygen free state for the mine.

A new mine during development prior to blanketing can be initially operated in an air ventilated condition employing a 12,000 CFM ventilating fan for the first section. When it is desired to place the mine in an inert condition, dampers provided in the gas duct work outside the mine can be rearranged so that the ventilating fan can begin to circulate the mine atmosphere. Inert gas can be supplied from the inert gas generator system to the discharge of the circulating fan and an equivalent amount of return gas can be vented as soon as the required one inch differential pressure between the mine and outside air has been established. In the event of an emergency, the dampers can be rearranged so as to discharge from the ventilating fan to the atmosphere and to intake into the mine directly from the outside atmosphere.

Future Planning

Much of the equipment for mining in oxygen free atmospheres is off-the-shelf; some of it must be modified and some developed from standard components. The inert atmosphere adds a severe caution on safety and reliability. The costs of operating a mine are substantial, and thus any program to demonstrate the process must utilize the minimum number of miners, and the minimum supplies and utilities.

Two additional phases are thus proposed for the oxygen free mining program aimed ultimately at demonstrating the utility of the process as applied to full scale mining. Phase II should have as its primary purpose the determination of the safety, reliability, and suitability of the key components of suits, life support systems, and communications gear for mining coal in an oxygen free atmosphere. The work should be conducted both above ground and below ground in a portion of an active mine which should be conventionally air ventilated.

It is reasonable for the Phase II program to train and suit up only two miners but to have these two men operate all five of the conventional pieces of mining equipment. It is anticipated that the suits and life support systems employed would be considerably modified during the course of the Phase II program. Phase II would also develop the detailed plans and specifications for all of the components for the proposed Phase III demonstration mine. It is anticipated that the Phase II program would cost approximately $700,000 and would take about a year and a half to complete.

Phase III should involve the construction of a demonstration mine and the operation of a full section with ten men suited and trained plus their replacements utilizing the life support systems evolved in Phase II. The Phase III program should be designed to develop information on the productivity and effectiveness of typical miners if the process is to be ultimately adopted by any significant segment of the industry. Men presently trained as miners must thus be the pool from which men would be chosen.

The proposed demonstration mine should employ one loading machine operator, one cutting machine operator, two shuttle car operators, one roof bolting machine operator, one coal drill operator and shot man, two maintenance mechanics, one general serviceman, one section foreman, and one mining engineer. Operation during Phase III need be only during the daylight shift, for one shift each day. Four shifts per week could be worked with one shift per week being used for critique and training.

It is anticipated that during Phase III, the demonstration mine would actually be operated in an inert atmosphere for a year's time and that the duration of the entire Phase III program would be two years. The Phase III program would result in the preparation of the estimates of the cost of construction and operation of a full scale mine, both for non-gassy and gassy operations based upon the experience gained in efficiency of operation as well as in service life and maintenance of the specialized life support equipment. It is estimated that the cost of the Phase III program would be approximately $2,000,000.

Site Selection

The site that should be selected for the proposed Phase II demonstration mine must be on leases currently available for operation, must be in a virgin seam in which there has been no other actual mining activity surface or deep in the part of the seam to be used, a minimum of 50" of seam height to allow reasonably uncramped operation, a seam outcropping above grade so as to allow drift entries, a non-gassy seam, and an active mine with working entries within a reasonable distance so that coal handling facilities, haulage, utilities and roads may be shared. In addition, a good probability of producing acid mine drainage during operation should exist.

Three leases, Red Jacket, Rock House, and Pond Fork, all within a radius of Holden, West Virginia, belonging to Island Creek Coal Company, met with the stated requirements. Field water samples were analyzed and laboratory column tests were run on samples of refuse from the adjacent active mines.

The best site of those studied for the construction of the proposed demonstration mine is adjacent to the newly active (July, 1970 production) Pond Fork mine of Island Creek Coal Company, located in Boone County, West Virginia.

Drainage from the mine area is into the Kanawha River Basin. A survey of records of other mining activity in this same seam in this same region, coupled with analyses of samples of drainage collected within the area, plus the tests run in the laboratory on columns, indicates a probability of mild acid drainage from the demonstration mine.

SECTION IV

INTRODUCTION

Intense public and private interest has been focused in recent years on the stream pollution and on the dust levels, and fire and explosion hazards associated with deep coal mine operation. Testimony in both the House and Senate on the Water Quality Improvement Act of 1970 emphasized the magnitude and importance of the mine drainage pollution problem and the need to advance the technology for abating such pollution. Concern over dust and fire and explosion hazards resulted in the passage of the Coal Mine Health and Safety Act of 1969, PL 91-173. The development of new technology to aid in solving simultaneously the foregoing problems associated with deep coal mining is the object of the study discussed herein.

It has been established that the oxidation of pyritic material associated with coal leads to the development of iron sulfate and sulfuric acid in the water draining from the coal mine. Early laboratory studies showed that exclusion of oxygen from the coal mine would retard or prevent the formation of acid mine drainage. Further laboratory studies performed by Cyrus Wm. Rice Division of NUS CORPORATION in 1968, under FWQA Contract No. 14-12-404, confirmed that oxygen exclusion from moist pyrites would result in reducing the production rate of sulfates by over 90% of that produced in air. A program to study the application of an oxygen free atmosphere to abandoned deep coal mines is currently under study by the Commonwealth of Pennsylvania's Department of Mines and Mineral Industries under Contract No. CR-81 with Cyrus Wm. Rice Division of NUS CORPORATION supported by FWQA Grant No's WPRD-227 and 14010EFL.

The concept of application of an oxygen free atmosphere to active deep coal mines originated with J. K. Rice of Cyrus Wm. Rice Division (RICE) of NUS CORPORATION in 1966. The concept involved the use of life support systems for the miners to enable them to operate the mining equipment in a mine blanketed with an oxygen free atmosphere. Preliminary conceptual studies indicated the possible success of the application in not only abating acid mine drainage but in eliminating both dust inhalation and fire and explosion hazards from mines. Other possible benefits that could occur included the elimination of rock dusting and the use of special explosion proof equipment. In the case of mines producing large quantities of methane gas, capture and sale of this gas would be possible.

The initial ground rules adopted for the feasibility study were as follows:

1. Maximum use was to be made of equipment that is available as is or available with minor modification.

2. The sealed mine was to be designed to allow use of all nitrogen, nitrogen plus methane, or all methane atmosphere with the oxygen content limited to a maximum of 0.1% v/v.

3. Any proposed demonstration mine was to be located adjacent to an existing active mine but not connected to it internally. This would allow the use of the coal handling and coal preparation facilities of the active mine to handle the coal produced in the demonstration program.

4. A refuge station was to be located in the sealed mine near the working face with the refuge ventilated separately from the outside.

5. Conventional rubber tired mining equipment was to be used.

6. Sizing of equipment and calculation of support requirements were to be based upon using one complete mining crew working one section, one shift per day.

SECTION V

MINERS' LIFE SUPPORT SYSTEM (MLSS)

The coal mine must be completely sealed. Oxygen free atmospheres of either 90% nitrogen-10% carbon dioxide, or 100% methane are proposed to purge and pressurize the mine to maintain a maximum 0.1% oxygen concentration in the mine. The recycling of the mine atmosphere, the heat generated by the mining equipment and the water within the mine will create a warm humid atmosphere. The minimum coal seam height, approximately 35 inches, as well as the design of the mining equipment seats prevents the mounting of the life support equipment on the miner's back.

The life support system proposed for use in the oxygen free mine must supply the miner with a cool carbon dioxide free breathing oxygen uncontaminated by mine atmosphere with a minimum amount of air leakage from the systems to the mine so as not to contribute significantly to the oxygen content of the mine. The system must keep the miner comfortable in a mine atmosphere at 100% relative humidity and must not unduly hinder him in his operation of conventional mining equipment. The rebreather section must be so constructed as to be easily carried by the miner and mounted onto the mining equipment; it must sustain a miner for his entire shift plus a 50% safety factor. Where possible, the system employed should be off-the-shelf and not require special development. The system must be extremely reliable yet remain uncomplicated and rugged

To determine the availability of off-the-shelf equipment and technology, inquiries were sent to various suppliers. On the basis of the returns, detailed discussions were held with Arrowhead Products Division - Federal - Mogul Corp., ILC Industries, Inc; Litton Systems, Inc, and MSA Research Corporation.

A trip was made accompanied by a NASA representative to Cape.Kennedy to the Bendix Launch Support Division to review the problems involved in maintaining large numbers of life support systems. Additional information was obtained by reviewing the In-Fab process developed and tested by the Universal Cyclops Corporation.

The Bioastronautics Data Book of the National Aeronautics and Space Administration (NASA-SP3006) was used to establish the criteria for the breathing system. A requirement of 0.2

pounds per hour of oxygen and a 1190 BTU per hour metabolic rate both equivalent to that of rowing a boat for pleasure were chosen for the average work load. The supply of 70°F air at 40% humidity provides a 600 BTU per hour evaporative heat loss equivalent to a sweat rate of 0.6 pounds of water per hour. An air circulation rate of 15 cubic feet per minute within the suit is required to provide evaporative cooling for the miner.

A review of the existing life support systems currently in use in mines indicates such units are being used primarily for rescue work. These units consist of face masks and back packs weighing approximately 35 pounds; they are limited to a 2 hour use; they are rebreather systems and rely primarily on compressed oxygen to supply the makeup oxygen to the rebreather system. This equipment is not satisfactory because of its 2 hour limit and it would be unreasonable to expect a miner to wear a 35 pound pack for an 8 hour day. The life support system should provide 12 hours of oxygen (50% excess) and should be capable of being mounted on the mining equipment while supplying the miner with oxygen.

A second consideration was that of a miner wearing a face mask for 8 hours. In a short period of time, a mask becomes quite uncomfortable and it is unreasonable to expect a person to work for 8 hours a day, 40 hours a week under these conditions. In addition, the warm, humid atmosphere expected in the mine would be very uncomforatable for the miner.

The chosen life support system must keep the man comfortable as well as supply oxygen. In addition, in order to maintain less than 0.1% oxygen in the atmosphere within the mine, the life support system must be of the closed circuit rebreather type leaking a minimum amount of oxygen into the mine.

A review of the literature and work being done by NASA and other organizations in the space program indicated there are two basic cooling systems being used to keep the wearer of life support systems comfortable. One system is to circulate a cool air throughout the extremities of a completely enclosed life support suit relying on evaporative cooling to keep the man comfortable. This is the system used by the launch support crews at Cape Kennedy and in the Titan Missile Program.

The second system is to use a liquid cooled garment underneath the outer gas tight life support suit. This garment consists of a series of small tubes knitted into the undergarment through which chilled water is circulated to remove body heat. Using this method there is no loss of body fluids and the amount of circulated air required to sustain the man is considerably less (1 cfm versus 15 cfm). The liquid cooled garment has found considerable use in the space program due to conservation of body fluids. It adds additional cost and complexity, however, since pumps and reservoirs for the coolant and an additional heat exchanger are required. The undergarment is more bulky and costly as well.

Investigation

The MLSS includes all components relating to breathing, communications and cooling either worn, carried by the miner or mounted on equipment. Three approaches were studied in choosing the equipment for the MLSS. The first was to use the existing back pack equipment currently being used for mine rescue work as discussed above. The second was to use a life support suit similar to those currently being used by launch support personnel in the Apollo Space Program and by service personnel in the Titan Missile Program and adapting to this suit a remote rebreather gas cooling system utilizing the suit as a breathing bag. The third approach was to use a helmet sealed at the face or neck, connected to a breathing vest supplied by a remote source of oxygen and incorporating the use of a liquid cooled garment.

Existing Mine Equipment

The unit being used in mines today that comes closest to meeting the demands of this project is the Scott-Draeger No. 174 (Scott Aviation)* back pack. This is one of the primary self-contained rebreather systems being used in mine rescue work. It has a 2 hour rating but it has a 4 hour capability. The oxygen bottle and CO_2 absorbing canister could be replaced in the mine refuge station and two changes would provide for an 8 hour working shift. A supply of oxygen bottles and CO_2 canisters would have to be stored in the mine. Using this technique, a miner could stay in the mine for an indefinite period. The disadvantages are as previously discussed - lack of cooling, face mask irritation, weight, back mounting, a short operating cycle. Availability and proven reliability are advantages. Leakage rate around the mask is variable and no data could be uncovered.

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Full Suit System

A life support system incorporating the complete enclosure of the miner within a protective suit (coverall type) and utilizing evaporative cooling for comfort control was part of the original concept of this project.

A major advantage of the full suit with connected helmet is that the man would not be required to wear a face mask and would not have to suffer the discomfort of a sweaty face within a mask. The full suit is able to provide a controlled atmosphere over the entire body, head and face to keep the miner comfortable. As mentioned previously, there are two types of cooling systems currently in use in full suit. The evaporative cooling system provides a large amount of cool air, a portion (40%) of which goes to the helmet for both breathing and cooling while the remaining (60%) is ducted to the various extremities of the body for cooling only. Two air ducts (tethers) are required to circulate the air from the external rebreathing module to the suit. The liquid cooled garment which is worn close to the skin, as previously described, requires two 1/4 inch tubes to circulate the water to an external pump and chilling source. These tubes are in addition to the dual tether required to supply breathing air to the man and to remove the moisture from the exhaled breath.

There are several disadvantages to the full suit system. The suit must be loose since it does not stretch and when worn is inflated slightly by the need to maintain a slightly higher pressure in the suit over the ambient atmosphere to prevent in-leakage. This slight inflation may tend to hinder the movements of the miner. The use of boots and gloves may further restrict the miner's ability to operate his equipment. The possibility of tearing the suit is a real one and makes a backup breathing system of prime importance. The tubes required to cool the miner and to supply breathing air would have to be so located as to not be in the miner's way when operating the mining equipment.

A full suit incorporating evaporative cooling, would require 15 cfm of air recirculation versus 1 cfm if a liquid cooled garment with only a helmet were used and only breathing air supplied to the helmet. The rebreather system blower would be much larger as would the tethers in the full suit system. The full suit is more difficult for one man to put on by himself than the helmet and vest. The full suit system may require a more involved maintenance and inspection program by reason of the greater wearing surface and the need for pressure integrity.

In spite of these disadvantages to the full suit system, it's estimated that it's modification for in-mine use would cost considerably less than the development of the helmet/vest system and the full suit with evaporative cooling is available now essentially off-the-shelf from several suppliers.

Helmet/Vest Systems

This system involves the use of a flight helmet developed by the Robertshaw Control Company,* Inc., with a breathing vest developed by the Applied Technology Division of Litton Systems, Inc.* These in conjunction with a rebreather module, and a liquid cooled garment would complete the life support system. No gas tight garment would be required. A wear-resistant outer coverall would be worn over the vest. Ordinary shoes and gloves would be used.

The Robertshaw Control flight helmet (AOH-1) is currently being used by the U. S. Navy. The pilots who have used this helmet prefer it over others they have used because it is more comfortable and less irritating.

The helmet, hinged at the top swings out at the back and clamps around the man's neck. A face mask within the helmet provides a tight seal preventing oxygen leakage from the helmet. This seal is made of silicone rubber which has proven to be nonirritating and can be adjusted so that three sizes of helmets will fit 95% of those required to wear them.

The breathing vest developed by Litton Systems, Inc., is a double walled vest filled with air which fits snugly around the man's torso. The oxygen is fed into the vest and the chest, expanding during normal breathing, forces this oxygen into the mask. On exhaling, the chest contracts and the vest expands making room for more oxygen. The exhaled breath by the use of valving would be recycled to the rebreating module. The liquid cooled garment would be worn under the vest and would be used to keep the miner comfortable.

As mentioned above, normal work clothes could be worn over the breathing vest and liquid cooled garment, and the miner would have complete freedom to use his hands and legs. His trips to the refuge station would be minimized as he would not have to remove a life support suit to relieve himself.

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

To complete this system, a remote rebreathing module located on the mining equipment would be required. This module would be generally the same as would be required for the full suit system, however, the amount of air being recirculated would be 7% of that required for the full suit system. In either system the heat rejection and oxygen and CO_2 requirements would be the same. The difference in the two breathing modules therefore, would be that a smaller blower would be required with the helmet/vest system, the tether would be smaller, liquid coolant lines, pump and reservoir would be added, and two heat exchangers, one for air, and one for coolant would be necessary. The cooling controls in the rebreather module would be more complicated in the helmet/vest systems than in the full suit evaporative system.

Breathing Apparatus

Consideration at first was given to a central system that could supply the requirements of the entire 10 man section. The concept envisioned a crew support vehicle carrying the O_2, CO_2 units plus the refrigeration unit. This vehicle would leave the mine with the crew and would be located near the working face during mining operations. Connections could be made by hose to reels on each piece of mining equipment similiarily as used for electrical power. The complexity of the hose system, liability to hose failure, and problems of regulation led to abandonment of the concept in favor of individual units, one per miner.

Each individual miner thus requires a complete self-contained rebreather system to furnish oxygen, CO_2 removal, and cooling. Since the breathing module can be mounted on the mining equipment or transport vehicle associated with the man, the only weight limitation is that a man must be able to comfortably carry at least the life sustaining component into the mine and mount it on his particular piece of mining equipment.

A review of the available breathing systems indicates that breathing oxygen can be obtained from the following sources: liquid oxygen, liquid air, compressed oxygen, compressed air, special mixtures of oxygen and nitrogen or helium, potassium superoxide, and sodium chlorate (oxygen) candles. These sources are currently being used in breathing apparatus generally for short periods of time. In most cases, the exhaled oxygen is vented to the surroundings. The choice between these sources is determined by the weight of the source per pound of available oxygen, the problems involved in recharging the breathing apparatus, the ability to control the rate of air to match metabolic requirements and the disposal of spent containers, and the limit of 0.2 cubic feet per hour of O_2 that can be vented to the mine atmosphere. The latter requirement rules out both continuous purge systems and the use of either liquid or compressed air since the nitrogen associated with the oxygen must be continuously purged.

Liquid Oxygen

Liquid oxygen is the most concentrated source of oxygen available, however, handling liquid oxygen is hazardous and clean room techniques must be used. The possibility of fires and explosions due to accidental spilling and contamination in the mine is a real one. Equipment using liquid oxygen could not be recharged in the mine due to the dusty conditions. Since the containers for cryogenic oxygen even though well insulated allow some heat flux, there is a constant bleed off of oxygen that if not consumed by the miner must be vented to the mine atmosphere. Control of vaporization of liquid oxygen to match demand is complex. While the heat of vaporization can be used to cool the miner, the amount of oxygen required for such cooling greatly exceeds the amount required for breathing and hence must be vented continuously from the system. The amount so vented greatly exceeds the 1 cubic foot per hour of air limit. Use of liquid oxygen for makeup to the rebreathing system requires a companion device for absorbing CO_2 from the recirculated breathing gas. The cost of liquid oxygen in quantity is 15¢ per pound, making it the most economical of the several sources.

Compressed Oxygen

Compressed oxygen is readily available in 2200 psig cylinders. Oxygen at this pressure has a specific volume of 0.0847 cubic feet per pound thus requiring a cylinder volume of 0.203 cubic feet for the 2.4 pounds specified for 12 hours. Two standard cylinders weighing 13-1/2 pounds full - 12 pounds empty containing 1-1/2 pounds of oxygen could be used to meet these requirements. A special cylinder could also be designed to meet these requirements. Extreme care must be used in handling the cylinders and cleanliness must be observed in making all connections. The ability to store oxygen in cylinders for considerable periods of time and to easily measure the amount in store by a pressure gauge is in its favor. The danger of coal dust would limit cylinder changes in the mine to emergency only and hence the full shift capacity would be required in the rebreathing unit or spare units would need to be used. The ability to use standard demand pressure regulators for controlling the rate of use is a major advantage. As with liquid oxygen, compressed oxygen requires the use of a CO_2 absorber in the rebreather circuit. The cost of compressed oxygen in cylinders is approximately 38.8¢ per pound.

Special-Oxygen Nitrogen Mixtures

The use of special compressed oxygen-nitrogen mixtures may be more desirable than the use of pure compressed oxygen, from the standpoint of the effects of pure oxygen on the man. These mixtures would be less hazardous to handle than pure oxygen and could be prepared at a filling station outside the mine where adequate safety precautions could be taken. The composition of the mixture would be regulated by the leakage rate from the life support rebreather system so as to maintain the normal 20% oxygen in the rebreather atmosphere. Maintaining this delicate balance with varying leakage rates from different suits would present a difficult control problem. A suit with lower leakage than that calculated for the gas mixture supplied could become depleted in oxygen below the value adequate for breathing. Costs would be similar to those for compressed oxygen alone.

Potassium Superoxide

Potassium superoxide is a solid that generates pure oxygen by the reaction of moisture and carbon dioxide in the air passing over it. A superoxide canister can deliver 0.34 pounds of oxygen per pound of initial weight. In addition, the superoxide canister removes moisture, carbon dioxide and odors. Other oxygen sources as pointed out previously require companion components for removing these items. This means that by changing one canister, the system using superoxides can be completely recharged and no additional components are required.

Superoxides have a long shelf-life and can be stored within the mine for extended periods of time for emergency purposes. Canisters can be designed to last up to 36 hours or supply several men at one time. Since the reaction is exothermic, additional cooling in excess of the man's metabolic requirement is necessary.

The disadvantage of superoxides is that they continue to generate oxygen after being removed from the breathing apparatus. If a canister were changed in the mine, it would have to be sealed to prevent the oxygen from contaminating the mine atmosphere. The recommended method for the disposal of spent superoxide canisters is to immerse them in water to dissolve the superoxide, thereby forming an alkaline solution. Disposal of large numbers of these canisters would present a problem.

A major disadvantage of the superoxides is controlling the rate of oxygen generation to meet changing requirements of the miner. Since moisture in the recycled breathing gas must be controlled for comfort purposes, additional moisture removal will occur in the chilling apparatus. The balance between the amount removed and the amount necessary to generate only the requirement for metabolism would be difficult to maintain. A still further disadvantage is that once the canister is used it will generate a set amount of oxygen dependent on the moisture and carbon dioxide present in the canister. The reaction cannot be stopped and restarted again as would be required by a miner visiting a refuge station. Any surplus capacity left in the canister at the end of the shift is also lost thereby increasing the cost of the oxygen. The cost of oxygen supplied by superoxide in the size canister required is $4.58 per pound of O_2.

Oxygen Candles

The oxygen (chlorate) candle is a mixture of powdered iron and potassium chlorate that when ignited burns to produce chemically pure oxygen. It is another solid source of oxygen that has a long shelf-life and could be stored within a mine if desired. These candles burn at a fixed rate and the reaction cannot be stopped until it goes to completion hence their use requires an accumulator system of some sort to prevent wastage of oxygen generated in excess of immediate requirements. They can be sized to provide predetermined amounts of oxygen, however, and are very compact. They supply 0.40 pounds of O_2 per pound of candle. CO_2 absorbers would have to be used with oxygen candles and additional cooling required above those for metabolism if they were to be used in the rebreathing module. The spent candle is a dense sintered material rich in chlorides and could present a disposal problem. Oxygen supplied by chlorate candles costs $6.25 per pound of O_2.

SPECIFICATIONS

Preliminary specifications for the Miners Life Support System (MLSS) were prepared and sent to those suppliers showing an interest in the project. These specifications were based on a full suit including gloves and boots capable of meeting a maximum of 1 cubic foot per hour leakage rate (at 1/4 psig) and incorporating evaporative cooling. Potassium superoxide was indicated as the most desirable source of oxygen for the rebreather system. The response to these specifications contained many helpful suggestions which were incorporated into the final specifications for the (MLSS).

One supplier indicated they could provide a suit incorporating gloves and boots which could meet a zero leakage rate under the operating conditions of the unit. Another supplier indicated they could meet the leakage specifications with a suit utilizing cuff and ankle seals rather than gloves and boots. Meeting the leakage requirement does not seem to be a problem.

Another supplier questioned the use of potassium superoxide because of the difficulty in controlling its starting, stopping and oxygen generation rate and recommended the use of chlorate candles. One supplier submitted a proposal for the self-contained rebreather system utilizing potassium superoxide as the oxygen source admitting the difficulties involved in controlling the operation of the unit and that it would require considerable development effort.

Final specifications for the Mine Personnel Suit (MPS) and the Mine Personnel Rebreather System (MPRS) were developed incorporating the supplier's suggestions pertaining to the preliminary specifications. A full suit enclosure including gloves and boots incorporating evaporative cooling was chosen as the system most readily available and requiring the least amount of development work. Compressed cylinder oxygen was chosen as the source of oxygen most readily adaptable and requiring the least amount of development effort. The following are the final specifications for the Miners Life Support System.

Miners Life Support System (MLSS)

The Miners Life Support System (MLSS) should be comprised of four basic components, the Mine Personnel Suit (MPS), the Mine Personnel Rebreather System (MPRS), the Mine Personnel Emergency Breathing System (MPEBS), and the Mine

Personnel Communication System (MPCS). All components should be modular in construction for easy maintenance and a common system must be used throughout the mine.

Mine Personnel Suit (MPS)

The Mine Personnel Suit (MPS) should be a low pressure suit similar to those used by launch support (NASA) and emergency ordinance disposal personnel (USN). It must be constructed in such a manner as to provide freedom of movement as well as comfort in the sitting and lying positions.

Two styles of suit construction can meet air leakage criteria and each style should be evaluated to determine which one is best suited for the mining operation. The basic difference between them being the use of wrist and ankle seals versus the use of ventilated gloves and boots. All other specifications for the suits would remain the same.

The basic suit should have rigid seal rings at the wrists and ankles to provide effective seals for the use of special boots and gloves. Ventilating air would be blown into these gloves and boots. The hand protection should be by a two glove system consisting of a lightweight inner glove and a heavy exterior glove. Each glove would make an air tight seal at the wrist so as to prevent air from escaping should either glove be torn. The two glove system also provides for the removal of the outer heavy glove to perform delicate work using the lightweight inner glove. Should the lightweight glove be torn, the heavy glove can be put on to stop the air leakage.

The basic suit should have incorporated in it the ability to install snug wrist and ankle seals capable of meeting the leakage rate criteria to permit the testing of the suit while ordinary shoes and gloves are used by the miners. Ventilation must be provided to the sealed area, while the hands and feet are exposed to mine atmosphere. This arrangement permits the use of bare hands in the performance of the work tasks.

The basic suit can meet a zero cubic foot per hour leakage rate when using special gloves and boots. The modified basic suit with wrist and ankle seals can meet the 1 cubic foot per hour leakage rate, but may present the problem of excessive leakage due to the miners attempting to relieve possible discomfort at the wrist and ankle seals. The wrist and ankle seals eliminate the need for special gloves and boots and the hazard of tearing the gloves.

The Mine Personnel Suit (MPS) should consist of the assembly of the following components:

A knitted full length arm and leg undergarment as the first layer next to the skin.

The second layer, Figure 1, should be a gas impervious suit of rubber coated fabric which is light in weight, meets the gas leakage specifications and has a distribution system to provide evaporative cooling (similar to the Navy's EOD suit, Industrial Environmental Protective Suit, Arrowhead Products SCAPE suit, etc.*).

The third or outer layer, Figure 2, should be a wear resistant work garment designed to protect the gas impervious layer from excessive scuffing and tearing.

The helmet would be attached by a clamping ring to the middle garment and be readily separable from the suit.

Special rubber gloves and boots complete the assembly for the basic style but would not be required for the alternate style using wrist and ankle seals.

Specifications Mine Personnel Suit (MPS)

These recommended specifications cover the proposed requirements for a special clothing assembly or Mine Personnel Suit (MPS) which will meet the gas leakage requirements, keep the operator comfortable and be protected from excessive abrasions and tearing. A man should be able to don this clothing without assistance.

All garments are to be sized and graded to fit those in the 95 percentile. The design is to be such that a minimum number of sizes would be required.

The first or undergarment is to provide complete leg and arm coverage and is to be made of absorbent knitted cloth to provide maximum comfort for the wearer and to permit easy evaporation of perspiration to the circulating atmosphere in the suit. Standard Long Johns or thermal underwear may be suitable for this application.

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

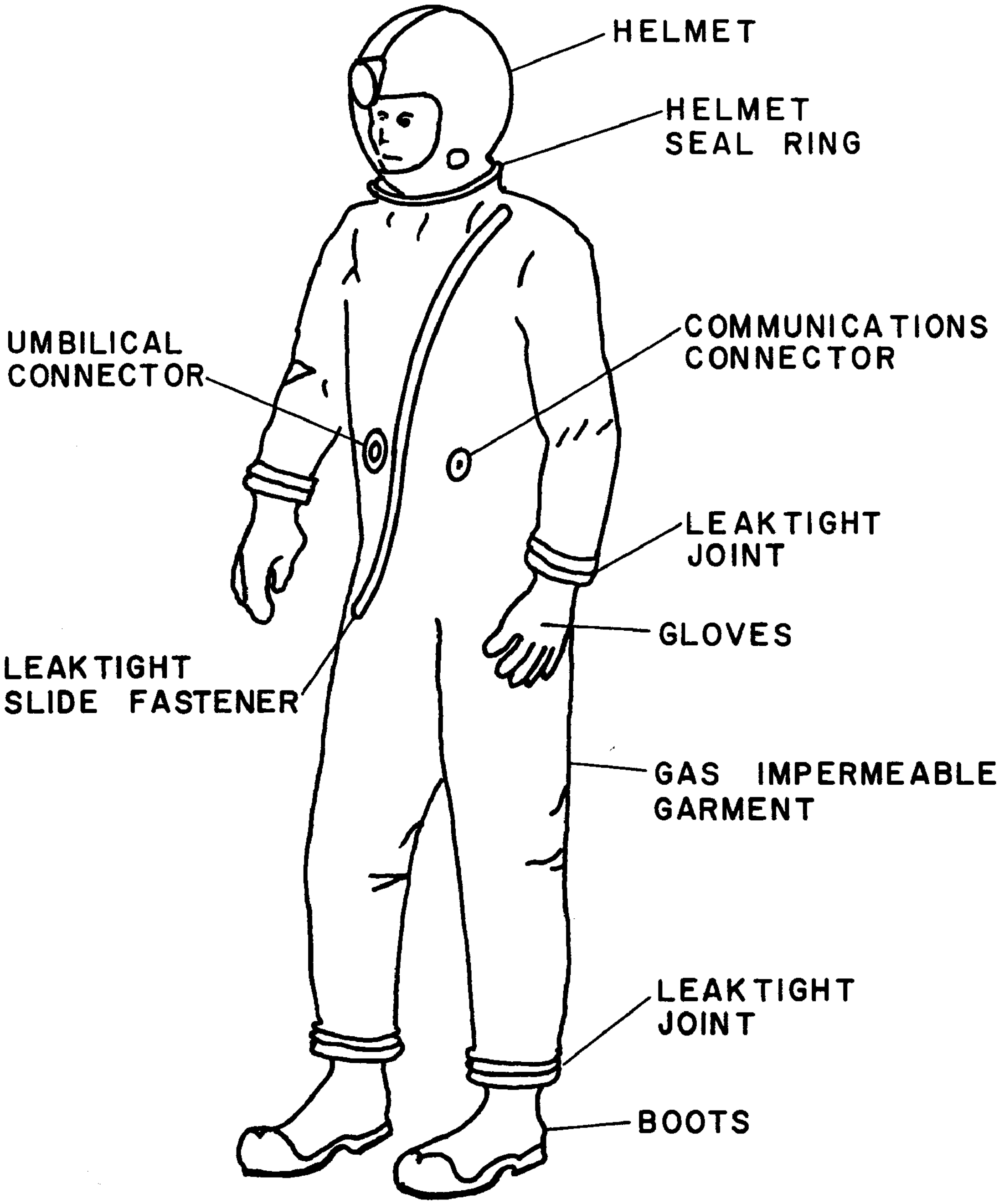


FIGURE I
GAS TIGHT MIDDLE GARMENT

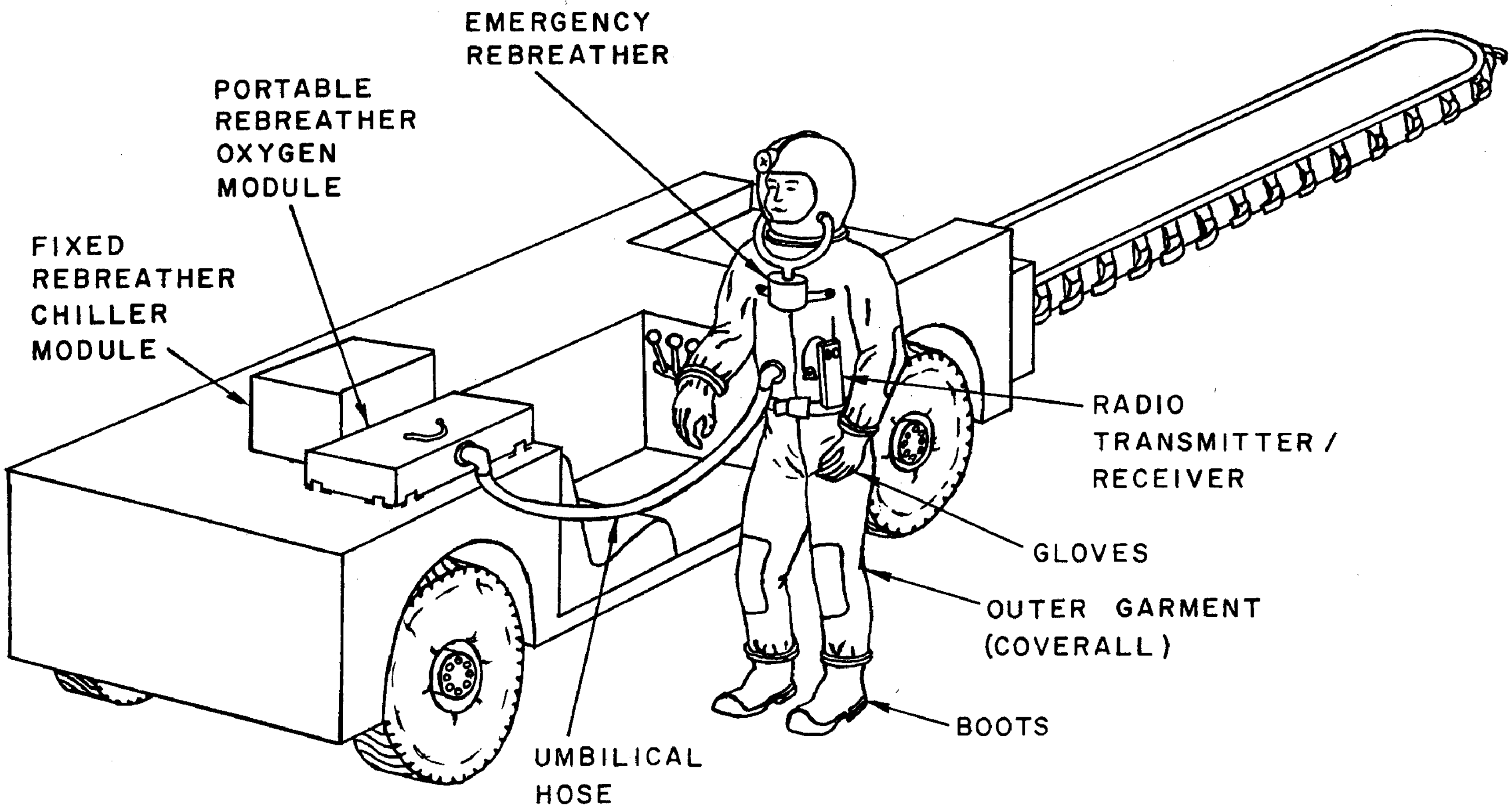


FIGURE 2
MINER IN LIFE SUPPORT SUIT

The gas tight suit or second garment is to be constructed of a lightweight gas impervious flexible material treated with an anti-static compound to prevent the buildup of static electricity. The suit is to be designed such that it can be put on and all gas tight closures wrist, ankle, and head can be made by the miner without assistance.

Slide fasteners are to be used for the opening into the suit and are to be of such design as to maintain the leakage at less than 1 cubic foot per hour at 1/4 psig. All hand and feet enclosures or seals are to be designed to maintain the leakage requirements and to provide maximum comfort.

The gas tight suit is to terminate at the neck area with a suitable attachment device for mating with a separate helmet or head enclosure. This device is to provide for rapid removal of the helmet in case of emergency. The seal must be shielded in a way that sheds accumulations of dust and is readily wiped clean before resealing.

Ventilation ducts to distribute cool air throughout the garment and their connecting point on the suit are to be located so as not to interfere during sitting, lying, or standing, or in the manipulation of the arms in front of the body while operating mining equipment.

The total assembly, including the helmet is to maintain a 1/4 psi differential over ambient pressure and must not leak in excess of 1 cubic foot per hour at this differential. A maximum of 1 inch water pressure differential is the specified normal working pressure in the suit. Inflation of the garment is to be held to a minimum at this pressure so as not to restrict movement.

Lightweight rubber gloves with the appropriate gas tight seals are to be provided to permit a high degree of finger dexterity. A second pair of heavy duty rubber gloves with appropriate gas tight seals is to be provided for use over the lightweight gloves to provide a double gas seal in case the outer glove should be torn.

Heavy duty gas tight steel-toed boots with appropriate gas tight seals are to be provided.

The exterior work garment is to be made of cotton twill or similar fabric currently being used for work clothes. This garment is to protect the gas tight garment from abrasion and tearing. Scuff pads and special pockets may be required for tools, supplies, etc.

The head enclosure (helmet) is to be made from a polymeric material and is to be a dome-type of sufficient size to permit complete unrestricted head mobility and vision. It is to be supported by the head and is to turn with head movements. Standard safety hat specifications are required. It is to be provided with a mounting bracket on top for a standard miner's lamp and is to be equipped to receive a single headset and lip microphone for communication purposes. Free flow of air is to be provided around the man's head for cooling and to prevent fogging of the visor. It is to be equipped with a voicemitter or tin ear over one ear for sensing in-mine noise. The visor is to be made of a scratch resistant material treated with lens anti-static compound.

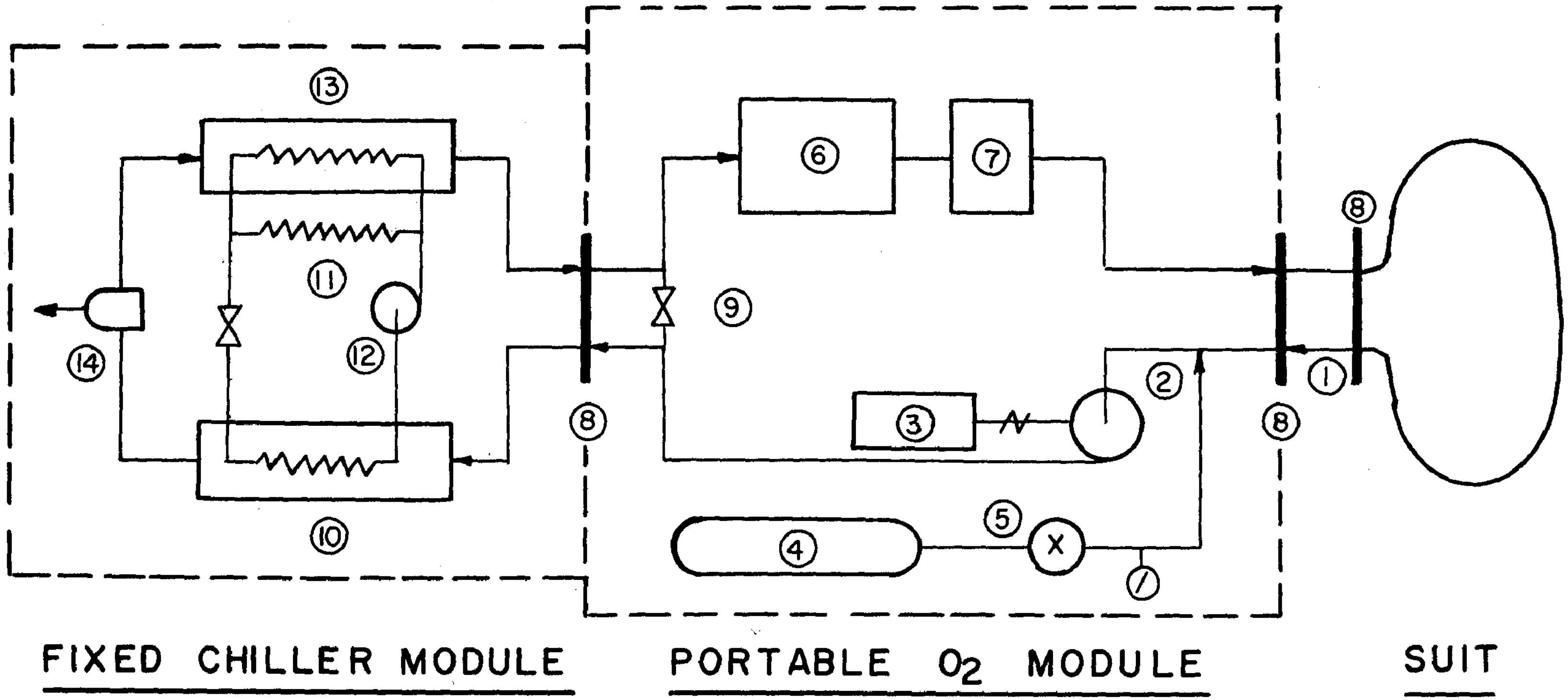
Mine Personnel Rebreathing System (MPRS)

The Mine Personnel Rebreathing System, Figure 3, should provide breathing oxygen for the miner during his entire stay in the mine. It should be of such a size and weight as to be easily carried by the miner and secured to the piece of mining equipment that he will be operating. The ambient leakage rate total from the Mine Personnel Rebreathing System (MPRS) and the MPS should be less than 1 cubic foot per hour at 1/4 psig differential. All hose connections are to be quick disconnects with positive shutoff. A standard configuration must be used throughout the mine.

The MPRS should be a self-contained rebreathing apparatus utilizing the gas tight suit (MPS) as a breathing bag. Compressed oxygen should be used as the oxygen source with a Baralyme CO_2 absorber and mechanical refrigeration for cooling. The use of the gas tight suit as a breathing bag requires the use of a blower to circulate the air from the suit through the rebreather and back to the suit. Figure 3 shows the basic components of the system.

Rebreather systems require 2 hoses (tethers), one to supply the air to the suit and the other to exhaust the air back to the rebreather unit. On standard rebreathing apparatus the length of the hose is fixed and normal breathing maintains adequate air flow. In this particular application, various lengths of hoses may be required for various functions. An 8 foot tether should be the standard length and should be satisfactory to supply the operator while attached to his piece of mining equipment without presenting too much of a problem of hose interference while in transit. It would also permit the miner to set his breathing module on the floor while inspecting the mining equipment and would give him some room for movement.

MINE PERSONNEL REBREATHER SYSTEM



1. UMBILICAL HOSE
2. D. C. BLOWER - 15 CFM
3. BATTERY
4. OXYGEN CYLINDER — 30 SCF
5. 2-STAGE DEMAND PRESSURE REGULATOR
6. BARALYME CO_2 ABSORBER
7. CARBON FILTER
8. SELF CLOSING QUICK DISCONNECTS
9. CHILLER BYPASS
10. COOLING UNIT
11. BYPASS CONDENSER
12. REFRIGERANT COMPRESSOR
13. HEATING UNIT
14. MOISTURE TRAP

FIGURE 3

In the case of maintenance men, a 20 foot tether may be required to provide adequate mobility for the performance of their tasks. Provisions should be made for the insertion of additional hose and the fan should be sized to maintain adequate ventilation under this extended tether system.

The final size and configuration of the MPRS will depend upon the room available for its mounting on the various pieces of mining equipment. In this regard, off-the-shelf components should be used for the initial evaluation of the system. Actual operating experience may require the future development of more compact equipment, specifically for this use.

Specifications Mine Personnel Rebreathing System (MPRS)

The MPRS should be comprised of five components or subassemblies designed to be rapidly assembled into a self-contained rebreathing system. It should be compact, lightweight (less than 60 pounds) and provided with the necessary case and handles for ease in carrying. It should be designed for easy assembly and maintenance. All subassemblies should be modular in nature so that they may be easily interchanged and all connections must be readily accessible and require the minimum amount of special tools for changing.

The following subassemblies make up the proposed MPRS.

1. Oxygen source - compressed oxygen
2. Control panel and manifold
3. Air recirculating unit
4. Carbon dioxide canister
5. Air cooling unit

The first four of the subassemblies should be combined at least initially in a single unit, an oxygen module, while the fifth comprises the chiller module. The oxygen module should be portable leaving and entering the mine with the miner while the chiller module remains on the assigned equipment. Quick disconnect fittings join the two modules. Ultimately the size and weight of the chiller module may be reduced so that the two may be combined in a single unit. The oxygen module must function to supply the miner with oxygen and CO_2 absorbing capacity at all times whether attached to the chiller module or being carried by the miner. Cooling of the miner obviously can only be accomplished when the both oxygen and chiller modules are joined.

Subassembly 1 - Contains a cylinder of compressed oxygen at 2200 psig containing 2.4 pounds of oxygen. It includes the necessary high pressure reducing valve, quick disconnect couplings, hoses, and valves so that the subassembly can be quickly installed in the rebreather system.

Subassembly 2 - The control panel and manifold contains the demand pressure regulator, the pressure relief valve, oxygen sensor, switches, power supply and warning alarms required to make the completed assembly a safe and reliable rebreather system. It is to maintain an 0.1 - 0.5 inch water pressure at the suction of the rebreather blower at all times.

Subassembly 3 - The air circulator contains a 15 cubic foot per minute blower using a universal AC-DC motor, a rechargeable battery capable of providing for 2 hours operation of the blower, and appropriate disconnects, couplings, valves, hoses, switches, and flow control units as required to develop a complete and reliable air circulation system and maintain a maximum 1.0 inch water pressure within the suit.

Subassembly 4 - The CO_2 absorber consists of a canister containing Baralyme absorbant along with appropriate hoses and disconnects, switches, valves, etc., to facilitate rapid assembly into the completed unit. The canister must be capable of absorbing 3.3 pounds of CO_2 generated by the miner in a 12 hour period.

Subassembly 5 - The air cooling unit is comprised of the necessary mechanical refrigeration and reheating system with the associated hoses, valves, and disconnects so that the unit may be quickly assembled into the completed unit. It is to remove 2,000 BTU per hour (1.0 pound per hour of water) and when coupled into the completed MPRS to deliver 15 cfm air at 70°F and 40% relative humidity to the suit.

The completed assembly of the five components is to supply 15 cubic feet of air per minute at 70°F and 40% relative humidity to the suit while maintaining a 1.0 inch water pressure maximum in the suit when using a 20 foot dual tether hose 1.5 inches in diameter each.

Mine Personnel Emergency Breathing System (MPEBS)

The Mine Personnel Emergency Breathing System (MPEBS) must provide oxygen to the miner in case of an emergency where the MPRS cannot operate or sustain the miner. It must be carried by the miner at all times and must be designed to be put into service with the least possible delay. It should be of the rebreather type making maximum use of the available oxygen source and must sustain a man for a minimum of 30 minutes.

Two systems were reviewed, each having equal promise. Both systems were based on having a built-in mouth piece in the helmet that the miner would bite on and breath through his mouth as in scuba diving. It will be impractical to use a nose clamp so the miner must be trained to breath through his mouth for extended periods of time.

In system A, the exhaled breath would discharge through a potassium superoxide canister where the carbon dioxide and moisture would be absorbed and free oxygen generated, and into a breathing bag. On inhaling, air would be supplied by the breathing bag. The mouth piece would be valved to control the various air flows. An oxygen candle would be used to supply the initial oxygen to fill the system until the superoxide became effective. Once started the system cannot be stopped and the canister must be discarded after use.

In system B, the exhaled breath would be discharged into a carbon dioxide absorbing canister able to absorb 0.14 pounds of CO_2 where the carbon dioxide would be removed. It would then discharge into a breathing bag. Oxygen from a small compressed oxygen cylinder able to hold 0.1 pounds of 2200 psig oxygen would supply (via a demand regulator) the makeup oxygen to the system. On inhaling, the air would be supplied by the breathing bag and the mouth piece would control the air flow. Oxygen would be available immediately and the system could be shut off at any time. The CO_2 absorber would have to be replaced after use, however, since there is no measure of the capacity remaining. The oxygen cylinder would be recharged after use.

Of the two systems, A was deemed to be the most compact and suitable for use in MPEBS.

Specifications - MPEBS

The Mine Personnel Emergency Breather System should be a self-contained rebreather system worn continuously by the miner. It must provide 30 minutes of oxygen and it's size and weight is to be held to a minimum. It is to be located in such a manner so as not to interfere with the miner while operating his equipment and must require a minimum amount of effort to put it in service.

The MPEBS should consist of the following:

A mouthpiece with associated check valves and hose built into the helmet.

Quick disconnects on the helmet for the hose.

One superoxide canister with a 30 minute rating with a chlorate candle starter.

One collapsible breathing bag.

The necessary hose to complete the assembly.

All hose couplings should be of the quick disconnect positive seal type of the same manufacture used for the main rebreather system. All hose should be lightweight, flexible and crush resistant.

Mine Lamps

The mine lamp used with the MLSS should be the standard miners lamp in use today (the MSA Mine Spot* for example). The MLSS helmet as proposed would contain a mounting bracket for this lamp. The battery may be the standard lead-acid battery with inner seals to prevent acid leakage regardless of the position of the battery. It is proposed that the present practice in handling, checking and charging the miner's lamp be used.

Mine Communication System - MCS

Radio transceivers utilizing an in mine radiating antenna system are proposed to provide the main communication network. Each miner should be equipped with individual transceivers to provide for communication within the mine. Each MLSS would thus be equipped with the necessary head set and microphone and the necessary connections for the transceiver. See Section VI for details and specifications for the MCS.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Miner's Life Support System Maintenance

The Bendix Launch Support Division has the complete responsibility of maintaining the life support systems used by the launch support crews (fuel handlers and ground crew) at Cape Kennedy. During a launch preparation, they can suit 1,000 men a week routinely. The suits are kept in a store room and checked out and in as required. When checked in, each suit is washed inside and out in a Freon spray cabinet and then inspected. All tears and abrasions are patched and the suit placed in the rack to be used again. Some of their suits are 5 years old.

The breathing apparatus is cleaned and inspected and the spent canisters discarded. New canisters and oxygen bottles are installed and the unit tagged and placed on the shelf ready for use. Extreme care is used in servicing this equipment and any part showing signs of wear is replaced. They do not wait for complete failure of the parts.

A comprehensive daily maintenance program must be established for the life support systems proposed as it is essential to hold malfunctions of the system to a minimum. Bendix has demonstrated at Cape Kennedy that this reliability can only be accomplished by a continuing maintenance program on all components involved in the system. The following program is an example of the type of maintenance and safety testing that is recommended.

The major components of the proposed MLSS are the underwear, gas tight suit (including gloves and boots), helmet, rebreathing apparatus, communication system, the emergency breathing system and the outer garment.

The underwear and outer garment would be issued to the miner and would be maintained as he is currently doing with his existing work clothing. All other items would be maintained in the store room and issued daily to the miners as required. Each component would have an identification number and be checked in and out of the storeroom using this number. In this manner a comprehensive record of the usage of the equipment can be maintained.

Individual maintenance records would be kept on each piece of equipment. The information to be logged would include the day the equipment was used and who used it, the day it was serviced and who serviced it, what type of service was required (routine inspection or replacement of parts), any comments by the user as to the status of the equipment and a listing of all spare parts used to repair the equipment. The maintenance card would be used to establish preventative maintenance schedules and indicate when this maintenance had been performed. For those pieces of equipment requiring routine overhaul, the maintenance record would be set up to indicate when these overhauls were due. Included in this maintenance record would be a logging of the actual time spent in maintaining the various pieces of equipment.

The maintenance record would be sufficiently comprehensive that adequate information would be available to determine the various costs involved in setting up and maintaining life support systems for use in mining operations. The record would also serve to point out areas of weakness within the life support system where additional work is required to improve the reliability and the economics of the system.

The life support system or any part thereof being returned to the storeroom would be signed in by the storekeeper and any comments of the user noted on the checkin slip. These units would be set aside and completely checked prior to being put back in the rack for the succeeding day's use.

The following procedures should be used with each particular item of life support equipment:

1. The gas tight suit should be hung in a cabinet where hot water containing a detergent can be sprayed inside and outside of the suit. The suit should then be removed from a spray cabinet and hung into a drying cabinet where hot air can be blown through the cabinet to dry the suit. Once the suit has been washed and dryed, it should be removed from the drying cabinet and inspected for tears and abrasions. Should any wear points appear a patch can be put on this area to prevent a breakthrough. Any spots of grease or heavy soiling should be hand scrubbed. Once the suit has been cleaned and repaired, it should be put on the rack for the succeeding day's use.

2. The communications gear should be removed from the helmet and the helmet wiped out on the inside with a wet sponge containing a detergent. The outside of the helmet should be washed with a sponge and detergent and the unit dryed. The helmet should be inspected for scratches on the viser and other points of damage. The communications equipment should be cleaned and reassembled in the helmet at which time the helmet should be placed in the rack for the succeeding day's use.

3. The radio transceiver should be checked to see that it is performing properly and all foreign material removed from the unit. It should be tagged, dated, and placed on the battery charging rack where it can remain until it is checked out the following day. It is not suggested that major maintenance be performed at the mine on the communication systems. In case of a malfunction of a unit, a spare unit should be substituted and the malfunctioning unit sent back to the factory for repair.

4. When the portable oxygen module of the rebreather system is returned to the storeroom, it should be sent to the maintenance shop for disassembly and servicing. The oxygen cylinder should be recharged, and the CO_2 absorber replaced. The pressure reducing valve and the chemical regulator should be checked for proper functioning. The battery should be recharged. The unit should be reassembled and placed in the rack for the succeeding day's use.

5. The chiller module would probably be replaced in the mine by maintenance personnel at regular intervals, and brought out of the mine for cleaning and testing. Capacity, refrigerant and power consumption would be checked.

Estimated Cost - Miners Life Support System (MLSS)

In response to the preliminary specifications submitted to them, Arrowhead Products Division, Federal - Mogul Corporation, Los Alamitos, California; MSA Research Corporation, Evans City, Pennsylvania; and ILC Industries, Inc., Dover, Delaware submitted preliminary quotations on the cost of developing a prototype of the MLSS. Only one quoted on developing the total MLSS, the other two quoting only on specific pieces.

In analyzing the quotation, one supplier will develop one complete MLSS for $27,500 and supply six additional units for $5,600 each. Another supplier will develop the gas tight suit only and supply two test models for $30,600 and 2 additional suits for $13,050. These would have to be mated with a rebreather system furnished by others. The third supplier will develop and supply four emergency breathing systems for $750 each and four rebreathing systems for $16,000 each. These would have to be matched to the gas tight garment.

In reviewing these costs with the suppliers, they estimate the mass produced cost of the MLSS to be $1500 to $2000 each after the development of a satisfactory system. The $2,000 figure should be used in projecting estimated costs for a full scale mine operation and construction.

SECTION VI

COMMUNICATIONS

Communications in deep coal mines can be divided into two categories, local and mine to control station. The former, or local communication is direct, and either aural or visual, without benefit of equipment, depending on the intensity of the mine's ambient sound level. The introduction of miners in life support suits with the attendant reduction in physical perception introduces a condition for all miners at all times that is comparable to that in the worst ambient sound level conditions in a conventional mine. New methods of communication will thus be required for men operating in life support suits.

The estimated communication needs in the oxygen free mine can be broken down into three categories:

1. Determination of ambient mine noises (machinery and roof) by the miner.

2. Communication between the miners and between miners and the mine control center.

3. Emergency communication systems from the miners to outside the mine.

Ambient Mine Noises

The miner normally depends on his hearing to detect the sounds of roof movement and, by the aid of a test hammer or probe, the presence of loose rock in the roof. He also depends on hearing to detect operating conditions of his equipment. With the miner enclosed in a life support suit, provision must be made to satisfy these two basic communication requirements.

It would be desirable to include an electronic device to permit the active monitoring of ambient mine noises for the determination of equipment failures, roof noises, etc. Ideally, this device would have the following characteristics:

1. The ability to automatically suppress ambient sound levels to a consistent and comfortable level for continuous monitoring.

2. The electronic compression action employed should be based on the average and not peak values to permit discrimination of sound peak values.

3. The system should be stereo and not monaural to enable the personnel to determine sound direction.

Manual gain monaural electronic devices are available that would achieve part of the above objectives, however, the complexity of adapting them to the available communication headsets and the radio communication link to be discussed later rules them out at least at this time. In addition, the units available are not suitable in their available form for the rough usage encountered in the mine.

Direct sound transmission through a taut diaphragm is used for voice communication in commercially available face masks associated with respirators and other breathing apparatus. Such a diaphragm can be readily installed in the helmet over one ear if necessary so that both mining equipment and roof noises may be heard directly by the miner. While this device in no way mitigates the health problem of high sound levels, it at least is simple and likely to serve adequately until suitable electronic devices can be developed.

Interperson Communication

Several communication systems were studied for use in a mine. The first system employed sound transmission through electronic speaker phones on each miner; the second employed hardwire connection through cables; the third utilized radio transmission from each miner.

An electronic noise monitor contained in the suit to determine roof and equipment noise could also provide the basis of a voice communication system for application in low intensity sound areas. Such transmission could readily be effected through the addition of a standard amplifier speaker assembly to the miner's communication system microphone. For machine operators in areas of high intensity sound in which normal voice transmission is of limited value, this voice transmission system would likewise be unsatisfactory.

An electrical cord could be provided to tie the miner into a machine mounted carrier current communicator or into a direct wire linkage through the power cable to other such operators. This would provide direct voice contact of the machine operators for maximum communication efficiency. This hardwire communication could also be utilized for mine to surface communications. It requires, however, additional wiring, and presents problems for miners not associated with equipment with trailing power cables. Mine foreman and maintenance personnel would have to plug in to local receptacles along the mine walls in order to communicate. A combination speaker phone and hardwire system would solve the problem but at the price of considerable complexity. The required equipment can be adapted from existing industrial components, however, the complications of matching and of providing the multiplicity of cables rules out the two systems at this time.

A radio communication system should meet the following criteria:

1. Continuous communication between all in mine personnel and/or the surface station at discretion.

2. Multiple frequencies to minimize cross talk between adjacent operating crews.

3. Freedom of miner movement and ability to communicate in high ambient noise level areas.

4. No dead spots or areas of low signal strength.

5. Availability of equipment suitable for use in the mine and low initial and maintenance costs.

The currently available commercial radio equipment for individual use does not uniformly fulfill each of the above requirements. The available equipment has been primarily designed for surface use and, hence, has been subjected to tight restrictions in both available frequencies and signal purity to comply with FCC regulations. The high frequency operation (VHF) of the commercially available transceivers is not optimum for underground use. The result is high initial cost, line of sight transmission with associated dead spots, and high signal strength loss. In order to minimize these latter two conditions, the basic transceiver system has been modified for underground work through the inclusion of a support antenna system coupled to a surface re-transmission station - a so-called "leaky cable" system. This system is in satisfactory use in subways and is thus available off-the-shelf.

As the size or complexity of the antenna system at these high frequencies is in direct proportion to the desired area of radio coverage, the total coverage of a mine should not be attempted. The area of coverage should probably be restricted to the working faces and any active entries or crosscuts utilized for transportation of personnel or material. Even with the antenna system, the miner would have to be in line of sight with the transmission cable for him to be able to communicate. The cost of the individual battery powered (rechargeable) transceivers is approximately $1,200 each. The outside transmitter costs $1,400. The costs of the cable are approximately $500/1,000 ft. Thus, the costs of the system are appreciable, however, the availability and reliability are also important. The maintenance of equipment of this nature can be estimated to be between $5 and $12 per unit per month, when the preventative maintenance is performed by the manufacturer which would be the practice for most mines. An estimation of the maintenance costs for the more demanding use in a mine would be hard to determine because no data exists for this particular use.

As previously mentioned, the high frequency systems now available are not considered optimum for subterranean use. Thus, the design of specialized communications equipment for mines was also considered. A system based on the more practical low frequency ranges for better signal distribution and would be considerably less complex, and less expensive.

The general reaction of the manufacturers of electronic communications equipment to the development of specialized equipment of this type was uniformly negative because of the relatively low potential market. One of the major mine supply companies indicated that they had recently completed a survey of new equipment and techniques in mining in Europe. The general conclusion was that no new communication techniques or equipment had been developed or utilized that did not have an American counterpart. At the present time, a low frequency radio communications system for emergency use has been devised by Pittsburgh Consolidated Coal Company in conjunction with Continental Oil Company for their own use. Information pertinent to this system has been requested.

Emergency Communicators

Local emergency communications by a miner in case of radio failure could be accomplished through the use of small

Freon powered whistles or horns that could be easily carried by the individual person. These units have a relatively long signal range and would be inherently fool-proof in use. Signals could be heard through the sound diaphragm in the helmet. The diaphragm would also allow short range voice communication between individual miners.

The emergency mine to surface communication would be best provided by the use of conventional hardwire telephone facilities located in the proposed refuge station. The lines for this communication service together with emergency station power may be conveyed in mine in covered ditches or may be conveyed out of the mine through boreholes and back overland to the mine offices.

Communications Equipment Selection

The only communications system available on which there is adequate experience is the VHF radio communications system employing the "leaky cable." An example is the system offered by Motorola*. The diaphragm in the helmet for the determination of mine noises should be adopted as described. The development of an all electronic ambient noise detection system should be considered for the future, however.

The Freon powered emergency signal devices are available as boat horns, fire alarm signals, personal alarms, etc., at reasonable costs and should be considered for use by each miner.

The preliminary specifications for the complete communications system are for equipment as offered by Motorola, Inc., since theirs was the the only interested response. These specifications are as follows:

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

REMOTE CONTROL BASE STATION RADIO

Manufacturer:	Motorola Communications and Electronics, Inc.
Model Number:	C73MHB-1100_R with carrier squelch
Frequency:	136-174 MHZ
RF Output:	110 watts minimum
Plate Input:	200 watts maximum
Input Voltage:	117 vac at 50/60 Hz
Dimensions:	22" wide x 30 1/4" high x 8" deep
Weight:	108 lbs.

ANTENNA CABLE

Conductors:	Two No. 10 AWG, Solid Bare Soft Copper
Dielectric:	Shaped polyethylene extrusion approximately rectangular, with rounded corners having an air hole in the center
Outer Covering:	.035" nominal wall of gray, flame-retardant polyethylene
Overall Dimensions:	1.5" x .800" nominal with rounded corners
Weight:	.35 pounds per foot, nominal
Installation:	Cable shall be properly installed on hangers at least 8" from all metal objects which shall be spaced no less than 8' nor more than 10'

Electrical Characteristics:

Characteristic Impedance	- 300 Ohms nominal
Capacitance	- 4.1 pf. per foot nominal
Velocity of Propagation	- 82%
Attenuation	- .7 db/100 feet maximum at 160 MHZ (Factory Test) .9 db/100 feet maximum at 160 MHZ
Dielectric Strength	- This cable is designed to withstand a 5,000 volt RMS potential applied from conductors to a water bath surrounding the cable. Since the cable is extremely buoyant, this test is conducted on short sample pieces forcibly held submerged below water.

Flame Retardancy:	Exceeds U/L-83 Vertical Flame Test
Reel Lengths:	For substantial production quantities, lengths up to one mile can be produced with reasonable allowance for some lengths as short as 1,000 feet.

ANTENNA CABLE (Cont'd)

Manufacturer: The Plastic Wire and Cable Corporation
Jewitt City, Connecticut
Contact - K. Strauss, New York City Office
212/597-2250

Figure 4 is a diagram of the communications-antenna system.

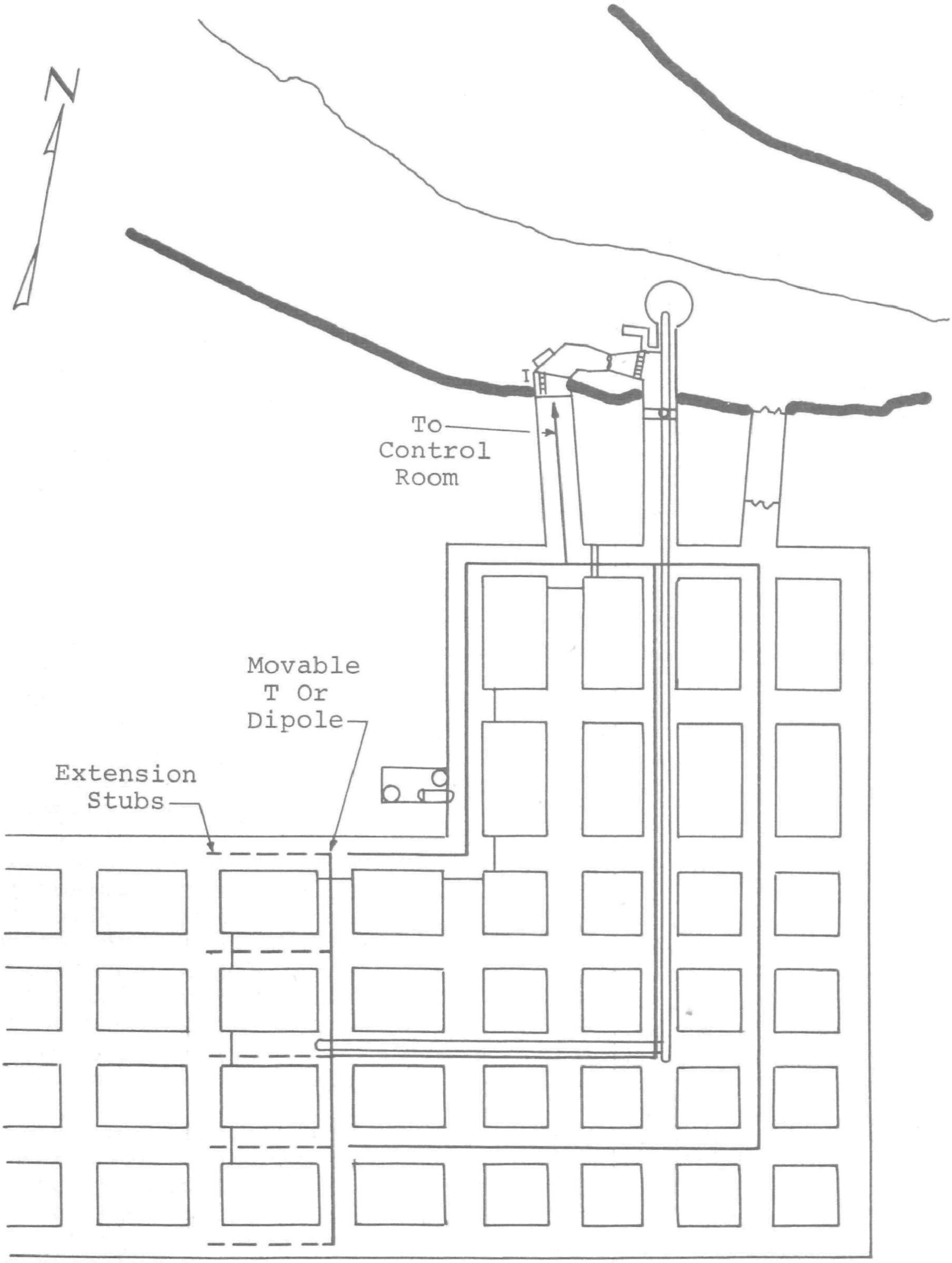


FIGURE 4
Proposed Communications Antenna System

SECTION VII

GAS BLANKETING SYSTEM

Laboratory studies involving the use of oxygen free atmospheres have indicated that the exclusion of oxygen in a mine should prevent the formation of acid mine water. Several different oxygen free atmospheres were tried with various degrees of success, nitrogen being the most successful (2). Nitrogen is the most plentiful of the gases and was chosen as the gas to be used. In the case of extremely gassy mines, the methane itself can be used as the oxygen free atmosphere. In either case, it is essential that oxygen be prevented from entering the mine to dilute the oxygen free blanket; 0.1% oxygen is the maximum allowable in order to prevent the generation of acid mine water.

Since all coal mines generate methane, some considerably more than others, it is essential that every effort be made to prevent the collection of a combustible mixture of oxygen and methane while operating the mine. In an oxygen free mine, gas locks which would permit personnel and equipment to enter and leave the mine and which would permit the continuous removal of coal must be designed so as to eliminate all possibilities of those mixtures developing. 5 to 15% methane in air is the explosive range. Below and above this, combustion takes place at a slower rate. The exclusion of all oxygen would eliminate the possibility of fires or explosions.

Three sources of nitrogen were investigated, cryogenic, compressed and natural gas fired combustion gas generators. The daily volume required (in excess of 500,000 cubic feet for the proposed test mine), the instantaneous peak requirement for personnel and equipment locking, and the high cost immediately ruled out the use of cryogenic or compressed nitrogen for small scale use such as in any test mine. However, on-site cryogenic generation of nitrogen may prove to be the most economical for a full scale operating mine.

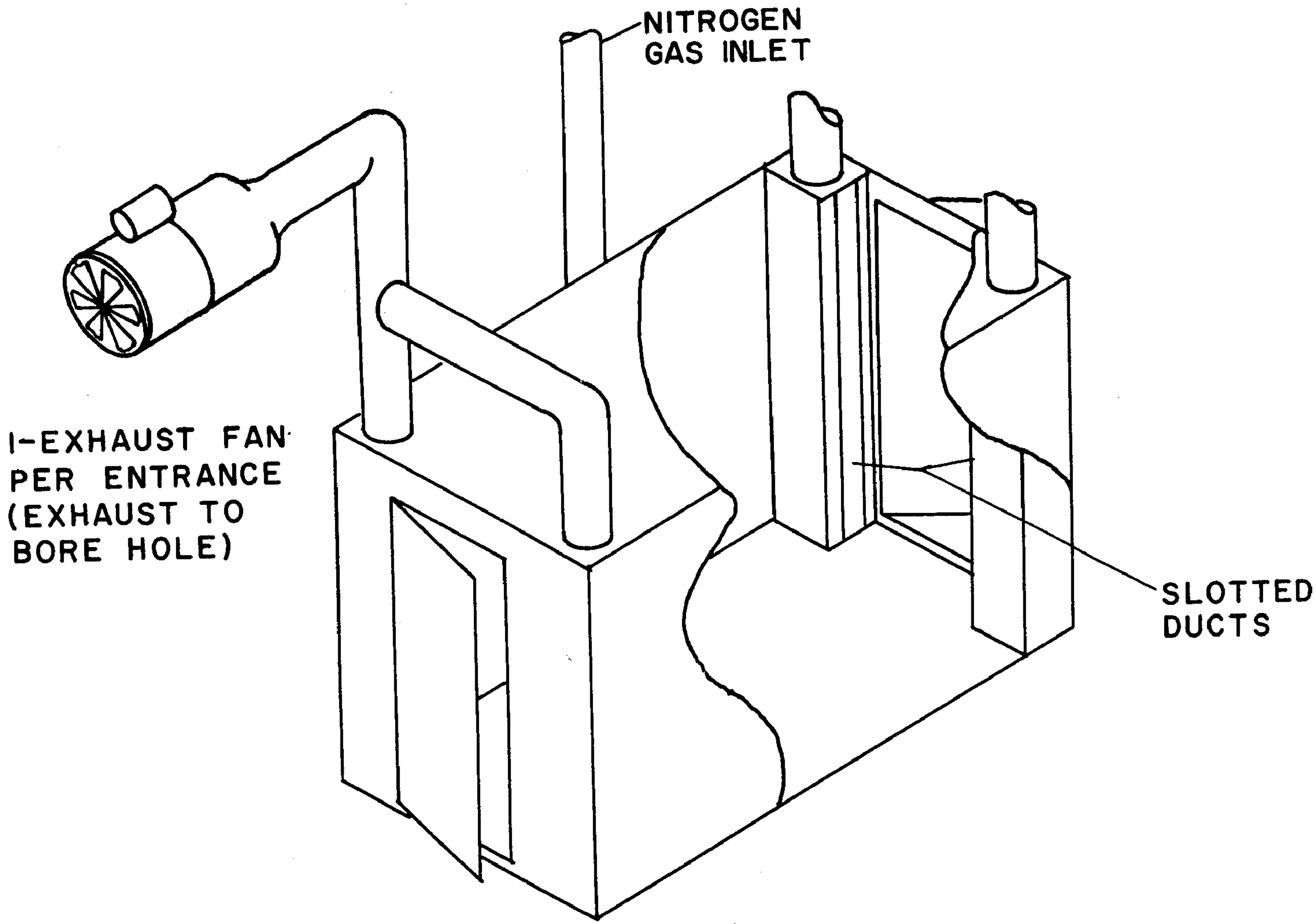
Natural gas fired inert gas generators are used extensively in the food, chemical and metal finishing industry to exclude oxygen from the product to prevent spoilage. Various compositions of gas can be obtained ranging from 99% nitrogen containing traces of carbon dioxide, carbon monoxide hydrogen and water, to 89% N_2, 11% CO_2 and traces of water with the price varying accordingly. The latter, being the most economical (approximately 10¢ per 1,000 cubic feet depending on natural gas price), is proposed for use in any test mine. Combustion exhaust gas has an advantage in that the carbon dioxide present can be used as a tracer to check for infiltration of the mine atmosphere into the proposed station, personnel, and equipment locks. Continuous monitoring of such areas for carbon dioxide would thus indicate the effectiveness of the locking system.

Blanketing Gas Requirements

After sealing a mine and completing the purging of the oxygen from the mine, additional blanketing gas will be required daily to replace gas lost during operation. Personnel and equipment locking into and out of the mine along with the removal of the coal from the mine require the major portion of this makeup gas. Additional gas is required to compensate for barometric pressure changes and uncontrolled leakage from the mine and to purge the small amount of O_2 leaking from the life support systems. The latter is estimated at 1600 cf per shift per man based upon 0.2 cfh leakage per man and a maximum of 0.1% O_2 in the mine atmosphere.

The personnel (Figure 5) and equipment (Figure 6) locks and the coal removal system (Figure 7) are proposed to consist of small rooms or a hopper between the mine and a refuge station or outside. The doorways into the rooms should be equipped with slotted plenums and exhaust fans which will generate an air curtain across the opening to prevent the mixing of mine or outside atmosphere with that in the gas lock. The fans should exhaust to the outside through bore holes and associated duct work. Blanketing gas under pressure can be piped directly to the gas locks to equalize the pressure within the lock and to provide an equal flow from the lock and the mine or outside into the slotted plenum. Using this principle, there should be no mixing of mine atmosphere or outside atmosphere with the atmosphere in the lock and the blanketing gas requirements should be held to a minimum.

It is proposed for illustrative purposes that the demonstration mine be operated one shift per day for 4 days per week. The fifth day would be devoted to reviewing the problem areas which may have developed, to making minor equipment changes and to reviewing safety procedures. Actual full scale operation in accord with general practice would be 5 days per week, two shifts per day.



PRELIMINARY REFUGE STATION
GAS LOCK DESIGN

FIGURE 5

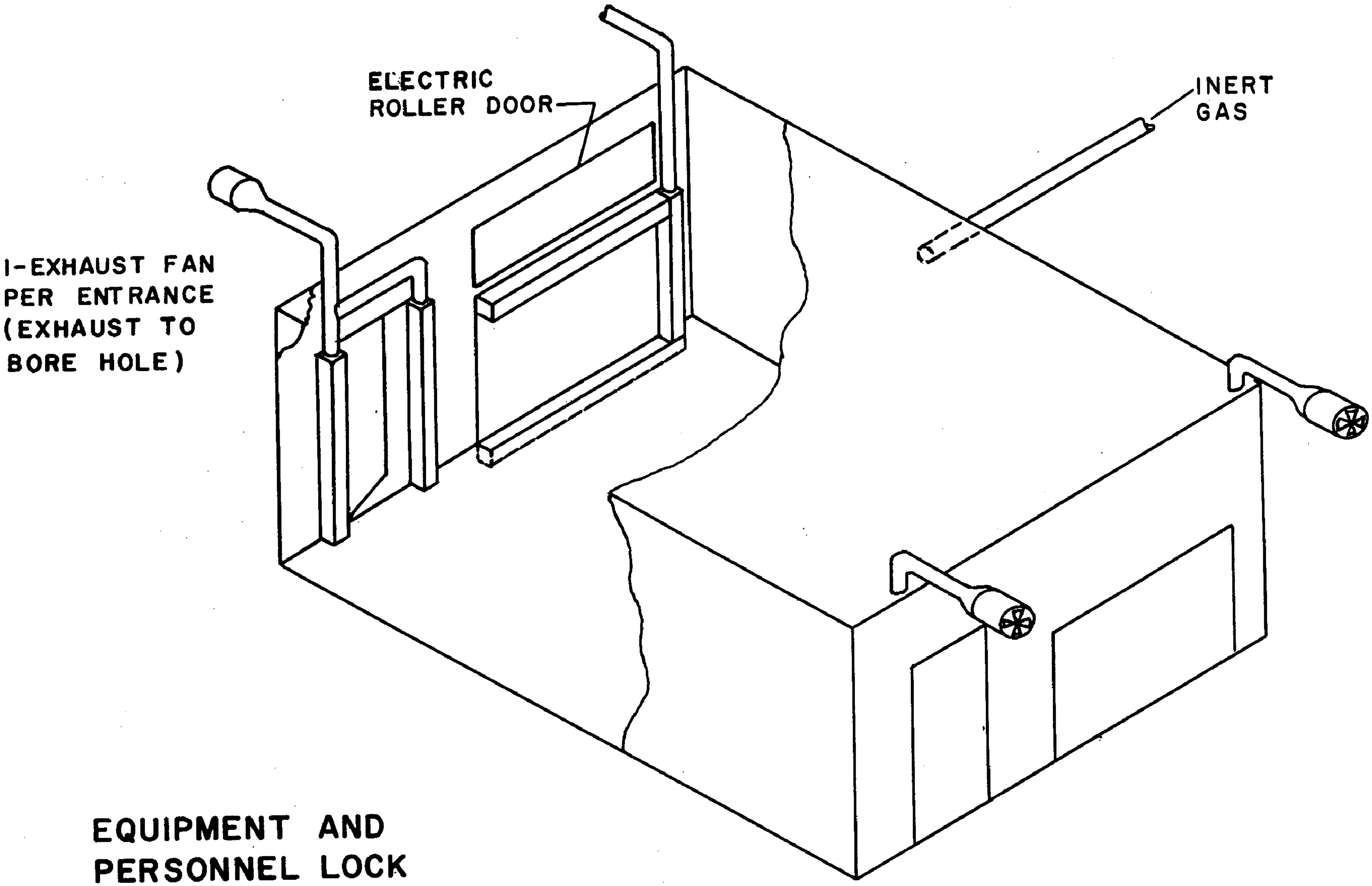

ELECTRIC
ROLLER DOOR
INERT
GAS
1-EXHAUST FAN
PER ENTRANCE
(EXHAUST TO
BORE HOLE)
EQUIPMENT AND
PERSONNEL LOCK

FIGURE 6

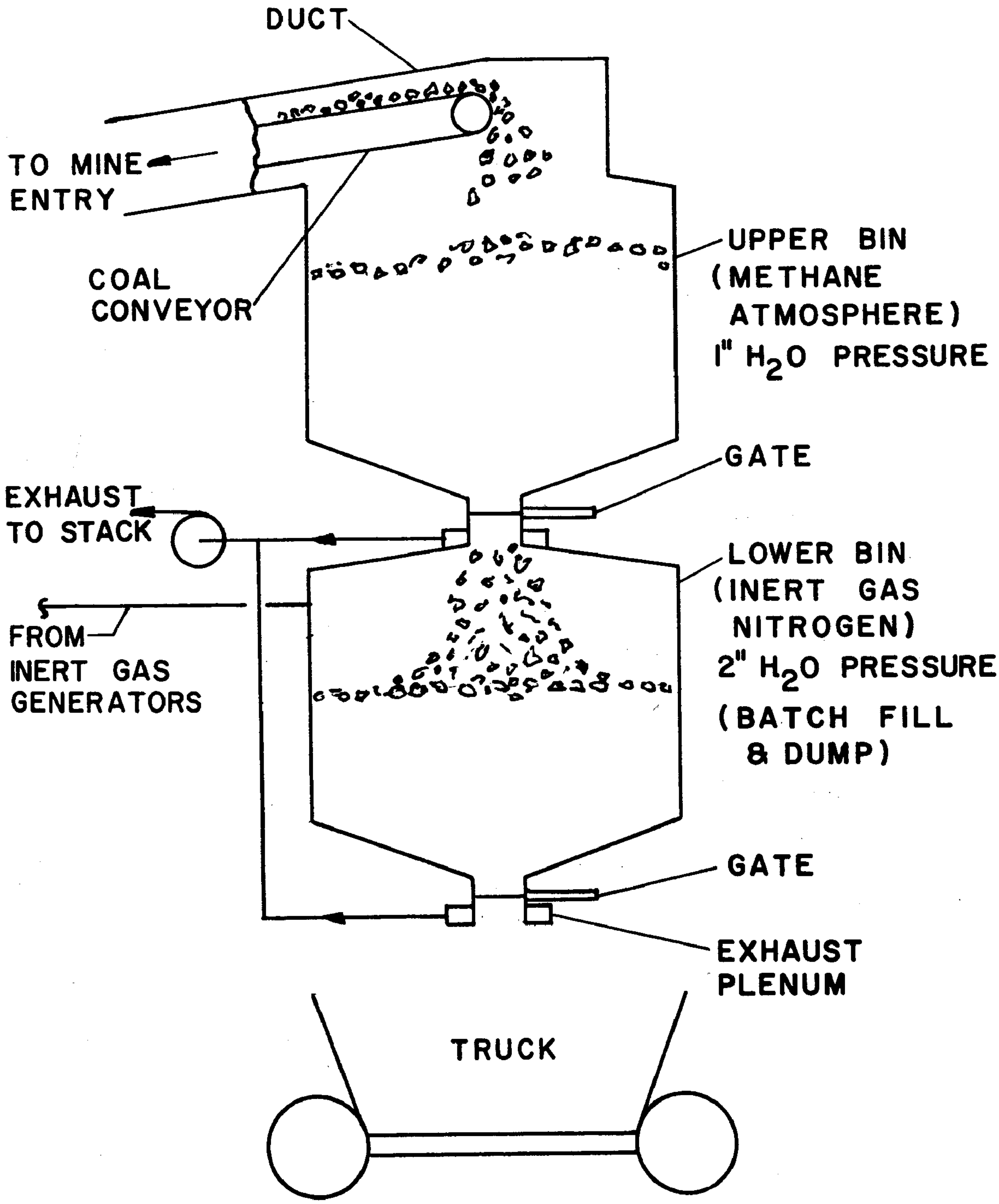


FIGURE 7
COAL HANDLING CONCEPT

The following calculation of blanketing gas requirements for a demonstration mine are based on the 4 shift per week schedule of operation and the gas leakage rate in the example is based on the volume of the demonstration mine anticipated at the end of 12 months of operation.

Personnel Locking

The section crew would enter and leave the mine once a shift in a man train passing through the equipment lock. Maintenance personnel, safety inspectors, engineers and visitors would enter through the mine entrance personnel lock. It is anticipated that every 2 hours, the miners would be relieved to go to the proposed refuge station for a rest break. Blanketing gas requirements were calculated on this basis.

It is estimated that the personnel locks in the single section demonstration mine would be used 100 times per 8 hour shift, each use requiring 1 minute per cycle. Using for the air curtain a 2,000 foot per minute entrance velocity into the slotted plenum, and a 1 inch slot 6 feet high on each side of the opening, each cycle would require 2,000 cubic feet of blanketing gas during the 1 minute cycle and a 2,000 cfm exhaust fan would be required. Additional gas would be required for longer cycles. The total gas requirements for personnel locking on the above basis for an 8 hour shift is therefore:

100 cycles X 2,000 cubic feet = 200,000 cubic feet of blanketing gas required for personnel locking per shift.

Equipment Locking

The man train taking the section into and out of the mine would require 2 cycles of the equipment lock. It is estimated that one supply train would also be required to service the proposed single the working section. It would also require 2 cycles of the equipment lock. One additional lock requiring 2 lock cycles is anticipated for the boss cars and maintenance items.

Trips	Purpose	Lock Cycles
1	Man Train	2
1	Supply Train	2
1	Boss car, Maintenance, etc.	2
3		6

It is estimated then that the equipment lock will be used 6 times per 8 hour shift. Each cycle is estimated to require 1/2 minute to open the overhead roller door, 1 minute to enter or leave the lock and 1/2 minute to close the door or a total of 4 minutes to enter and leave the lock. A horizontal plenum 10 feet long with a 1 inch slot using an entrance velocity of 2,000 feet per minute for the air curtain would require 4,000 cfm of blanketing gas during the cyle and a 4,000 cfm exhaust fan would be required. The blanketing gas requirements for equipment locking in the demonstration mine example is thus as follows:

4 minutes X 4,000 cfm X 6 cycles = 96,000 cubic feet of gas required for equipment locking per shift.

Coal Removal

A daily volume of blanketing gas would be required to replace the volume of coal removed from the mine. An additional volume of gas would be required to replace the gas lost in the voids (40%) of the coal when removed from the mine. Additional gas would be required to purge the coal hopper of either methane or oxygen prior to or after discharging coal.

It is estimated that 450 tons per day of coal would be removed in an 8 hour shift in the demonstration example. This coal as it leaves the mine has a density of 85 pounds per cubic foot (60% coal 40% voids). The volume of gas required to replace the coal removed is therefore:

$$\frac{\text{450 tons X 2,000 pounds}}{\text{85 pounds per cubic feet}} = \text{10,600 cubic feet per 8 hour shift}$$

It is proposed that the coal could be removed from the mine through a double hopper system, Figure 7. The coal would discharge through a 3 foot square opening with a slotted plenum on two sides.

Air would be drawn through a 1 inch slot in the plenum at the rate of 2,000 feet per minute and discharged to the atmosphere. A 1,000 cfm exhaust fan would be required. As the coal is loaded into the bottom hopper (coal gas lock), the upper plenum would exhaust to atmosphere while blanketing gas would enter the lower hopper. When the lower hopper is discharged to the truck, the lower plenum would be exhausted while blanketing gas would enter the lower hopper. Using this arrangement, no oxygen should enter the batch hopper.

The lower hopper would hold 15 tons of coal which in this example is estimated to be the capacity of the trucks used for hauling the coal. During maximum capacity operation, 450 tons ÷ 15 tons per truck equals 30 truck loads of coal per shift. It is estimated it would take 3 minutes to load first the batch hopper and then the truck. On this basis, it will require

30 trucks X 3 minutes X 1,000 cfm or 90,000 cubic feet of blanketing gas per shift to remove the coal from the mine.

Barometric Change - Leakage

A barometric change of 1 inch of mercury in 24 hours on a mine volume of 1,000,000 cubic feet (similar to that in the proposed demonstration mine at the end of 12 months) causes a volume change of 34,000 cubic feet. In order to maintain a constant differential pressure, this volume would have to be injected or removed into the mine depending on whether there is a rise or fall in the barometric pressure. A typical maximum rate of barometric pressure change is 0.2 inches of mercury per 3 hours. Under these conditions, 6,800 cubic feet per hour for 3 hours would be required to maintain constant differential pressure in the mine in question.

It is estimated that uncontrolled gas leakage from a mine could be as much as 10% of the total mine volume per day (1,000,000 cubic feet). This would include that lost to barometric pressure changes. This amounts to 100,000 cubic feet per day of which 34,000 cubic feet would be attributable to volume change resulting from barometric pressure change. This leakage estimate is based on the abandoned mine pressurization studies previously referred to (3).

Total Blanketing Gas Requirements

Using the proposed demonstration mine as an example, the total blanketing gas requirements based on a 1,000,000 cubic feet mine volume and a one shift per day operation may be calculated as follows:

Use	Volume Required Cubic Feet Per Shift	Cubic Feet Per Day
Personnel Locking	200,000	200,000
Equipment Locking	96,000	66,000
Coal Replacement	10,600	10,600
Coal Removal	90,000	90,000
Barometric Pressure Change		34,000
Leakage		66,000
Total	396,000	496,000

The blanketing gas generators would therefore be designed to supply 400,000 cubic feet per shift of blanketing gas.

Blanketing Gas System

The major portion of the blanketing gas must be suppled on a demand basis in large volumes in a short period of time to operate the various gas locks. Gas generators sized to meet the total shift requirement do not have the ability to meet this instantaneous demand. It is therefore essential that a means of storing and delivering the blanketing gas be incorporated into the system.

Gas Holder

A gas holder could perform the several functions desired. It could be used to maintain a constant positive pressure in the mine to prevent oxygen leakage into the mine. It would thus act as the lung of the mine allowing expansion and contraction during barometric pressure changes. It could serve as an accumulating tank to supply large volumes of gas on demand and as a reservoir to supply gas during outages and startups of the gas generators.

The gas holder should be able to supply the gas requirements for the two nonoperating shifts and to replace the gas lost due to leakage and barometric change. 100,000 cubic feet per day is the estimated requirements for these items in the stated example of which 66,600 cubic feet would be required during the second and third shifts. A 100,000 cubic foot gas holder would be satisfactory to meet these needs.

Such a gas holder would be 74 feet in diameter and 26 feet high and is proposed to maintain a 2 inch water pressure on the gas. It would contain water seals and the necessary heating to prevent freezing. Preliminary figures supplied by a manufacturer indicates an erected cost of $425,000 and a 10 month delivery date.

Blanketing Gas Generators

As noted in the previous table the gas demand per operating shift far exceeds the demand for the nonoperating shift and thus determines the size of the blanket gas generators. In the example case two units rated at 25,000 cfh each should be able to supply the 400,000 cubic feet of gas per 8 hour shift.

Preliminary quotations indicate these generators could cost $16,000 each. They are normally skid mounted and a minimum of installation expense would be required. An installed cost of $20,000 could be used, thus three generators, two on stream and one standby would cost $60,000.

Each gas generator of the foregoing size requires 300 gpm of cooling water at 80°F or 200 gpm at 60°F. Well water at 60°F would be the most desirable water source and it would require a 600 gpm well. If sufficient well water is not available, a cooling tower would be required with 10-15 gpm of well water for makeup. Preliminary estimates for a 1,000 gpm cooling tower are $30,000 installed including all foundations, basins, pumps, tower, and electrical system.

Figure 8 is a skematic diagram of the gas blanketing system proposed as an example for the demonstration mine, and Figure 9 shows the general layout of the gas distribution system in the mine. The following is a summary of the capital costs associated with the blanketing gas system as sized for the demonstration case:

Item	Cost
100,000 cubic foot gas holder	$425,000
3 - 25,000 SCFH gas generators	60,000
1 - 1,000 gpm cooling tower	30,000
Distribution system in mine	25,000
Total	$540,000

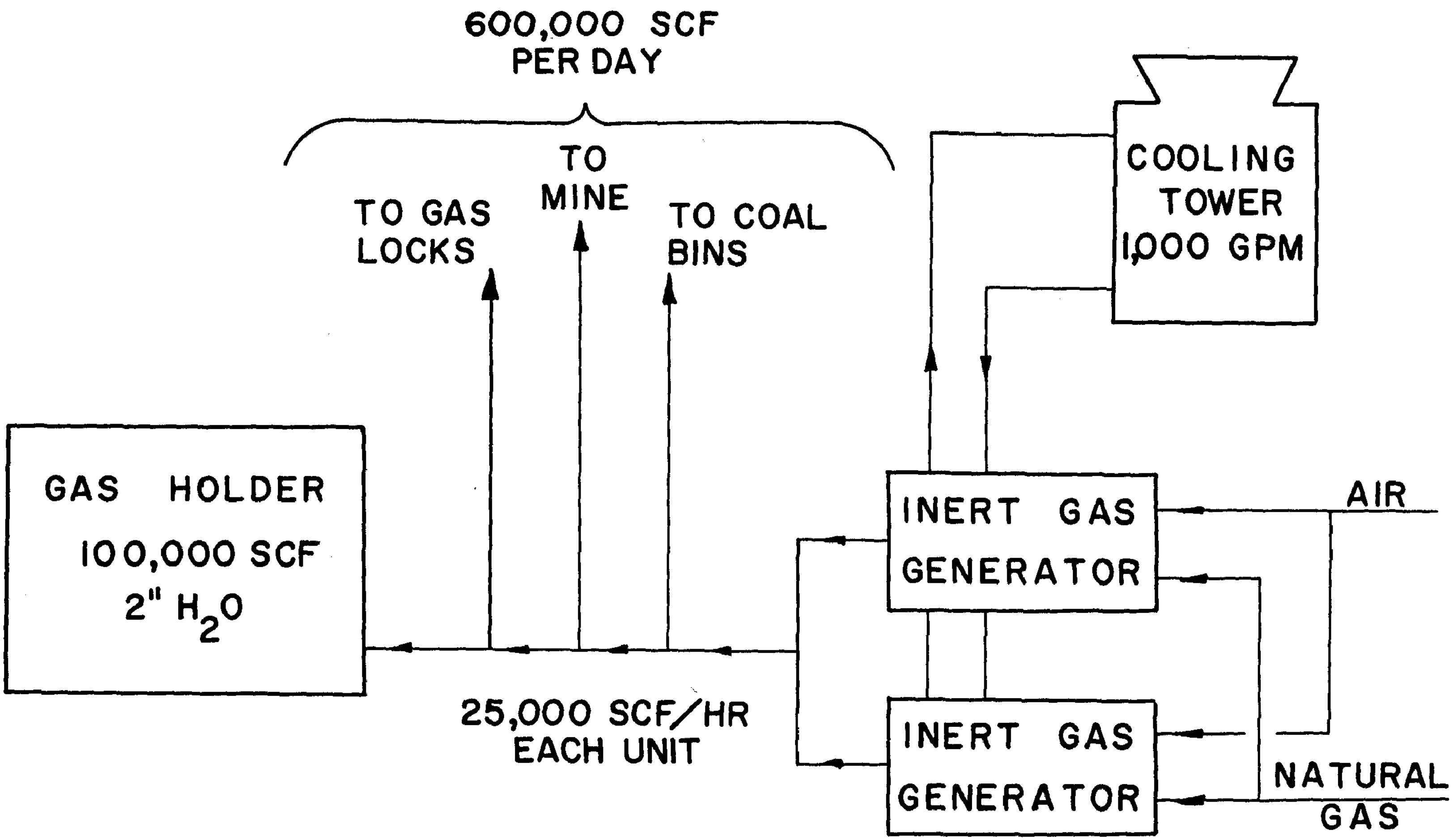


FIGURE 8

INERT GAS SYSTEM DEMONSTRATION MINE

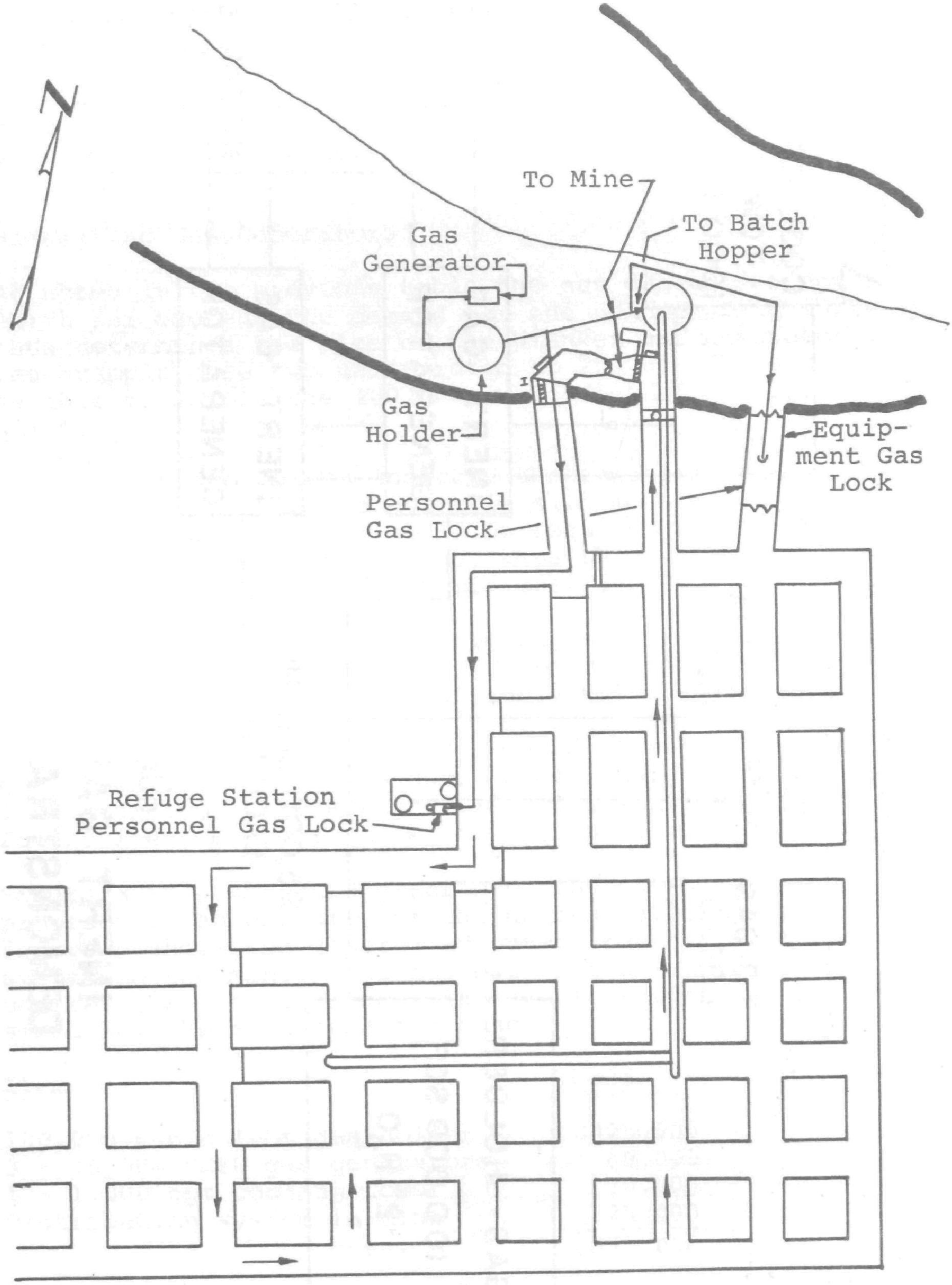


FIGURE 9

Blanketing Gas Distribution System
Demonstration Mine

SECTION VIII

DUST AND HEAT CONTROL

The electrical power required to operate the several pieces of equipment used in mining coal results ultimately in the generation of heat in the working face area. In normal air ventilated mining operation, the heat from the electrical drive motors is released to the air being circulated past the equipment. In some instances, the heat generated by the conveyor motor drives is transferred to the coal by coolers in contact with the conveyor belt.

The amount of air circulated past the working face is determined in an air ventilated mine by the need to dilute and sweep away methane gas released by the newly mined coal, rather than by the need to remove heat from the mechanical and electrical equipment. Such air movement also serves to remove dust generated by the coal handling from the working face. The flow of air for these purposes can vary from 2,000 to 20,000 cfm per section depending on the gaseousness of the coal seam, the type of mining equipment being employed and the dust control measures in effect. In the latter instance, water sprays containing wetting agents are used particularly on the cutting machine to reduce the amount of dust generated. Present regulations in the Health and Safety Act of 1969 require a minimum of 9,000 cfm at the working face.

Since removal of heat in an air ventilated mine has not been a consideration in setting up air requirements, measurements of the amount of heat generated, the amount absorbed by the fresh coal, the amount dissipated to the other parts of the mine, and the amount finally exhausted to the outside air were not able to be found. Removal of heat, however, in the oxygen free atmosphere, whether nitrogen or methane, becomes the determining factor in designing any gas movement within the mine.

The amount of heat generated can be estimated from the installed horsepower of the electrical motors on each piece of equipment in use at the working face, plus an estimate of the fraction of the installed continuous duty capacity that is actually used. The Table 1 shows as an example how the heat load estimate was derived for the single section in the proposed demonstration mine. Such a calculation would be approximately correct for a single section in any conventionally equipped deep coal mine.

TABLE 1

OPERATIONAL HEAT LOAD

Source	Motors Installed	Installed Max BTU/hr.	Usage Factor	Continuous Load BTU/hr.
Cutting Machine	1 - 250 HP	636,250	0.3	191,000
Loading Machine	1 - 160 HP	407,200	0.3	122,000
Shuttle Cars	2 - 95 HP	483,550	0.4	194,000
Roof Bolter	1 - 30 HP	76,350	0.4	30,000
Coal Drill	1 - 30 HP	76,350	0.4	30,000
Feeder Breaker	2 - 75 HP	381,750	0.375*	143,000
Conveyor Belt	1 - 100 HP	254,500	0.1	25,000
Boss Cars	3 - 2 HP	15,270	0.1	2,000
Tractor	2 - 20 HP	101,800	0.1	10,000
Personnel		14,000		14,000
		2,447,020		761,000

*Factor of 0.5 for 75 HP conveyor motor and 0.25 for 75 HP breaker motor.

The 761,000 BTU/hr. continuous heat load is associated with a section activity that would produce 500 tons per shift of raw coal. If the efficiencies operating in the inert gas are lower, it would be expected that the equipment usage factor would likewise be lower and thus the continuous heat load less than the 761,000 BTU/hr. shown in the table.

In considering the heat problem, it must be kept in mind that the mine atmosphere in a sealed mine will become saturated with water vapor at whatever temperature is allowed. Since the miner's suits are proposed to operate at a maximum of 74°F., condensation on the face plate and on the suit will result if the mine temperature exceeds 74°F. It is necessary, therefore, that temperature at the face not exceed this value.

Two alternative methods can be considered for removal of the foregoing heat load:

1. Rejection to mine atmosphere circulated past the working equipment

2. Liquid cooling of the motor drives by chilled coolant supplied to the equipment from outside the mine

Method 1 above has two sub-alternatives; local recirculation by fan through a local chiller unit, and general recirculation by a fan external to the mine through an external chiller unit.

Liquid cooling, while possible, has several very serious disadvantages:

1. Special liquid cooled motors would be required

2. Trailing coolant hoses would add to the difficulties already encountered by trailing electrical cables and trailing water spray hoses

3. Pipelines for supply and return would have to be laid to the working area from outside the mine

Liquid cooling was rejected on the basis of the foregoing considerations.

Local recirculation of the mine atmosphere by a local blower taking suction from portable ducting or from passages created in crosscuts by temporary stoppings still requires that the coolant be piped to and from the chiller coil associated with the blower. Also, the blower and coil and associated piping would have to be moved as mining progresses.

General recirculation of the mine atmosphere on the other hand, allows use of the original air ventilating fan with only a change in duct work to permit return of the fan discharge to the mine. It also allows the chiller unit to be located outside the mine with minimum piping all of which would be permanent. General recirculation would require, however, that passageway for the gas be maintained by stoppings from the entry back to the working face.

On the basis of the above considerations, local recirculation of gas was rejected in favor of general recirculation utilizing the ventilation fan installed external to the mine for the initial air ventilated portion of the operation of a mine planned for a subsequent oxygen free atmosphere.

When looking at the problem of heat transfer to the mine walls, it is necessary to look at the relationship $\frac{Q}{A} = \frac{K}{L} \times \Delta T$. It is obvious under a steady application of heat, that as L increases, that is, the surrounding strata is heated up and the linear path for conduction increases, the heat flux will decrease. The mine walls become in effect an infinitely thick insulation albeit a poor one. This situation is entirely analogous to pipelines buried in soil. After a period of time, the rejection of heat to the mine walls becomes negligible as can be seen when L becomes infinitely large. Heat flux versus time is thus a straight line log log plot.

In an air ventilated coal mine, the mine walls appear to serve as an accumulator taking heat from the outside ventilating air in the summer and rejecting heat to the incoming air during winter. How much of the heat generated by the mining equipment eventually finds its way to the outside atmosphere is not known. On the basis of the above general considerations, it was decided to disregard any rejection of heat load to the mine walls since any error in this decision results in the need to transfer less heat by outside refrigeration.

In calculating the amount of heat rejection to the outside atmosphere that will be required when all of the mine atmosphere is recirculated, consideration can be given to the heat taken up by the raw coal as it is mined and conveyed through the mine to the outside. On the basis of 500 tons per shift at normal efficiency, and assuming a maximum mine temperature of 74°F. for the return gas, it appears reasonable to assume that the coal mined will be raised from 55°F. to 65°F. by the time it discharges to the hopper outside of the mine. The amount of heat so absorbed would be 375,000 BTU/hr. The heat remaining that must be rejected by mechanical refrigeration of the recirculating gas is thus approximately 400,000 BTU/hr.

The amount of mine gas to be recirculated to provide the required cooling at the working face must still be based on the amount of heat to be removed at the face less that going directly into the coal as a result of energy conversion. If one-third of the cutting machine energy is assumed to go into raising the coal temperature, then 696,000 BTU/hr. remain to be removed by the gas. If it is assumed that the gas arrives at the face at 55°F. at 100% relative humidity and is heated to a maximum of 74°F. at 100% relative humidity (moisture from coal sprays plus that from roof, floor, and walls), then a maximum of 12,000 cfm will be required for one section in a conventionally equipped mine.

It is believed that substantially more heat than the 64,000 BTU's assumed above will go directly into the coal as a result of the mechanical work performed on it, and thus the 12,000 cfm circulating gas should be more than adequate to provide the required cooling at the maximum expected capacity of the equipment without exceeding the 74°F. maximum gas temperature permitted.

Figure 11 shows in diagrammatic fashion the scheme developed as an example for the proposed demonstration mine on the basis of the foregoing discussion. The mine atmosphere would be conveyed in ducts external to the mine through the ventilating fan (12,000 cfm) through the chiller coils, and back to one of the entries to return to the working face. Dampers in this duct system would permit changeover from recirculating mine gas under a sealed system to exhausting the mine atmosphere to the outside air while drawing in fresh outside air through the passageway direct to the working face. Such an arrangement would allow the atmosphere in the mine to be changed rapidly in the event of an emergency that required returning the mine to an air ventilated status.

The chiller coil located in the duct work external to the mine would be supplied with chilled water from a Freon-water heat exchanger. The coil would also have a provision for recycled spray water to supplement the 1 gpm of condensation as an aid in flushing dust from the condensing surfaces. A total of 50 tons of mechanical refrigeration would provide approximately 50% excess capacity over the expected load per section. This excess capacity should be more than adequate to compensate for any reduced heat pickup by the mined coal from that estimated above. The mechanical refrigeration would reject heat to the atmosphere using a Freon to air condenser, the latter arrangement being much preferred and much less costly to install at this size unit than a water cooled condenser with a cooling tower. The expected installed cost of the unit is $50,000 to include the coils and sprays, as well as the pumps, refrigeration unit, and switchgear. Power consumption is estimated at 50 KW total at maximum load which at $0.01/KWHR is $4 per day based on single shift operation for the single section.

The general recirculation of gas also solves or at least does not worsen the dust problem at the working face. The 12,000 cfm provided at the face should move dust from the equipment operation equally as well as it does in a conventional air ventilated mine using water sprays on cutters, face drills and loading machines. The heavier dust fractions will settle out in the passageways followed by the return gas to the outside of the mine. The lighter dust fractions may or may not remain to reach the chiller coil. No data could be found on dust loads of mine ventilating fan exhaust. Such information may be obtained in the future on new mines with relatively short air passageways similar to the condition existing in the proposed demonstration mine.

Dust that reaches the chiller coil will be removed to some degree by the wet surfaces and condensation taking place. The spray water can provide one more step of scrubbing if required. It is possible that data would show the need for further scrubbing and, if so, such equipment can be added at a later date.

It is concluded that the system proposed will be adequate for dust control without special dust removal equipment and that such can be added readily at a later date if required.

SECTION IX

IN MINE SYSTEMS

Development of a new drift mine for operation in an oxygen free atmosphere should start as any ordinary mine with normal air ventilation. It is proposed that the construction of a demonstration mine proceed in the same fashion. Entries typically should be driven on 60 feet centers and crosscuts on 80 feet centers. The mine most probably would be developed to the third set of crosscuts in normal atmosphere and the first waystation or refuge station driven into the right rib of the right heading to intercept two 10 inch boreholes, Figure 10, drilled from the surface, Figure 11. The sequence of mining would typically be as follows: the roofbolter would go into the right side entry and secure the top by drilling holes on a 5 feet square pattern and installing steel roof bolts. This unit would move to the left or next entry and be followed by the cutting machine, which in turn would be followed by the coal drill to drill and shoot or break the coal loose for the loader to move in and clean up the material.

Waystation or Refuge Station

The refuge station suitable for single section use should be developed under 20 feet wide and approximately 40 feet into solid coal as in Figure 11. This area should be graded to provide about 7 feet of height in order that the miners could stand upright at all times. This area should be sealed off from the remainder of the mine by concrete blocks plastered with cement and bituminous based materials to insure its being gas tight. Entrance to the refuge must be through a gas lock. The refuge station should maintain a normal atmosphere at normal pressure by ventilating through the previously mentioned two 10 inch boreholes from the surface as in Figure 10. All necessary materials and supplies must be available in the refuge station to insure survival for an extended period of time (days). Sanitary toilet facilities must also be available along with appropriate safety and rescue equipment. Emergency suit repair equipment as well as spare miners' life support systems and communications equipment must also be maintained in the refuge.

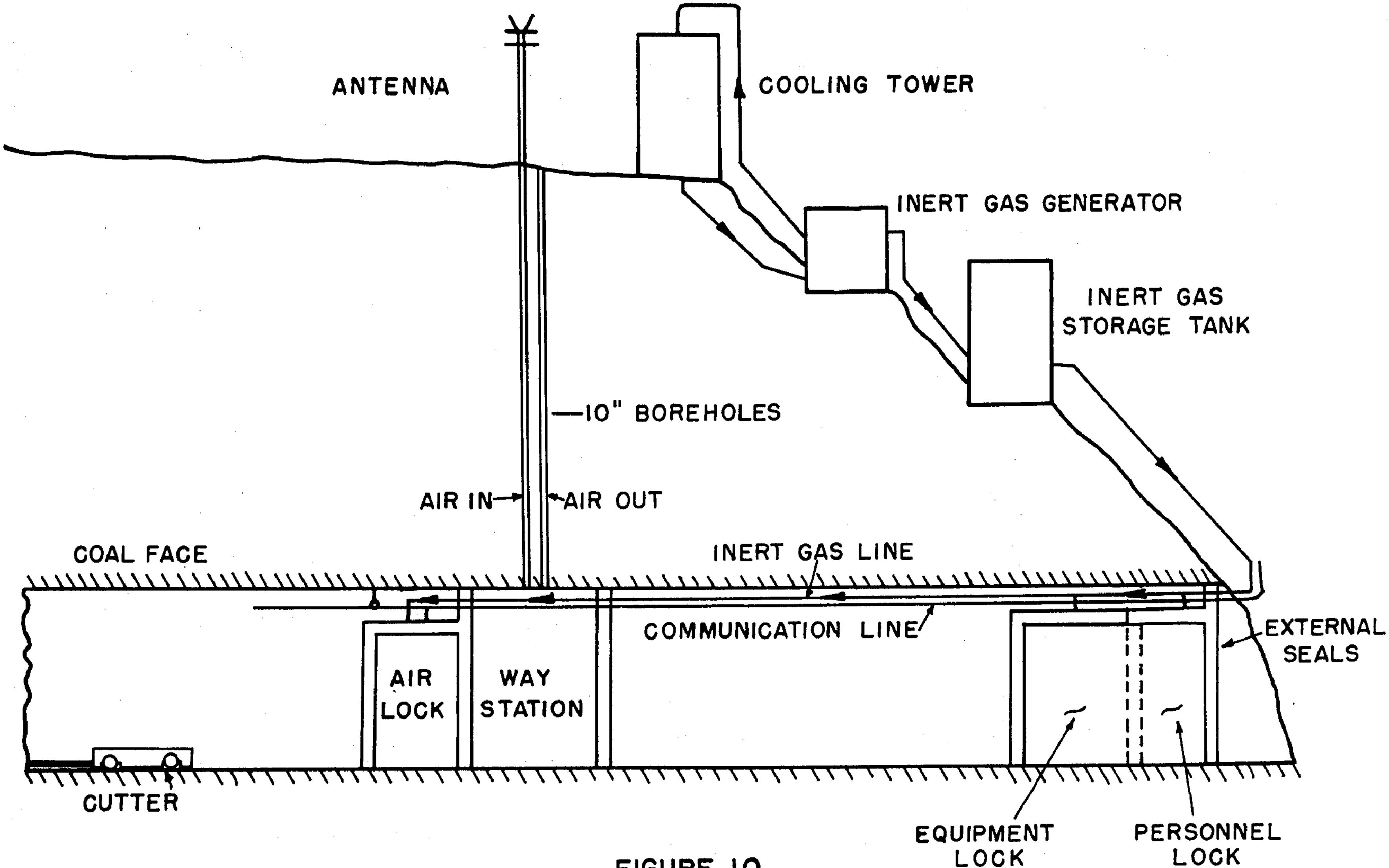


FIGURE 10

SECTION OF MINE AND COVER

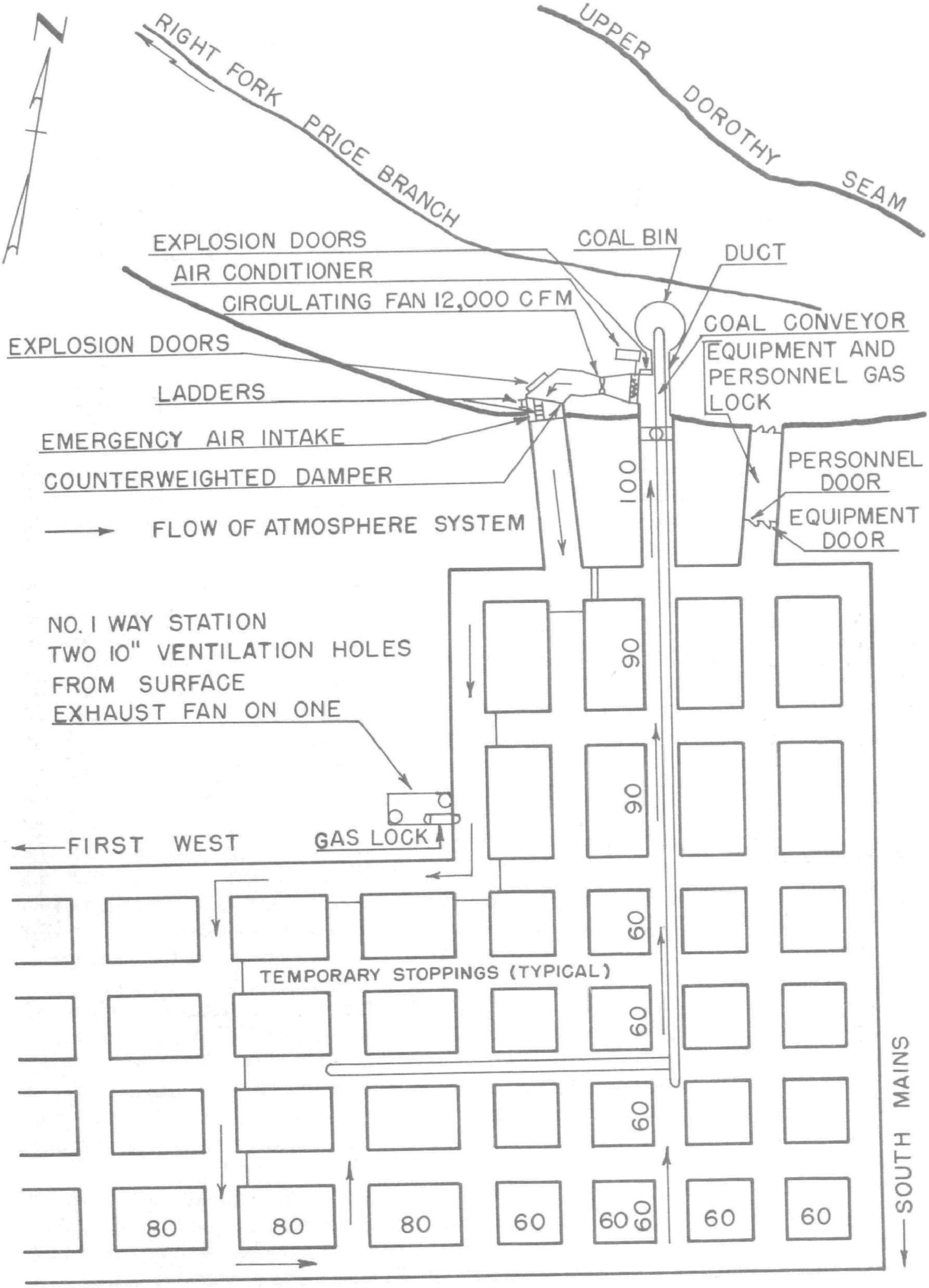


FIGURE 11

PLAN OF DEVLOPMENT AND ATMOSPHERE CONTROL SYSTEM

Gas Locks

Gas locks provided for personnel entry into the refuge stations and for personnel and equipment entry and egress from the sealed mine proper should be constructed with two doors interlocked so that only one door will open at any time. One of the entries to the mine must be equipped with a large gas lock designed to allow the largest piece of mining equipment to be moved through the lock for egress from the mine for major maintenance. It must also be equipped with a smaller personnel gas lock to allow miners to enter and leave the mine, as illustrated in Figure 10.

Ventilating System

A second entry should contain the ventilation fan, as shown in Figure 11, which should be ducted back to the conveyor entry for recirculation of the oxygen free atmosphere during operation under such oxygen free conditions. Circulation can be at a much reduced rate, probably closer to 12,000 cubic feet per minute for the five face section, however compared to 50,000 CFM for air ventilation. Cooling coils must be used in the ventilation duct outside the mine as previously discussed in order to remove the heat from the circulating gas, such heat being picked up from the operation of the mining equipment. The inert atmosphere for the proposed demonstration mine as described earlier is the exhaust from the combustion of natural gas.

Materials Removal

A third entry should have the conveyor belt installed in it. The belt as it emerges from the mine should be contained in a duct extending from the entry to the top of an external coal bin. This coal bin, as discussed in the section on Gas Blanketing, should be a two section bin with a gate valve between each and at the exit from the lower bin. Coal should discharge into the upper bin under the atmosphere of the mine, which atmosphere should be maintained within the duct and in the top of the bin. Inert gas should be supplied to the lower bin to purge it during such time as coal is transferred from the upper bin to the lower bin. Inert gas should also be supplied to the lower bin when coal is being discharged from it into the truck for transport to the preparation plant. It is possible to use tracked coal cars within the mine to carry coal from the working sections to a loading point for the conveyor. In a single section mine such as the proposed demonstration mine, this would be impractical. The conveyor belt thus should extend along one entry to the crosscut adjacent to the working faces where a feeder breaker would be installed.

Mine Lights

The problem of lighting within an oxygen free mine was simplified when a design for the miner's helmet was selected which permitted the miner to swivel his helmet with the turning of his head. Such an arrangement allows the present mine lamp to be used and attached as at present, as described in the section on Miners' Life Support Systems. The sealed beam lights currently used on permissive mining equipment are satisfactory and should continue to be used.

Mining Equipment

Conventional rubber tired mining equipment should be used in the proposed demonstration mine, though the process should be applicable to continuous as well as long wall mining. The equipment should have the necessary electrical connections and supports to carry the Miner's Rebreather Systems. All equipment for use in the proposed demonstration mine should be powered by 440 volts A.C. with the exception of the shuttle cars and supply and personnel carriers. The recommended 250 volt D.C. supply for the shuttle cars should be provided by a 112 1/2 KW rectifier. The supply tractor, boss cars, and personnel carriers should be powered by conventional 96 volt batteries. An oil circuit breaker should be installed to insure safe conditions on the section. All power should be cut off if the breaker is tripped.

In the proposed demonstration mine, the loader and feeder breaker should be mounted on caterpillar-type conveyances and all other mining equipment mounted on rubber tires.

A complete list of all inside mining equipment for the single section in the proposed demonstration mine is as follows: cutter, loader, two shuttle cars, roof drill, coal drill, feeder breaker, conveyor belt, complete set of electrical components for supply of the face equipment, three boss cars, two personnel carriers, and a supply tractor and supply car.

While the mining equipment recommended for the proposed demonstration mine would be approved permissive type, the electrical systems on equipment for future full scale mines operating in a methane atmosphere must be specially designed for the purpose. Provision must be made in such instances to either pressurize with nitrogen gas a sealed electrical system or to provide an enclosed but unsealed system able to be quickly purged completely using nitrogen gas every time the equipment passes through a gas lock.

SECTION X

PERSONNEL PROGRAM

If new or existing mines in the bituminous coal industry are to utilize the oxygen free atmosphere process to any significant extent, it is necessary that at least initially men presently trained as miners be the pool from which men would be chosen for training for operation in such mines. Discussion with National Aeronautics and Space Administration was held on their experience with skilled labor at Cape Kennedy. Island Creek's experience with miner training was considered. It is concluded that present job specifications should be employed for each of the men involved, supplemented with thorough physical examinations and only sufficient psychological testing to determine that the individual would be able to operate in a life support suit.

Conventional deep mines as well as the proposed demonstration mine employ loading machine operators, cutting machine operators, shuttle car operators, roof bolting machine operators, coal drill operators and shot men, maintenance mechanics, general servicemen, section foremen, and mining engineers. While many conventional mines are operated two shifts per day, it is recommended that the proposed demonstration mine be operated only during the daylight shift, for one shift each day. In this latter instance, four shifts per week should be worked with one shift per week being used for critique and training.

The following detailed job descriptions which are typical for the foregoing personnel and should be used for the proposed demonstration mine personnel as well. Each of the following job descriptions include as required, the function, responsibility, activities, relationship to other personnel, and authority:

Loading Machine Operator

Function

As a member of the mine production force, he receives his work assignments from the section foreman. In a safe and orderly manner, he loads coal that has been cut and shot from the face. He loads this coal onto a shuttle car.

Responsibility

He is accountable to the section foreman.

He must perform his assigned duties in a manner as to insure the safety of his fellow workers and the safety of the mine.

He is charged with the responsibility of reporting to his section foreman any repairs that are needed to be made to his machine.

Preproduction Activities

He is to find out from his section foreman into which working place he is to go.

He is to check his loading machine to see if it is in operating condition. After determining that his machine is in operating condition, he then directs someone to put the power on the machine.

Production Activities

Tram the loader to the designated place as instructed by the section foreman.

Check the working place for safe conditions. He is to check the roof for safety. Notify the section foreman as to the safety of the working place.

Break the cut on center line of roadway. Load the cut coal into a shuttle car.

When cut coal is loaded, he re-checks the top and sets safety posts as needed.

Tram the loader to the next place as designated by the section foreman, and repeat the production cycle.

Cutting Machine Operator

Function

As a member of the mine production force, he receives his work assignments from the section foreman. His function is to under cut coal in places as they become available to him, according to rib lines as marked by the section foreman. He is to cut the coal in a manner so as to insure the maximum loadability.

Responsibility

He is accountable to the section foreman.

He must perform his assigned duties in a manner as to insure the safety of his fellow workers and the safety of the mine.

He is charged with the responsibility of reporting to his section foreman any repairs that are needed to be made to his machine.

Preproduction Activities

He is to find out from the section foreman into which working place he is to go.

He is to check the cutting machine to see if it is in operating condition, and see if the cutter bar has sharp bits in it. After determining that his machine is in operating condition, he then directs someone to put the power on the machine.

Production Activities

Tram the machine to the working place that the section foreman has designated.

Check the working place for safety conditions. He is to check the roof for safety and make a gas test with a gas lamp. Notify the section foreman as to the safety of the working place.

Sump the cutter bar into the right side of the face. Cut across the face. Pull machine back and put a bar lock on the bar.

Re-check the roof for safety. Make a gas test with a gas lamp.

Tram the machine to the next working place. Check the cable for proper length, and see that it is out of the roadway. Repeat the production cycle.

Shuttle Car Operator

Function

As a member of the mine production force, he receives his work assignments from the section foreman. In a safe and orderly manner, he is to transport the coal by shuttle car from the loading machine at the face to the loading point inside the mine. His function at certain times may be that of hauling supplies from the supply hole to the face.

Responsibility

He is accountable to the section foreman.

He must perform his assigned duties in a manner as to insure the safety of his fellow workers and the safety of the mine.

He is charged with the responsibility of reporting to his section foreman any repairs that are needed to be made to his machine.

Preproduction Activities

He is to find out from his section foreman into which working place he is to go.

He is to check his shuttle car to see if it is in working condition. After determining that his machine is in operating condition, he directs someone to put the power on the machine.

Production Activities

He moves his machine to the working place.

His machine is loaded with coal by the loading machine. He transports this coal to the loading point. He unloads the coal onto a belt feeder or an elevator, which in turn loads the mine cars.

He returns to the loading machine and repeats this cycle.

<u>Roof Bolting Machine Operator</u>

As a member of the mine production force, he receives his work assignments from the section foreman. In a safe and orderly manner, he roofbolts and/or timbers the roof to prevent roof falls; and to further insure the safety of the working place.

Responsibility

He is accountable to the section foreman.

He must perform his assigned duties in a manner as to insure the safety of his fellow workers and the safety of the mine.

He is charged with the responsibility of reporting to his section foreman any repairs that are needed to be made to his machine.

Preproduction Activities

He is to find out from his section foreman into which working place he is to go.

He is to check his roofbolting machine to see if it is in operating condition. After determining that his machine is in operating condition, he then directs someone to put the power on the machine. He then checks to see if he has enough supplies to last the shift and advises the section foreman of his supply needs.

Production Activities

Move the machine to the working place as assigned by the section foreman.

Examine the roof and ribs for safety condition. Set safety posts as determined by mine management in accordance with safety regulations.

He proceeds to drill the roof to pre-determined depths and install roofbolts into the drilled holes. The roofbolting pattern is based on a roofbolting permit obtained from the Department of Mines.

He moves his machine to the next working place and repeats the production cycle.

<u>Coal Drill Operator</u>

As a member of the mine production force, he receives his work assignments from the section foreman. As a coal drill operator, his function is to drill all coal that is available to him as directed by the section foreman.

Responsibility

He is accountable to the section foreman.

He must perform his assigned duties in a manner as to insure the safety of his fellow workers and the safety of the mine.

He is charged with the responsibility of reporting to his section foreman any repairs that are needed to be made to his machine.

Preproduction Activities

He is to find out from the section foreman which working place he is to go.

He is to check his machine to see if it is in proper operating condition. A check should also be made to see if the bit is sharp. He then directs someone to put the power on the machine.

Production Activities

He is to move the machine to the working place that is designated by the section foreman.

He then checks the working area for safety conditions. He makes a gas test and checks the roof. He is to advise the section foreman of any unsafe conditions.

He proceeds to drill as many holes in the face as the drill pattern requires. This pattern is designated by the mine management to insure the safest way of producing the maximum loadability from the coal that is shot from the face. He pulls the machine back from the face. He then takes another gas test with his gas lamp. He reports any unsafe condition to his section foreman.

He proceeds to the next designated working place and repeats the production cycle.

Maintenance Mechanic

Function

As a member of the mine maintenance force, he is accountable to the Chief Electrician and is responsible for carrying out the following operations, activities and assignments: Maintain all mine equipment in a safe and efficient manner. Receive reports on mechanical, electrical and hydraulic failures and make necessary arrangements to correct these conditions.

Responsibility and Authority

The maintenance mechanic is responsible for and has the authority to act in carrying out his assigned activities:

He will utilize his assigned tools, facilities and available services, in the most effective manner possible to complete scheduled work as assigned.

He will make sure that any personnel assigned to him, in the form of a helper, is thoroughly trained in safe and effective methods and procedures and will report any deficiencies.

He will see that all preventive maintenance measures are carried out as scheduled.

He will attempt to minimize time loss due to breakdowns. He will report all maintenance measures and activities to the Chief Electrician.

He will make all necessary repairs to all equipment assigned to him and will assure that all machinery is functioning properly.

Relationships

The maintenance mechanic will observe the following relationships:

The Chief Electrician

He is accountable to the Chief Electrician for the fulfillment of his assigned duties.

Others

He will conduct no other relationships.

<u>Time Clerk</u>

Function

To maintain time cards for the payment of union employees in accordance with the contractual wage rates. To maintain records of mine inventories.

Responsibility and Authority

Responsibilities

He is accountable to the Division Controller for the proper performance of the following duties:

> To maintain records, receive and disbursement of mine inventory including:

Roofbolts
Timbers
Rockdust
Lubricants
Spray oils
Other necessary supplies

To maintain records of tonnage and costs.

To maintain good relations with our suppliers.

To conduct business within established policies at all times in an ethical manner.

Authority

Authority is granted to commensurate with assigned duties.

Relationships

He has a liaison relationship with the Mine Superintendents and other Staff and Operating Personnel to secure and impart information of mutual benefit.

Section Foreman

Function

As a line member of management, he is accountable to the Mine Foreman and is responsible for carrying out the following operations and activities:

Producing quality coal to objective standards;

Safety of men and equipment on section; maintaining section to specification of Federal, State and Company policy;

Maintaining section on proper projection;

Ordering supplies for future use;

Keeping the Mine Foreman advised of conditions of section to enable proper planning; and

Other similar activities as assigned by the Mine Foreman.

Responsibilities and Authority

The Section Foreman is responsible for and has the authority to act in carrying out activities, programs and schedules as approved by the Mine Foreman.

Responsibilities

He will utilize his assigned equipment, facilities and personnel in the most effective manner possible to assure maximum use of all of his facilities in the production of quality coal.

He will make sure that all personnel assigned to his section are thoroughly trained in safe and effective methods and procedures and will follow-up to assure that these are followed at all times.

He will instruct members of his crew in preventive maintenance of his assigned facilities:

To minimize production loss due to breakdowns; and to extend operating life of assigned facilities.

He will investigate and report on grievances and complaints and will counsel and advise his crew to maintain good will and maximum effort.

He will take all practicable steps to assure that foreign matter such as slate, metal, wood and rubbish are not mixed with coal sent to the preparation plant.

He will conduct weekly on-the-job safety meetings and maintain an adequate safety program, including a thorough investigation of injuries and safety incidents, a complete "job observation" at least monthly, and planning for effective accident prevention. This will include provisions for good housekeeping on his section and all other areas under his supervision. He will contribute to cost reduction in his operations:

By improving labor utilization;

By eliminating waste in materials and supplies;

By contributing projects to his mine's cost improvement program.

He will maintain all required records in good order and will issue operating and production reports as scheduled.

Authority

He will recommend to the Mine Foreman any unusual maintenance, improvements or replacements which may be necessary to maintain current or anticipated production requirements.

In consultation with the Mine Foreman, he will consider and make recommendations for the following:

> Hiring, promotion, demotion, transfer or dismissal of personnel; and
>
> Operation of his assigned activities in accordance with Company policy.

Relationships

The Section Foreman will observe and conduct the following relationships:

The Mine Foreman

> He is accountable to the Mine Foreman for the fulfillment of his assigned activities and schedules, and for the proper interpretation of his responsibilities and authority.

Other Mine and Staff Department Heads

> He will consult with the Mine Foreman as to the extent of advice and assistance that may be required.
>
> In no way will he assume, nor will he be delegated, any function, authority, responsibility or relationship specified as belonging to another member of management.

Others

> He will consult with the Mine Foreman as to the establishment of other relationships considered necessary for the proper accomplishment of his function.

<u>Mining Engineer</u>

Function

As a staff member of management is accountable to the Chief Mining Engineer for carrying out the following operations and activities:

Advise and assist the Chief Mining Engineer in conducting the Company's prospecting activities and in coordinating mining engineering functions.

Responsibility and Authority

The Mining Engineer is responsible for and has the authority to act in carrying out activities, programs and schedules as approved by the Chief Mining Engineer.

Responsibilities

He will assist the Chief Mining Engineer in the development of broad mining engineering objectives, policies, programs and procedures;

He will assist the Chief Mining Engineer in planning current and long-range development of currently operating mines including overall mine layout, projections, ventilation, roof control, haulage and drainage, making recommendations on selection and utilization of mining equipment;

He will follow-up authorized mining engineering projects as directed by the Chief Mining Engineer;

He will prepare current production and mine life graphs as directed; correlating this information with future mine development programs as directed by the Chief Mining Engineer;

He will assist the Chief Mining Engineer in scheduling, making or having made regular property inspections;

He will supervise diamond drilling and churn drilling; interpret analyses of core and channel samples, and report information received, making necessary recommendations to the Chief Mining Engineer;

He will direct the activities of the drafting operation in the mapping of specially assigned mine workings.

Authority

In consultation with the Chief Mining Engineer, he will consider and make recommendations for the operation of his assigned activities in accordance with established company policies, and advice to his subordinates in the proper use or conformance with various policies and procedures.

Relationships

The Mining Engineer will conduct the following relationships:

The Chief Mining Engineer

He is accountable to the Chief Mining Engineer for the fulfillment of his assigned activities and schedules, and for the proper interpretation of his responsibilities and authority.

Psychological Testing

In the selecting and evaluating of personnel for mining in an oxygen free atmosphere, it must be kept in mind that the requirements must not be in excess of those currently used for the present employees in modern conventional mines. It is envisioned that this mining technique, once developed, may be broadly used in the industry. It is necessary, therefore, that the basic requirement for employees remain essentially the same as they are now so as to make it possible to retain and utilize existing personnel.

The fact that miners are used to cramped quarters and to carrying the miner's lamp, rules out claustrophobia and the objection to some additional weight in a majority of the cases. It is to be expected, however, that in a few instances, the close confinement within the Miner's Personnel Suit (MPS) will be objectionable to some people and they will not be able to tolerate this confinement. The only practical test to evaluate this aspect is to actually have the subject wear the MPS and observe his reactions and comments. The Bendix Launch Support Division at Cape Kennedy uses this technique to screen personnel to determine those mentally suited to tolerate the close confinement within this type of enclosure for extended periods of time.

All miners have already been instructed in the use of the self rescue pack and many of them have had experience with the self contained rebreather back packs currently being used in mine rescue work. They have a basic understanding of the methane-oxygen relationship as well as the carbon dioxide problem existing in the mine and their effect on the miner and the mines' operation. In this respect, they already had some of the basic knowledge required for the understanding and use of the Miners' Life Support Systems.

Universal-Cyclops in their In-Fab Program made extensive use of psychological testing in their selection of personnel to be used on the project. They came to the conclusion that the best technique to follow in the selection of personnel for a project of this type was to select personnel from within the company with whom they were familiar and knew had a stable and predictable personality. If this is not done, experience reveals that there is difficulty with psychological testing which is the least accurate of all tests.

It is recommended that the personnel selected for use in the proposed phases of the development program should be hand-picked for their stable and predictable personality, their youth and knowledge of mining techniques and equipment, their cautiousness, their curiosity about new and different ideas, their ability to rationalize, their desire to improve mining conditions and to be a part of a mining program degressing considerably from conventional mining techniques. Those selected should display qualities of leadership as they could be future instructors and mine foremen.

Medical Testing

A thorough medical examination must be an important part of the personnel evaluation and selection program. The medical record should include complete documentation of an individual's medical history with remarks from the examining physician. The medical examination should include:

Height	Abdomen
Weight	Arteries
Color of Hair	Extremities
Eyes	Internal Region
Ears	Spine
Nose	Skin
Mouth	Genito-Urinary Disease
Neck	Urinalysis
Heart	Blood Pressure
Lungs	Serology

Any defects that may disqualify an individual and his specific work limitations.

The height, weight, respiration rate, blood pressure, hearing ability, urine analysis and reflex actions should be checked at regular intervals and as frequently as weekly in the proposed demonstration program.

Training

A training facility should be located outside the entry of the sealed and blanketed mine and should contain a classroom, a small gas lock chamber in which men can become accustomed to the safety of their suits and apparatus, and an enclosed garage in which individual pieces of mining equipment may be operated by the men while wearing the life support suits so that they can become accustomed to such operation before having to perform it within the confines of the mine proper. Approximately one month is anticipated for training a ten man crew for a single section in an air atmosphere before they would begin operations in a mine under an inert blanket. During the conduct of the proposed demonstration program, one day each week would be utilized for retraining in safety procedures as well as in developing revisions to operating techniques.

The training program for the crew to be used in an oxygen free atmosphere mine utilizing life support systems must be comprehensive in the use of the selected life support system as well as in all of the mining techniques used in conjunction with these systems.

The training program should consist basically of three parts. Part one being strictly classroom discussions and review of the various components. Part two should be the testing and familiarization with the system components as related to the operation of the mining equipment using the training facilities at the mine mouth. Part three should involve actual mining operations with all men in suits but in a section of the mine maintained for this purpose in an air ventilated status.

The classroom discussions must include an introduction to and purpose of the project, miner's protective suit, miner's mine personnel rebreather system, mine personnel emergency rebreathing system, mine personnel communication system, and safety.

In the case of the proposed demonstration mine, the introduction should include as well a complete review of the project including the benefits to be derived from it.

The mine personnel suit should be discussed and all personnel made familiar with the construction of the suit, how it operates, what maintenance procedures are required to keep the suit in proper condition, what malfunctions of the suit are likely, and how to test the suit for air tightness so that mine atmosphere does not infiltrate the suit.

All men must be expected to become completely familiar with the construction and operation of the rebreather system, and its maintenance. They must also become familiar with those symptoms which might indicate a malfunction in the rebreather system.

The miner must become completely familiar with the operation of the emergency rebreathing system and its care and maintenance.

The miners should also be instructed in the maintenance and operation of the communication system and its capabilities as well as the backup or emergency procedures provided.

The safety features of all components of the life support system must be continuously reviewed as a continuing part of an overall safety program. It is anticipated that all likely situations would be examined in order to determine what steps would have to be taken to assure the miner's safety.

Part two of the training program should be the demonstration and testing of the various components by the trainees using the training gas lock for familiarization with operation in an inert atmosphere. The miners should run selected pieces of mining equipment in the training garage external to the mine to become familiar with the installation of the rebreather system on the mining equipment as well as the problems involved with the tether system, vision, and hearing. Confidence in the operation of the life support system must be gained.

Part three of the training program follows the completion of classroom and equipment familiarization. The mining crew should be suited up and taken into the demonstration air ventilated training section of the mine where they should actually work a face under air ventilated conditions so that they may further develop their confidence in the system and refine their ability to work their equipment while wearing the suits and supported by their rebreather. When part three is completed, the men should be able to begin operation in an oxygen free atmosphere.

SECTION XI

INSTRUMENTATION

Monitoring of the atmosphere in a mine and of the mine water discharge is an essential part of the oxygen free atmosphere process. This data is necessary to control the operation of the mine, maintain safety procedures, determine the requirements for blanketing gas and the effectiveness of the process on the quality of the water discharged from the mine. Continuous monitoring of critical areas (gas locks) is essential to provide instantaneous data for safe operation. Routine programmed sampling should provide adequate data in other areas. The discharged water quality should not change rapidly enough to warrant the establishement of continuous monitoring equipment except for possibly pH and conductivity. Water samples collected at regular intervals should be analyzed during the course of the mine operation.

The following monitoring and sampling system for Gas Quality Measurement and Water Quality Measurements are typical of those for full scale blanketed operations and are shown for the proposed demonstration mine as an example.

Gas Quality Measurements

Monitoring of mine atmosphere quality is essential in order to control contamination from either suit leakage, gas lock leakage or from outside atmosphere. It is also essential to provide detection of hazardous or explosive conditions if they exist. Such monitoring requires a combination of analytical instruments which must provide:

1. Intermittent measurements of gas composition at selected points throughout the mine.

2. Continuous measurement of key componenets of the atmosphere in critical areas where personnel safety is of prime importance.

3. Intermittent measurements of the physical characteristics of the mine atmosphere such as temperature, pressure, and humidity.

By using a combination of sequential analyzers for general data gathering of noncritical points and continuous analyzers at points most significant to personnel safety an effective instrument system is possible.

The points that should be included in a sequential analysis scheme are as follows (See Figure 12).

Point 1 mine atmosphere between working face and entrance
Point 2 refuge station personnel gas lock
Point 3 refuge station
Point 4 equipment gas lock
Point 5 personnel gas lock
Point 6 coal gas lock hopper
Point 7 working face
Point 8 inert gas generator effluent
Point 9 outside ambient atmosphere (physical properties only)

The points that require continuous gas quality monitoring include the refuge station (point 3) and its personnel gas lock (point 2) and the personnel gas lock arrangement (point 5) and the equipment gas lock (point 4). In addition physical properties including humidity, pressure and temperature should be continuously monitored at the inlet and outlet sides of the air conditioning unit as well as at point 9. Temperature and humidity measurements at other points in the mine would best be achieved by using portable instruments.

The points for sequential analysis for gas composition include points 1 through 8. There is no need to monitor the gas quality of the outside atmosphere (point 9).

In the proposed demonstration mine example the continuous and sequential gas quality analysis instruments should be located in the control room and should receive gas samples from points 1 through 8 by means of a continuous sampling system as shown in Figure 13. Gas should be pumped with individual vacuum pumps from each point through a series of filters and condensate traps to the control room as shown in Figure 14. Each sample line should be split into two streams, one for the sequential analyzer and the other for the continuous analyzers. Monitors for combustibles should be located at the points of sampling in the two gas locks.

The instruments for measurement of physical properties should be located in the control room since they can receive electrical signals from sensing elements located at the points of measurement. In the case of full scale well developed mines, certain of the refuge stations could be used for location of the measuring instruments was to reduce the length of the sampling lines. Results would then be telemetered to the control room.

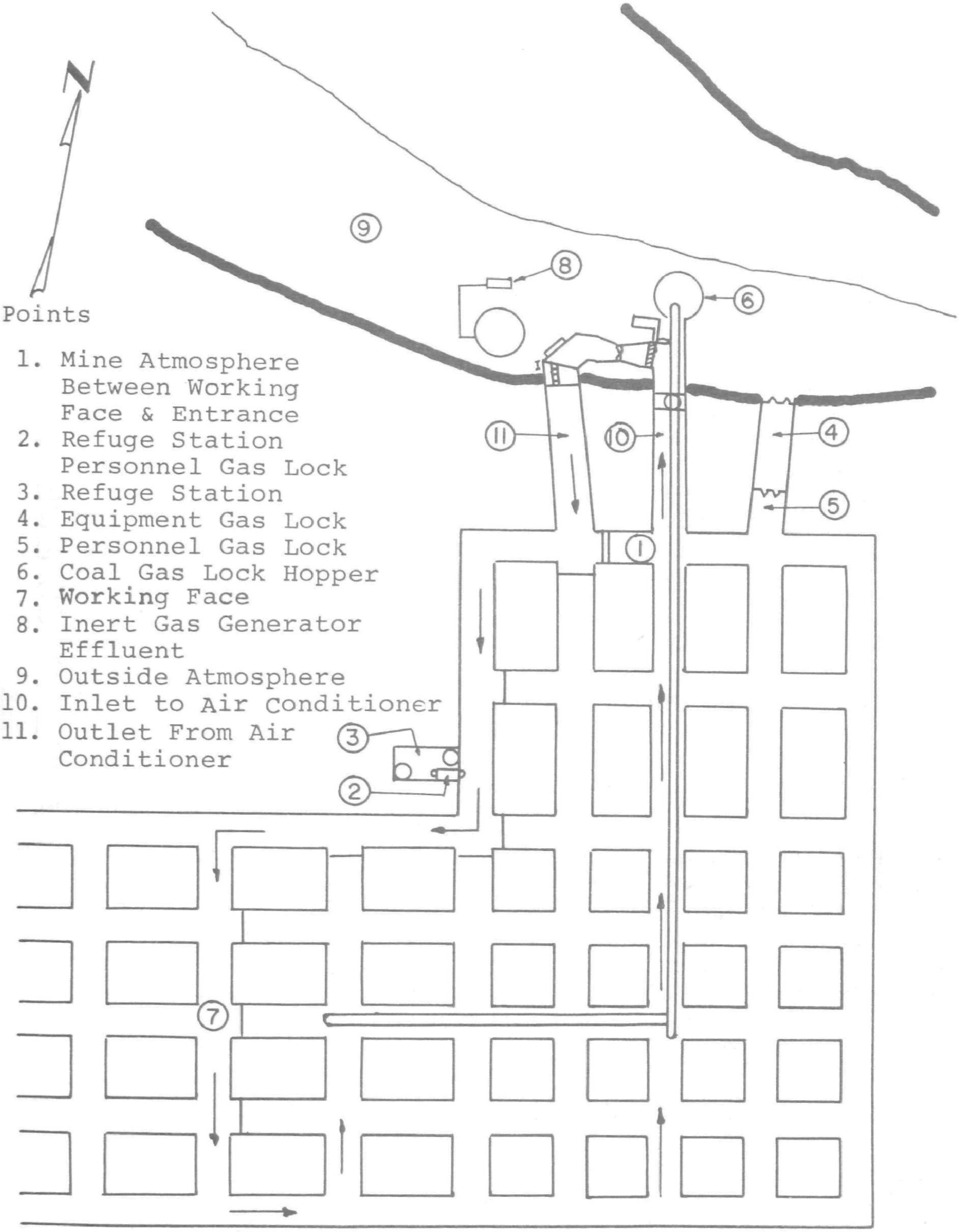


FIGURE 12

Sampling Points

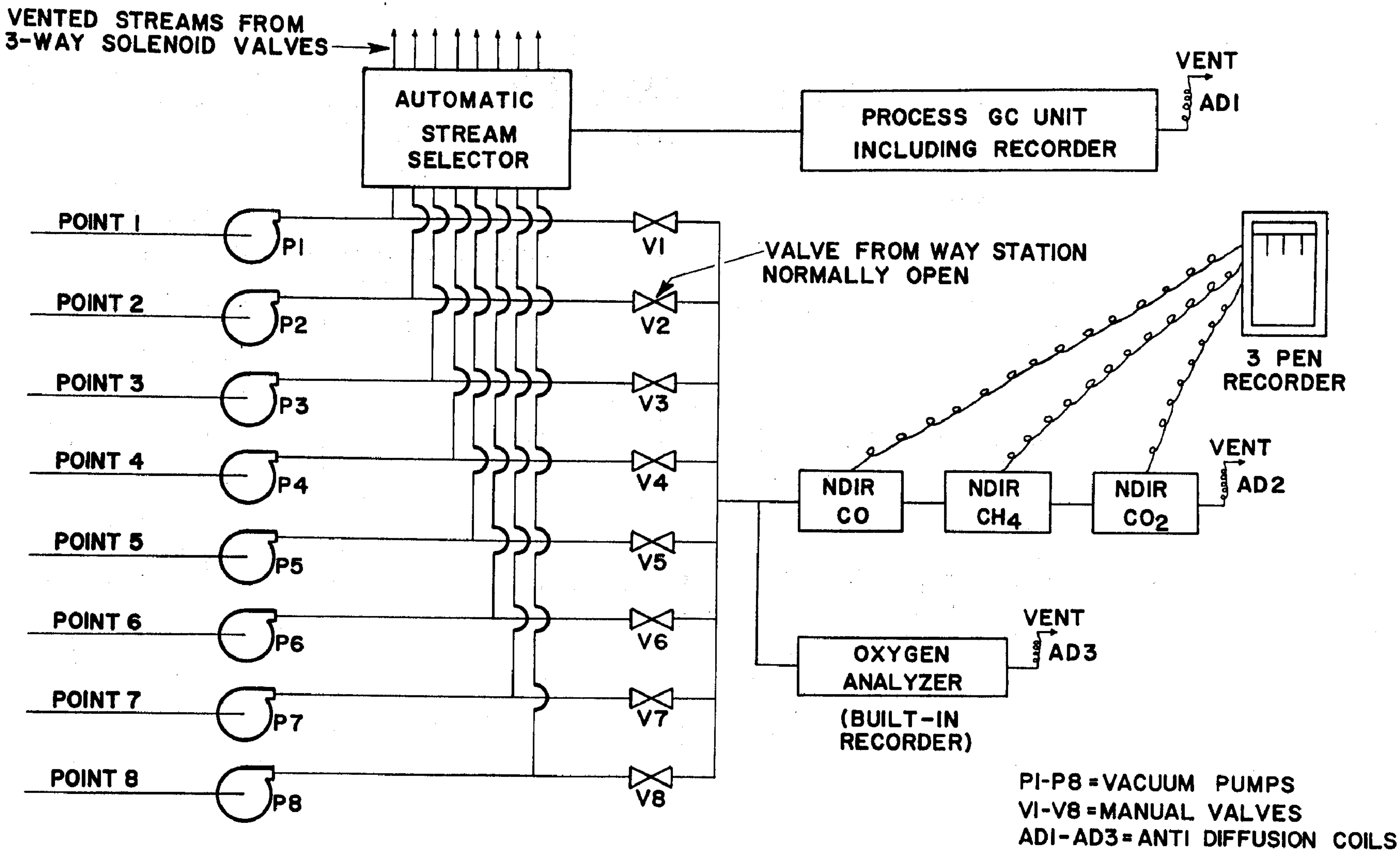
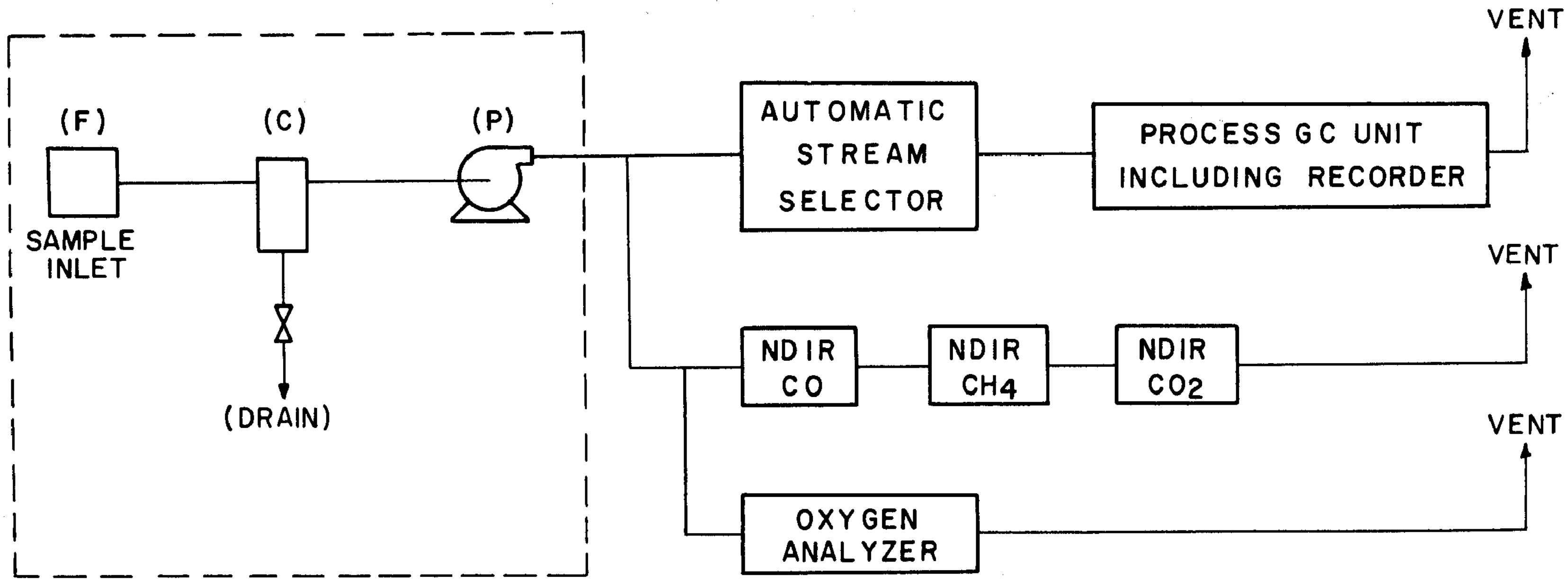


FIGURE 13

SAMPLING SCHEME



TYPICAL (8) PLACES

(F) AUTOMOTIVE AIR FILTER (PAPER CARTRIDGE TYPE)
(C) FILTER WITH CONDENSATE TRAP
(P) VACUUM PUMP

FIGURE 14
GAS SAMPLE LINES

The principal sources of information for the gas quality instrumentation were the Beckman Instrument Company and the Mine Safety Appliance Company. The instruments suggested are based on their experience in the area of process instrumentation.

Continuous Analysis Instruments

The refuge station (point 3) gas quality should be monitored on a continuous basis. The gases analyzed should include 1) carbon monoxide, 2) methane, 3) carbon dioxide, and 4) oxygen. The first three gases can be handled by three non-dispersive infrared analyzers connected in series. The fourth, oxygen can be analyzed by either a polarographic or a paramagnetic type analyzer connected in parallel to the infrared units. The results should be recorded by a multipoint unit.

The sample stream for this continuous analysis system should be taken from a manifold that is common to sample points 1 through 8. Each stream should pass through shut off valves prior to entering the manifold. With this arrangement one of the eight sample streams can be continuously monitored at a time. During normal operations the valve connected to the refuge station sample line should be open and the others closed. If the need should arise any one of the other sample streams may be continuously analyzed by merely shutting off the refuge station valve and opening one of the other required valves.

Continuous combustibles analyzers should be located at the refuge station personnel lock (point 2) and the equipment personnel lock (point 5). These instruments serve to warn of the presence of a combustible gas mixture resulting from mixing of air and mine atmosphere and thus indicate the need for additional purging of the gas locks. These instruments include three lights: one indicates power on, a second indicates conditions are safe and the third indicates unsafe conditions. A warning alarm should be used in conjunction with the third warning light.

A standard weather instrument package including an anemometer, aerovane, dry and wet bulb thermometers, and a rain gauge should be used with transmission to appropriate recorders in the control room.

Sequential Analytical Systems

The sequential analysis instrumentation system should include a process gas chromatograph, an automatic stream selector unit, and vacuum pumps, PVC sample lines, filters and condensate traps (Note: taps are taken at the outlet of each pump for the manifold connected to the continuous analyzers). This process gas chromatograph instrument must be able to analyze for 1) carbon monoxide, 2) methane, 3) carbon dioxide, 4) nitrogen, and 5) oxygen. Each measurement cycle for the five components requires approximately 6 minutes to complete. All 8 sample streams, therefore, should be able to be analyzed within approximately 50 minutes.

For safety purposes, the automatic stream selector should be able to be switched to manual operation should the need occur to look at a particular gas stream out of the programmed sequence.

Measurement of Pressure, Temperature and Humidity

Humidity and temperature sensors should be installed on the inlet and outlet of the air conditioner. The data thus obtained enables the efficiency of the air conditioner to be monitored and provides information on the temperature and humidity change within the mine.

Pressure changes within the mine should be monitored with a differential pressure instrument relative to the outside atmosphere. Outside atmospheric pressure measurements should be made with an absolute pressure recorder and displayed together with the differential on a two pen recorder. Differential pressure measurements should also be made across the ventilation fan.

The most practical approach to temperature and humidity measurements within the mine, is to perform them manually. This eliminates a multiplicity of sensors and connecting wires which might pose a problem. Temperatures and humidities should be recorded periodically by mine personnel using a sling psychrometer.

ESTIMATED INSTRUMENTATION PURCHASE COSTS
BASED UPON PROPOSED DEMONSTRATION MINE

Continuous Analysis Instruments

1. Nondispersive infrared analyzers	
a. Carbon monoxide	$ 2700
b. Carbon dioxide	2600
c. Methane	2800
2. Oxygen analyzer (with recorder)	3300
3. Combustibles analyzers (3)	2600
4. Three-pen recorder	1000
5. Miscellaneous hardware	1500
Total	$16500

Sequential Analyzer

1. Process gas chromatograph including: programmer, analyzer, automatic stream selector, pumps, tubing, filters, valves, etc.	$12000

Pressure Temperature Humidity Instruments

1. Absolute Pressure Recorder	$ 500
2. Temperature	
a. Dial thermometers (5)	75
b. Thermocouples (2)	60
c. Recorder (1)	200
3. Humidity	
a. Fixed sensors (2)	500
b. Portable unit (1)	200
4. Weather Station	3500
Total	$ 6000

Water Quality Monitoring

Continuous monitoring and sampling should be conducted for a few key parameters of drainage from a sealed mine and in the case of the proposed demonstration project, from the adjacent air ventilated mine. The degree of surveillance after a preliminary period should be dictated by the analytical results. The results will probably be influenced by the effectiveness of the mine sealing techniques and the ability to maintain a constant low oxygen concentration in the mine atmosphere. Composite sampling for periodic analysis for other parameters should supplement the continuous measurements.

Information on samplers and monitoring equipment is abundant but data on use of the equipment is sketchy and limited. It appears that most of the suppliers are of the small job shop type and service maintenance of the equipment is questionable.

The investigation into continuous multiparameter monitoring systems covered three makes: 1) Schneider, 2) Geodyne and 3) Automated Environmental Systems. The specifications for the three appear to be very similar. ORSANCO uses the Schneider instrument.

Composite samplers evaluated included the following:
1) Serco, 2) Pro-Tech and 3) N-Con

The Serco sampler is made of lightweight aluminum and is compact. It requires no electrical or plumbing hook up for its use in field operation. The unit is evacuated by means of a vacuum pump. Upon evacuation of the sample bottles, valves are closed and the unit is then ready for sampling. The samples are taken by suction. A hand-wound timer can be set to open valves to individual evacuated bottles at intervals of 1 hour, 30, 15, 10, or 5 minutes. The sampler case is insulated. To further control temperature of the samples, the sampler can be heated with canned heat in cold weather or cooled with ice in the collection of certain samples.

The Pro-Tech sampler uses electrical energy to obtain composite samples automatically. The sample is delivered to the sampler from a submersible magnetic-drive pump which is placed in the liquid to be sampled. The unit operates on a continuous flow principle, returning the uncollected sample to waste. Sample volume is determined by the setting of a solid-state timing control, together with the sampler repetition rate, and the duration of the flow signal received from the flow recording device. The weather-proof sampler case is made of aluminum with durable baked-vinyl finish. All tubing, valves, fittings and hardware are of PVC, nylon, brass, and stainless steel construction.

The N-Con is a battery operated sequential composite type sampler. The instrument is capable of collecting twenty-four 500 ml composite samples over a period of 8, 12, or 24 hours. The sampler is easily portable by one man and provides the convenience of a single inlet tube. The operator sets the desired number of hourly aliquot samples and adjusts the volume control for aliquot sample volume. When all 24 bottles have been filled, the sampler automatically shuts itself off.

Each unit has its good and poor features but from an overall standpoint the Serco sampler should be used for the following reasons:

1. It is compact and lightweight.
2. It does not require electrical hook up for field operation.
3. It is insulated.
4. Temperature can be controlled with ice or canned heat.

In reviewing the sampling and analytical requirements for the proposed demonstration mine, it was determined that the characteristics of the local stream would probably not vary rapidly enough to warrant the expense of continuous analysis. It is expected in general that a sealed mine discharge does not appear to warrant continuous analysis for the full range of parameters of interest. Periodic samples for laboratory analysis for parameters other than pH and conductivity should be taken of the mine water discharge.

In the case of the demonstration mine these samples should initially be taken weekly in order to establish base line data and later on monthly to develop a complete seasonal record. Continuous analysis for pH and conductivity of the mine discharge should be made and the results recorded in the control room. Continuous surveillance of pH and conductivity should detect any periods of rapidly changing water characteristics that may result from mine atmosphere quality changes.

Continuous pH and conductivity recorders are available commercially from many sources. Separate locally mounted sensing elements with standard recorder output should be used at the mine water discharge pond to transmit the output to a multipoint recorder located in the control room. In the case of the proposed demonstration mine a similar installation should be made at the adjacent active mine with the recorder located in the mine office or other convenient building.

To conduct the composite sampling program on the Serco samplers one for each discharge with extra sample bottles, a spare vacuum pump and additional component parts such as sampling heads, rubber sampling lines, spring driven clocks, etc. should be provided. Dependent on varying operating conditions individual samples should be analyzed for the following parameters.

pH	Total acidity
Conductivity	Dissolved solids
Total iron	Manganese
Dissolved iron	Chlorides
Total alkalinity	Sulfates

The proposed Serco samplers and spare parts are estimated to cost approximately $1200 each. The instruments are available with deliveries of 30 - 60 days. The samples collected by these samples should be preserved as recommended by the analytical laboratory and sent to the laboratory for analysis.

SECTION XII

DATA COLLECTION

An operational data acquisition system plays an essential role in the conduct of major projects. Such a system should accumulate all pertinent data on personnel, equipment and facilities utilized in the preparation and operation of the oxygen free atmosphere mine. Data recorded should include capital, operating and maintenance costs associated with the equipment and facilities; physical and psychological records on all personnel; production logs; and detailed maintenance records. Such data is necessary for a thorough evaluation of inert gas mining operations so that system modifications may be developed, and comparative analysis of inert gas mining operations may be made with those of a standard mine.

The data acquisition system should be designed to collect and present data in several formats consistent with the type of data being collected. Data records should include standard report forms (i.e. production, safety, medical, supervisory, injury, etc.), cost accounting records, equipment service records, strip chart records and time reports. Where possible, existing report forms should be utilized to acquire the same base line data commonly maintained on standard mining operations. All record formats should be so designed that they can readily be utilized for computer input for more sophisticated data analysis. The frequency of recording data and the type of record maintained depend on its relative importance to analysis of inert gas mining operations.

Data of a general nature kept on each item of system equipment and facilities should include a description of the item; model, item or identification number; list of associated spare parts; and the capital cost of the item and any spare parts.

Installation cost data for erecting equipment in the mine and outside the mine should be recorded on a daily basis showing labor, supplies and utility services required for all items installed. Service and maintenance costs should likewise be maintained on a daily basis on all items from the time of installation.

All of the aforementioned cost data will be required, as applicable, for each of the following systems or items, as well as operating data unique to the system or item itself.

Inert Gas Generation System

Capital cost data on equipment for this system should cover the blower, burner, gas holder, cooling units, filters, ductwork, piping, accessories and recommended spare parts.

Service and maintenance costs should be readily discernible in terms of the period of initial charging as opposed to the time of standard operation of the mine. The purpose for such separation of costs is to subsequently provide a more reasonable basis of cost comparison with other system operating costs. An hourly record of such costs should be maintained as well as associated data including the date and time an item was taken from service, date and time the item was returned to service, down time per shift, reason for repairs, and a description of the repairs performed.

The initial charging record of the mine should include the date and time that inert gas blanketing began and the date and time that it was determined that the inert gas blanket was suitably established. Under normal charging conditions, general system data collected during the course of the mine operation will include a daily record of date, starting and quitting time for each shift and non-shift period, shifts per day, and the volume of the mine atmosphere. Mine and ambient temperature and pressure should be logged hourly. The mine breathing rate (inert gas makeup to mine or in the case of a methane atmosphere, the gas bleed off rate) should be recorded continuously as should the flow to personnel, equipment and material gas locks.

Normal operating data for the gas generators during initial charging and regular operation should include the production rate in SCFH, SCFH of natural gas fired, gpm and delta T of the cooling water used, wet and dry bulb temperature of the product gas, composition of the inert gas discharged, and the blower power consumption.

The gas holder serves as a collection facility for the inert gas generated. It maintains a sufficient reserve to supply the inert gas system requirements of the mine under the most demanding conditions of gas lock operation, mine breathing, and maintenance of the mine atmosphere. During initial mine charging and standard operation, data which should be recorded to monitor gas holder operation should include the pressure and temperature of the gas in the holder, and the holder volume in SCF (continuous record). The gas holder should maintain a reserve supply of inert gas during normal operation of the demonstration mine and all measurements should be continuously monitored and logged regularly at the mine's control center.

Gas Quality System Data

The quality of the atmosphere in each major component of the mine system should be determined continuously as previously discussed. Log sheets should be maintained, with two entries per shift, for each item continuously recorded or indicated on system instrumentation. A log sheet record should be maintained which indicates each dangerous CH_4 reading with respect to the time of initial occurrence and the length of time that the condition existed.

Water Quality Data

In the case of the proposed demonstration mine, a comprehensive sampling and monitoring program for water surveillance at both mine sites should be conducted over the period just preceding and throughout the demonstration mine project. A major reason for collecting such water quality data is to provide good comparative data on the effects of the two different mining techniques and the quality of mine drainage.

The mine discharge at each mine location should be monitored on a continuous basis for their pH, conductivity and flow rate. Maintenance of a log of these measurements once per shift should provide sufficient indication of operating conditions and/or the need for system modifications.

In any new sealed mine operation weekly grab samples should be taken initially of mine drainage. After the initial sampling period, changes in weather, stream flow and operating practice may warrant modified sampling schedules.

Characterization of the water quality from each grab sample should be determined by standard analytical procedures for pH, conductivity, dissolved solids, total iron, total alkalinity or acidity, manganese, chlorides, sulfates and suspended solids.

The effectiveness of the mine seal in eliminating oxygen in the mine atmosphere and in turn eliminating mine acid discharge should be determined by the results of the sampling and analysis program.

Life Support System

The entire life support system (suits, helmets, emergency breathing equipment, rebreather, and communications) should be evaluated to determine the adequacy and effectiveness of all components with respect to operations in the sealed mine.

Log sheets should be maintained on each man's reactions and problems with system equipment as well as a service record for system equipment itself. Data on capital costs, operating costs, maintenance costs, and reports on repairs, failures, cleaning and inspection should be maintained on log sheets as routine practice.

Data maintained on the three parts of the miner's life support suit (undergarment, middle garment and outer garment) should include the number of garments required per man, unit cost of each garment, period of usefulness, date placed in service, date of replacement, and the comfort, fit and freedom of movement attainable under the weight and restrictions of the suit. When replacement of a garment is required, a separate data record should be maintained and include the reason for replacement, date of each occurrence, cost of replacement, and the parts required for repairs.

Additional information documented on the middle garment should include the results of routine pressure/leakage tests, suitability of quick disconnect connectors and connections in terms of leakage and proper fit, effective utility of boots and gloves, and an evaluation of abrasive wear.

The record maintained on the miner's helmet should include general data and replacement records similar to those kept on the miner's suit. Information peculiar to the helmet which should be kept in addition to the aforementioned includes an evaluation of dust and fogging problems associated with the visor, effectiveness of the earphone and voicemitter communication equipment and line of sight vision problems.

The emergency breathing system equipment is necessary for sustaining operating personnel within the mine atmosphere upon failure of the main rebreather system. The record maintained should include an identification or serial number of each potassium superoxide canister, source and date of manufacture, date canister is placed in service, serial number of emergency rebreather in which placed, and date of replacement.

The mine personnel rebreathing system is considered to be the most important part of the life support system to each miner as he works in the inert gas atmosphere. A log record should be kept on the unit as a whole as well as on each major component of the system.

Data on the carbon dioxide absorber used to purify the air system should include the serial number, source and date of manufacture, date installed and removed, serial number of rebreather in which it was installed, and any problems of operation.

Common data recorded on the air conditioning portion of the mine personnel rebreather filters, recirculation blower, and the tether hose should include unit costs, frequency of replacement, parts required, replacement costs, and problems associated with use. In addition, the results of regular capacity tests should be maintained on the air conditioning portion; the results of regular tests for pressure drop should be kept on the recirculation blower; the results of pressure/leakage rate tests and the extent of abrasive wear should be maintained on the tether hose.

Miners should be interviewed or given questionnaires periodically to ascertain their reactions to life support equipment operation. Data of a general nature should be obtained for the system such as adequacy of power source, replacement or recharging of power source, malfunctions, effectiveness of any warning alarm system, maintenance per unit, remedial action required in system design, and the number of units required per man.

The communications operation within the mine should also be monitored. A primary consideration should be the capital cost of the system components which includes battery powered transceivers, earphones, microphones, coaxial cable, remote transmitting station equipment, closed circuit TV system, and the antenna system. Maintenance data, as earlier defined, should be acquired; they should include a record of routine inspections, battery replacement frequency, recharging requirements, labor utilized, and associated service costs. Other general data should include the quality of TV reception, dust problems on the TV camera lens, and voice transmission reception from miner to miner, miner to control room, refuge station to control room, and miner to refuge station.

System Mining Equipment and Facilities

A record should be maintained on all major operating equipment used in the mining of the coal, as well as on the control room equipment utilized for system surveillance.

The operating cost record maintained on the aforementioned equipment should include data on battery recharging and on the replacement of consumables such as cutting heads and drill bits, roof bolts, explosives, tires, etc.

Mine Operation

A detailed record of coal production should be maintained for each shift and each day that the mine is in operation. The log sheet for this purpose should include the number of cuts of coal per miner; cuts of coal per day; tons of coal removed per day (actual against projected); number of shifts worked per day; cost of associated labor, supplies, overhead, services, and delays incurred (mechanical, condition, coordination minutes, percent of delay time, percent of face time).

Data accumulated on the miners and their performance should include a shift and daily record of time spent in the mine by the miners, time spent at the face, travel time in, travel time out, tons loaded, actual tons per man, expected tons per man, performance ratio, number of mine cars loaded number of cuts made, tons obtained per cut, standard and actual crew size, standard and actual tons mined per shift, standard and actual tons mined per man, and standard and actual total tons mined.

A separate record should be maintained for any additional general supplies required to produce coal.

Weather Station

Meterology data should be collected at the mine site. Such data should include wind direction, velocity, barometric pressure, temperature, humidity and amount of rainfall.

In-Mine Facilities

Records of capital costs and maintenance costs should be maintained for all major in-mine facilities. Capital cost data should be compiled at the time of purchase for the high voltage cable, mine lighting equipment, dust collection system equipment, refuge station facilities, personnel locks, equipment locks, product removal equipment, and ventilation system equipment.

The data log on the personnel locks in the mine should include a record of the number of times passage is made, the number of personnel per passage, time required to complete passage through the lock, amount of leakage at the lock, inert gas demand when transfer occurs, volume of gas exhausted to atmosphere, and volume of gas required to maintain the lock atmosphere. A similar record should be maintained on the equipment locks and refuge stations.

Personnel

Complete medical records should be maintained on all mine personnel before and during their service in the oxygen free mine. These medical records should contain basic data on the physical condition of each miner as well as/or the psychological effects on the miner that may be due to working in the specialized atmosphere and conditions of the sealed mine.

Personnel records on a worker's physical condition should include the person's name, address and telephone number; and a record of physical defects, previous mine injuries which include information on type, duration and persistent problems. Basic information, which should be checked initially on a weekly basis and later on a monthly basis should include height, weight, respiration rate, blood pressure, hearing ability, urine analysis and reflex actions. This basic information should be reviewed as collected, to determine significant trends and changes which might warrant further tests or alteration of mine operating procedures.

The questionnaire portion of the physical record form should inquire whether the miner has or has had shortness of breath, asthma, tuberculosis, chronic bronchitis, lung disorders, or coughed up blood; and if so, when and for how long has such a condition existed. The record should also contain an up-to-date listing of when and where the person's lungs were last X-rayed; and X-rays should be scheduled at yearly intervals to keep a thorough record. Indication should also be given if the miner has ever had silicosis or other lung disease; and if so, a detailed description of each occurrence should be made. Complete information on all injuries requiring surgery should be maintained and should include a description of the injury, surgery performed, time and duration of occurrence and any after effects.

Safety

The mine must be under constant scrutiny to maintain the safest operating conditions possible for personnel working in the oxygen free atmosphere. A dust count should be taken at the mine face and at the ventilating fan at the beginning and end of each shift to develop and maintain a relationship with visibility. The mine must have scheduled monthly inspections from which a comprehensive report must be made, giving special attention to gas lock operation, gas circulation adequacy, and conditions which would conceivably produce fires or explosions.

All data collected should be recorded on log sheets or be transferred to same from automatic monitoring equipment readouts or indicators. In this form, all data should be in a format acceptable for transferral to computer input media, if desired. Where possible, existing data acquisition forms should be used. Some existing forms should be modified to include inert gas atmosphere operational data and some new forms should be designed for the collection of information peculiar to the oxygen free operation.

Maintenance of Standard Report Forms

Standard report forms should be maintained by all classifications of mine personnel on the operations of the oxygen free mine.

Records routinely kept on air ventilated mines and which should be maintained for both methods of mining include the following representative forms and records:

Miner's rating sheet - a report sheet on basic mine operations conducted per day.

Daily and weekly time sheets - used to record setup time, maintenance time, and production hours worked.

Maintenance request form
Unit repair report
Repair job record
Job order form
Trailing cable - shop work report
Trailing cable work report summary
Stationary air compressor daily inspection form
Coal skip hoist inspection form
Mine fan daily inspection
Overhauled equipment performance report
Maintenance shift report summary
Equipment maintenance work sheet
Monthly report of equipment overhauled
Equipment location and repair case history record
Summary of work accomplished
Electric motor or armature repair, case history record
Daily report of units or major parts changed on equipment
Equipment overhaul - monthly report of jobs completed
Daily record of breakdown or delay repairs and shop work assignments
Summary report of operating shifts, maintenance labor, and equipment delays
Record of equipment overhaul dates and place of overhaul
Personal data record
Daily safety inspection report
Factors for safety program appraisal
Record of air measurements

Some existing forms need to be revised to incorporate data unique to the inert gas mining operations and new forms need to be developed solely because of the new method of mining. Examples of such data records are as follows:

Miner's acknowledgement sheet on safety procedures instruction - a form exists for standard mining practices but a new one should be developed to incorporate new requirements imposed by inert gas atmosphere mining operations (i.e. instruction in use of the suit, breathing apparatus, lock procedures, etc.)

Check sheet for safety program appraisal.

Check sheet for breathing system operation - new form required.

Foreman's injury report - a standard form already in use should be modified to include the cause of injury; injury caused by equipment, breathing system, or suit failure and the nature of the failure; psychologically caused injury date, time, and location of site at which injury occurred.

Medical report forms - reporting all physical examinations performed.

Medical report summary form - for weekly or monthly comparison of the major physical data on each person (i.e., respiration rate, blood pressure, weight, etc.).

Supervisor's rating sheet - a new form should be developed to evaluate the inert mine operations (i.e. actual inert gas mine productivity versus anticipated, and as compared to standard operations).

SECTION XIII

SAFETY

Of paramount importance at any mine site is the safety of the personnel who work there; consequently, the effective planning and implementation of safety procedures in the mine as well as for operation of the external systems and facilities are a principle concern. Island Creek Coal Company, Department of Safety, for example has a proven program to keep in step with modern mining practices and the regulations of the state mining authorities. The personnel at the proposed demonstration mine site must be expected to make safety the first consideration.

General Safety Rules

1. No persons other than specified personnel on duty or other authorized persons may be permitted to enter the proposed demonstration mine or buildings or adjacent premises unless properly authorized by the Project Director.

2. Good housekeeping must be practiced in and around the mine.

3. All personnel upon entering the mine must go direct to their working position and no person may loiter in or about the mine.

4. Personnel must not tamper with any door, regulator or stopping used for atmosphere control or with any machinery or equipment in or about the mine except in the discharge of his duty.

5. Personnel must not ride on timber or other supply trucks. No one may ride on top of tractor or in shuttle cars.

Handling of Explosives and Blasting

1. No hole may be charged or fired in any place where an explosive gas mixture can be detected.

2. Only clay or other non-combustible or approved material may be used for stemming, and the drill holes must be stemmed according to law.

3. Proper warning must be given by the shotfirer when shots are to be fired, by calling out "FIRE" three times about ten (10) seconds apart. All entrances to places being blasted and to the adjacent place when a breakthrough is being blasted must be vacated and no one may be permitted to enter until blasting operation is completed. The shotfirer must see that these safety precautions are taken.

Machinemen and Drillers

1. Machinemen and drillmen upon entering a working place must bring their machine to a complete stop outby the last open breakthrough and it must not be moved again until a thorough examination has been made of the area inby that point for loose coal and bad roof. Additional examinations at frequent intervals (at least every 20 minutes) must be made while the machine and drills are operating in the face area.

2. The reverse lever on the controller must be set at neutral and the brakes tightly set when mining machines and drills are not tramming and when parked at working faces.

3. Miner or loader operators, machinemen and drillmen must use every precaution when tramming to prevent injuries to themselves and collision with other equipment.

4. The bit clutch must be disengaged and the cutter chain or cutter ring locked with a safety bit guard or other suitable device designed for this purpose, when the machine is being trammed or is parked.

5. The front bits must be removed from the cutter bar of the cutting machines or it must be guarded while tramming.

Miner and Loading Machine Operators

1. Extreme care must be used in moving machines from place to place. The operator must keep his conveyor boom in such position as to prevent knocking out timbers or contacting power or communications lines. Machines must not be trammed from place to place with gathering head of conveyors in motion and safety chains must be used on the gathering arms of loading machines and cutter rings of miners. Reflectors or lights must be installed on the rear of such machines.

2. Unauthorized personnel must not be permitted at the working face while machines are in operation.

3. No person may stand along the side of the boom while it is in operation.

4. Miner helpers or other persons must not work or stand at the face in front of or near the gathering head when loading or other mobile machines are operating unless in full view of operator.

5. The operators must not leave the controls while the miner or the loading machine is in operation or in motion, and they must give every consideration to the safety of other persons when loading and unloading cable.

6. The operator or other designated person must test the roof between car changes and when working ahead of permanent roof supports (where temporary supports are used) using a testing bar or other approved device provided for that purpose.

Timbermen - Roofbolters

1. It must be the duty of each roofbolter, timberman and helper to make a careful examination of the roof and surrounding conditions before beginning work in any place, and do that which is necessary to make the place safe. Safety posts or jacks must be used during bolting operations.

2. Safety posts or jacks must be used where bolts are used for roof support during cutting, drilling, blasting and loading operations if the employees have to go beyond the last permanent timber or roof support.

3. A danger sign must be put up if a place is left in an unsafe condition and the place is not completely bolted or timbered by the end of the shift.

Outside Facilities

1. All outside personnel must observe all precautions to insure safety to himself and all other persons.

2. All outside men must see that their working tools are kept in a safe condition.

Since a mine planned for oxygen free operation should be constructed initially using normal air ventilating techniques, all current safety and fire regulations including the foregoing would have to apply to the mine during that period. Nonflammable hydraulic fluids, fire resistant belts, and fire sensors should be used on the belt conveyor and all other requirements of the Federal Coal Mine Health and Safety Act of 1969 should be applied to the mine at least for the period of initial air operation. Chemical fire extinguishers should be available at the working face, on each piece of mining equipment, on permanent electrical installations, temporary electrical installations, and at the refuge station. In addition, a water line should be run parallel to the belt conveyor to the loading point and fire hoses should be provided according to the Health and Safety Act. In addition, a water reservoir of approximately 3,000 gallons should be maintained as a water supply source for the water system for emergency use.

During the period of purging a mine with an oxygen free atmosphere, there should be no personnel within the mine proper. No person should be sent into the mine until the gas quality monitors within the mine indicated that the mine had been purged and that the oxygen concentration was below that able to support combustion.

The proposed mine design recommends the circulation of the gas within the mine for cooling and dust control. The mine ventilating fan should be used to recirculate this air and the necessary stoppings erected to direct the inlet air flow to the working face. This design should provide the necessary air currents for cooling and dust removal at the working face. The ventilation passage also could provide an emergency escape route that could be rapidly purged with outside air should there be an emergency that would require such action. All outside dampers and explosion doors should be constructed in such a manner as to be able to provide fresh air to the mine in a minimum amount of time. Should an emergency develop requiring such action, all power to mine should be shut off externally except that required to operate the ventilating fan.

Before entering a mine in an oxygen free atmosphere all life support equipment must be checked out by the miner following a prescribed check list. He must check to make sure that a new CO_2 canister has been installed and that his oxygen bottle is full. Once he has dressed in his suit he must check the suit for pressure tightness. Following this he must test the oxygen module of the rebreather to see that it is functioning properly and that he is getting an adequate breathing supply. During this latter checkout, the oxygen module should be connected to a fixed chiller module provided in the checkout room. Gas quality monitors must be used to check on the performance of the complete system after a 5 minute or so test operating period.

In the mine entrance gas locks and in the refuge station the doors of the gas locks must be mechanically interlocked so that both doors cannot be opened at the same time. Also, a combustible gas indicator should be located in the gas locks that would indicate whether it was safe to proceed from the gas lock into the refuge station. The inside of the gas lock must be coated with a non-sparking coating. If the gas locks are performing properly, there should be no possibility of a combustible oxygen-methane mixture occurring. As a precaution, however, these non-sparking features must be incorporated.

Oxygen can enter the sealed mine in the battery compartments, wiring conduit and motors of that equipment routinely entering and leaving the mine. All conduit on this equipment must be purged with nitrogen and sealed to maintain a nitrogen atmosphere in the conduit or purged with nitrogen each time it transits the locks. All motors likewise must be gas tight and be purged with nitrogen prior to completing the gas seal or purged each time as above. Every effort must be made to prevent oxygen from entering the mine, or in the case of a methane mine, of methane from leaving the mine in the void spaces in electrical equipment.

A 3,000 gallon storage tank or water reservoir must be maintained as a supply for the water distribution and fire prevention system. A gasoline driven water pump should be incorporated so as to provide for fire protection in the event of power failure.

With the exception of the refuge station and the resuscitators all of the safety items to be incorporated for the sealed mine should follow standard practice for an air ventilated mine in compliance with the Federal Health and Safety Act of 1969.

The emergency treatment and removal of injured personnel from an inert gas blanketed mine requires somewhat different procedures than currently being used in air ventilated mines. The major concern is that of keeping the injured man supplied with oxygen during emergency conditions. In the case of a full scale mine operating under these conditions, the injured personnel would be taken to the refuge station for emergency treatment should immediate transportation by personnel carriers not be available.

In the proposed demonstration mine since it would be of limited size, it would probably be more expeditious to remove the injured from the mine directly.

In all cases of serious injury within a sealed mine, it can be assumed that the life support system would have been ruptured. The first action therefore should be to see that the injured man has a supply of oxygen; the next action should be to control any bleeding that may be taking place.

If the injured man is conscious, he should be able to use his emergency breathing system until assistance can arrive. Mine personnel upon observing the extent of injury should make the decision as whether the injured man can be safely moved to either the refuge or out of the mine while continuing to use the emergency breathing apparatus. If there is danger in removal while on the emergency systems, the resuscitator should be secured from the nearest source. The helmet should be removed from the injured miner, and the resuscitator applied. The latter will supply breathing oxygen for the man without requiring any extra effort from him. First aid treatment should then be given and the injured man removed from the mine.

Since shock is one of the major problems in case of accident, it is essential to keep an injured victim warm; it is also important under the conditions in a sealed mine that the injured man be placed on a resuscitator as quickly as possible. The gas tight garment and underwear will permit the retention of body heat and assist in keeping the man warm prior to his removal from the mine.

In the case of an injury where the man is trapped for an extended period of time, it is essential that the rescue or aid party sees that an adequate supply of oxygen is available for the injured party. It is necessary, therefore, for all miners to know the time limits of all resuscitators and other equipment used for this emergency work and that emergency oxygen bottles for replacement be available in the refuge station.

In case the injured is unconscious, the helmet should remain on until the resuscitator has been secured and brought to the location. There are several minutes of breathing atmosphere in the helmet and suit. As soon as the resuscitator is brought to the scene and readied for application, the helmet should be removed from the injured party and the resuscitator applied. The resuscitator should be of such a type that it will supply a positive oxygen pressure to the individual in a rhythmic fashion so as to simulate the normal breathing cycle, the resuscitator should supply only the oxygen required and act as a demand breathing system.

It is not anticipated that specialized equipment beyond that currently being used for mine rescue and safety work covered be required for the oxygen free mine, with the possible exception of the resuscitator. The major difference would be the location of this emergency equipment. All emergency equipment must be readily available in the vicinity of the refuge station in the mine. Without having to enter the refuge station, additional units should be located in the electrical substation, and in the boss cars. Spare oxygen bottles for the resuscitators and as well as spare emergency equipment should be kept in the refuge station.

The resuscitator recommended is the MSA-Special Portable Resuscitator. It weighs 45 pounds and contains 40 cubic feet of oxygen which should last for 1-1/2 hours. In an emergency, 2 men could be supplied with oxygen. This unit supplies forced ventilation when breathing has stopped, however, when normal breathing resumes, it supplies oxygen on demand.

SECTION XIV

PROJECTED MINING COSTS

On the basis that the projected production costs for the suits and life support units are approximately correct as previously discussed and further that the productivity of the miner will not change substantially, estimates can be made of the added capital cost of placing a deep coal mine in an oxygen free atmosphere and of the added cost of operation under such conditions.

A 5,000 ton per day deep coal mine with conventional equipment is a reasonable size to use as an example. Five operating sections with a total two shift per day work force of 180 men appears typical for such a mine. In calculating nitrogen gas requirements in the case of a nitrogen blanketed mine, a 1,000 acre mined area (pillars remaining) is a satisfactory basis. A gas production of 15×10^6 cubic feet per day is reasonable if it is a gassy deep mine of this size.

Table 2 shows the estimated effect of oxygen free atmosphere on the average cost of construction of the 5,000 ton/day mine. No credit was taken for capital cost increases in an air ventilated mine that may be required to meet the conditions of the new Mine Health and Safety Act. The cost for inert gas (nitrogen) generation and storage would include the gas compression facility in the case of the gassy mine.

The estimated operating costs are shown in Table 3. In this instance, no effort was made to list those costs that remain the same whether in air or in inert gas.

It is important to note that the added depreciation and interest on the additional capital constitutes the major portion of the increased costs of operation under an oxygen free atmosphere. In the absence of natural gas recovery, the increased operating cost is approximately 3% of the value of the coal produced. This amount may well be offset by the increased costs proposed as associated with the new safety act.

If natural gas can be recovered and sold at $0.30 per thousand at the mine, the impact of this added income is substantial and would obviously offset any reductions in mine efficiency that might occur using the oxygen free atmosphere process.

It is apparent that the oxygen free atmosphere process should be demonstrated to develop firm estimates of capital and operating costs as well as productivity. It is also apparent that the first applications of the process are likely to be in highly gassy deep mines.

TABLE 2

PROJECTED CAPITAL COSTS

Capital Costs Estimate	Normal Air Ventilation	Without Oxygen
Item		
Construction Cost including Mining Equipment, Coal Preparation Facilities, and Site Preparation	$\$10 \times 10^6$	$\$10 \times 10^6$
Non-Permissive Electrical Equipment	-	(300,000)
200 Life Support Suits, with Rebreather and Emergency Pack	-	300,000
200 Communication Units with Headsets	-	300,000
Inert Gas Generation Storage and Distribution	-	500,000
Air Conditioning and Dust Control	-	200,000
Refuges	-	100,000
Instrumentation	-	100,000
Net Capital Cost	10.0×10^6	$\$11.2 \times 10^6$

TABLE 3

PROJECTED OPERATING COSTS

Operating Cost Estimate	Dollars/year: Normal Air Ventilation	Dollars/year: Without Oxygen
Item		
Labor Cost @ $50/day Total	2.3×10^6	2.1×10^6
Life Support Systems Maintenance Suits, Packs and Communication	-	0.10×10^6
Life Support Supplies, CO_2 Absorbers, Oxygen, etc.	-	0.2×10^6
Electric Power	0.09×10^6	0.07×10^6
Rock Dust	0.15×10^6	-
Roof Bolts	0.88×10^6	0.88×10^6
Inert Gas, Air Conditioning	-	0.08×10^6
TOTAL	3.42×10^6	3.43×10^6
Depreciation and Interest	1.6×10^6	1.8×10^6
Sale Value of Coal Produced	7.2×10^6	7.2×10^6
Sale Value of Natural Gas Recovered	-	1.5×10^6

SECTION XV

MINE SITE EVALUATION

The site to be selected for any proposed demonstration mine must be on leases currently available for operation, must be in a virgin seam in which there has been no other actual mining activity surface or deep in the part of the seam to be used, a minimum of 50" of seam height to allow reasonably uncramped operation, a seam outcropping above grade so as to allow drift entries, a non-gassy seam, and an active mine with working entries within a reasonable distance so that coal handling facilities, haulage, utilities and roads may be shared. In addition, a good probability of producing acid mine drainage during operation should exist.

Three leases, Red Jacket, Rock House, and Pond Fork, all within a radius of Holden, West Virginia, belonging to Island Creek Coal Company, met with the stated requirements for the proposed demonstration mine site. Field water samples were analyzed and laboratory column tests were run on samples of refuse from the adjacent active mines.

One site is located in the drainage area of the Kanawha River Basin in Boone County, West Virginia. The other two sites are located in the drainage area of the Big Sandy River watershed. All three sites are located as shown in Figure 15.

Both watersheds lie in the geographical ridge areas designated as the Appalachian Plateau and Valley Ridge Provinces. The region is geologically characterized by anticlines and synclines with an associated Pennsylvanian type Paleozoic rock classification. The general area contains great thicknesses of sandstone and shale and some limestone beds. As a result of such rock structure, coal is found in abundance and a moderately large groundwater supply is available.

The specific watershed of the first proposed site is the Price Branch of Pond Fork of the Little Coal River which flows into the Coal River, then to the Kanawha River, and finally to the Ohio River. The Coal River is a lesser tributary of the Kanawha River and is characterized as a natural-flow stream. The junction of the Coal River is below Charleston, West Virginia, along Zone 2 of the Kanawha River. The Kanawha River is the fourth largest

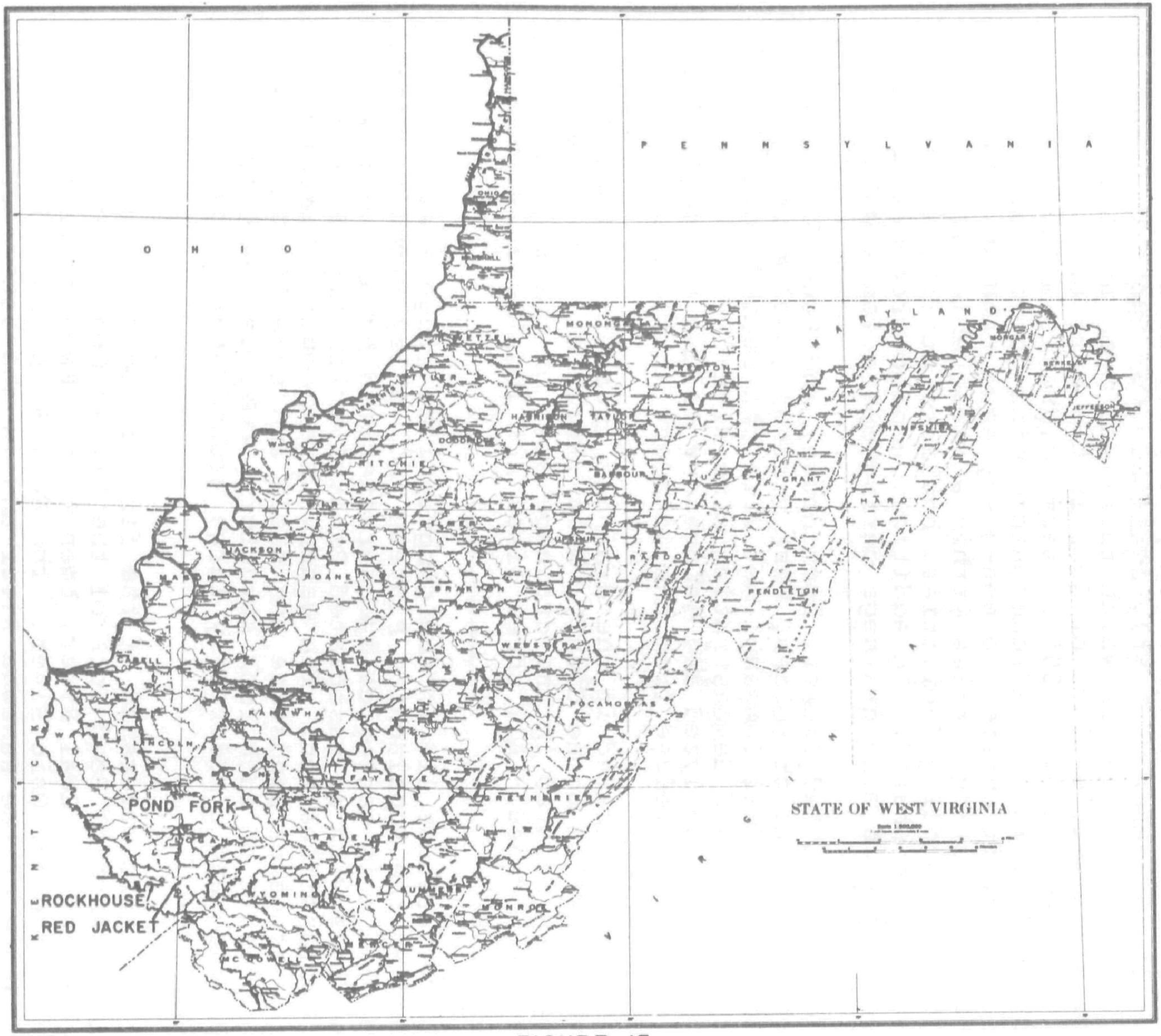


FIGURE 15

WATERSHEDS - KANAWHA AND BIG SANDY RIVERS

tributary to the Ohio River and joins it at Point Pleasant, West Virginia. The Kanawha River and its tributaries drain a 12,240 square mile area, of which 8,470 square miles lie within West Virginia.

The Kanawha River from Charleston to Winfield, including the mouth of the Coal River, is devoid of oxygen during low stream flows in summer.

Very little water quality data for Price Branch of the Pond Fork has been accumulated. Analytical data obtained to date from U. S. Geological Survey published reports is included in Table 4.

The second alternative is the Rock House Fork site near Ragland in Mingo County, West Virginia. The specific watershed of this mine is the Slate Branch of the Rock House Fork of Pigeon Creek. Pigeon Creek flows into the Tug Fork of the Big Sandy River, which finally flows into the Ohio River.

The third alternative is the Mate Creek site near Red Jacket in Mingo County, West Virginia. The specific watershed of this mine is the Pats Branch of Mate Creek. Mate Creek flows into the Tug Fork of the Big Sandy River at Matewan, West Virginia which then flows into the Ohio River at Kenova, West Virginia. The Big Sandy River drains an area of 4,280 square miles, of which 1,550 are drained by Tug Fork.

Again, very little water quality data has been accumulated for the Slate Branch of Rock House Fork, Rock House Fork of Pigeon Creek, Pats Branch of Mate Creek or Mate Creek. Analytical data obtained to date from U. S. Geological Survey published reports on Tug Fork, Pigeon Creek, and the Big Sandy River is included in Table 5.

The Pond Fork site would remove coal from the Dorothy seam. The true Dorothy seam is a member of the Kanawha Group, a series of coal seams which have been and are now mined in Boone County, West Virginia. The Kanawha Group seams lie below the Freeport seams of the Allegheny Series and include from the top:

No. 5 Block
Coalburg
Winifrede
Chilton
Hernshaw
Island Creek
Alma

TABLE 4

KANAWHA RIVER BASIN

Stream Sampling Site and Drainage Area, in Sq. Mi. (in Parenthesis)	Date	Water Discharge (cfs)	pH	Aluminum (Al)	Total Iron (Fe)	Total Manganese (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Sp. Cond. (micromhos at 25°C)	pH
Cherry River at Fenwick, W. Va. (287)	05-20-65	72	7.4	0.1	0.09	0.03	17	17	75	7.4
Meadow River at Mallen, W. Va. (287)	05-20-65	107	7.3	.1	.07	.03	27	27	115	7.2
Kanawha River at Kanawha Falls, W. Va. (8,367)	05-20-65	5,070	7.4	.1	.06	.00	55	17	138	7.2
Loop Creek at Robson, W. Va. (42.3)	05-20-65	14.7	6.9	.1	.02	.82	20	368	762	7.1
Elk River at Queen Shoals, W. Va. (1,147)	05-19-65	287	7.2	.0	.05	.00	20	18	84	7.2
Marsh Fork at Edwight, W. Va. (128)	05-17-65	64.9	7.6	.2	.02	.17	53	114	360	7.6
Pond Fork at Madison, W. Va. (138)	05-17-65	64.3	7.3	.1	.03	.32	24	201	490	7.2
Little Coal River at Danville, W. Va. (270)	05-17-65	117	7.2	.1	.04	.21	31	188	485	6.7
Big Coal River at Ashford, W. Va. (393)	05-17-65	153	6.9	.1	.03	.05	30	116	331	7.2

SOURCE: Biesiecker, J. E., and J. R. George, Stream Quality in Appalachia as Related to Coal-Mine Drainage, 1965, Geological Survey Circular 526, Washington, 1966.

TABLE 5

BIG SANDY RIVER BASIN

Stream Sampling Site and Drainage Area, in Sq. Mi. (in Parenthesis)	Date	Water Discharge (cfs)	pH	Aluminum (Al)	Total Iron (Fe)	Total Manganese (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Sp. Cond. (micromhos at 25°C)	pH
Tug Fork at Roderfield, W. Va. (208)	05-21-65	558	7.2	0.1	0.10	0.00	105	77	351	7.3
Dry Fork at Laeger, W. Va. (228)	05-21-65	130	6.8	.1	.08	.02	231	68	580	7.8
Pigeon Creek at Naugatuck W. Va. (142)	05-21-65	26.6	7.2	.0	.08	.12	55	334	843	7.1
Tug Fork near Kermit, W. Va. (1,185)	05-21-65	468	8.0	.2	.18	.03	188	165	690	7.8
Rockcastle Creek at Clifford, Ky. (121)	05-21-65	23.9	7.2	0.0	0.22	0.05	30	18	165	6.8
Russell Fork at Elkhorn City, Ky. (554)	05-20-65	900	6.8	3.1	.06	.01	26	30	120	6.9
Levisa Fork at Fishtrap, Ky. (386)	05-20-65	157	7.2	.1	.07	.00	50	173	471	7.3
Shelby Creek at Shelbiana, Ky. (110)	05-20-65	76.8	7.4	.1	.04	.00	70	91	324	7.3
Beaver Creek at Martin, Ky. (228)	05-20-65	138	7.4	.1	.08	.16	62	104	359	7.0
Johns Creek near Van Lear, Ky. (206)	05-19-65	27	7.4	.1	.15	.00	18	16	85	7.4

SOURCE: Biesiecker, J. E., and J. R. George, Stream Quality in Appalachia as Related to Coal-Mine Drainage, 1965, Geological Survey Circular 526, Washington, 1966.

No. 2 Gas
Powellton
Eagle
Douglas

There is a good deal of discrepancy in the existing literature regarding the Dorothy seam. According to Mr. Paul Price, who is a retired consultant formerly with the West Virginia Geological Survey, the Dorothy is a premium seam and is actually a split from the Winifrede seam. Because of its high quality (0.6% S) and its attractive reputation and market potential, small operators in the area sold coal from less desirable seams, such as possibly the No. 5 Block, as being Dorothy coal. Additionally, very little attention was paid by operators in actually identifying specific seams. The Pond Fork mine seam is probably from the Coalburg strata or a split therefrom. Both alternative sites also remove coal from the Coalburg strata.

Examination of the diamond drill hole logs for the three sites shows that no pyrites were identified in the log of Pond Fork whereas some pyrites were located 85 feet above the Coalburg seam for Rock House Fork. Pyrite is also often concentrated in binders, sulfurballs, lenses, clays, shales, and rider coal bands located in as well as immediately above coal seams. Laboratory analyses of samples of binders, sulfurballs, and lenses indicate that these materials are often high in pyrite, occasionally as high as 94% pyrite(12). Quantitative analyses indicate that different strata vary a good deal in total sulfur content(13). Analyses of several strata follow:

Source	Total Sulfur	Pyritic and Sulfate Sulfur	Sulfate Sulfur
First Draw Slate	0.92	0.83	-
First Rider Coal	5.87, 6.41	5.32	0.51
Second Draw Slate	0.71	0.68	-
Bone	0.54	-	-
Third Rider Coal	8.55	7.97	2.43

Predicting whether any new coal mine will produce an acidic water discharge during mining is risky. The drill logs of the three sets as mentioned show minimal pyrites but also a minimum of limestone above the coal. The Dorothy seam is low in sulfur but has not been extensively mined in the areas concerned. The information available from the drilling and other records, and from communication with the West Virginia Department of Natural Resources, indicates a better than even chance that mining at either of the three sites will eventually produce acid drainage.

Mine Drainage Quality - Published Data

Significant mine drainage pollution occurs in both the Coal River and the Little Coal River (Pond Fork site). The 1969 Revision of "Stream Pollution by Coal Mine Drainage in Appalachia," U.S.D.I., FWPCA, Cincinnati, Ohio[13], states that the entire 52 miles of Little Coal River and the entire 96 miles of its tributaries are continuously polluted by mine drainage. Sulfate concentrations in excess of 250 mg/l are frequently encountered in the Coal River watershed.

Although no specific data on the quality of drainage from Dorothy seam mines has been uncovered, some data (as early as 1934) was presented on other seams than being mined in Boone County.

Acreage of West Virginia Coal
Seams in Boone County - % Composition

	Acreage	% Sulfur	Acidity	Lbs./Day Acid
Lower Kittanning	37,152	1.33	200	1,500
Stockton	57,632	0.86	250	68
Coalburg	54,598	0.80	350	11,750
Winifrede	163,968	0.65	100	745
Chilton	148,544	0.75	Alk	
Hernshaw	208,000	3.13	Alk	
Williamson	12,800	1.82	NR	NR
Cedar Grove	238,592	0.61	500	1,260
Alma	253,056	1.32	3,500	27,100
No. 2 Gas	230,016	1.51	NR	NR
Powellton	19,200	0.97	NR	NR
Eagle	19,200	0.86	NR	NR

NR - Not Reported

It was further reported[14] in 1954, that the following seams (known to be mined in Boone County) contained acidity as ppm $CaCO_3$:

Seam	ppm Acidity as $CaCO_3$
No. 5 Block - Kanawha	500
Coalburg - Fayette	350
Winifrede - Mingo	100

Seam		ppm Acidity as $CaCO_3$
Alma	- Logan	3,500
No. 2 Gas	- Kanawha	800

Many parts of the Kanawha Basin produce mine discharges which are alkaline rather than acidic, due to the presence of limestone or other alkaline deposits in the area. The important indication of pyritic oxidation, however, is the sulfate ion, which is incompletely or not reduced by such neutralization processes.

It has been estimated(13) that approximately 500 miles of streams in the Big Sandy River Basin (sites of Rock House and Red Jacket) are polluted by coal mine drainage or activities related to coal mining. The tributaries of Tug Fork are apparently the most seriously affected with an estimated 58 miles of streams continuously polluted by mine drainage. Although these streams are, for the most part, highly mineralized and often contain fine coal and silt, they are not generally characterized by high acidity concentrations. The Tug Fork and Big Sandy River watersheds reflect the influence of mine drainage in total mineralization and high sulfate, iron and manganese concentrations.

In 1936(14), it was estimated that the drainage from an average West Virginia coal mine amounted to approximately 1,000 gallons per acre per day. Using this information along with the alkalinity-acidity determinations, the following table of quantities of drainage and acid produced were calculated:

Coal Mine Drainage in West Virginia
and Acid Produced by Seams

Seam	Drainage (Gals. per Day)	Acid (Lbs. per Day)
Sewickley	6,135,000	234,056
Redstone	2,684,000	26,204
Pittsburgh	50,228,000	1,304,956
Bakerstown	3,106,000	6,228
Upper Freeport	12,824,000	368,414

Coal Mine Drainage in West Virginia
and Acid Produced by Seams (Cont'd)

Seam	Drainage (Gals. per Day)	Acid (Lbs. per Day)
Upper Kittanning	1,789,000	16,370
Lower Kittanning	11,653,000	35,569
Stockton	1,468,000	2,988
Coalburg	7,870,000	34,649
Winifrede	13,777,000	11,248
Cedar Grove	28,583,000	654,410
Alma	9,992,000	108,220
Sewell	18,240,000	72,515
Total	168,349,000	2,875,827

SOURCE: Herndon, L. K., and W. W. Hodge, Coal Seams of West Virginia and Their Drainage, Proc. West Virginia Academy of Science, Vol. 9, pp. 39-61, Feb., 1936.

Coal Mine Drainage in West Virginia and
Acid Produced by Watersheds

Watersheds	Drainage (Gals. per Day)	Acid (Lbs. per Day)
Monongahela	61,898,000	1,755,064
Ohio	11,592,000	177,879
Kanawha	48,289,000	157,363
Guyandotte	31,775,000	711,426
Tug - Big Sandy	11,511,000	53,470
Potomac	3,284,000	20,625
Total	168,349,000	2,875,827

SOURCE: Herndon, L. K., and W. W. Hodge, Coal Seams of West Virginia and Their Drainage, Proc. West Virginia Academy of Science, Vol. 9, pp. 39-61, Feb., 1936.

Using these drainage and acid figures, and assuming that the operations in the different seams would continue at the same rate, the following was calculated for the annual increase in acid production:

Estimated Annual Increase in Coal Mine Drainage from Principal Acid Producing Seams and Acid Production in West Virginia

Seam	Acreage	Drainage (Gals. per Day)	Acid (Lbs. per Day)
Sewickley	378	378,000	15,800
Redstone	50	50,000	48
Pittsburgh	2,200	2,200,000	62,000
Bakerstown	21	21,000	43
Upper Freeport	163	163,000	6,640
Upper Kittanning	19	19,000	77
Lower Kittanning	545	545,000	2,220
Stockton	21	21,000	43
Coalburg	118	118,000	396
Winifrede	478	478,000	390
Cedar Grove	2,510	2,510,000	71,800
Alma	293	293,000	8,370
Sewell	2,040	2,040,000	8,300
Total	8,836	8,836,000	176,127

SOURCE: Herndon, L. K., and W. W. Hodge, Coal Seams of West Virginia and Their Drainage, Proc. West Virginia Academy of Science, Vol. 9, pp. 39-61, Feb., 1936.

Another study[15] completed in 1954, confirmed the acidity of drainage reported from the Coalburg seam; however, it has also been pointed out that all of the coal seams in this area also produce alkaline drainage and some do so predominantly.

Mine Drainage Quality - Field and Laboratory Studies

Samples of mine drainage were collected from the three proposed sites during the period October, 1969 - February, 1970. In addition, samples of coal refuse from mines in the area of the three sites were collected for column studies in the laboratory. The results of the analysis of the field samples are shown in Tables 6, 7, and 8.

TABLE 6

FIELD SAMPLE
POND FORK MINE DISCHARGE (SITE D)

Date Sampled	Nov. 26	Dec. 12	Jan. 5	Jan. 15	Feb. 23
M.O. Alkalinity ($CaCO_3$)	202	34	28	12	10
Total Acidity ($CaCO_3$)	8	18	8	2	4
Chloride (Cl)	17	12.1	14.5	14.0	17.0
Sp. Conductance (25°C) mmhos	405	140	125	101	97
pH	7.7	6.3	6.7	6.2	6.3
Calcium (Ca)	44.2	12.8	6.8	7.0	6.0
Magnesium (Mg)	23.5	11.5	7.2	5.0	6.0
Hardness ($CaCO_3$)	208	80	46	38	40
Sulfate (SO_4)		27.5	28.1	46.9	28.6
Total Iron (Fe)	0.47	5.62	0.74	0.61	0.42
Total Aluminum (Al)	0.26	0.49	0.03	0.58	0.60
Manganese (Mn)	0.05	0.05	0.05	0.07	0.06

TABLE 7

FIELD SAMPLE
ROCK HOUSE MINE DISCHARGE (SITE E)

Date Sampled	Nov. 26	Dec. 12	Jan. 5
M.O. Alkalinity ($CaCO_3$)	62	74	68
Total Acidity ($CaCO_3$)	3	12	10
Chloride (Cl)	13.0	12.1	15.8
Sp. Conductance (25°C) mmhos	225	250	235
pH	7.8	6.8	6.9
Calcium (Ca)	19.2	27.2	23.0
Magnesium (Mg)	13.4	12.5	11.5
Hardness ($CaCO_3$)	104	120	106
Sulfate (SO_4)		44.5	39.7
Total Iron (Fe)	1.33	8.45	0.14
Total Aluminum (Al)	0.92	0.06	0.13
Manganese (Mn)	0.05	0.05	0.06

TABLE 8

FIELD SAMPLE
RED JACKET MINE DISCHARGE (SITE F)

Date Sampled	Nov. 26	Dec. 12	Jan. 5	Jan. 15	Feb. 23
M.O. Alkalinity ($CaCO_3$)	44	66	68		68
Total Acidity ($CaCO_3$)	6	10	4	6	6
Chloride (Cl)	15.8	15.8	18.2	24.0	20.0
Sp. Conductance (25°C) mmhos	190	215	350	530	290
pH	7.1	7.1	7.3	7.6	7.4
Calcium (Ca)	16.8	30.0	47.0	54.0	27.0
Magnesium (Mg)	6.7	5.8	7.7	25.0	7.0
Hardness ($CaCO_3$)	70	100	150	238	96
Sulfate (SO_4)		34.2	75.0	106.0	53.5
Total Iron (Fe)	0.86	0.32	0.21	0.32	0.59
Total Aluminum (Al)	0.30	0.36	0.01	0.26	0.54
Manganese (Mn)	0.05	0.05	0.05	0.08	0.05

The coal refuse samples were ground to 8 x 30 mesh and loaded in three columns as shown in Table 9. Analyses of the coal refuse samples is shown in Table 10. The test column flow sheet is shown in Figure 16. Tests for conductivity and pH were made daily on the column effluent. Once per week samples of effluent were collected and analyzed more completely. The results of the weekly analyses are shown in Tables 11, 12, and 13. The results of the daily tests are plotted in Figures 17, 18, and 19. The columns were in operation from November, 1969 through February, 1970.

Summary of Factors

The following are factors affecting a conclusion as to the most desirable site of those examined from a drainage quality viewpoint for a proposed demonstration mine:

1. The Dorothy seam (a split from the Winifrede seam) or the Coalburg seam, while of uncertain identity, geographically speaking, have never been cited as large acid producers even though they are known to produce acid.

2. The presence of limestone deposits in the Kanawha River drainage area lessens the chances of serious acid drainage pollution problems.

3. Although the core samples of the Rock House Fork site definitely indicate the presence of pyritic material, this may well be a local condition and may not exist as a continuous or widespread strata.

4. The absence of limestone or other alkaline material, along with the presence of pyrite in the overburden, might reasonably lead one to believe that any drainage eminating from this Coalburg seam would be of a rather poor quality.

5. Nearby mines, draining into Pond Fork, Price Creek and other streams produce an acidic discharge.

6. The general watershed of both Little Coal River and Coal River are considered to be continuously polluted by drainage from mines. Since many seams are currently under mining operations, and the true Dorothy seam is not completely identified, one might well conclude that existing Dorothy seam mining is now producing an acidic or alkaline drainage high in sulfate content.

7. The laboratory column studies show that the Pond Fork site refuse produces mildly acid drainage while the other

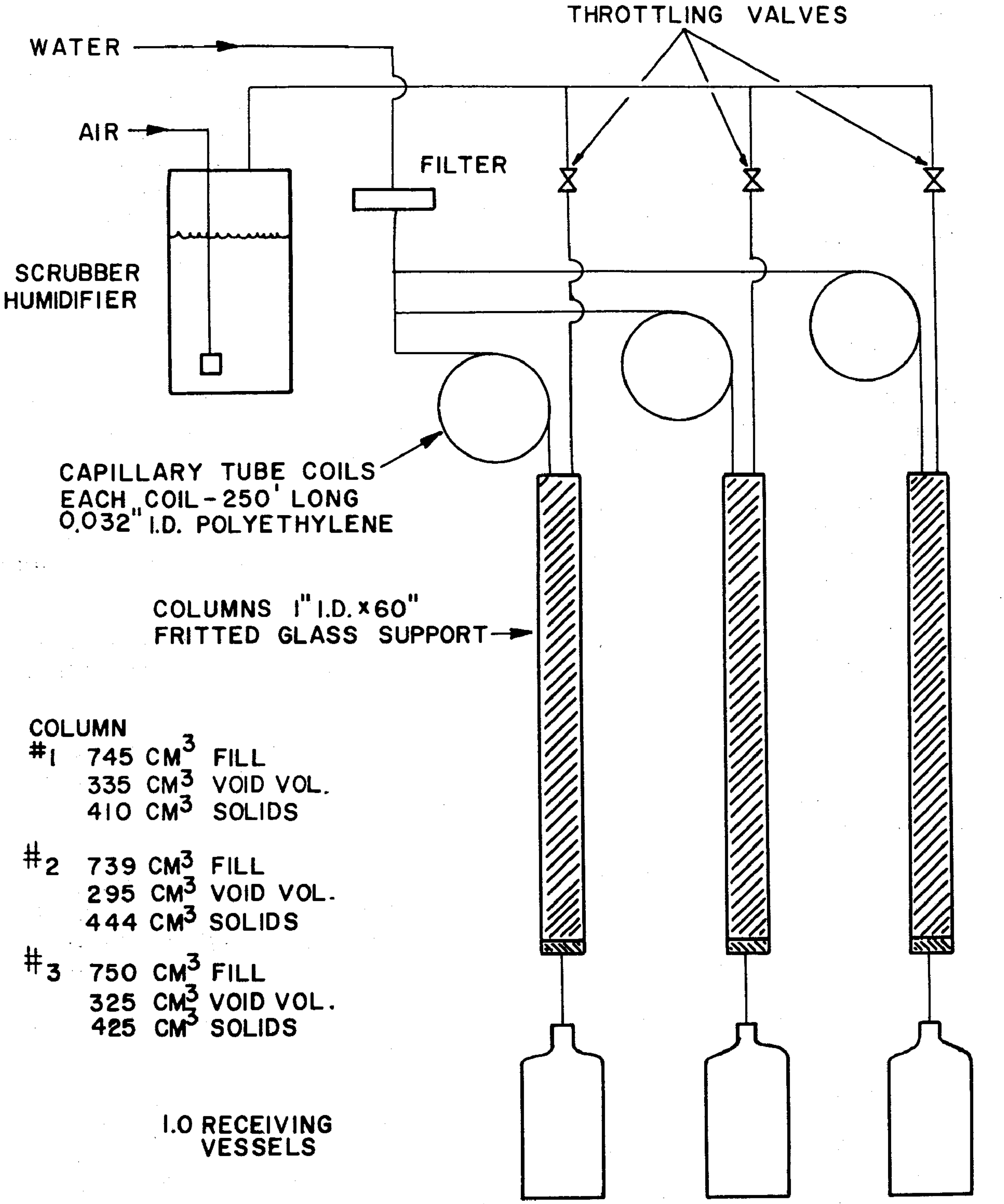


FIGURE 16

TEST COLUMN ARRANGEMENT

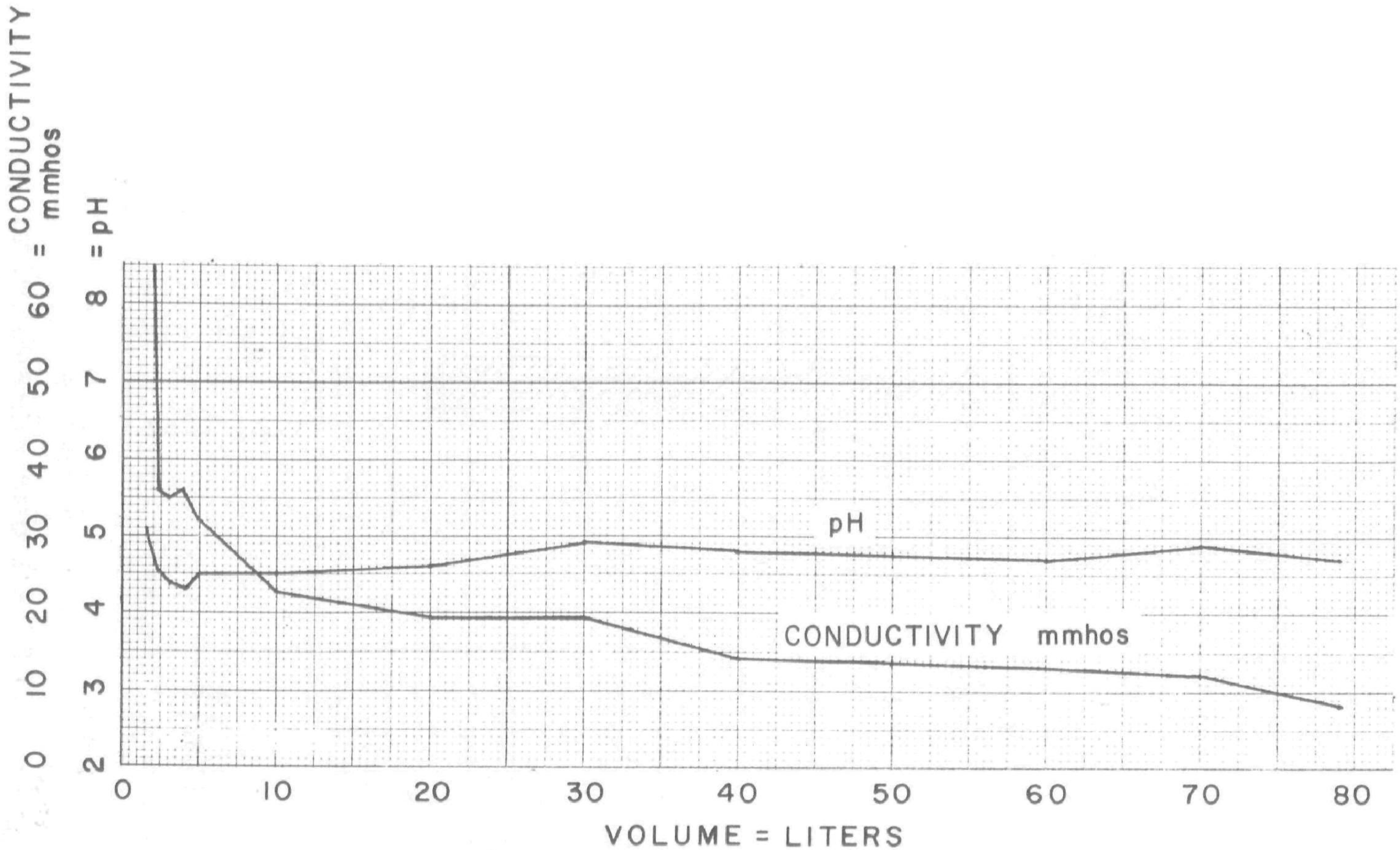


FIGURE 17

REFUSE SAMPLE, POND FORK (SITE G)

COLUMN EFFLUENT

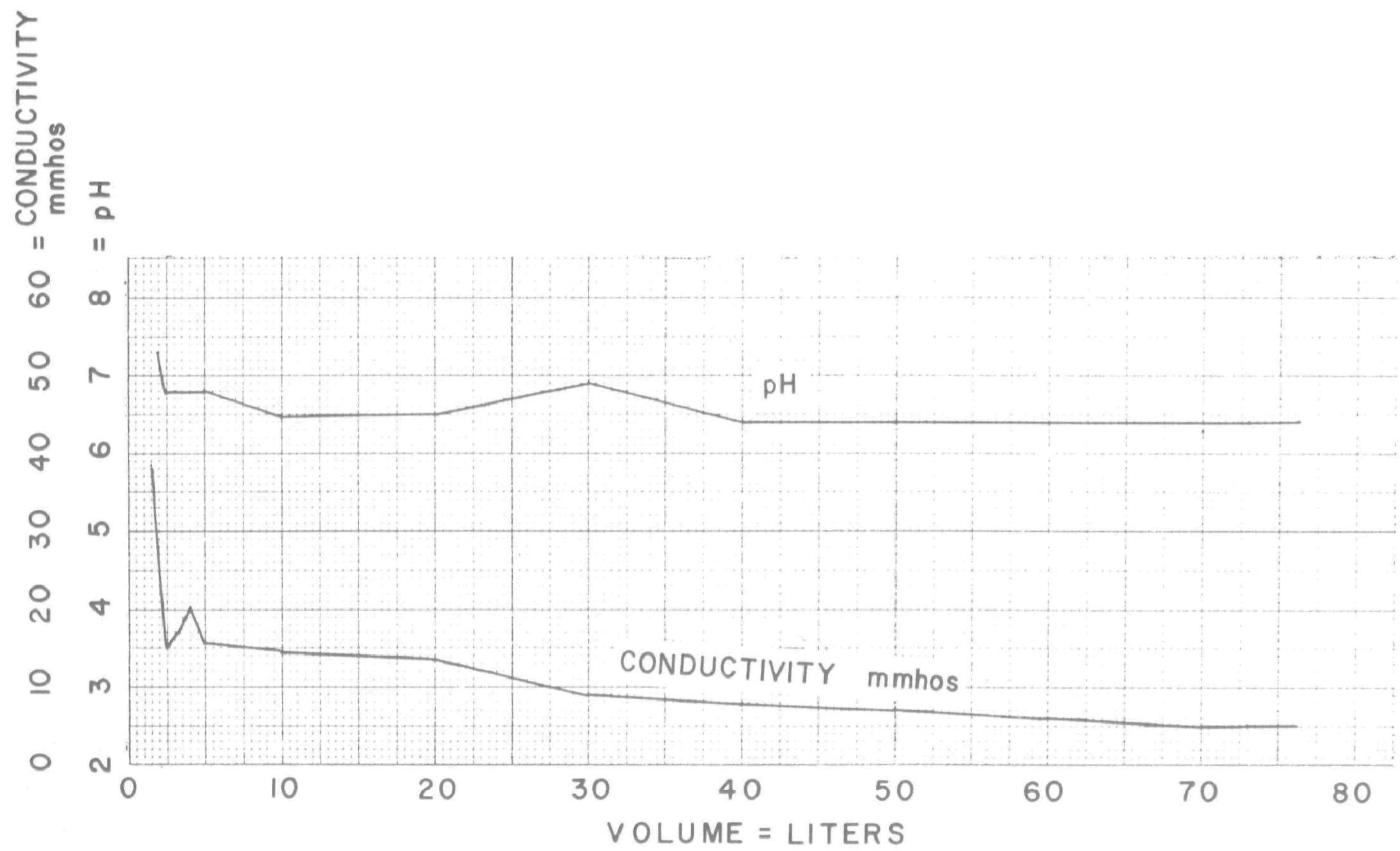


FIGURE 18

REFUSE SAMPLE ROCKHOUSE FORK (SITE H)

COLUMN EFFLUENT

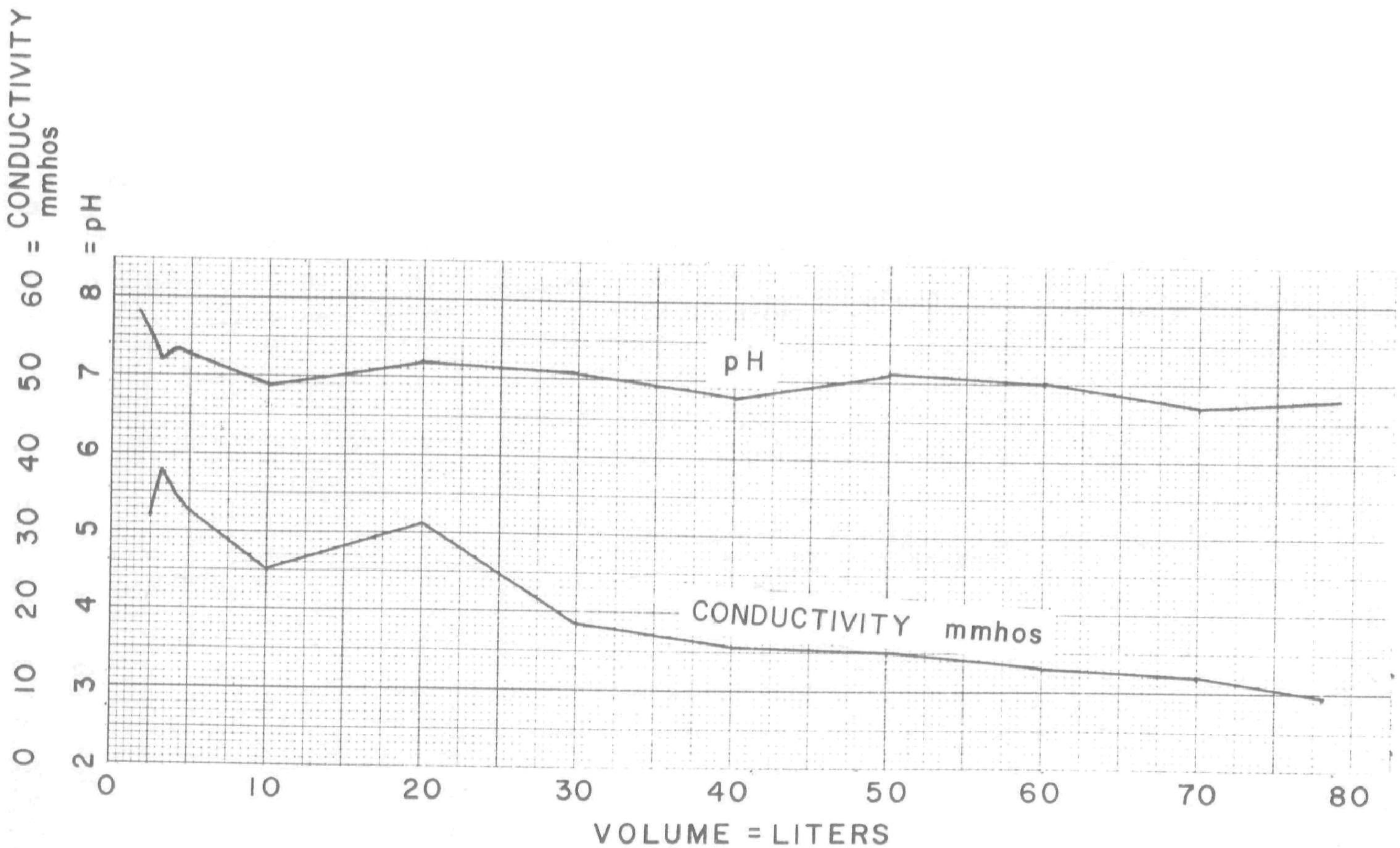


FIGURE 19
REFUSE SAMPLE, RED JACKET (SITE 1)
COLUMN EFFLUENT

TABLE 9

COLUMN TEST CONDITIONS

Columns: 1" (2.54 cm) diam. x 60" (152 cm) with fritted glass support

Loading	Site	
#1	Pond Fork	146.6 cm depth* 745.0 cm^3 fill vol. 335.0 cm^3 void vol. 410.0 cm^3 solids vol.
#2	Rock House	145.4 cm depth* 739.0 cm^3 fill vol. 295.0 cm^3 void vol. 444.0 cm^3 solids
#3	Red Jacket	147.6 cm depth* 750.0 cm^3 fill vol. 325.0 cm^3 void vol. 425.0 cm^3 solids vol.
Water		- demineralized 0.5 - 0.6 cc/min. rate
Air		- water washed and humidified 3.0 - 4.0 cc/min.

*Backwashed and drained

TABLE 10

COAL REFUSE SAMPLES

Items	Pond Fork	Rock House	Red Jacket
Silica (SiO_2)	31	37	32
Iron (Fe_2O_3)	0.5	0.5	0.5
Calcium (CaO)	1	1	1
Magnesium (MgO)	1	1	1
Sulfur (SO_3)	1.0	1	1
Aluminum (Al_2O_3)	11	15	13
Chlorine (Cl)	1	1	1

* * * * *

X-ray Diffraction			
Silicon Dioxide ASTM 12-708	15	15	10
Alpha Quartz ASTM 5-490	15	15	10

Results reported as percent

TABLE 11

POND FORK REFUSE - COLUMN EFFLUENT (SITE G)

	1969-1970														
Date Sampled	Nov. 17	Nov. 24	Dec. 1	Dec. 8	Dec. 15	Dec. 23	Dec. 29	Jan. 6	Jan. 14	Jan. 19	Jan. 26	Feb. 3	Feb. 9	Feb. 16	Feb. 23
Volume, Cumulative liters	2.2	7.9	13.0		21.5	28.8	30.3	38.7	44.8	48.2	53.3	58.9	64.1	69.3	74.2
M.O. Alkalinity ($CaCO_3$)	2.3	2.3	2.0	2.0	4.0	4.0	2.0	2.0	2.0	6.0	2.0	1.0	2.0	6.0	4.0
Total Acidity ($CaCO_3$)	2.0	4.0	2.0	3.0	2.0	2.0	3.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0
Chloride (Cl)	4.0	4.0	13.3	13.3	9.7	12.1	12.1	10.9	14.5	8.0	3.6	10.9	13.3	12.0	13.3
Sp. Conductance (25°C) mmhos	48.1	30.2	21.0	20.0	17.5	16.5	16.0	14.0	20.0	13.0	13.5	13.5	13.0	12.5	7.5
pH	4.7	4.7	4.9	4.5	4.6	4.6	4.7	4.6	4.9	5.5	4.8	4.7	4.6	4.7	6.0
Calcium (Ca)	1.6	0.4	2.0	0.4	1.2	0.2	0.5	0.6	0.2	0.1	0.1	0.2	0.2	0.4	0.4
Magnesium (Mg)	3.8	0.7	0.7	0.8	1.2	0.4	0.4	0.8	0.4	0.4	1.0	0.3	0.2		0.4
Hardness ($CaCO_3$)	19.6	3.9	5.0	4.4	8.0	2.4	2.8	4.6	2.0	1.9	4.4	1.8	1.6		2.8
Sulfate (SO_4)					39.0	18.3	12.2	11.6	8.5	25.6		3.03	2.73	9.17	0.15
Total Iron (Fe)	0.049	0.024	0.020	0.032	0.048	0.061	0.034	0.063	0.019	0.012	0.018	0.005	0.008	0.005	0.005
Total Aluminum (Al)	0.12	0.12	0.020	0.11	0.015	0.071	0.050	<0.01	<0.01	0.018	0.046	0.03	<0.01	0.05	0.04
Manganese (Mn)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<.05	0.06	0.11	<0.05	<0.05	<0.05

TABLE 12

ROCK HOUSE FORK REFUSE - COLUMN EFFLUENT (SITE H)

Date Sampled	1969-1970 Nov. 17	Nov. 24	Dec. 1	Dec. 8	Dec. 15	Dec. 23	Dec. 29	Jan. 6	Jan. 14	Jan. 19	Jan. 26	Feb. 3	Feb. 9	Feb. 16	Feb. 23
Volume, Cumulative liters	2.2	7.8	12.8		21.0	28.1	29.7	36.7	42.8	46.2	51.2	56.9	62.0	67.1	72.1
M.O. Alkalinity ($CaCO_3$)	12.0	4.6	8.0	8.0	6.0	6.0	4.0	4.0	6.0	1.0	4.0	2.0	6.0	2.0	6.0
Total Acidity ($CaCO_3$)	2.0	2.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0
Chloride (Cl)	4.0	4.0	16.9	14.5	13.3	13.3	10.9	13.3	15.6	8.0	2.4	9.7	12.1	12.0	13.3
Sp. Conductance (25°C) mmhos	31.3	23.1	13.0	13.0	11.0	10.0	9.6	8.0	8.0	7.4	8.8	7.0	6.6	6.5	6.0
pH	6.7	6.4	7.1	6.7	6.2	6.7	6.2	6.2	6.5	6.7	6.6	6.3	6.3	6.2	6.5
Calcium (Ca)	0.8	0.4	0.6	0.3	0.5	0.5	0.6	0.5	0.4	<0.1	<0.1	0.2	0.3	0.4	0.4
Magnesium (Mg)	<0.1	<0.1	0.4	0.8	0.4	0.2	0.2	0.2	0.2	0.5	1.6	0.2	0.2		0.1
Hardness ($CaCO_3$)	2.0	0.7	3.2	4.2	3.0	2.0	2.4	2.0	2.0	2.0	6.1	1.4	1.6		1.6
Sulfate (SO_4)					39.0	14.6	8.5	4.9	4.3	19.5	<0.05	<0.05	3.90	<0.05	0.24
Total Iron (Fe)	0.094	0.59	0.040	0.097	0.049	0.034	0.010	0.051	0.011	0.010	0.012	0.008	0.011	0.018	0.014
Total Aluminum (Al)	1.0	1.5	0.14	0.08	0.08	0.13	<0.01	0.07	<0.01	<0.01	0.05	0.07	<0.01	0.03	<0.01
Manganese (Mn)	0.02	0.02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	<0.05	<0.05

TABLE 13

RED JACKET REFUSE - COLUMN EFFLUENT (SITE I)

Date Sampled	Nov. 17	Nov. 24	Dec. 1	Dec. 8	Dec. 15	Dec. 23	Dec. 29	Jan. 6	Jan. 14	Jan. 19	Jan. 26	Feb. 3	Feb. 9	Feb. 16	Feb. 23
	1969-1970														
Volume, Cumulative liters	2.2	8.0	13.0		21.1	28.2	29.8	39.2	45.5	48.9	54.1	59.8	65.7	70.4	76.9
M.O. Alkalinity ($CaCO_3$)	16.0	9.2	14.0	16.0	12.0	10.0	10.0	10.0	8.0	4.0	5.0	8.0	4.0	4.0	8.0
Total Acidity ($CaCO_3$)	2.0	2.0	2.0	2.0	4.0	2.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0	2.0	1.0
Chloride (Cl)	4.0	4.0	15.7	15.8	12.1	13.3	12.1	12.1	14.5	12.0		14.5	13.3	18.0	15.8
Sp. Conductance (25°C) mmhos	52.5	31.7	30.0	29.0	23.0	20.0	20.0	17.0	15.0	15.0	17.0	14.0	14.0	11.3	10.8
pH	7.3	6.7	7.3	7.1	6.6	7.1	6.2	6.5	7.0	7.0	6.9	6.8	6.5	6.9	6.7
Calcium (Ca)	2.4	1.5	2.6	2.1	1.8	2.0	1.9	2.2	1.7	0.8	0.9	1.3	1.2	1.6	1.3
Magnesium (Mg)	1.9	1.0	1.3	1.2	0.9	1.2	0.8	0.4	0.5	1.4	2.2	0.5	0.4		0.3
Hardness ($CaCO_3$)	13.8	7.9	12.0	10.2	8.4	10.0	8.2	7.2	6.4	7.7	11.3	5.4	4.6		4.6
Sulfate (SO_4)					23.2	15.9	14.6	7.3	7.9	31.7	<0.05	<0.05	0.98	5.56	4.6
Total Iron (Fe)	0.040	0.009	0.003	0.020	0.029	0.039	0.013	0.010	0.008	0.009	0.006	0.007	0.009	0.005	0.001
Total Aluminum (Al)	0.18	0.04	0.02	0.06	0.02	0.07	<0.01	<0.01	<0.01	<0.01	0.04	0.08	<0.01	0.02	<0.01
Manganese (Mn)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	0.06	<0.05	<0.05	<0.05

two do not. The Red Jacket effluent was highest in hardness and sulfate.

8. The field samples from the three sites were not acidic and were very similar in overall quality; the pH from Pond Fork was slightly lower than the other two; sulfates were highest in the Red Jacket samples.

9. The refuse analyses showed all three low in sulfur with Pond Fork refuse containing slightly more sulfur than the rest.

Final Selection

The conclusions drawn from the foregoing are that there is better than an even chance that the mine drainage from the Pond Fork site will be mildly acid and that this factor coupled with a favorable position and seam height for the area of the seam that could be used for the test result in the selection of the Pond Fork site for the proposed demonstration mine.

SECTION XVI

EXTERNAL SYSTEMS AND FACILITIES

The proposed demonstration mine if constructed at the selected site would be located near but separate from the Island Creek Coal Company's Pond Fork Mine (See Figure 20). The external facilities while peculiar to the selected site and smaller than those for a full scale mine are typical of the facilities required for an oxygen free atmosphere mine.

Site Preparation

The access road and part of the grading for the demonstration mine site will have been completed by work done in the course of surface mining along the contour by a contract surface miner. The level area available for the outside facilities (Figure 21) will be approximately 125 feet wide and 700 feet long. The face of the high wall over the demonstration mine openings is a sandstone, and the top makes up for good roof control, a very short distance inside the openings.

Power Supply

Power is currently metered at a source about 6000 feet from the demonstration mine openings at twelve (12) KVA. A power line of 12 KVA capacity would be installed and the power conveyed from auxiliary transformers at 4160 volts for use inside the demonstration mine and for the outside associated facilities.

Water Supply

Water would be acquired by drilling a well and pumping the water to a storage tank to supply water for gas generation, inside mine use in the refuge station and use in surface buildings. Should there be a problem of water shortage by well drilling, an alternate water supply is available 6000 feet from the demonstration mine at Island Creek Coal Company's Pond Fork Mine, and could be piped by gravity to the demonstration mine site. The well water would be treated as required for potable usage.

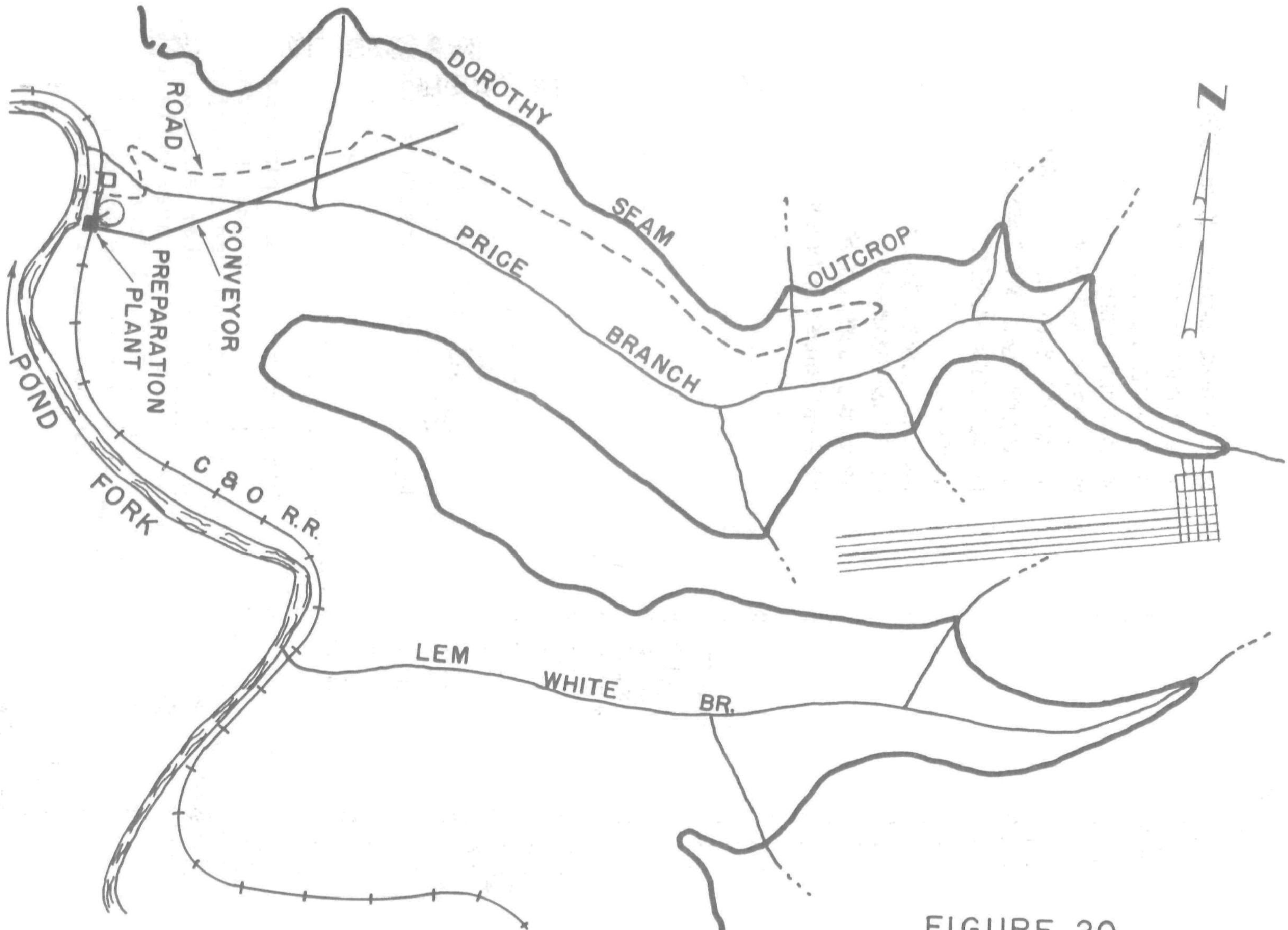


FIGURE 20
MINE LOCATION MAP

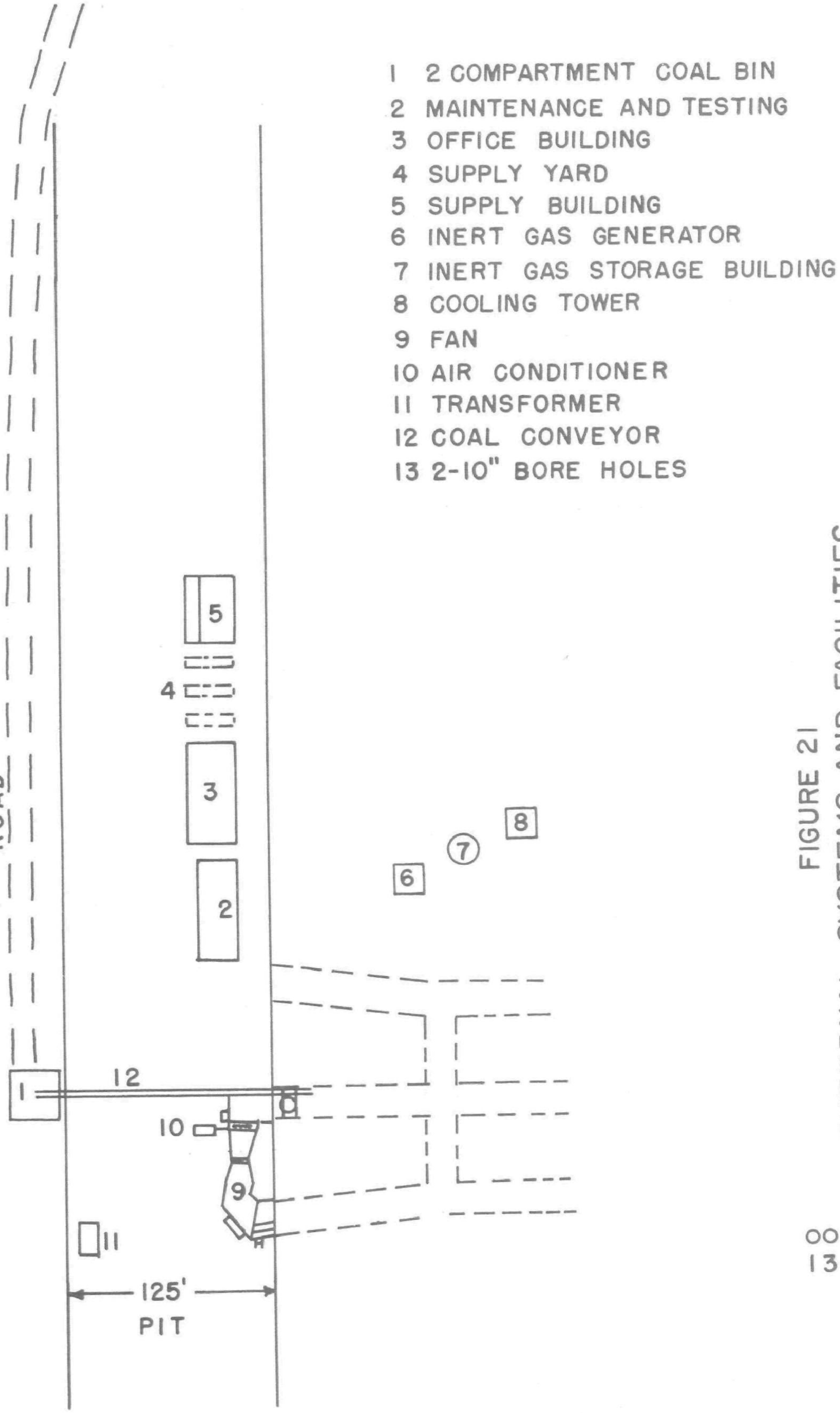


FIGURE 21
EXTERNAL SYSTEMS AND FACILITIES

Office and Control Building

The main office, Figure 21, would be a metal building approximately 60 feet long and 30 feet wide. This building would be partitioned off in areas to accommodate the mine foreman, time clerk, mining engineer, chemical engineer, non-oxygen room for testing suits, study room, room for storing life support equipment, change room with lockers for personal clothes and belongings, and a shower room with toilets and lavatories. This building would be set on a concrete base and trimmed inside with suitable material to accomplish the task demanded of that particular room. Adequate sewage treatment would be an integral part of this building. Heat would be of the baseboard electrical type.

Maintenance and Testing Shop

The shop, Figure 21, would be a metal building 60 feet long by 24 feet wide, and would have the battery charging station as well as the batteries on charge. Batteries would be handled by an overhead traveling crane. Another area, totally enclosed and heated, would act as a repair shop and a training area as well as serve as an area for all types of testing of materials and equipment necessary in the proposed demonstration mine program. Heat in this building would be electrical-blowing space type heaters.

Storage Facilities

Storage for all types of mine supplies, Figure 21, would be housed in a steel building approximately 40 feet long and 20 feet wide with a truck height platform to make unloading of supplies as easy as possible. Bins for different types of supplies would be provided so that easy access is afforded as well as maintenance of an accurate running inventory. Timbers would be stored in rows as shown in Figure 21, in a manner that trucks, delivering these timbers, could back between rows and unload. The supply cars taking timbers into the mine could back into the same stalls for easy loading. The storage of life support units would be handled in the main office and control building.

SECTION XVII

ACKNOWLEDGMENTS

The excellent cooperation and technical assistance of L. E. Day and A. F. Phillips of the National Aeronautics and Space Administration is gratefully appreciated.

The assistance of J. R. Fleming, Manager Product Development, and C. Leffler of Arrowhead Products Division, Federal-Mogul Corporation; of D. Curtis, Manager of Research, Applied Technology Division, Litton Systems, Inc.; of C. H. Staub, Director Marketing Division, MSA Research Corporation; and of R. Clew, Bendix Launch Support Division, Cape Kennedy is acknowledged with sincere thanks.

To William Bellano, then President and Chief Administrative Officer of Island Creek Coal Company, our grateful appreciation for recognizing the potentials of this new technology.

Mr. Stonie Barker, Jr., W. F. Diamond, and R. C. Taliaferro of Island Creek Coal Company, who with their project associates J. K. Rice and D. J. Motz of Cyrus Wm. Rice Division, NUS CORPORATION, directed and guided this Phase I engineering feasibility program.

The support and technical advice of the United States Bureau of Mines, and their program representative Milton Skow is gratefully acknowledged.

The support of the project by the Federal Water Quality Administration and the excellent technical guidance provided by A. Cywin, E. P. Hall, and D. J. O'Bryan, Jr., the Grant Project Officer, is acknowledged with grateful appreciation.

SECTION XVIII

REFERENCES

1. Braley, S. A., "Summary Report of Commonwealth of Pennsylvania, Department of Health Industrial Fellowship, No's 1 through 7," Mellon Industrial Fellowship No. 326B, 1954.

2. Bell, W. E., "Studies of the Effect of Gas Atmospheres on Pyrite Oxidation," Final report under Federal Water Quality Administration Contract No. 14-12-404 to Cyrus Wm. Rice Division, NUS CORPORATION, Pittsburgh, Pennsylvania, April, 1969.

3. "Gas Requirements to Pressurize Abandoned Deep Mines-A Study of the Use of Inert Gases to Eliminate Acid Pollution from Abandoned Deep Mines," A report of the Commonwealth of Pennsylvania, Department of Mines and Mineral Industries under Project No. CR-81, Federal Water Quality Administration Project No. WPRD-227, 1968.

4. "Space Cabin Atmospheres Part 1 - Oxygen Toxicity," National Aeronautics and Space Administration SP-47, 1964.

5. "Bioastronautics Data Book," National Aeronautics and Space Administration SP-3006, 1964.

6. "Space Cabin Atmosphere Part 3 - Psychological Factors of Inert Gases," National Aeronautics and Space Administration SP-117, 1967.

7. "Portable Life Support Systems," Ames Research Center Conference, May, 1969, National Aeronautics and Space Administration SP-234, 1970.

8. Jackson, J. K., and Blakely, R. L., "Application of Adsorption to Spacecraft Life Support Systems," Missile and Space Systems Division, Douglas Aircraft Company, Inc.

9. Mills, E. S., G. V. Colombo, and R. A. Neustein, "Evaluation of Carbon Dioxide Sorption Techniques for Hydrospace Application," Douglas Aircraft Company, Independent Research and Development Program, Account No. 81641-001.

10. "Engineering Criteria for Spacecraft Cabin Atmosphere Selection," Advanced Biotechnology and Power Department, Missile and Space Systems Division, Douglas Aircraft Company, Inc., Douglas Report DAC-59169, November, 1966, under National Aeronautics and Space Administration Contract No. NASW1371.

11. Potter, A. E., Jr., and B. R. Baker, "Static Electricity in the Apollo Spacecraft," Manned Spacecraft Center, Houston, Texas, National Aeronautics and Space Administration Report No. TND-5579, December, 1969.

12. Lorenz, Walter C., and Edward C. Tarpley, "Oxidation of Coal Mine Pyrites," Bureau of Mines RI 6247, 1963, 13 pp.

13. "Stream Pollution by Coal Mine Drainage in Appalachia," U.S.D.I., FWQA, Cincinnati, Ohio, Revised 1969.

14. Herndon, L. K., and W. W. Hodge, "Coal Seams of West Virginia and Their Drainage," Proc. West Virginia Academy of Science, Vol. 9, pp. 39-61, Feb., 1936.

15. "Drainage From Bituminous Coal Mines," Research Bulletin No. 25, West Virginia University Bulletin.

SECTION XIX

PUBLICATIONS

1. Rice, J. K., and R. C. Taliaferro, "Mining in an Inert Atmosphere," Presented at the 1970 Coal Convention and Exposition, American Mining Congress, Cleveland, Ohio, May, 1970.

2. Rice, J. K., "The Use of Inert Gas to Eliminate Acid Pollution by Abandoned Active Deep Mines," Presented at the Third Symposium on Coal Mine Drainage Research, Pittsburgh, Pennsylvania, May, 1970.

3. "Inert Atmosphere in Mines Could Abate Acid Drainage," Chemical and Engineering News, 48, May 18, 1970, pp. 33-35.

4. Rice, J. K., "Health and Safety When Mining in an Inert Gas Atmosphere," Statement to the Subcommittee on Labor, Senate Committee on Labor and Public Welfare on Coal Mine Health and Safety, 1969.

5. Rice, J. K., "Acid Mine Drainage Abatement from Deep Mines by Inert Gas Blanketing," Testimony before Water Pollution Advisory Board, Pittsburgh, Pennsylvania, 1968.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1970 O - 409-917