Kovac

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DEVELOPMENT OF GUIDELINES FOR RESCUE CHAMBERS, VOLUME I

Contract J0387210

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The U.S. Bureau of Mines (USBM) awarded a contract to Foster-Miller, Inc. to develop guidelines for designing, constructing, stocking, and maintaining rescue chambers in underground mines. This report develops information and recommendations which could be used by a mine operator who desired to install a rescue chamber.

Volume I covers the following major areas: atmospheric life support, configuration and construction, chamber location, power and lighting, equipment and supplies, communications, and psychological aspects and training.

Volume II contains the following appendices: History of Barricading, Chamber Pressurization Considerations, Diffusional Infiltration of Gas, Compressed Air Storage, Location Examples, and Psychological Aspects.

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FOREWORD

This report was prepared by Foster-Miller Associates, Inc., Waltham, MA, under USBM Contract No. J0387210. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of Pittsburgh Research Center with John Kovac acting as Technical Project Officer. Larry Guess was the Contract Specialist for the USBM. This report is a summary of the work recently completed as a part of this contract during the period July 1978 to July 1982. This report was submitted by the authors on 31 October 1983.

All cost information in this report is stated in 1983 dollars. Most of the cost data was assembled during 1979; these figures were increased by 40 percent to reflect up-to-date costs as of mid-1983.

The technical effort was performed by the Mining Division of the Engineering Systems Group, with John McCoy as Program Manager and Randy Berry as Senior Engineer. Donald Mitchell did the research and analysis of the History of Barricading.

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1. INTRODUCTION

1.1 Background

Under Section 315 of the 1969 Coal Mining Health and Safety Act, "the Secretary, or any authorized representative of the Secretary, may prescribe in any coal mine that rescue chambers properly sealed and ventilated be erected at suitable locations in the mine to which persons may go in case of emergency for protection against hazards." The rationale behind this law is that when miners must escape a mine, circumstances may arise that block exit routes. In this event, the trapped miners must be protected against noxious air and secondary explosions.

A 1970 report by the Committee on Mine Rescue and Survival Techniques of the National Academy of Engineering (1) stressed the importance of providing a shelter near the working face to protect miners against the hazards of explosions and noxious gases. This report speculates on the transfer of life-support technology from the aerospace industry to underground use. Emphasis was placed on the potential for technology application rather than feasibility or suitability.

Following the work of the National Academy of Engineers, the USBM contracted with Westinghouse Corporation to develop a self-contained rescue chamber. In the resulting program, completely self-contained chambers were designed, built and tested (2). The resulting chambers consisted of subassemblies which were maneuvered into a cross-cut where assembly was completed. All life-support provisions, atmosphere control, food and water, etc., were provided within the chamber. In testing, this chamber proved to be cumbersome and too labor intensive to erect. Furthermore, during explosion trials, seals between modules failed and man-testing of the chemically based atmosphere controls system performed marginally.

In light of this experience, the USBM contracted to Foster-Miller Associates (FMA) the task of designing reusable explosion-proof bulkheads. The concept behind this study was to construct a rescue chamber in a cross-cut by erecting a pair of explosion-proof bulkheads across the cross-cut. The results of this study (3) showed through explosion testing that the concept for constructing rescue chambers is feasible.

With the knowledge that an explosion-hardened chamber could be constructed, the USBM contracted FMA to develop a set of rescue chambers guidelines. The development of these guideline requirements and the specific guidelines are reported herein.

1.2 Philosophy of Escape

Controversy shrouds the implementation of underground rescue chambers. One side argues that rescue chambers are a life saving tool, while the other argues that rescue chambers may seduce miners away from escape thereby contributing to a net life risking situation. The background statement to the scope of work under which this program was performed indicated that, "In the event of a fire or explosion in a coal mine, the Bureau of Mines considers the primary means for men to escape from underground is by their own egress through properly designated and well maintained escapeways. However, in the event all exit routes are blocked, the trapped men must be protected against noxious air and secondary explosions until rescued." With this background, the FMA project staff has avoided entanglements in the controversy and has directed the program towards the pragmatic view that the job is to determine what is the best way to implement rescue chambers and not to determine whether rescue chambers are desirable, necessary or undesirable. Only through this sort of approach can the technology for rescue chambers be advanced, thereby allowing a rational decision on implementation.

1.3 General Purpose

These guidelines are to aid mine engineers and MSHA officials in the implementation of underground rescue chambers in coal mines. No argument is made here for the necessity of a rescue chamber in any particular mine. Mines are complex networks which must be considered on an individual basis to determine whether a rescue chamber is needed or appropriate for that mine. If there is a mine such that the probability of escaping is doubtful then the installation of a rescue chamber may be considered. These guidelines aid the engineers responsible in two ways:

a. Allow him to make a cost estimate of the various types of rescue chambers and to compare those costs to other mine modification(s) required to achieve an acceptable escape plan

b. Provide guidance for the detailed design and implementation of rescue chambers.

While this document prescribes many elements which must be considered and/or included, latitude is provided for the onsite engineer to design elements and implement methods consistent with local practice.

1.4 History and Practice

The concept of rescue (refuge) chambers dates at least from the 1930's, with documentation from the United States (1, 2, 3, 4, 6), Canada (7), the United Kingdom (8), Germany (9), and the USSR (10). It is generally accepted that the idea originated with the practice of entrapped miners barricading themselves in a good air region in order to separate themselves from a region of fire and smoke. The obvious extension of barricading in an emergency is to have prepared barricaded sites (chambers, shelters, etc) provided with a kit of supplies useful for survival until rescue is achieved.

A detailed study of the history of barricading was undertaken as a part of this program. Forty-one mine accidents occurring during the time period 1940 through 1980 were identified in which barricading could be considered an appropriate safeguard. The results of this study are presented in Appendix A, History of Barricading. Figure 1 summarizes the actions of miners in those 41 accidents. It is clear that barricading has saved lives, and equally true that others have died behind barricades - usually because the barricade was poorly constructed, and/or because rescue was not timely enough. Properly-designed refuge chambers can improve upon barricades in terms of both better construction and lesser dependence on prompt rescue.

Installed underground rescue chambers have used forced air to control the breathing atmosphere. There are two methods used:

a. Air forced through a borehole from the surface

b. Air forced through compressed airlines from a surface compressor.

Examples of the borehole type have been built in a Pennsylvania coal mine* and at the Peckfield Colliery, United Kingdom (8).

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* Sites visited by program staff member.

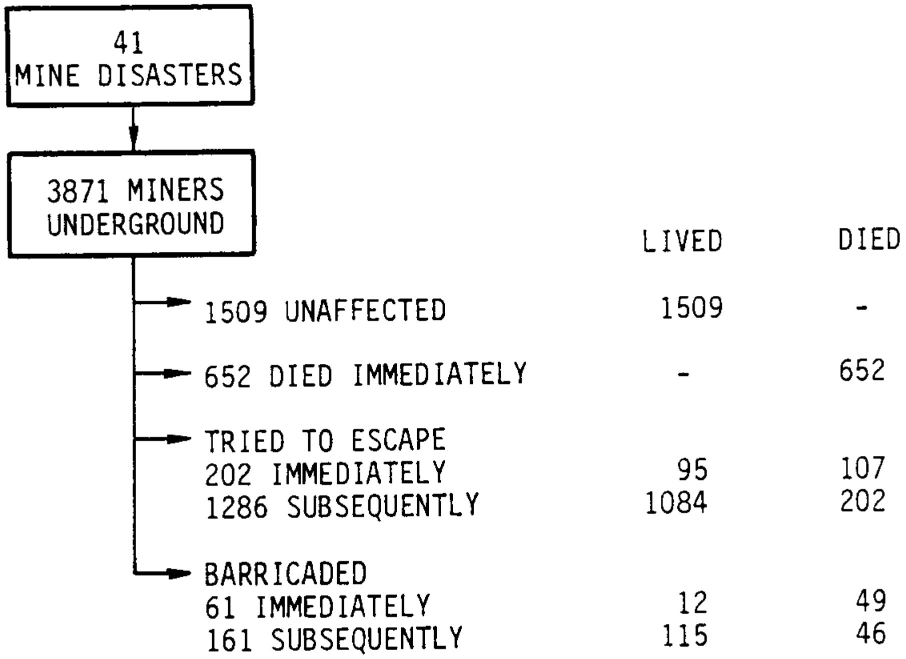

FIGURE 1. - Actions of miners in 41 fires and explosions, 1940 - 1980.

Compressed airline supplied chambers have been built in several metal/nonmetal mines in the United States* and Canada*, and a few coal mines in West Germany (9). At this writing, only one case is known of these chambers being used in an emergency. The 27 miners who waited for rescue inside this chamber in a Tennessee zinc mine were included in the lives saved by barricading data listed in Figure 1.

The USBM had two exprimental rescue chambers built under contract with Westinghouse in the late 1960's (2). These were explosion-proof chambers built on the surface and moved underground. Some of the atmosphere control system depended on a self-contained system for chemically processing and removing CO and CO_2 from the atmosphere. Tests of the life support equipment

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* Sites visited by program staff member.

indicated that while this approach was viable, more development and experience would seem necessary before the systems could be deemed reliable.

Since the most likely mine incident which would warrant the use of rescue chambers in coal mines is explosion and fire, and since secondary explosions can be expected, a key requirement is that the rescue chamber be hardened against explosion. The technology for building explosion-proof bulkheads exists. USBM had such bulkheads designed, built and successfully tested under contract with FMA (3). Hence, miners can be protected from explosion while inside the chamber.

The guidelines presented herein are based on historical practice and a conservative application of existing technology which is used in order to assure a high reliability. However, rescue chambers are like parachutes and lifeboats in that they must be considered an aid to possible survival, not a life assurance tool.

1.5 Organization of Guidelines

The guidelines are presented by topic subsection. Each subsection has a discussion of the topic, followed by specific, prescriptive guidelines for the topic.

Topics are presented in the following order:

a. Life support in chambers

b. Configureation and construction of chambers

c. Location procedures for chambers

d. Power and lighting for chambers

e. Equipment and supplies for chambers

f. Communication for chambers

g. Psychological and training aspects.

While the order is somewhat arbitrary, the rationale used was based on convincing the reader that life can be supported in a refuge chamber, then outlining the size, construction, location, equipment and training requirements.

2. ATMOSPHERIC LIFE SUPPORT IN RESCUE CHAMBERS

2.1 Technical Discussion

2.1.1 Philosophy

A safe, breathable atmosphere is of prime importance in maintaining human life. Toxic and/or oxygen-depleted atmospheres limit life expectancy to times of at most a few minutes, whereas people have survived days without water and weeks without food. If a satisfactory atmosphere is not assured for entrapped persons in a rescue chamber, all other efforts, plans and equipment associated with implementing, maintaining and using the chambers can be futile.

The methods for maintaining atmosphere control and shelters have been reported from a wide variety of sources (1-2, 4, 10-11). In addition to those sources, FMA used an inhouse expert on submarine life support equipment, a consultant at Scott Aviation, and various telephone calls were made to companies performing life support research such as Lockheed Missiles and Space Company and Mine Safety Appliance. Further, a National Technical Information Service (NTIS) search was studied. The results of the information found from all of these sources indicate that a large number of chemical methods for maintaining a life supporting atmosphere exist. However, none of the chemical processing methods appear to be suitable at this time for use in underground rescue chambers. Most of the high technology life support systems used on submarines or on space craft have experienced considerable specific development to those areas. Further, they depend upon large quantities of power to operate which may not be assumed when installed underground in emergency shelters. Also, it seems to be a characteristic of these high technology systems that they are prepared for specific missions; they are not kept in a standby mode to be used in case of emergency for underground rescue chambers.

The Westinghouse study cited earlier (2) had selected and tested a chemical life support system. Surface testing with this system indicated that there was a lack of technical development. This lack of development showed itself during man testing when some of the equipment experienced partial failures. The conclusion drawn from this exprience is that any high technology life support system intended for rescue chambers will have to undergo a program of research, development and demonstration before it is appropriate to be specified in guidelines. In the absence of this technical development, low technology systems with equipment familiar to mine mechanics must be specified.

To assure a satisfactory atmosphere, these guidelines have taken a very conservative technological approach for the supply of a breathing atmosphere to rescue chambers. Forced air is required to be supplied in all cases. Three types of chambers are permitted by these guidelines, as follows:

a. Air supplied through a borehole

b. Air supplied through redundant compressed airlines

c. Air supplied from a chamber located compressed air storage battery (cylinders).

While all three of these types of chambers can be designed to support life they are not of equivalent quality. Since a borehole is independent of all mine systems, therefore removed from any damaging effects of a disaster, the borehole can be assumed to be the most dependable for air supply in addition to providing a conduit for communication and transportation of material. The reliability of the airline supply depends on the high probability that one of two or more redundant airlines will survive the mine disaster events. Similar to the borehole, air supply from the airline is indefinite. This implies that life may be maintained in the chamber for many days after water, food and other supplies have been exhausted. This provides some extra time for rescuers to effect removal of entrapped miners. The reliability of stored compressed air depends on a rigorous testing and maintenance program during normal mine operations. An obvious weakness of the stored air chamber is that the supply is finite and that rescue efforts can not suffer any delays beyond the design time of the air supply. Cost is a less readily observable disadvantage of compressed air storage. For a single chamber installation with a design time of 2 weeks (210 mandays), compressed air storage requires an expenditure about ten times that of a borehole or an airline supplied chamber. Because of cost, it is expected that chambers with stored compressed air will be rare, and used only where the probability exists that persons can be recovered from the chamber within a few hours.

In the following subsections, the details of breathing air requirements and supply approaches will be described.

2.1.2 Human Respiration

The power source for vital human functions is the oxidation of carbon and hydrogen. The details of metabolism are beyond the scope of this discussion other than to state that food supplies the necessary carbon and hydrogen and that inhaled air supplies the necessary oxygen. The body can store food (converted to fat) for long periods of time; but oxygen cannot be stored for more than a few minutes, nor can life exist for more than a few minutes if the vital organs, for example the brain, do not receive fresh oxygen. Oxygen deprivation may occur through an inability to inhale, a lack of sufficient oxygen in the inhaled air, and by a chemical interference. An example of chemical interference occurs when carbon monoxide exists in the inhaled air. Carbon monoxide reacts in preference to oxygen with the hemoglobin in the red blood cells. Since hemoglobin is the vehicle by which oxygen is transported to body tissue, the cells are thus starved for lack of oxygen. When the tissue cells are deprived of oxygen below a certain level, unconsciousness and death results.

Other chemicals in the atmosphere may also produce adverse physiological effects. High levels of carbon dioxide trigger rapid respiration and can cause incapacitation through hyperventilation effects.

The general requirements for a breathable atmosphere are presented in Tables 1 through 4. The most likely mine disasters involve fire. Mine fires are characterized by poor combustion of carbon and hence high levels of carbon monoxide. Although carbon monoxide is the most important toxic gas, other toxic gases may be present also. Table 5 shows some other toxic gases with their tolerable limits.

The following subsection derives the quantitative requirements for breathing air.

2.1.3 General Breathing Air Requirements for Rescue Chambers

Developed in this subsection is the minimum airflow required by a person enclosed in a rescue chamber. Oxygen consumption and CO_2 exhalation rates for an assumed level of activity are examined. The results indicate that the minimum airflow requirement is set by the flow required to hold down the CO_2 level to a tolerable concentration.

TABLE 1. - Oxygen and air inhalation rates in human breathing*

Activity	At Rest	Moderate	Very Vigorous
Respiratory rate/minute	12-18	30	40
Air inhaled/respiration in.^{3}	23-43	90-120	150
Air inhaled, ft^3/day	335	2,625	5,000
(ft^3/min)	(0.23)	(1.82)	(3.47)
Oxygen consumed:			
ft^3/day	14.4	100.8	144
ft^3/min	0.01	0.07	0.10
Respiration quotient	0.75	0.9	1.0

*Mine Ventilation and Air Conditioning, Howard L. Hartman, The Ronald Press, New York, 1961.

TABLE 2. - Effects of oxygen deficient atmosphere*

Oxygen Content Percent by Volume	Effect on Humans
17	Faster, deeper breathing
15	Dizziness, buzzing in ears, rapid heart beat
13	May lose consciousness if exposure prolonged
9	Fainting, unconsciousness
7	Life endangered (equivalent to 5-1/2 mi. elevation)
6	Convulsive movements, death

*USBM Miners Circular No. 33 (1954), p. 2.

TABLE 3. - Effects of CO_2 levels on humans*

Carbon Dioxide Content Percent by Volume	Effects on Humans
0.5	Maximum allowable concentration** - no effect in 8 hr
1.0	Slight increase in lung-ventilation rate
2.0	Lung-ventilation rate up 50 percent
3.0	Lung-ventilation rate up 100 percent, headaches appear
5.0	Lung-ventilation rate up 300 percent - severe headaches and breathing is laborious
10.0	Can be endured for only a few minutes
12.0	Quick loss of consciousness

*Fire and Noxious Gases - Effect on Internal Environments of Protective Shelters - J. Enoch Johnson and Eugene A. Ramskill, U.S. Naval Research Laboratory.

**MAC is the Maximum Allowable Concentration as recommended by the American Conference of Governmental Industrial Hygienists, U.S. Public Health Service, and USBM.

TABLE 4. - Effects of CO levels on humans*

Carbon Monoxide Content Percent by Volume	Effects on Humans
0.01	Maximum allowable concentration - no effect in 8 hr
0.02	Headaches in 2 to 3 hr
0.04	Headaches and nausea in 1 to 2 hr
0.08	Headaches and nausea in 45 min, collapse in 2 hr
0.16	Headaches and nausea in 20 min and possible death in 2 hr
0.32	Headaches and dizziness in 5 to 10 min, and possible death in 30 min
0.64	Headaches and dizziness in 1 to 2 min, and possible death in 10 to 15 min

*Ibid.

TABLE 5. - Major gases evolved from materials used in mines (8)*

Material	Major Toxic Products
Neoprene conveyor belts	HCL, CO, CO_2, SO_2, CS_2, H_2S, benzene, formic acid
Polyvinyl chloride (PVC) conveyor belts	HCL, CO, CO_2, vinyl chloride, benzyl, chloride, benzene, toluene, phenol
Polystyrene-butadiene conveyor belts	HCL, CO, CO_2, H_2S, CS_2, methyl chloride
Urethane foams	HCL, CO, CO_2, aniline, chlorethanol
Wood (treated and untreated)	Acrolein, formaldehyde, acetaldehyde, HCN, formic acid

*Adaped from Paciorek, K.L., and others. Coal Mine Combustion Products Identification and Analysis, Annual Report, USBM Contract H0133004, August 1974.

Product	EEL (60 min)* (ppm)
Hydrogen chloride (HCL)	10
Carbon disulfide (CS_2)	50
Hydrogen sulfide (H_2S)	10
Acrolein (CH_2CHCHO)	0.2
Carbon monoxide (CO)	400
Sulfur dioxide (SO_2)	10
Formaldehyde (CH_2O)	3
Nitrogen dioxide (NO_2)	10

*Elevated exposure levels.

Note: Exposure above the listed EEL's would seriously impair emergency escape activities. (The EEL's are not strictly based on miner's work activity or environment and thus should be used only as a guideline to estimate danger from these gases).

The air supply must both provide oxygen and carry off the metabolic waste product CO_2 (assume no chemical removal of CO_2). The amount of O_2 a person requires and the amount of resulting CO_2 produced depends on the activity level (see Table 1). In these calculations, it is assumed that the activity level is four-fifths resting and one-fifth moderate activity. Steady-state calculations based on this mix of activity are justified by the assumption that there are several persons in the chamber with about one out of five persons on watch monitoring equipment and doing housekeeping tasks while the remaining four are resting or talking.

From Table 1 and the assumed activity level, the metabolic oxygen demand may be calculated as follows:

$$\frac{14.4 \text{ scf } O_2}{\text{resting man/day}} \times \frac{4}{5} + \frac{101 \text{ scf } O_2}{\text{moderate man/day}} \times \frac{1}{5} = \frac{31.7 \text{ scf } O_2}{\text{man/day}}$$

Similarly, the respired CO_2 may be calculated as follows:

$$\frac{10.8 \text{ scf } CO_2}{\text{resting man/day}} \times \frac{4}{5} + \frac{90.7 \text{ scf } CO_2}{\text{moderate man/day}} + \frac{1}{5} = \frac{26.8 \text{ scf } CO_2}{\text{man/day}}$$

If air is assumed to contain 21 percent oxygen (volume), the rate of air required to supply the necessary metabolic O_2 is calculated as follows:

$$\frac{31.7 \text{ scf } O_2}{\text{man/day}} \times \frac{1 \text{ scf air}}{0.21 \text{ scf } O_2} = \frac{151 \text{ scf air}}{\text{man/day}}$$

Table 3 shows the effects of CO_2 concentrations on people. If a CO_2 concentration of 1 percent is set as an upper design limit and if dilution is used to remove CO_2 from the atmosphere, then the air demand for dilution is:

$$\frac{26.8 \text{ scf } CO_2}{\text{man/day}} \times \frac{100 \text{ scf air}}{1 \text{ scf } CO_2} = \frac{2{,}680 \text{ scf air}}{\text{man/day}}$$

Since the airflow to dilute CO_2 (2,680 scf/man/day) is larger than the airflow to supply metabolic O_2 (151 scf/man/day), the dilution demand dominates, thus specifying the minimum air supply flow as:

$$\frac{2{,}680 \text{ scf}}{\text{man/day}} \times \frac{1 \text{ day}}{24 \text{ hr}} = \frac{112 \text{ scfh}}{\text{man}} \text{ or } \sim\frac{1.9 \text{ scfm}}{\text{man}}$$

If the chamber activity level should increase above the assumed value used to generate the minimum air supply requirement, then the CO_2 level will rise above the 1 percent value specified. However, there will still be sufficient oxygen supplied by the air for life support. This provides some safety factor since there are chemical adsorption methods which can be used to remove carbon dioxide in this type of emergency.

There are many methods reported for the removal of CO_2 by adsorption, however, the more practical candidates are adsorption on the following (11):

a. Soda lime

b. Baralyme

c. Lithium bromide.

Of these three, soda lime is recommended because it is the least costly. The adsorption process may be performed by placing the soda lime in packed bed canisters and using a blower to force air through the bed. A downstream air filter is needed to capture the entrained soda lime dust which is irritating to eyes and mucous membranes. Alternatively a passive bed CO_2 scrubber can be made by spreading the powdered soda lime out in a thin pad, for example on brattice, such that the area exposed to the atmosphere is large. Both methods have been used for control of submarine atmospheres. For rescue chambers, the passive pads are favored since it removes the need for a mechanical blower which might fail due to a long standby period.

Passive pads are not without drawback. Due to the irritating nature of soda lime powder and the fact that some dust will become suspended during the process of spreading out the powder, some discomfort is expected. However, this is an emergency procedure expected to be used only if the activity level increases the CO_2 level to the uncomfortable range; it is not intended to be used continuously.

The procedure for making a passive CO_2 scrubber is to spread the soda lime out on a brattice cloth, sheet, or blanket in as thin a layer as possible so as to expose a large surface area to the atmosphere. Gloves and goggles should be provided to protect persons handling the soda lime. Once the CO_2 level has been reduced to a tolerable level, the soda lime should be carefully removed from the pad and returned to the original storage cans.

The best method for determining the adsorption effectiveness is to measure the CO_2 concentration in the atmosphere. For quantitative estimates of the amount of soda lime required, consider that 4.2 lb of soda lime is needed to absorb 1 lb of CO_2. By previous calculation, it was shown that under assumed activity levels about 27 scf of CO_2 was produced per man/day. (The airflow requirement was based on removing this CO_2 rate.) If a safety factor of two is selected, then provisions should be made to adsorb an equivalent quantity of CO_2, that is, 27 scf. The quantity of soda lime required is calculated as follows:

$$\frac{27\left(\frac{\text{scf CO}_2}{\text{man/day}}\right)}{359\left(\frac{\text{scf}}{\text{lb-mole}}\right)} \times \frac{44\text{ lb* CO}_2}{\text{lb-mole CO}_2} \times \frac{4.2\text{ lb soda lime}}{1\text{ lb CO}_2} \cong 14\left(\frac{\text{lb soda lime}}{\text{man/day}}\right)$$

The Westinghouse study (2) indicated evolved heat will not be a problem.

The quantity of soda lime required for the safety factor of two may be determined by multiplying 14 lb/man/day by the design number of man/days. Approximate cost may be determined at the rate of $0.50/lb for soda lime (1979 price).

2.1.4 Control of Hazardous Gas Infiltration

The source of hazardous gases in a disaster will be outside the chamber. Carbon monoxide is the most important toxic gas likely to be present during a fire/explosion disaster; methane is also likely to be present. Methane is an explosion hazard and in high enough concentrations can displace oxygen and contribute

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*Based on the U.S. Pharmacopoeia minimum of $\frac{0.238\text{g CO}_2}{\text{g soda lime}}$.

to suffocation. Experience (4) has shown that construction of a leak-free chamber for underground use is improbable. Therefore, if the pressure outside the chamber becomes larger (for example, rising barometric pressure) than inside, hazardous gases can be forced into the chamber. While chemical methods exist (1, 2, 4) for controlling these substances (for example, the catalyst hopcalite for oxidation of CO to CO_2 and electro-chemical cells for oxidation of methane), no technology has been successfully developed and *demonstrated* for underground rescue chamber applications, where there are long standby times and very limited power available to operate the necessary machinery. The Westinghouse chamber program is the only attempt and demonstration was not successful (2). The approach recommended in these guidelines is to use the forced breathing air to pressurize the chamber thereby preventing the infiltration of hazardous gases.

In a steady-state, it is obvious that forcing air into the chamber will overpressurize it relative to the outside of the chamber. However, there are conditions such as barometric pressure changes, ventilation fans starting and stopping, temperature changes and moisture condensation which may allow the pressure outside the chamber to temporarily exceed the pressure inside the chamber.

The two most important pressure change conditions are due to barometric pressure changes and ventilation fan changes. Consideration of the effects of these changes is shown in Appendix B. Results of these considerations are that a forced air rate of 1.9 ft^3/min/man can keep pace with even the fastest changes in barometric pressure. However, exhaust fan stoppage (or forced fan starts) can require a larger forced air requirement than just for respiration. If the differential pressure across the fan is less than 10 in. of water, then forced air to the chamber should be the larger of 28 ft^3/min or 1.9 ft^3/min/man times the number of men. If the fan differential pressure is larger than 10 in. of water, than an analysis similar to that performed in Appendix B should be made, and the forced air flow adjusted upward to assure quality of chamber atmosphere.

An analytical check indicated that no infiltration into a pressurized chamber of hazardous gas should occur due to molecular diffusion against the over pressure of the chamber (Appendix C).

In summary, a forced air supply to a rescue chamber of 28 scfm or 1.9 scfm/man times the number of men (whichever is greater) should provide a suitable chamber atmosphere by providing:

a. Adequate oxygen

b. Removal of respired CO_2

c. Protection from infiltration into the chamber of hazardous gases.

2.1.5 Application

2.1.5.1 Borehole Supplied Air

As mentioned earlier, a rescue chamber with a borehole connected to the surface is of the highest quality because a borehole is totally isolated from the rest of the mine. The borehole can supply air, food, water, power and communications, thereby permitting a high degree of flexibility for coping with almost any emergency situation. Furthermore, if the entrapped miners are to be removed through a large escape borehole, the supply borehole aids as an accurate guide for the appropriate drilling location.

A schematic borehole configuration is shown in Figure 2. At the surface is an airtight shelter which protects the top of the borehole during standby periods, plus permitting the fan to force air down through the borehole while leaving the hole open for lowering materials when the chamber is in use. The borehole should have a minimum inside diameter of 6 in. so as to provide sufficient room for power and communication cables to be installed and still permit materials to be lowered or raised through the hole. The hole must be cased and grouted to preserve the hole and seal out water.

A means should be provided to allow air to escape *out of* (but not into) the rescue chamber and to measure the rate of outflow. The easiest method would be to install a vent tube which leads out of the chamber through a flow meter and a check valve to the mine. The flow through the vent tube must be maintained at or above the airflow requirement for that chamber. Since there will be air leaks around the bulkhead, the total airflow to the chamber will be larger than the value measured by the flowmeter. This is a conservative procedure which provides a safety factor. In addition to measuring airflow, the differential pressure between the chamber and the mine should be monitored with an aneroid pressure gauge (for example, a Magnehelic®). A liquid manometer should not be used as the liquid can be blown out of the tube thereby destroying the seal between the chamber and the mine.

For practical depths, the airflow resistance of a 6-in. borehole may be neglected since the flow resistance around the bulkhead is much greater than the borehole. Therefore, the borehole resistance need not be considered in fan selection. The

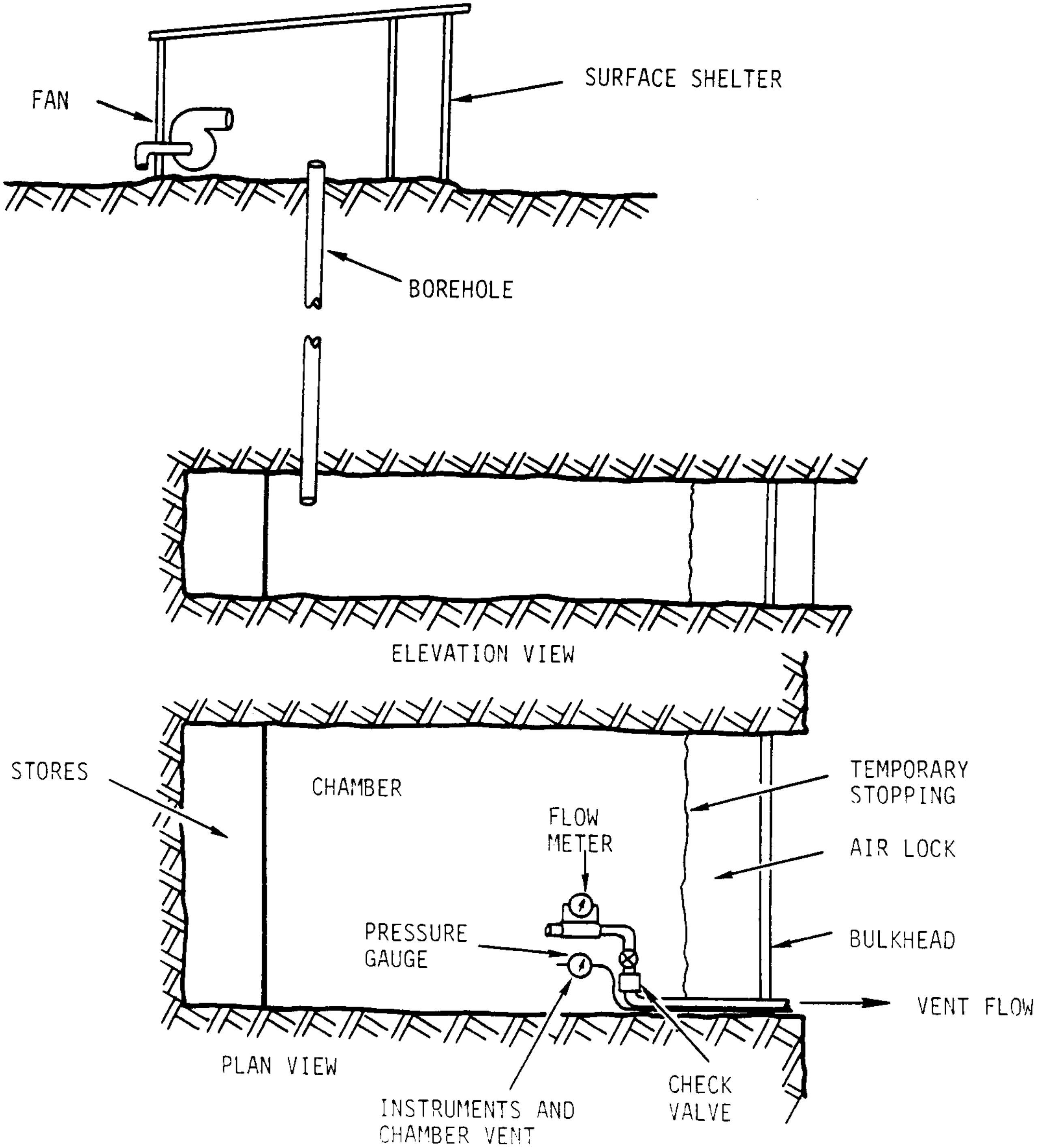

FIGURE 2. - Schematic of borehole supplied rescue chamber

best procedure for fan selection is to choose a fan that will supply an air flow of 3 to 4 times the required flow at a differential pressure across the fan of at least 5 in. of water plus the pressure of the mine if the mine ventilation is forced fan type. The extra flow capacity is to accommodate air leaks in surface shelter, borehole and chamber bulkhead.

On completion of construction, the system must be tested to ensure that proper airflow to the chamber is achieved. The surface shelter and the rescue chamber are to be closed up and the fan started. With the chamber pressurized to 5 in. of water or greater above the mine pressure, the design flow rate should be measured flowing through the vent tube. If design flow is not achieved, areas of air leaks should be sought out and sealed until sufficient flow is measured.

The major cost of a borehole connected rescue chamber is associated with drilling the hole. While cost can vary considerably with location, a typical cost based on recent FMA experience may be taken as $53*/ft cased and grouted. A rough typical cost of the surface shelter has been estimated at about $10,000* including fan, while the cost of instruments and controls (flowmeter, pressure gauge and valves, etc.) is estimated at about $700.*

2.1.5.2 Airline Supplied Air

A rescue chamber with airline supplied air has the advantage of an indefinite supply of air. It does not provide the flexibility of a borehole connected chamber since only air can be supplied through the airlines. Even with redundant airlines, safety is somewhat less than using a borehole because the airlines are passing through the mine and could be damaged or contaminated during the mine disaster.

A schematic of a rescue chamber with a compressed airline supply is shown in Figure 3. Two redundant compressed airlines are brought into the chamber from a compressor on the surface. The reliability of the air supply depends on the probability that separate redundant airlines will survive a mine disaster. Therefore, routings of the two (or more) airlines should be widely separated. Obviously the two airlines should not be run in the same entry. A possible example of separation is to bring one line underground from the closest portal while bringing a second line from the surface through a power borehole. The air pipes should be installed consistent with the successful practice for pipe (air or water) installation within the particular mine, taking into consideration stability of roof, ribs and floor.

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*1983 dollars; see Foreward

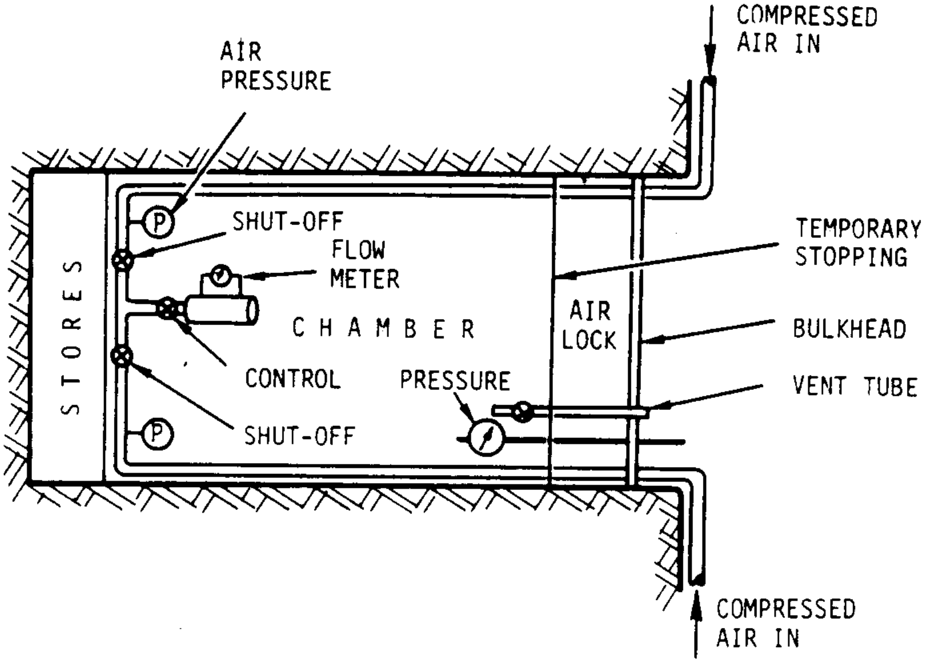
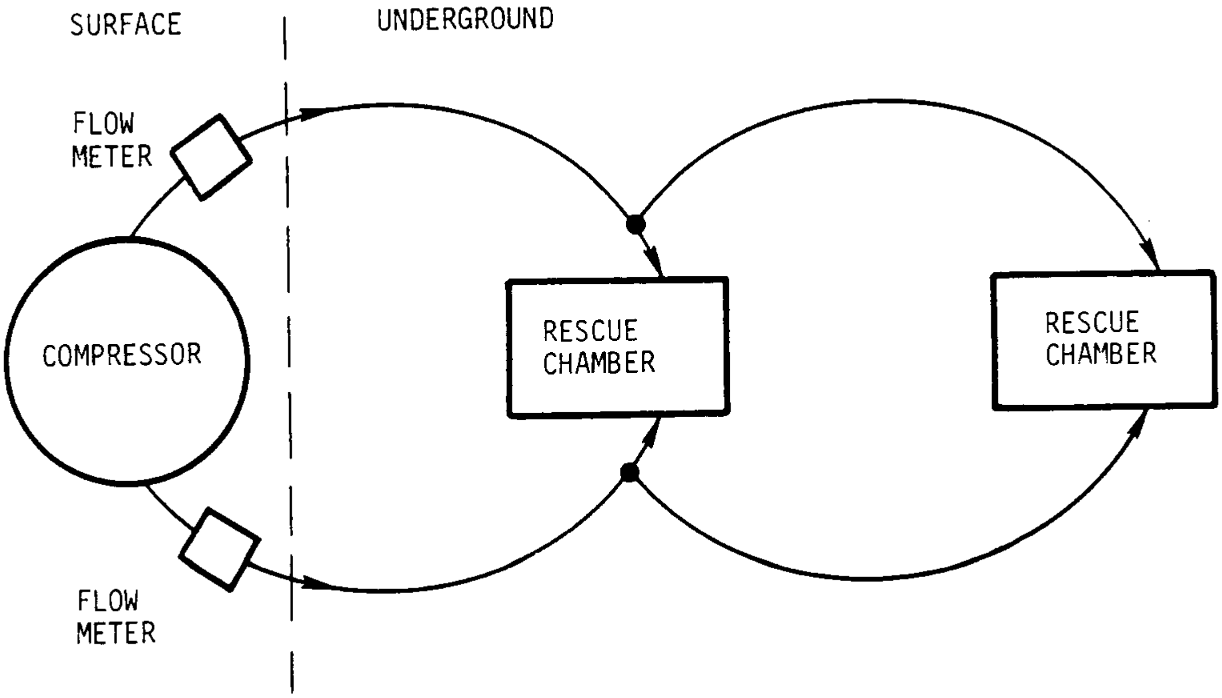


FIGURE 3. - Schematic of compressed airline rescue chamber.

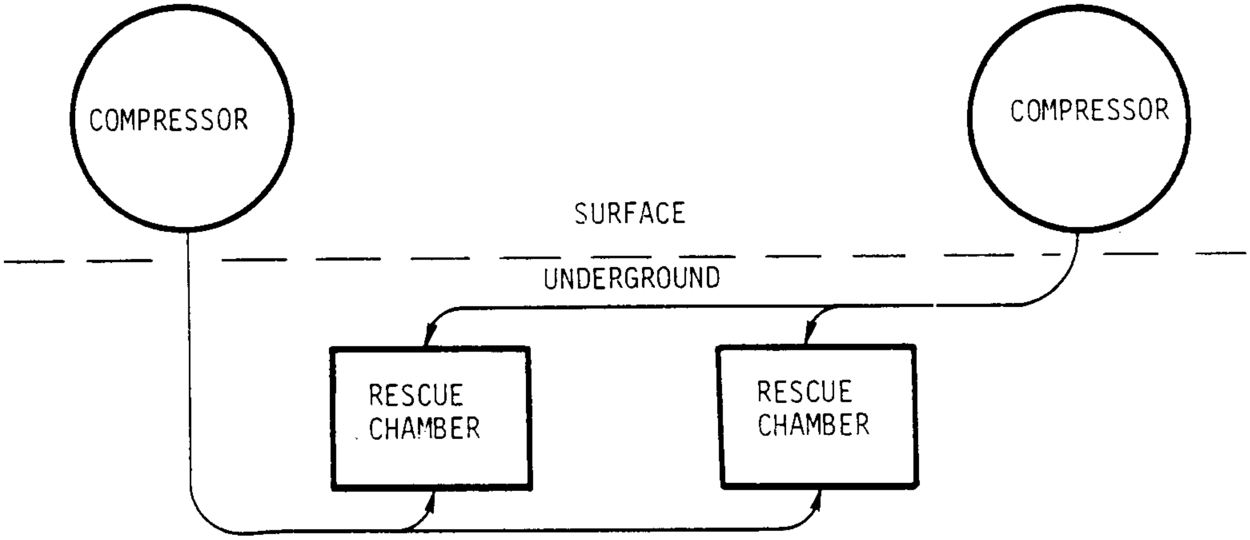
A pressure gauge should be installed on each airline as well as shutoff valves which can be closed individually if a broken airline occurs. The lines shall be tied together with a control valve and flowmeter at the pipe exit. The air outlet should be located as far as practical from the bulkhead in order to promote a cross flow of air in the chamber. A vent tube with a check valve and control valve must be installed through the bulkhead to permit sufficient air to leave the chamber. A differential pressure gauge must be installed to monitor the chamber overpressure.

Once installed, the system shall be tested with the chamber sealed. At design airflow, an overpressure of at least 5 in. of water must be achieved with the vent tube valve shut off. If this overpressure cannot be maintained, then areas of air leaks must be sought and sealed until 5 in. of water overpressure is achieved.

Either singular or multiple compressors may be used. Figure 4 a and b shows these approaches schematically. When a single



a) SINGLE COMPRESSOR SUPPLY



b) SEPARATE COMPRESSOR

FIGURE 4. - Singular and multiple compressors.

compressor is used, flowmeters must be installed in each branch line in order to detect line breaks. If the flow rate through a broken line is large enough to reduce supply pressure (overload the compressor), the flow in that branch must be reduced until the compressor can supply rated pressure. Compressors must be selected with reserved capacity (safety factor) of at least twice the flow required for the rescue chambers supplied by each line (for example, in Figure 3 the single compressor shown must have a capacity four times the demand of the sum of the two rescue chambers shown). Compressor supply pressures must be 100 lb/in.^{2} at flow design capacity if the air supply is to be used for power in the chamber (see Section 5).

Airline pipe must be sized such that pressure drop is not excessive. Table 6 shows receiver pressures as a function of selected flows with a supply pressure of 100 lb/in.^{2}. Since rescue chamber power may be extracted from the compressed air flow, the pipe should be sized to provide approximately 90 lb/in.^{2} or larger at the chamber. Except for very long or short airline, a 1-in. IPS pipe is suitable.

If it is assumed a pipeman and helper can install 300 ft of pipe/day* and the combined direct and indirect labor cost is $360**/day and if a typical 1-in. pipe price is $90/100 ft, then the installation cost of pipe/thousand ft is:

$$\frac{\$360}{300} \times 1000 \text{ ft} + \frac{\$90}{100 \text{ ft}} \times 1000 \text{ ft} = \$2{,}100/\text{thousand ft}$$

For typical installations, the cost of piping is the dominating cost. The cost of a compressor is likely to be less than $7000. An additional budget of $1400 should cover miscellaneous valves, flow meters, gauges, etc.

2.1.5.3 Air Supplied From Compressed Air Storage

If a situation exists where neither a borehole nor airlines can be installed, it is possible to construct a chamber with a self-contained air supply. As mentioned at the beginning of Section 2, a self-contained air supply system provides the least flexibility in terms of time available to achieve removal of the entrapped miners, and is definitely the highest cost to implement if significant man/days of air supply are provided. A reasonable

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* 300 ft/day based on underground construction experience of FMA staff.

**1983 dollars; see Foreward.

TABLE 6. - Delivered pressure by pipe size

P_o, Receiver pressure (lb/in.^{2}) with supply pressure = 100 (lb/in.^{2}), air flow = 30 scfm

(28 ft^3/min minimum chamber flow)

Pipe Distance (L) (ft)	(lb/in.^{2}) 3/4 in. IPS	1 in. IPS	1-1/4 in. IPS	1-1/2 in. IPS
2,000	84	95	99	99
4,000	60	90	98	99
6,000	-	85	97	98
8,000	-	79	95	98
10,000	-	-	94	97
P_o =	$\sqrt{(100)^2 - 1.47L}$	$\sqrt{(100)^2 - 0.459L}$	$\sqrt{(100)^2 - 0.1119L}$	$\sqrt{(100)^2 - 0.0520L}$

P_o, Receiver pressure (lb/in.^{2}) with supply pressure = 100 (lb/in.^{2}), air flow = 60 scfm

Pipe Distance (L) (ft)	(lb/in.^{2}) 1 in. IPS	1-1/4 in. IPS	1-1/2 in. IPS
2,000	81	96	98
4,000	57	91	96
6,000	-	86	94
8,000	-	81	92
10,000	-	76	90
P_o =	$\sqrt{(100)^2 - 1.67L}$	$\sqrt{(100)^2 - 0.419L}$	$\sqrt{(100)^2 - 0.190L}$

P_o, Receiver pressure (lb/in.^{2}) with supply pressure = 100 (lb/in.^{2}), air flow = 90 scfm

Pipe Distance (L) (ft)	(lb/in.^{2}) 1 in. IPS	1-1/4 in. IPS	1-1/2 in. IPS
2,000	52	90	96
4,000	-	80	92
6,000	-	68	87
8,000	-	-	82
10,000	-	-	77
P_o =	$\sqrt{(100)^2 - 3.66L}$	$\sqrt{(100)^2 - 0.898L}$	$\sqrt{(100)^2 - 0.900L}$

Equivalent pipelength per standard elbow

IPS (in.)	Equivalent Length (in.)
3/4	1.2
1	1.6
1-1/4	2.2
1-1/2	2.6

Data adapted from Compressed Air and Gas Handbook, Compressed Air and Gas Institute, N.Y., 1973 design time for rescuers to reach entrapped miners is 2 weeks via drilling an escape shaft (5). Only if a reasonable alternative plan exists which offers a shorter rescue time can a chamber air supply be designed for less than 14 days. If a plan exists and a shorter design time is used, the air supply must be sized to provide at least 2 days more air supply than the period of the plan. For example, if a plan exists where removal of an entrapped miner is expected in 1 day, then a 3-day supply of air must be provided.

The regulation of the release of air into the chamber should be similar to that for an airline air supplied chamber (see Figure 3) incorporating the following features:

a. Flowmeter

b. Cross flow

c. Vent tube

d. Differential pressure gauge to measure chamber over prssure.

Additionally, a pressure regulator(s) shall be installed such that the air delivery pressure from the air storage is 90 to 100 $lb/in.^2$.

In Appendix D, cost and size of a typical compressed air system are developed. A cost of about $2400 to $2800/man/day is expected with air tank storage volume of about 22 to 16 ft^3/man/day.

2.1.6 Technological Developments

The potential for technical developments in life support systems for self-contained chambers exists. Life support technology for aerospace vehicles and submarines has advanced well beyond the brute force techniques of stored compressed air. There are, however, significant differences between underground rescue chamber characteristics and the other systems. Particularly significant is that rescue chambers have long standby times and their use is unscheduled (no time immediate to the mission for preparation). The energy available for the operation of life support equipment such as fans and controls is severely limited. Recent developments of oxygen self-rescuers based on the liberation of oxygen from solid KO2 which requires no mechanical driving power, offer some hope that the solid chemical approach could be developed for self-contained rescue chambers which would reduce cost to a tolerable level (lower than borehole cost). A particular technical problem is the prevention or elimination of hazardous gases which can be forced into the chamber. Until the development and successful demonstration of such a system is achieved, such approaches are not recommended; hence they are outside these guidelines.

2.2 Guidelines for Atmospheric Life Support

2.2.1 Method

The atmospheric life support system of any rescue chamber shall be of a forced air type. Three methods of supplying air are covered by these guidelines:

a. Air forced from the surface through a borehole directly connected to a rescue chamber

b. Compressed air forced from a surface compressor(s) through redundant (two or more) airlines to the rescue chamber

c. Compressed air stored as part of the rescue chamber underground (self-contained).

Discussion of each type is given previously in subsection 2.1.5.

2.2.2 Air Flow Requirements

The design air flow to each chamber shall be at least 28 scfm or 1.9 scfm/man times the number of men contained in the chamber, whichever is the larger value. This flow shall be achieved with the chamber pressurized to at least 5 in. of water gauge greater than the mine just outside the chamber. For chambers with stored compressed air, this flow rate shall be maintained for at least 14 days unless a reasonable plan exists for removing the entrapped miners in a shorter period. For cases with such a plan, the above specified air flow rate shall be maintained for at least 2 days longer than the time expected in the plan.

2.2.3 Air Flow Instrumentation

A flowmeter(s) shall be installed within the chamber to monitor the flow of breathing air (see subsection 2.1.5). A differential pressure gauge shall be installed within the chamber such that chamber pressure relative to the outside mine may be monitored.

2.2.4 Soda Lime

A sealed store of soda lime shall be provided for emergency absorption of CO_2 (see subsection 2.1.3). The store shall be sufficient for 14 days or 196 lb/person (capacity of chamber). Gloves shall be provided for the handling of the soda lime.

2.2.5 Testing

On completion of a chamber installation the air flow performance shall be tested to ensure that flows and pressures are equal to, or better than design requirements. Any deficiency in performance shall be rectified. Retesting shall be performed semiannually. If compressed air storage is used, the air capacity shall be checked every 90 days with any deficiency in capacity replaced.

2.2.6 Training

All miners likely to use the chamber shall be instructed in the startup and operation of the breathing air system including the use of a passive soda lime pad in the event that CO_2 concentration exceeds 1 percent (see subsection 2.1.3). This training shall include the measurement of gas concentrations using gas detection tube apparatus.

Within the chamber, instructional information for the breathing air system including graphic (pictorial schematic) displays shall be posted. During training, the instructional information shall be used. The information presented shall include at least the following:

a. Air flow schematic

b. Location of the valves, pressure regulators, gauges, air tanks, and routing of airlines through the mine

c. Listing of readings (calibrated) for the setting of flows and pressures

d. Directions for making and using a soda lime CO_2 scrubber

e. Directions for air flow and chamber pressure control.

3. CONFIGURATION AND CONSTRUCTION

This section discusses the factors pertinent to the configuration and construction of rescue chambers. These discussions provide the background and reasoning for the guidelines which are formulated in the final subsection of this section.

3.1 Technical Discussion

The major factors which should be considered during the design and construction of rescue chambers are:

a. Size and area requirements of rescue chambers

b. Configuration and construction of bulkheads

c. Roof support requirements for rescue chambers.

These factors are elaborated on in the following subsections.

3.1.1 Size and Area Requirements

A rescue chamber is implemented by sealing off both ends of a crosscut or the front end of a dead heading with explosion-proof bulkheads. The space between the bulkheads (or between bulkhead and dead end) is used as shelter and is equipped with emergency provisions capable of sustaining trapped miners for several days.

Before the construction of bulkheads is initiated, an accurate estimate must be made of the space the bulkheads must enclose. This space or internal volume must be sufficient for:

a. Storing emergency supplies and equipment

b. Comfort of persons using the chamber

c. Construction of air locks.

Since the cross-section of the rescue chamber can be considered to be constant, an estimate of the length of the crosscut to be enclosed by the bulkheads must be made to satisfy the above requirements.

3.1.1.1 Requirement of Storing Emergency Supplies and Equipment

Emergency supplies and equipment are planned to be stored at the back of the chamber. Section 6 provides a detailed list of equipment and supplies that must be permanently maintained and stored in the rescue chamber. The volume required to store food, water, bunks (folded), self-rescuers, first aid supplies and other sundry materials would be about 105 ft^3 maximum. For an 18 × 6 ft crosscut this would require 1 ft of the length of the crosscut to store the necessary supplies and equipment.

Table 7 summarizes the volume requirements of equipment and supplies to be stored in the chamber.

3.1.1.2 Requirements for Comfort

The space requirements for persons in the shelter are estimated on the basis of 15 ft^2*/person. For 15 persons, this would necessitate at least 225 ft^2 or 12.5 ft length of a crosscut 18 ft wide.

TABLE 7. - Summary of estimated volume for equipment and supplies

Item	Total Volume ft^3	Volume/Person ft^3/person
Food	35	2.30
Water	20	1.33
15 Self Rescuers	10	0.67
2 First Aid Kits	8	0.50
15 Bunks (folded)	30	2.00
Sundry Materials	1	
Gas Detector Tubes, Pumps	1	
Total	105	6.80

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*Based on civil defense space allowances(11).

3.1.1.3 Space Requirements for Airlocks

Once the chamber has been occupied during an emergency, it is advisable to construct a second, temporary stopping inside the explosion-proof bulkhead in order to create an airlock. This will minimize the risk of the chamber atmosphere being contaminated by mine air if persons enter or leave the chamber subsequent to its original occupation.

This stopping would be constructed of wooden framing and brattice material stored in the chamber. It may be desirable to construct the frame beforehand.

The temporary stopping should be spaced a minimum of 2 ft from the bulkhead. If there is a bulkhead with a door at each end of the chamber, an airlock must be built for each end. Thus, either 2 or 4 ft of chamber length must be allowed for airlocks.

3.1.2 Configuration and Construction of Bulkheads

Three different explosion-proof bulkheads for refuge chambers have been designed, fabricated and successfully tested under USBM Contract (3). All three designs featured modular, prefabricated metal panels which could be reused. The type of panels and methods of attachment were different in each design in order to provide systems which could adapt to the broadest possible range of coal mining conditions in the United States. The three basic designs were as follows:

a. *Channel-Turnbuckle Bulkhead* (Figure 5). This design utilizes roof bolt and footing box anchorage and is used in mines where the roof and floor are both competent. The bulkhead components consist of off-the-shelf aluminum channel members (12 in. wide × 5 in. flange × 5 ft long), roof bolts (1-1/2 diam × 24 in.) with turnbuckles, and footing boxes. The channel members are arranged back-to-back for height adjustment. The lower channel is anchored in a footing box which is grouted in place in a trench excavated into the mine floor. The upper channel is connected to a third channel bolted flat against the mine roof and further anchored by connection through a turnbuckle to a 1-1/2 diam roof bolt.

   These assemblies bolt together, flange-to-flange, to form a bulkhead in 1 ft increments for crosscuts of any width. The height limitation from the bottom of the footing box in the trench to the top of the roof channel is from 6 ft 1-1/2 in. to 7 ft 1-1/2 in.

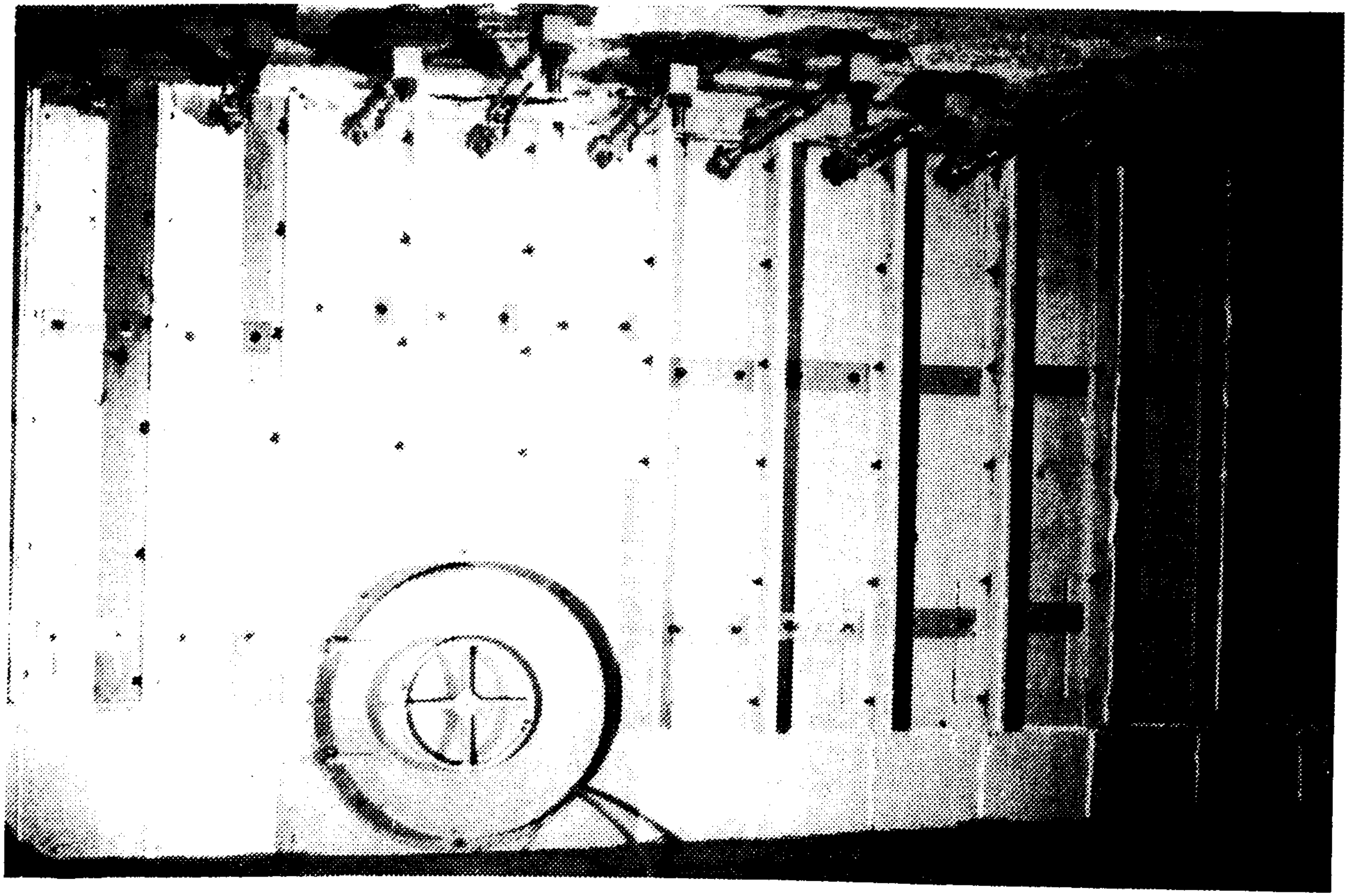


FIGURE 5. - Channel-turnbuckle bulkhead.

b. *Truss Bulkhead* (Figure 6). This design transmits the explosion forces into the floor alone and is used in mines where the floor is competent rock but the roof is weak. The pinholes in the roof only resist negative pressure to prevent overturning. The main components of this bulkhead are 4 × 8 steel box beam posts with sliders that fit inside at the top for height adjustment. These posts fasten at the bottom to footing boxes which are grouted in place in a trench excavated into the mine floor. Connected near the top of the posts to the rear are large angle struts which transmit force down to a second set of footing boxes 5-1/2 in. behind the front set. Horizontal ties at the bottom complete a triangle to stabilize the posts and angle struts. Decking assemblies of high strength corrugated steel and 2 in. box beams attach to the front of the posts. A door also attaches.

The bulkhead width is adjustable in increments of 27 in. for crosscuts of any width. The height limitation from the bottom of the footing boxes in the trench to the mine roof is from 6 to 7 ft. This includes 2 in. of clearance at the top for the urethane foam seal.

c. *Arch Bulkhead* (Figure 7). Here explosion forces are transmitted to the rib coal walls of a crosscut; this design is used in mines where both the roof and floor conditions are poor. This bulkhead is a 17 ft radius tunnel-lining often found in subway or other tunnels, but turned on its side and broken down into components of a weight two men can handle. The liner plates are 2 ft wide (high) by either 3 ft or 1-1/2 ft long. The structural members are 6 in. H beam ribs, either 3 ft or 4-1/2 ft in length. Most mine openings up to 20 ft can be accommodated by various combinations of ribs and liner plates in increments of half plates (1-1/2 ft). Maximum width bulkhead is 20 ft-10 in. across. The height is 6 ft-11 in. including 2 in. of clearance at the bottom and 2 in. at the top for the seal. A layer of liner plates can be omitted for a bulkhead height of 4 ft-11 in.

Reinforced concrete abutments in the rib coal spread the reaction forces.

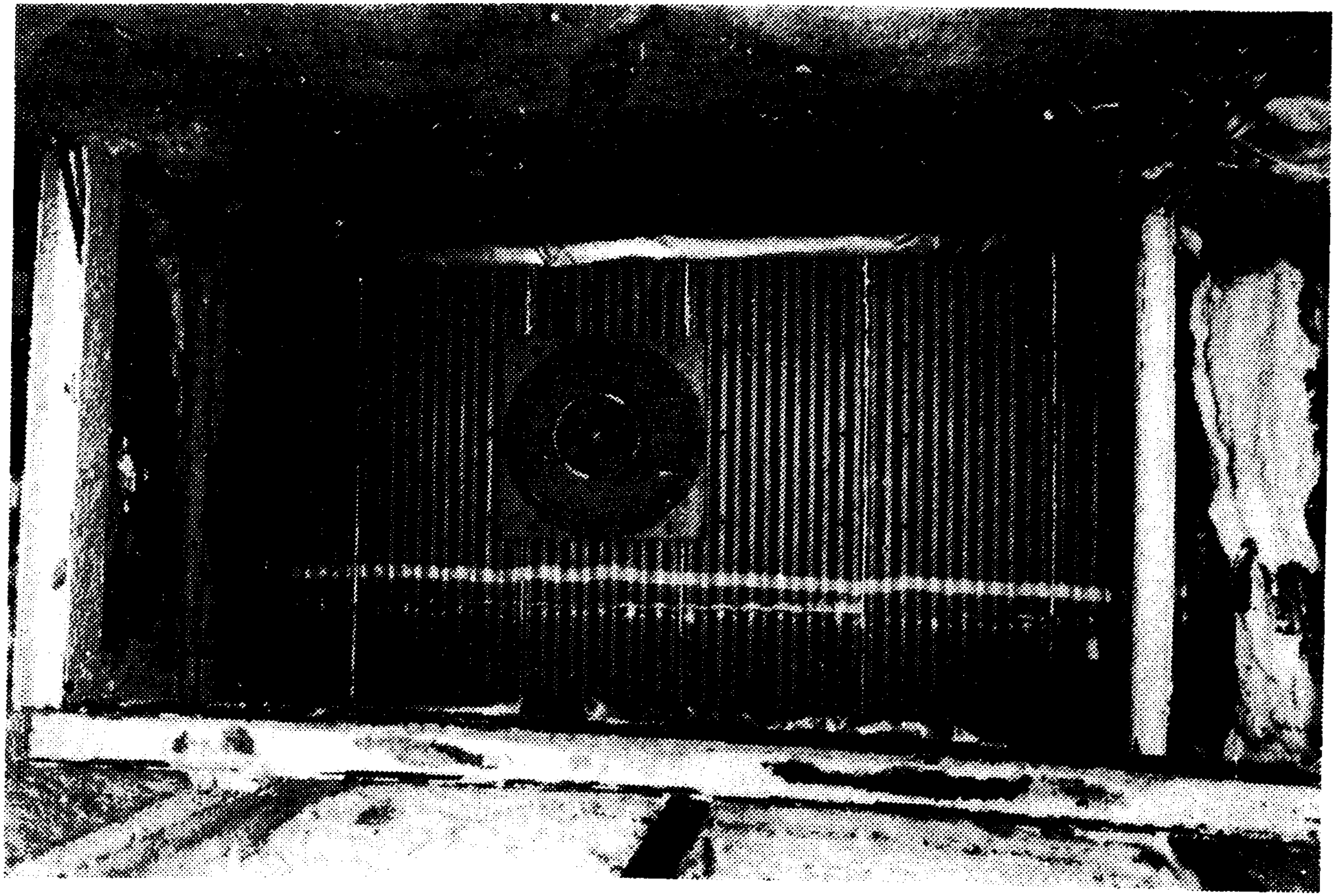


FIGURE 6. - Truss bulkhead.

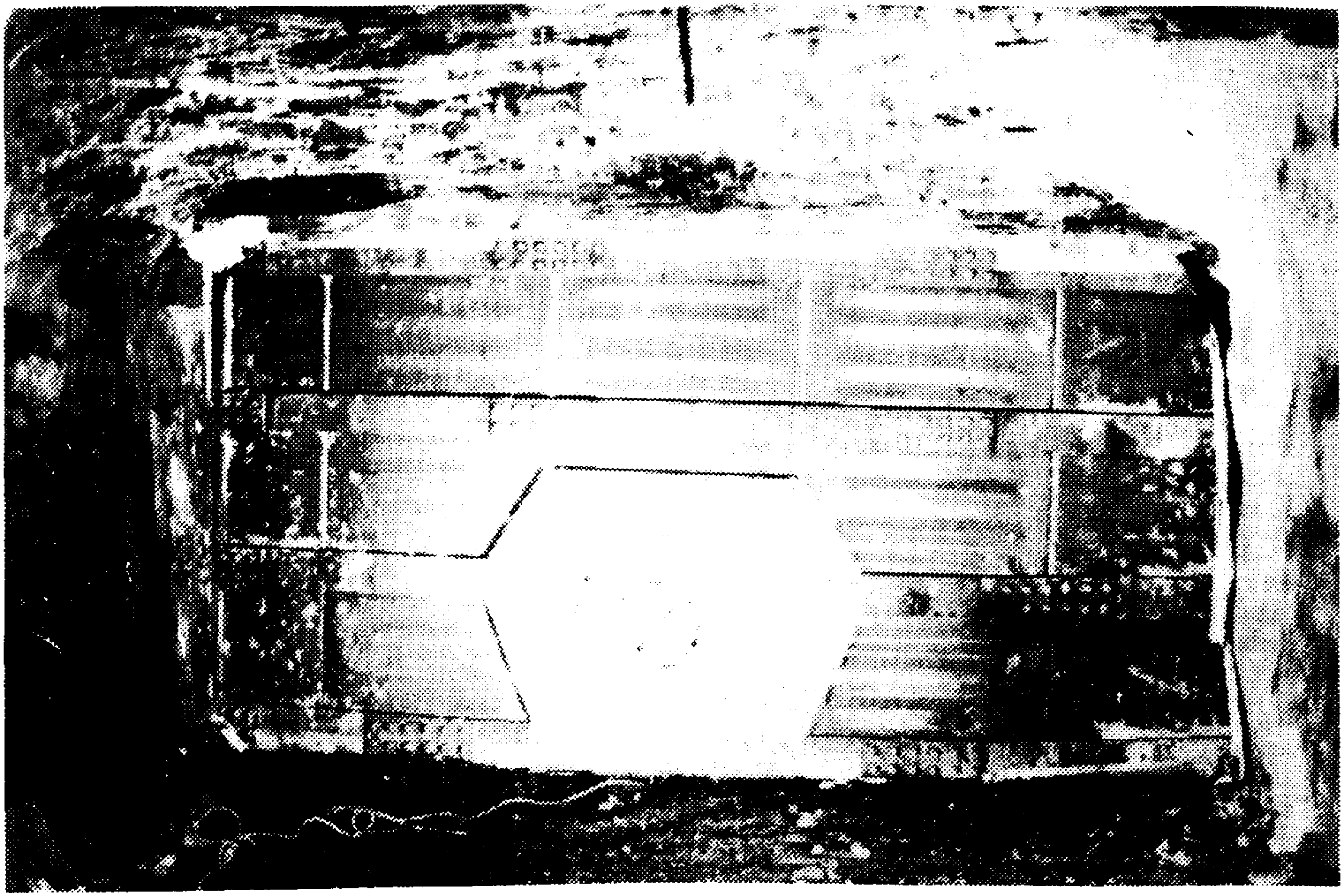


FIGURE 7. - Arch bulkhead

Sealing to the mine opening around the periphery of all three bulkheads is accomplished with urethane foam and thin gauge aluminum flashing bent in such a way it will flex rather than break when a shock wave moves the bulkhead. Internal joints in the bulkheads are sealed with silicone rubber sealant.

3.1.3 Roof Support

It is essential that the roof of a rescue chamber remain stable during the life of the chamber. *Sloughing* of roof may occur particularly if the stratum is sensitive to moisture. It is advisable that the roof be treated with a mine sealant to prevent deterioration of roof rock when this problem may be anticipated.

Minimum requirements for West German coal mines indicate that the area where rescue chambers are erected should be shotcreted (9). Shotcreting not only seals the chamber but provides some roof support.

Although the roof of the refuge chamber will already have been bolted, additional roof support should be considered whenever the refuge chamber is scheduled to remain in place for a long time.

The different kinds of support that can be considered are:

a. Wire mesh

b. Steel beams or rails

c. Steel or timber sets

d. Steel arches

3.1.3.1 Wire Mesh

In many mines, the roof is reinforced by roof bolts and wire mesh. The mesh is normally extended across the roof and down the rib from 6 to 18 in. Cement-sand mortar, often referred to as "gunite," usually is applied as a 2 to 3 in. layer, to prevent weathering of roof rock.

3.1.3.2 Steel Beams or Rails

Steel beams or rails supported by concrete block walls can provide excellent protection of both roof and ribs in a refuge chamber. This method of support is presently being used in an installed chamber in Pennsylvania. Figure 8 shows a support

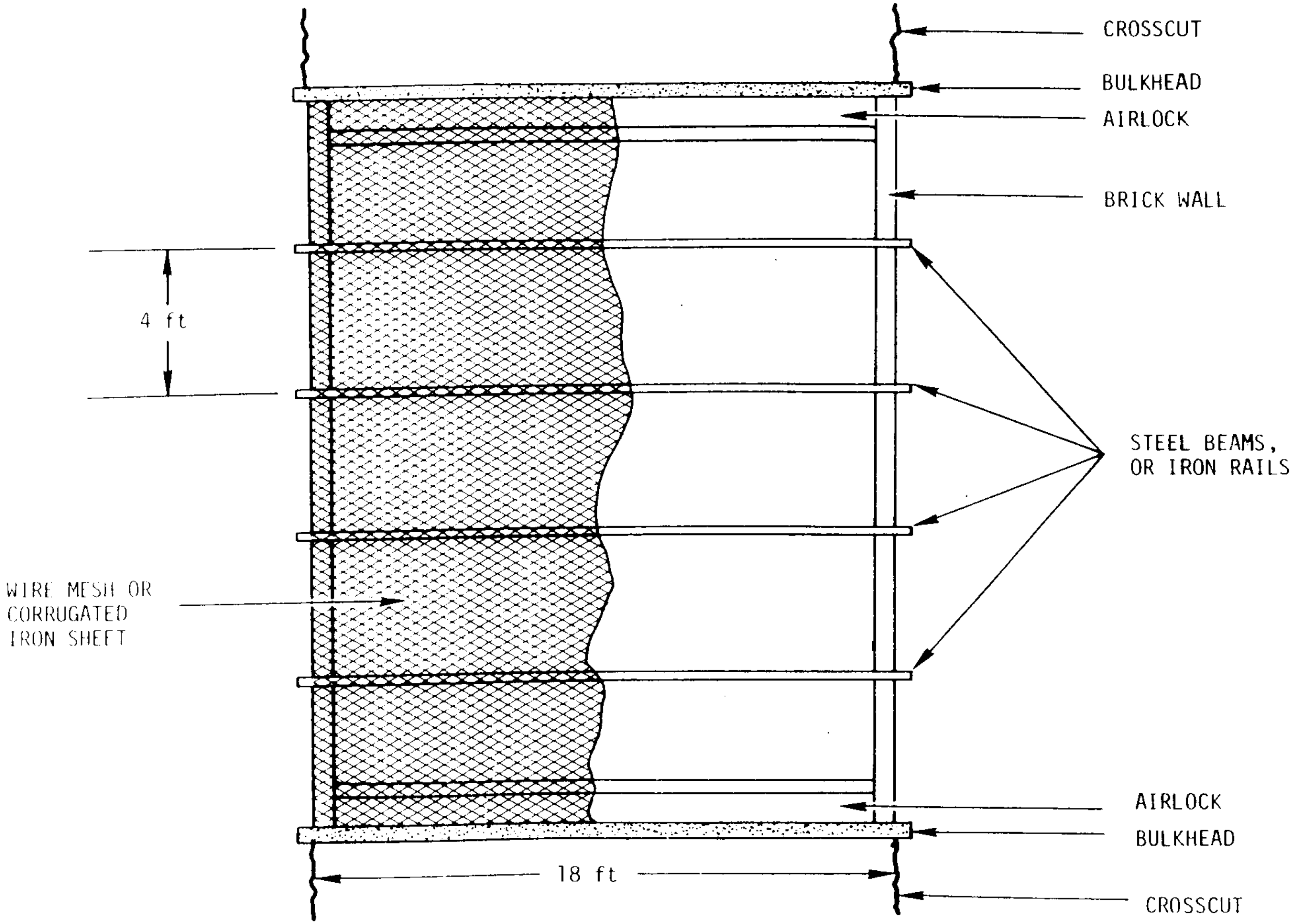


FIGURE 8. - Support plan for rescue chamber using steel beams or rails with wire mesh or corrugated iron sheet.

plan for the rescue chamber using this form of support. Wire mesh, as described earlier, can be used to prevent the entry of roof rock into the chamber. In the Pennsylvania mine, corrugated sheets were placed on top of the rails because of the presence of combustible material overlying the seam.

3.1.3.3 Steel or Timber Sets

The simplest timber set consists of a crossbar, cap or header supported on two upright posts, as shown in Figures 9 and 10. This type of roof support is similar to the use of cinder block and headers described in the previous subsection, except that the posts do not provide much protection from rib sloughing. Where this is a problem, it might be desirable to place corrugated sheet behind the posts.

3.1.3.4 Steel Arches

In cases where movement of the roof is expected, yieldable steel arches can be used (Figure 11). Generally, three U-shaped arched segments are overlapped to provide a large area of contact at the yielding joints, which are clamped to provide resistance to yielding. Although they are high in initial cost,

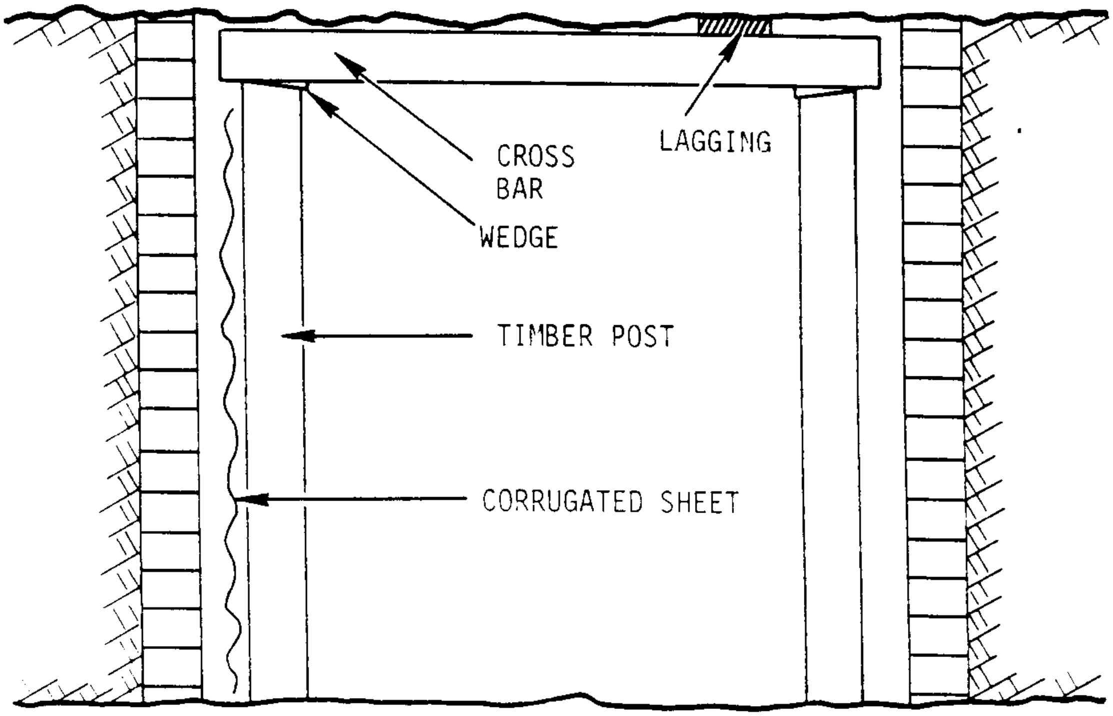


FIGURE 9. - Timber set.

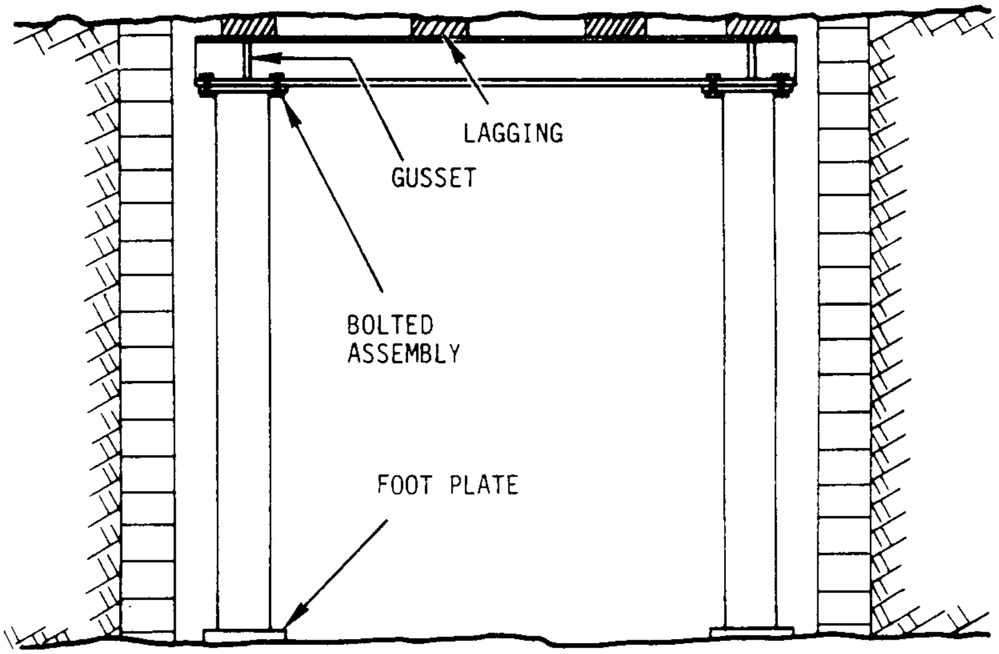


FIGURE 10.- Steel set support.

yieldable steel arches provide dependable, long, maintenance-free service. The arches can be spaced 4 ft apart to provide high support density. Yieldable arches are used under severe conditions where extensive movements can occur due to the presence of faulted ground or in areas of subsidence.

Rigid steel arches have been used for support of permanent mine entries. In coal mines, two-piece rigid arches are usually used. Tie rods are used with either type of arches for lateral stability. All voids between the arch structure and roof should be thoroughly backfilled.

3.1.3.5 Selection of Supports

The proper selection of a support requires the consideration of:

a. Magnitude and type of forces expected on the support after installation

b. The amount of roof and bottom convergence anticipated at the site

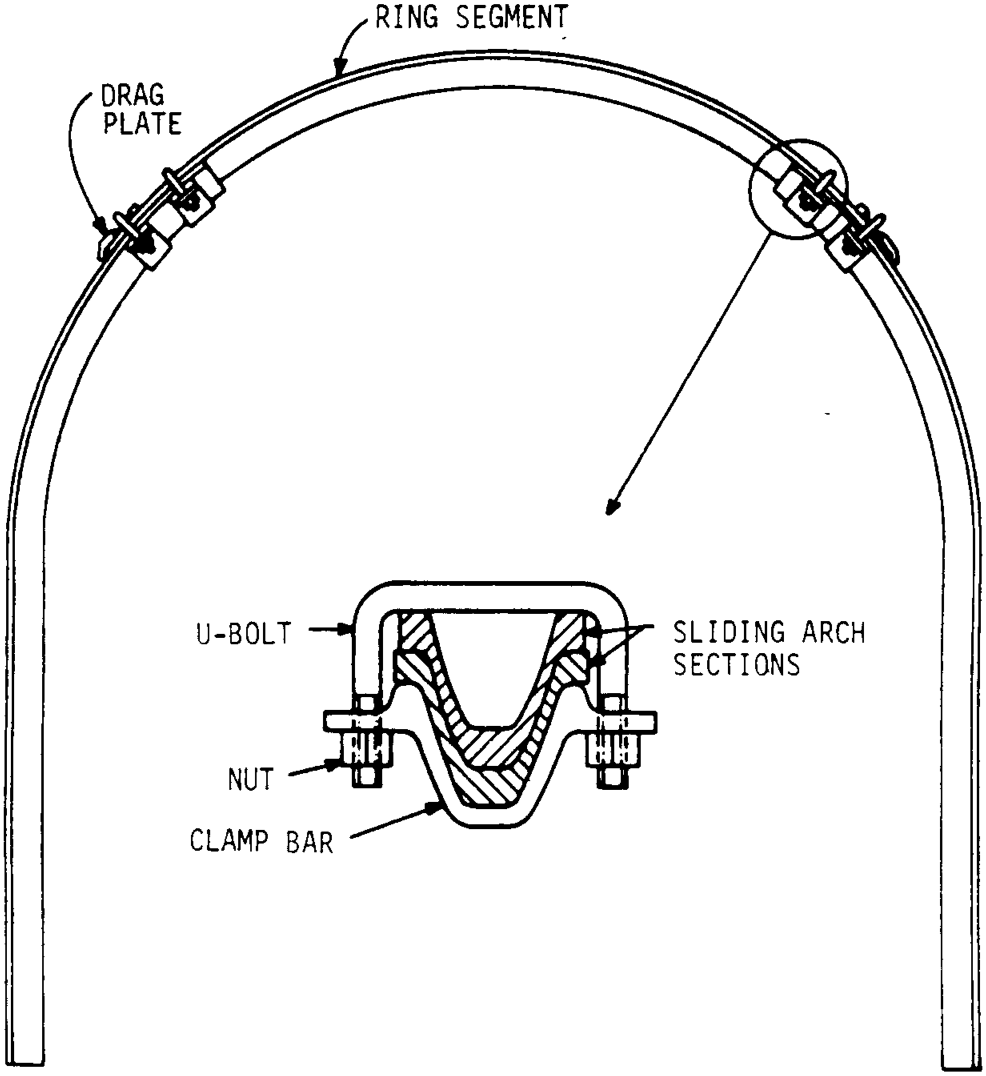


FIGURE 11. - Yieldable arch structure.

c. How permanent the opening and thus the support must be

d. Environmental conditions to which the support will be subjected

e. Economic factors consistent with safety.

Support costs are shown in Table 8.

3.1.3.6 Standby Ventilation

During standby periods methane may build up in the chamber or the atmosphere may become oxygen-deficient. To preclude this the chamber must be ventilated during standby periods.

For borehole-connected chambers, a small amount of "leakage" should be permitted through the borehole. Other types of chambers require other means. A West German approach is shown schematically in Figure 12 (9). In some cases a small fan may be needed.

3.2 Guidelines for Configuration and Construction

The following are guidelines for configuration and construction:

a. All rescue chambers shall be of adequate size and area to provide:

   1. Sufficient space for storing emergency supplies and equipment

   2. Sufficient space (minimum of 15 ft^2/person) for the comfort of individual miners.

TABLE 8. - Comparative support costs

Type	Direct Cost* $/linear ft of Rescue Chamber	Cost/Person
Wire mesh	50-70	67-93
I-beams	140	186
Used rails	70	93
Steel arches	180	240

*Direct cost includes only material and labor costs, in 1983 dollars.

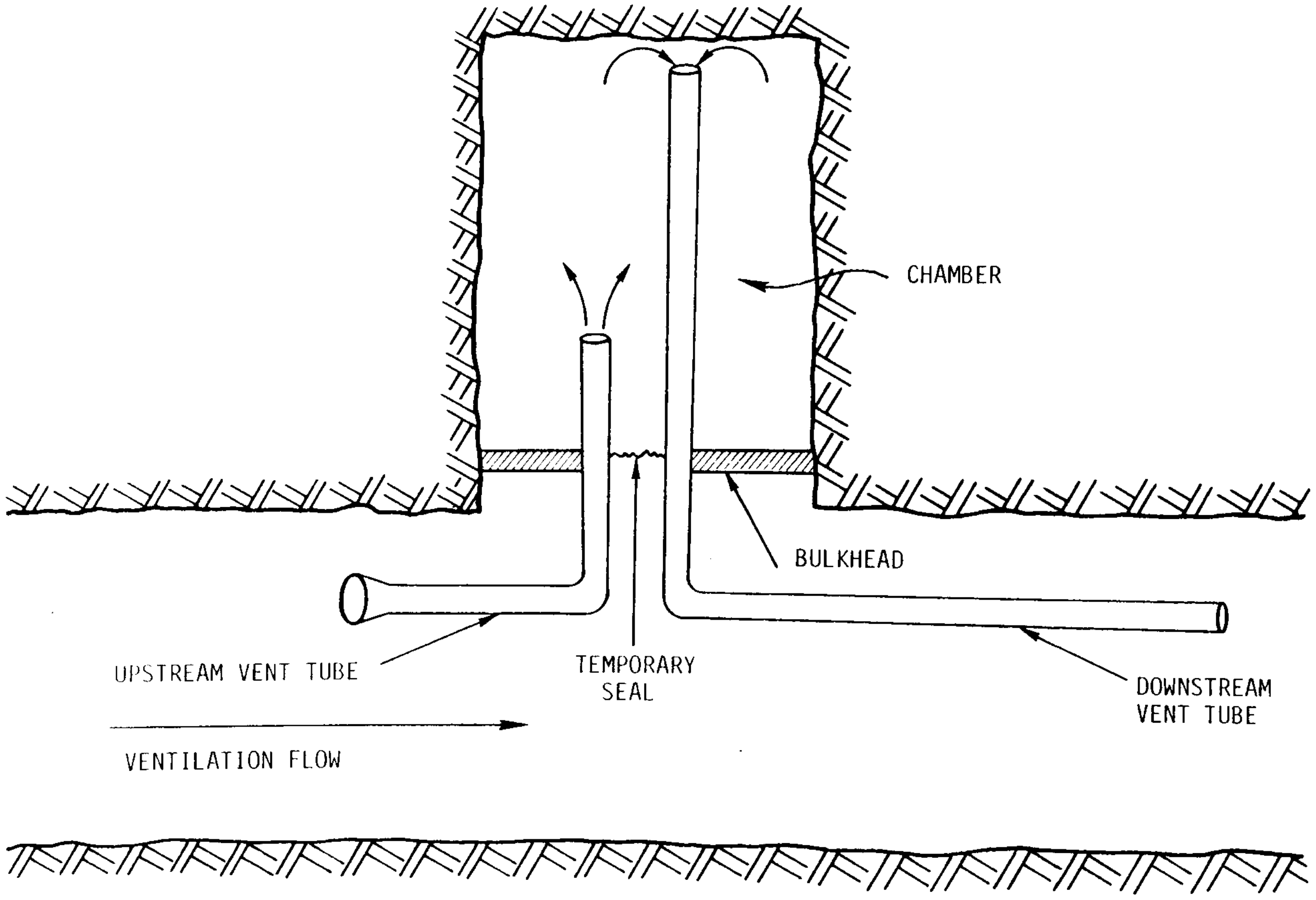


FIGURE 12. - Schematic of standby rescue chamber ventilation.

b. All rescue chambers shall have airlocks located inby the rescue chamber from the bulkhead(s). The airlock(s) in the rescue chamber shall be constructed by erecting a temporary stopping(s) with materials stocked in the chamber. The stopping(s) shall be adequately sealed against the ribs, floor, and roof of the entry.

c. All rescue chambers shall have appropriate explosion-proof bulkheads, compatible with underground conditions.

d. The walls of the rescue chamber shall be lined with a minimum one-brick thick wall.

e. All rescue chambers shall be adequately supported by artifical means for the entire life period of the chamber.

    1. Where roof bolting is the only method of permanent roof support, the applicable criteria in 30 CFR 75.200-7 (a), (b), (c) and (d) of the Full Roof Bolting Plan shall apply.

    2. Where roof bolting may be inadequate or insufficient, all rescue chambers shall be supported by adequate additional or alternative artificial means.

f. Other measures as may be necessary depending on local conditions shall be installed to safeguard the lines of persons seeking refuge in the chamber.

g. The rescue chamber must be maintained in such a manner that it is well-ventilated with fresh air when not in use.

4. CHAMBER LOCATION GUIDELINES

4.1 Discussion

4.1.1 Introduction

The purpose of this subsection is to provide guidelines for the location of rescue chambers that will be applicable, at least in a general way, to most underground coal mines. It is impossible to anticipate every possible variation in circumstances; the guidelines will no doubt have to be modified according to the judgment of the individuals most familiar with each situation. The reasoning behind the guidelines is provided so as to aid such individuals in their decisions.

The application of the chamber location guidelines to five actual working coal mines is presented as Appendix E. Included is a cost comparison of borehole and compressed air life support systems for each.

4.1.2 Background

The Secretary or an authorized representative of the Secretary may prescribe in any coal mine that rescue chambers, properly sealed and ventilated, be erected at suitable locations in the mine to which persons may go in case of an emergency for protection against hazards. Such chambers shall be properly equipped with first aid materials, an adequate supply of air and self-contained breathing equipment, an independent communication system to the surface, and proper accommodations for the persons while awaiting rescue, and such other equipment as the Secretary may require. A plan for the erection, maintenance, and revisions of such chambers and the training of the miners in their proper use shall be submitted by the operator to the Secretary for his approval.

Previous work on the doctrine of rescue chamber location consists of FMA's report on the design of reuseable explosion-proof bulkheads (3), and a study of rescue shelters by Ward, et al. (6), of the Pittsburgh Technical Support Center of MSHA.

The FMA report makes a distinction between temporary and permanent shelters, and proposes that temporary shelters be maintained within a maximum distance of each face, based on seam height, and that permanent shelters be maintained at the mouth of each working section. This scheme results in a very large number of rescue chambers, which certainly are not all required.

The Ward report discusses four basic options for chamber location:

a. In the immediate face area on each section

b. At some maximum distance from the face

c. At the mouth of each section

d. At miscellaneous sites selected on a mine-by-mine basis.

The first two options are rejected by Ward for the following reasons:

a. Miners may be tempted to remain in the chambers, inby a fire, unnecessarily

b. Borehole access from the surface is not assured

c. Frequent moves of the chamber are not conducive to proper construction and maintenance

d. The hazard of inundation.

The third option, the mouth of each section, is considered to have advantages over the first two in being more permanent and being accessible to persons other than the face crew. It has the same disadvantage of all guidelines based on arbitrary location according to mine layout in that access from the surface is not assured.

Ward considers the fourth option, miscellaneous sites selected on a mine-by-mine basis, to be applicable to special situations such as some older mines where it is not possible to provide two independent escapeways for each section. This option most closely follows the letter of the rescue chamber regulation. It is this option that also most closely resembles the location guidelines as developed for this analysis, as explained in the following subsection.

4.1.3 Location Rationale

The guidelines for the location of rescue chambers as described in this subsection derive from the concept of the rescue chamber as a "second chance." Evacuation must remain the primary means of rescue in any emergency.

A rescue chamber must be located so as to provide a realistic "second chance" when it has become apparent that escape through both escapeways is impossible, without enticing a person to enter the chamber unnecessarily when evacuation is still viable.

The above concept implies three basic criteria of chamber location:

a. It must be located in the same direction from the working face(s) as the escape route.

b. It must be readily accessible from both escapeways.

c. It must be within 1 hr of foot travel of the face areas it is to protect. This assumes that miners have access to a 1 hr O_2 or filter self-rescuer.

A rescue chamber can be provided with life support either through a borehole to the surface or by an underground compressed air line. The former is superior to the latter because of the airlines susceptibility to damage during an emergency. This implies a fourth basic criterion of rescue chamber location - accessibility of the surface above the chamber.

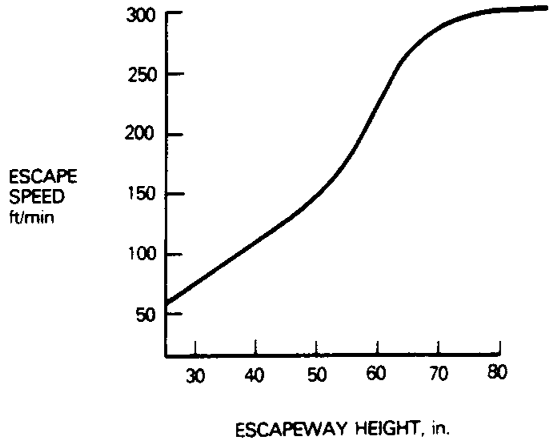
A consideration in some mines will be the problem of flooding. The rescue chambers are designed to sustain life for two weeks; a chamber should not be located in a structural low point that is likely to flood within that time should pumping stop.

If a crosscut chamber is to be used, a final requirement is that the chamber not be located between an intake and a return, in order to preclude a pressure differential across the chamber that would cause mine air to enter the chamber.

4.2 Location Guidelines

The selection of a location for a rescue chamber at a particular mine should proceed from the general to the specific along the following lines:

a. Using the mine map, identify working faces that are more than 1 hr from the surface by escapeway, on foot, (travel distances shown in Figure 13).



NOTE: DECREASE SPEED BY 15 PERCENT IF USING A SELF-RESCUER. DECREASE SPEED BY 10 PERCENT FOR POOR TRAVEL CONDITIONS (LOOSE GROUND, POOLS OF WATER).

FIGURE 13. - Average escape speeds in an underground coal mine.

Reference: Berry, et al, Recommended Guidelines for Oxygen Self-Rescuers, Vol. III - Escape Time Studies, USBM Contract Report No. J0199118, June, 1983.

b. Place the following information on overlays:

1. Intake and return escape routes, starting at each face from (a) above, for a distance equal to 1 hr of travel

2. Areas on the surface where physical and legal conditions permit the drilling of a borehole and installation of the borehole surface facilities

3. Areas of the mine that can be expected to flood within two weeks if pumping stops.

By superimposing the overlays, the areas that may be suitable for a rescue chamber are made readily descernable. These are the areas in which escapeways from several, prefereably all, of the sections to be protected are contiguous, and which are overlaid by surface conditions suitable for boreholes and are outside the 2-week flood zone.

The candidate areas can now be further narrowed down by keeping in mind the following guidelines, as mentioned earlier:

a. Locate the chamber where intake and return escapeways are close together, and where the chamber is readily accessible from either.

b. Locate the chamber so that as few persons as possible must, at any point, travel in a direction away from the portal in order to reach the chamber.

Intersections of entry systems naturally attract attention as satisfying the above requirements. Location of man-doors in stoppings should also be considered in order to place chambers at locations accessible from different airways.

A further consideration is that crosscut chambers be constructed only between two intakes or two returns, so as to prevent differential ventilation pressure from forcing mine air into the chamber.

In many cases, of course, it will not be possible to satisfy all of the requirements of an ideal chamber location, so that trade-offs will have to be made among the various criteria. In this situation, priority should be given to obtaining a site for a borehole. If the chamber cannot be located adjacent to an escapeway, directions to the chamber should be clearly posted in all escapeways. A chamber could also be located a short distance off the escape route to the surface if the way to the chamber and the way back to the escape route is clearly marked.

If it is *not* possible to obtain a site for a borehole, then air must be supplied by a compressed air line, and the chamber can be located according to the in-mine access guidelines.

Chamber location guidelines are summarized in the logic diagram shown in Figure 14.

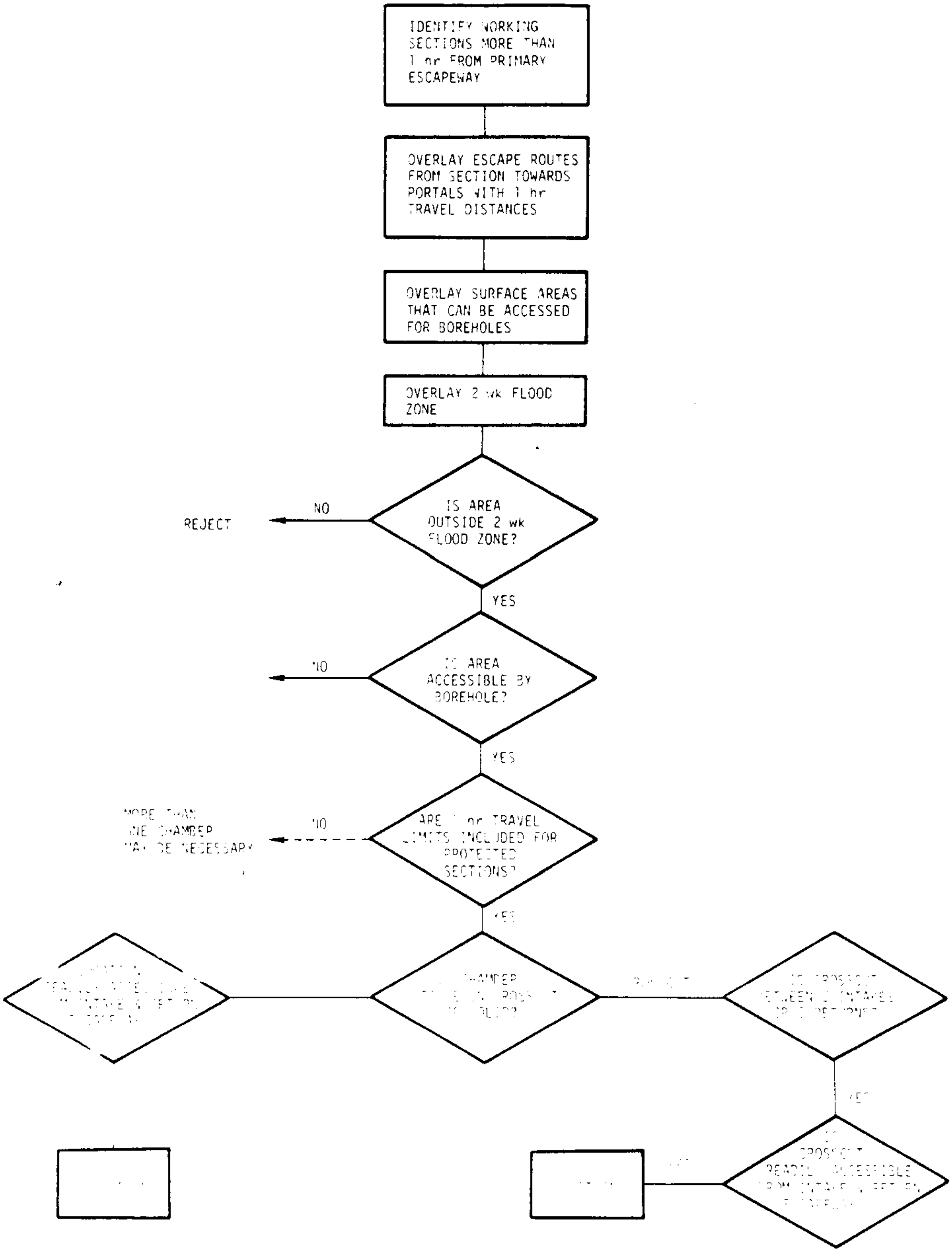


Figure 14. - Chamber location logic

5. POWER AND LIGHTING

5.1 Technical Discussion

During operation of rescue chambers, the critical power requirements are for:

a. Lights

b. Communications equipment

c. Instruments.

Communications are critical for both aid in rescue of the entrapped miners and for the psychological well being of the chamber occupants. While recovery of miners can be achieved without communications, the operation would be far more stressful on both rescuers and the entrapped, which could result in persons undertaking far greater chances than necessary.

Most required instrumentation does not require power other than possibly a manual air pump or small batteries.

In addition to the obvious practical requirements, lighting of the chamber is a psychological requirement.* Persons deprived of light will be under much higher stress than those with light available to them. This stress can decrease the efficiency of coping with the entrapment and have some persistence after a person is rescued.

Because of the importance of lighting, a nonelectrical fallback light source is recommended, such as chemilluminesence light tubes. These tubes give off a cool low temperature light due to chemical reactions. Tubes with a 12-hr light life cost about $2.10 (1983 price).

There are several general sources of power available, including:

a. Power line

b. Batteries

c. Motor/generator set

d. Human power.

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*See Appendix F, especially Section F.4.4.2, page 112 (Vol.II).

Within these guidelines several of these sources are recommended. However, all electrical installations must meet MSHA requirements for permissibility. For a chamber connected to the surface by a borehole, it is required that a power line from the surface be installed in the borehole and that this line be dedicated to rescue chamber use only. It is not to supply power to any other place in the mine. With such a line, all chamber power requirements can be met.

For chambers without a borehole connection to the surface, a dedicated power line is not considered practical because all power into the mine is likely to be cut off during a disaster. For these chambers, a combination of power sources is recommended. Batteries are recommended for instruments and communications equipment. Dry cells are to be stored in sufficient quantity to operate the respective equipment for more than 14 days of operation. These stored batteries are to be replaced before half their shelf life time has passed. Additional power is to be extracted from the compressed airstream to power at least one chamber light. Commercial air motor/generator light units exist which provide light from a compressed airline in a single packaged unit. Other air motor/generator units may be used. For a rough estimate of power available assume 350W for each 30 ft^3/min from a 100 $lb/in.^2$ air supply.

Optionally, other power sources may be installed in addition to those described above. However, such equipment must not introduce additional hazards, such as:

a. Fire or explosion

b. CO or CO_2 contamination to the chamber atmosphere

c. Oxygen depletion of the chamber atmosphere

d. Overheating of the chamber.

5.2 Guidelines for Power Supply

5.2.1 General

Rescue chambers shall have sufficient lighting, and power for instruments and communications equipment.

5.2.2 Lighting

All rescue chambers shall be equipped with a store of 12-hr chemilluminesence lighting tubes sufficient to last 30 days, that is, 60 tubes.

5.2.3 Batteries

Batteries shall be available to operate any stored equipment for the design use time of the chamber with one complete set of spares. All batteries shall be renewed with fresh ones when or before one-half their shelf life is reached.

5.2.4 Testing

All power supplies shall be functionally tested on completion of the installation of the rescue chamber and on or within 30 days of the previous test. All deficiencies shall be corrected.

5.2.5 Other Power Sources

Other power sources are permitted in addition to those stated in subsections 5.2.2 and 5.2.3 (see discussion in subsection 5.1), providing they satisfy MSHA permissibility requirements or a variance is granted.

6. EQUIPMENT AND SUPPLIES

6.1 Discussion

6.1.1 General

The previous sections have discussed the design, construction and atmospheric conditioning of rescue chambers. This section provides a detailed list of equipment and supplies that must be permanently stored and maintained in the rescue chamber in order to fulfill its ultimate purpose.

The major items that must be provided in the rescue chamber are:

a. Food

b. Water

c. Miners' first aid and medical supplies

d. Self-rescuers

e. Gas detectors

f. Cots, blankets

g. Sanitary supplies

h. Body pouches

i. Sundry materials

These items are discussed in more detail in the following subsections.

6.1.2 Food

Food requirements are generally agreed to be 1740 calories/person/day. Military rations are most suitable for survival purposes and provide sufficient calories to keep a person active. A single meal of military C-ration comes in a package measuring about 15.5 cm × 12.5 cm × 8 cm (1550 cm^3). Considering three meals/person/day, the total volume of food for 15 people to last 14 days would be

$$3 \times 15 \times 14 \times 1550\ cm^3 = 34.5\ ft^3 \simeq 35\ ft^3$$

For a rescue chamber 6 ft high and 18 ft wide, this would occupy about 0.32 ft or about 4 in. in depth.

The total cost of food when estimated at the rate of \$2.80* per meal** would be \$1,760.00. An analysis of a typical military ration meal reveals that at least 31.3 gr of protein, 0.36 gr calcium, 0.69 gr phosphorus and 0.005 gr iron are supplied by each meal. For three meals a day this would far exceed the recommended daily consumption of 75 gr protein, 0.69 gr calcium, 1.32 gr phosphorus and 0.0015 gr iron as suggested in Handbook of Chemistry and Physics.

The Westinghouse (2) report on Coal Mine Rescue and Survival Systems suggested the military ration (MIL-F-43231), Food Packet, Survival, General Purpose) which could also be considered for the rescue chamber requirements. This military ration also meets all the requirements and can be a viable alternative.

Other types of food, such as camping foods, could be considered for storage. However, a detailed analysis of these alternatives would be required to assure that they had adequate nourishment and shelf life.

6.1.3 Water

Sufficient quantities of drinking water must be provided to the occupants of the rescue chamber to replace their body moisture loss due to insensible perspiration and sweating. The dotted curve in Figure 15 shows the amount of moisture evaporated by *sedentary* adults for various dry bulb temperatures. Not included is moisture loss in the urine and feces or for any other reason. When these losses are included, the total moisture loss is much greater as indicated by the solid line curve in Figure 14.

Test data on water consumption during shelter occupancy tests indicate that the water consumption tends to follow the evaporative heat loss curve (11).

For a safety factor, assume a high chamber temperature such that the water requirement is about 2-1/4 quart/person/day. This is a somewhat higher requirement than the 2 quarts/person/day used in the Westinghouse study (2).

The total water requirements in the rescue chamber for 15 people to last 14 days would be 15 × 14 × 2-1/4 = 473 quarts or 118 gal.

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*All dollar figures in 1983 dollars; see Foreword.

**Telephone conversations with ration vendors.

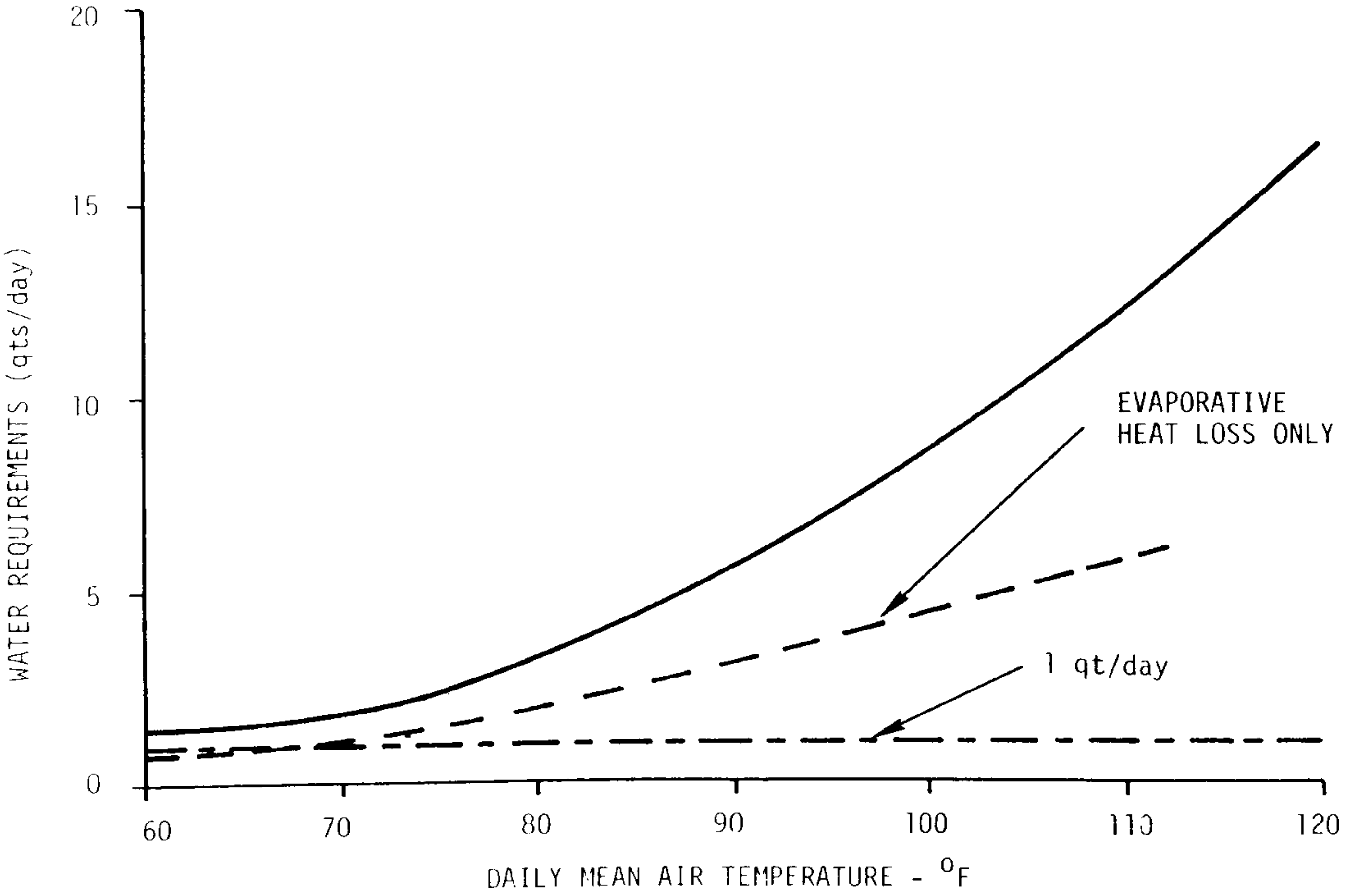

FIGURE 15. - Daily water requirements to avoid dehydration in man at rest.

The water is to be stored in 24 5-gal plastic containers costing about $5.00 each. The containers would occupy about 17 ft^3 of space in the chamber. A teaspoon of liquid bleach would be added to the water in each container to assure long storage life.

6.1.4 Miners' First Aid and Medical Supplies

First aid equipment to be supplied is the standard miners' first aid station kit. This kit contains:

1 Army stretcher

1 Rubber blanket

2 Wool blankets

3 Splints, wood, 22 × 4 × 1 1/2 in., for broken-back splinting

1 Splint, wood, 42 × 6 × 1/2 in.

2 Splints, wood, 84 × 6 × 1 in. for broken back splinting

6 Splints, 18 × 3 1/2 × 1/4 in.

2 Inflatable Jobst splints, full leg

2 Inflatable Jobst splints, full arm

24 Triangular bandages, 40 in.

8 Compress bandages, 4 in.

4 Pkg compress bandages, 16, 2 in.

1 Pkg adhesive bandages, 16, 1 × 3 in.

2 Tourniquets

1 Foille ointment, 1/2 oz

1 Ammonia, aromatic spirits, 2-oz bottle

While somewhat arbitrary, it would seem that a miners' first aid station should be installed at the rate of one station/five persons. For example, a rescue chamber designed for 15 persons should have three first aid stations available. The cost of a miners' first aid station is about $530 each. Additionally, each person should be provided with a wool blanket which can be used for general protection as well as first aid use.

6.1.5 Self-rescuers

The number of reserve self-rescuers to be stored in the rescue chamber should correspond to the number of persons taking refuge in the chamber. The new compact 1 hr self-contained oxygen self-rescuers are a significant development and could be utilized by the persons in the shelter. For a rescue chamber sheltering 15 persons at least 15 self-rescuers of the self-contained oxygen type should be stored and maintained inside storage containers.

The self-rescuers currently cost about $600 each. Total cost for self-rescuers would $9000.00.* The maximum storage volume required would be 10 ft^3.

6.1.6 Gas Detectors

The persons in the rescue chamber should monitor the quality of the air in the rescue chamber. For this purpose, gas detectors for carbon monoxide, carbon dioxide, hydrogen sulfide and methane should be provided.

The monitoring of CO, CO_2 and H_2S can be carried out using the Universal Tester Pumps. Glass detection tubes, containing chemical reagents specific to the gas being monitored, have break off tips which fill the orifice of the pumps. They indicate the presence of the gas being analyzed by a color change. The pump costs $210.00 and the tubes are packaged in boxes, each box containing 10 tubes. Each box of tubes costs about $17.00. The number of spare tubes for each type of gas is estimated as:

$$1 \text{ tube/hour} \times 14 \times 24 = 336 \text{ tubes}$$

Therefore, about 34 boxes of tubes for each gas have to be purchased. The cost would be:

$$34 \times 3 \times \$17.00 \approx \$1730.00$$

The tubes have a minimum 2-year shelf life.

The modern methane detectors use sealed rechargeable 2.4V nickel-cadmium batteries. These units can provide up to 200 readings before requiring recharging and cost about $590.00 each. Recharging takes about 14 hr. If methane is to be monitored every 5 min, at least two detectors should be provided in the rescue chamber.

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*1983 dollars; see Foreword.

Nickel-cadmium batteries must be run through deep discharge cycles periodically or they lose their capacity to fully discharge. For this reason, an effort should be made to obtain methanometers which can use alkaline cells. Information on battery maintenance is given in Section 5.

6.1.7 Bunks, Sanitary Supplies and Sundry Materials

Double deck bunks constructed of 1 in. tubular aluminum can be provided in the rescue chamber for comfort. This type of bunk is easily available from major department stores and costs about $70.00*/double bunk. They can be folded when not in use and are about 39 in. high when opened.

Comparable wooden (pine) bunk beds cost about $350.00 each.

Cost of bunks = 70 × 8 = $560.00

A sanitary approved toilet which uses disposable bags can be provided. These toilets can be easily obtained from camping suppliers and cost less than $15.00 each.

Blankets, accounted in the emergency supply, can be used when the occupants are resting.

6.1.8 Sundry Materials

Caulking is useful for sealing purposes should there be any leaks. Aluminum wire can be used to hang clothing. Picks, hand shovels, duct tape, electrical tape, canopeners, and flashlights prove handy during emergency situations.

Table 10 gives a cost summary for supplies.

6.1.9 Body Pouches

In an emergency situation which would require the use of a rescue chamber, there is the possibility that miners will receive injuries which will result in death while the person is inside the rescue chamber. Bodies in the rescue chamber are problematic to the living in that considerable psychological stress may occur (see Section 8). A large factor producing this stress is the odor of decay as well as the sight of the body. To reduce the stress, the use of body pouches is recommended. These are plastic bags which shield the body from sight and seal in the odors of decay.

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*1983 dollars; see Foreword.

TABLE 10. - Cost summary

Food	$1760.00
Water Containers (Plastic) (24 × 5.00)	120.00
First Aid and Medical	2650.00
Oxygen Self-Rescuers (600 × 15)	9000.00
Gas Detectors	
a. CO, CO_2, H_2S	1880.00
b. Methane	1180.00
Bunks	560.00
Toilet	15.00
Sundries	100.00
	Total ≃ $17,265.00

Body pouches may be purchased from local mortuary suppliers or morticians for a cost of about $50.00 each. The number of pouches that should be stocked is difficult to estimate. A safe number is one equal to the design population of the chamber as this would allow for a possible overload case.

6.2 Guidelines for Equipment and Supplies

6.2.1 Food

Food shall be stocked in rescue chambers at the rate of 1740 calories/person/day based on the design number of people and design duration. This food shall be packaged for long-term storage, such as MIL-F-43231.

6.2.2 Water

Water shall be stocked in a rescue chamber at the rate of 2 1/4 quarts/person/day based on the design number of people and the design duration. The water is to be stored in 5 gal containers and treated against bacteria growth (see subsection 6.1.3).

6.2.3 First Aid Station

A miners' first aid station shall be stocked in a rescue station at the rate of one station per five persons (based on design). Additionally, wool blankets at the rate of one/person (based on design number) shall be stocked.

6.2.4 Gas Detectors

A gas detector tube pump and detection tubes shall be stocked in rescue chambers. The detector tubes shall be for CO, CO_2 and H_2O all for the lowest level of detection available except for CO_2 which should indicate up to 3 percent. Tubes for each gas shall be stocked at the rate of one tube for each hour (design hour).

Two methane detection instruments shall be stocked in each chamber.

6.2.5 Cots

A sleeping cot shall be stored at a minimum of one for each person (based on design number).

6.2.6 Toilet

At least two sanitary toilets shall be installed in each chamber. These toilets may be of the seat and plastic bag type as used in camping. Sufficient bags must be supplied.

6.2.7 Body Pouches

Body pouches (see subsection 6.1.7) shall be installed at the rate of one/person based on design.

6.2.8 Other Materials

Other materials shall be stored in the rescue chamber as discussed in subsection 6.1.7.

6.2.9 Inspection and Maintenance

All stored materials shall be noted on an inventory list. The material stored shall be inspected periodically in intervals not to exceed 6 months and any materials missing from the inventory list or noted deficient shall be replaced.

7. RESCUE CHAMBER COMMUNICATIONS

7.1 Discussion

7.1.1 General

Rescue chambers can save lives without communications to the surface; however, two-way communications between the entrapped miners in the chamber and the rescuers offers considerable aid and efficiency in the process of removing the entrapped as well as offering psychological comfort to chamber occupants. In order to ensure chamber-to-surface communications, these guidelines specify the installation and maintenance of redundant communication links. The particular systems installed depend on the type of rescue chamber and the present (1979) state-of-the-art of mine communications in the United States. Reference is made to some emerging communication systems, and provisions are made within the guidelines for the application of this technology once it has become commercially available.

The prime communication system covered by these guidelines shall be telephones. Both the mine pager phones, and the less commonly used (underground) some powered phones are specified. Installed redundant lines are required as protection against the loss of communication due to cable breakage. A seismic system is specified as a fallback in case all phone lines are severed. Not specified, but permitted by these guidelines, is the use of electromagnetic wireless links which may be installed in addition to the phone and seismic links.

The remainder of this section discusses the telephone instruments, the wiring requirements, the seismic systems and two emerging wireless technologies. Subsection 7.2 presents the specific requirements for rescue chamber communications.

7.1.2 Telephones

The code of Federal Regulations, Title 30, Mineral Resources, requires communications in underground coal mines. As a result, all coal mines presently have an installed telephone system, usually a mine pager phone system. Rescue chambers should take advantage of these already installed systems.

Reference 12 is suggested as a reference for the technicalities of pager phone systems and the techniques of underground wiring.

Sound powered phones have advantages for use in rescue chambers. The instruments are sturdy enough for military use and no electrical power is required even up to ranges of 30 mi over No. 19 AWG cable.*

Transmission by sound powered phones works as a speaker in reverse. Air pressure variation (sound waves) from a voice moves a diaphram which moves a magnetic field across a coil. This generates an electrical signal that is conducted over a cable to a receiver where the electrical signals drives a speaker in a telephone handset. The only source of power is the voice.

Various types of sound powered telephones are available. For rescue chambers, a pair of simple handsets located at the surface and within the rescue chamber is sufficient. Such instruments cost about $120 each (1983 price). These simple instruments do not have a signaling (ringing) system, however, but blowing a police whistle can provide a suitable signal at the other phone if a telephone watch is maintained.

The next subsection discusses methods for connecting rescue chamber telephones with surface communication stations.

7.1.3 Connecting Lines

Redundancy in connecting telephone lines between rescue chambers and a surface communication station(s) will be used to ensure against loss of communication. Two methods are required by these guidelines: a loopback of the pager phone line and a dedicated line for a sound-powered phone.

Both of those connecting methods are shown schematically in Figure 16. The loopback line is good general practice, as it protects the mine pager phones against loss of communications due to a line break, even during normal mine activities. In a mine emergency which requires the use of a rescue chamber, the loopback line provides two independent pager phone lines to the surface, with a likelihood of at least one line surviving the cause of the emergency. A necessary feature of this system is the transfer switches shown next to both surface and chamber pager phones. These switches must be of an environmentally sealed, double-pole, double-throw type. If one of the lines connecting the surface phone to the rescue phone is short-circuited, these switches can be used to transfer the phones to the good line.

The sound-powered phones must be connected to a separate dedicated cable, which is routed along a path independent of the loopback pager phone lines. All telephone lines must have lightning protection installed. Furthermore, care should be taken not

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* Stromberg - Carlson Brochure

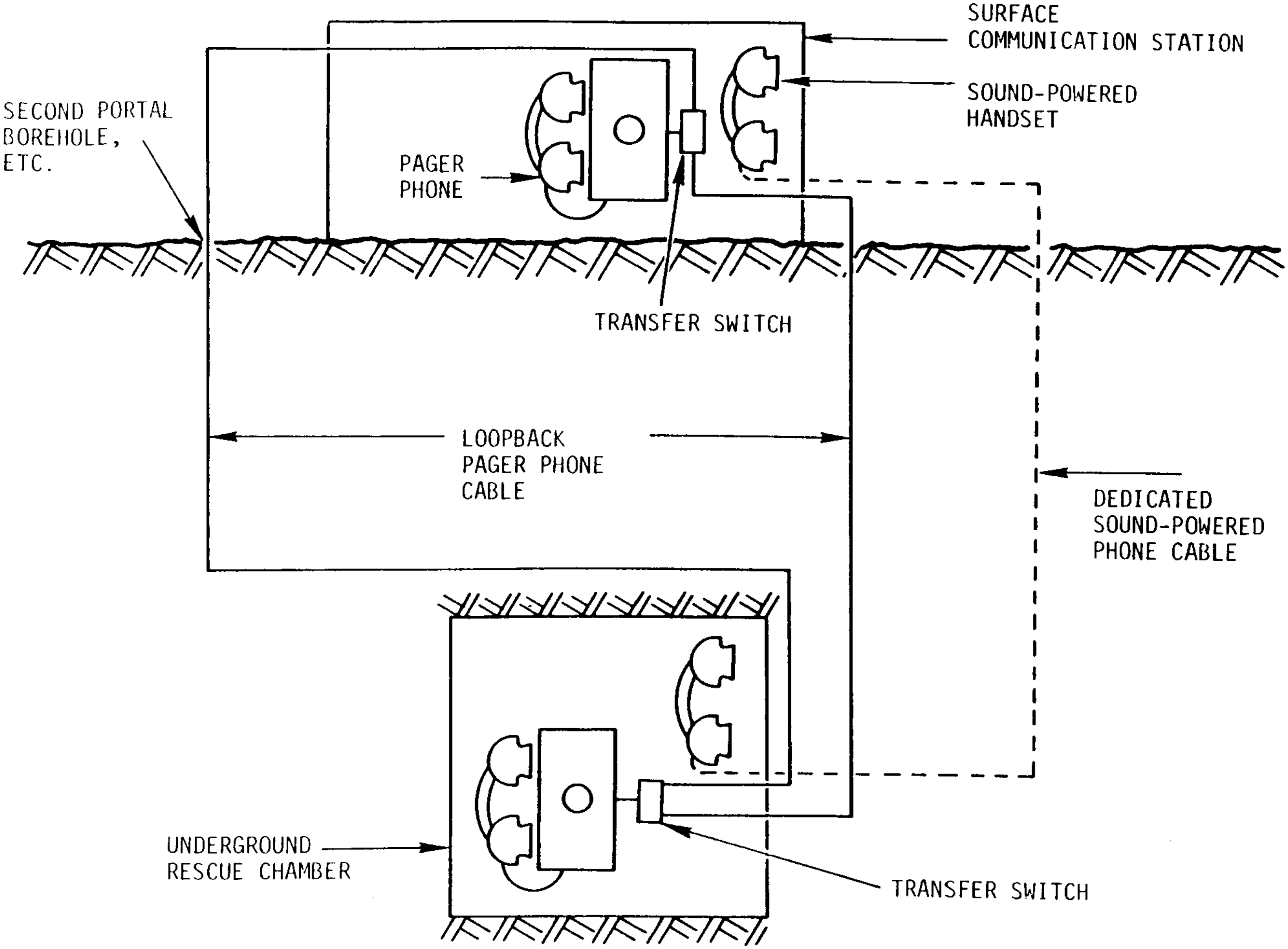

Figure 16.- Schematic of connecting telephone lines.

to install phone lines in proximity to power cables so that in an accident situation, it will be impossible for high voltage to be connected to the phone lines.

The typical cost of installing mine phone cable may be estimated on the basis of a wireman and helper installing 2000 ft of cable during a shift at a combined cost of $365.* Taking the cost of cable and miscellaneous hardware as $350/1000 ft, the installed cost of 1000 ft of cable may be estimated as:

$$\frac{\$365\ (\text{labor})}{2000\ \text{ft}} + \frac{\$350\ (\text{materials})}{1000\ \text{ft}} = \frac{\$350}{1000\ \text{ft}}$$

If circumstances should conspire such that there is a loss of both pager phone and sound-powered phone, then a fallback primitive seismic signaling device could be resorted to. This is described in the following subsection.

7.1.4 Seismic Signaling

Seismic signaling is probably the oldest form of mine signaling. It is based on the detection of through-the-earth vibrations produced by miners impacting the mine roof or ribs with a heavy object. The modern version of seismic signaling uses geophones on the surface to detect the vibrations underground, and surface detonation of explosives to signal back to the underground miners who hear or feel the vibration due to the explosions.

Simple procedures and codes have been established for this type of signaling. MSHA has Mine Rescue and Survival Teams that travel to disaster sites and operate the surface seismic signaling equipment. Information from MSHA on signaling codes and procedures should be obtained and copies placed within the chamber for use, if necessary, by entrapped miners. Additionally, impacting tools, such as timber, should be placed in the rescue chamber. Recommended are a 40 lb timber (about 4 ft long) for two person use, and a 10 lb timber for single person use.

7.1.5 New Technology for Communications

There exists emerging technology in electromagnetic, through-the-earth, wireless communications. These systems are not commonly available for use in the United States at this time (1979); however, they are well advanced and could become readily available under favorable circumstances.

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*1983 dollars.

Two systems will be mentioned herein which are most likely to have impact in the near future. A USBM trapped miner system which operated at voice or ultra-low frequency has been developed and tested through prototype stage. At present, this is a portable system carried by the miner and powered from his cap lamp battery. If the equipment becomes commercially available, systems could be installed within the rescue chamber.

The other system is a medium frequency radio developed, sold and used in South Africa. Presently this system has not met United States permissibility requirements. However, the potential exists that this equipment could become available for use in the United States in the near future, and hence could be installed in a rescue chamber.

These guidelines permit, but do not require the installation of a new communications system, in addition to the required telephone and seismic systems.

7.2 Guidelines for Communications

7.2.1 General

Rescue chambers shall have the following installed communications equipment. This equipment shall include:

a. A mine pager phone on a loopback line with transfer switches at the phone underground and on the phone on the surface as described in subsection 7.1.3

b. A sound-powered phone pair located in the rescue chamber and at a surface location connected by a dedicated line as described in subsection 7.1.3

c. Equipment and directions for seismic through-the-earth signaling as described in subsection 7.1.4.

The telephone equipment shall be installed and maintained by the methods described in "Technical Guidelines for Installing, Maintaining and Inspecting Underground Telephone Systems," a USBM Handbook, U.S. Departmentof the Interior (1978 or subsequent versions).

7.2.2 Borehole Connected Rescue Chamber

A borehole connected rescue chamber shall have the sound powered phone line installed up through the borehole to the surface.

7.2.3 Airline Supplied and Stored Compressed Air Rescue Chambers

Airline supplied and stored compressed air rescue chambers shall have all telephone lines run via independent routing while underground. At each point where a cable from a rescue chamber reaches the surface, it shall be clearly marked stating that the cable is a telephone cable to a rescue chamber with the location of the chamber indicated.

The mine emergency map shall clearly show the routing of sound-powered phone lines to aid underground rescue teams in finding a point to tap into for direct communications to the chamber.

7.2.4 Operation and Training

All mine personnel likely to use the rescue chamber shall be instructed in the use of communications systems, including the use of the transfer switch on the pager phone, the use of the sound-powered phone, and the use of the seismic signalling device.

Directions for use of communications equipment shall be posted in the rescue chamber.

Mine personnel shall also be instructed in identifying and preventing the cutting of the phone cables to rescue chambers before or during a rescue attempt.

7.2.5 Testing and Maintenance

All communications equipment in a rescue chamber shall be tested for proper operation on installation and every 6 months thereafter. Any deficiencies shall be immediately corrected.

8. PSYCHOLOGICAL ASPECTS AND TRAINING

8.1 Discussion

Discussion of the use of rescue chambers has frequently raised the question of what will be the psychological effects on the miners, such as: their ability to cope with the situation well enough to look out for their physical well-being; and the possibility of long-term psychological impairment to miners who have experienced entrapment. As part of the development of these guidelines, the psychological aspects of the use and training for use of these guidelines were examined.

This examination is presented in detail in Appendix F. Although the data based is limited, conclusions indicate that miners will be able to cope successfully with using rescue chambers, and that long-term after-effects are not expected.

Examination of cases where miners have been trapped for long periods has indicated two particular requirements. One is that chamber lighting is required, the other is provision must be made for removing dead bodies from sight and more importantly shielding the living from the odor of decaying bodies. Both of these items have been provided for elsewhere in these guidelines (lighting under power, body containment under supplies).

8.2 General

The expected psychological problems associated with prolonged confinement to rescue chambers are: anxiety, withdrawal, apathy, aggression, hostility, depression and irrational, impulsive behavior.* Miners are expected to suffer more from the immediate shock of the disaster itself, and the resultant presence of dead and injured persons, than any other variables. Initial shock and panic will be the immediate symptoms of the disaster. Disbelief, confusion and disorientation will probably be present for the first few hours. Some phobic reactions to the possible recurrence of the disaster can also be expected. The way in which miners are able to cope with this *initial* shock should determine how successfully miners tolerate their confinement. After the immediate shock effects have worn off, which should not last more than a few hours, the miners will suffer some anxiety, in the form of survival guilt. The miners are expected to feel discomfort from the confinement itself, but such discomfort is expected to be superceded by the more potent effects associated with death. There will be increasing anxiety as the number of days of confinement increases, especially if the miners

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*The general conclusions in this section are based upon the discussion and documentation in Appendix F, Volume II and the 77 references cited therein.

are in a chamber that has a limited supply of stored compressed air. But this anxiety, which in extreme cases such as limited air supply and/or loss of communications can be expected to reach intolerable limits by the 13th or 14th day, will be due more to the fear that they will not be rescued than to anything else. It is not expected that any temporary or permanent psychological incapacitation will occur. The effects of group standards upon individual behavior are expected to discourage this.

8.3 Guidelines for Psychological Aspects

A training program which accomplishes the following is recommended:

a. Teaches the miners how to respond effectively to the immediate disastrous condition, which will likely be a mine explosion. Responses which must be learned in this section of the program are:

    1. How to detect the nature of the disaster. Is it a mine explosion? Is it a major roof fall? Where is it located?

    2. How to protect oneself from the immediate effects

    3. How to decide whether to attempt to escape or to seek refuge - a function of the particular mine

    4. What symptoms to observe in others and in oneself that are a result of the trauma, and how such symptoms can be controlled.

b. Teaches the miners how to care for the injured, and how to operate emergency equipment, such as:

    1. The 1 hr breathing devices

    2. The carbon dioxide removal agents

    3. Getting communication to the outside.

c. Teaches miners how to deal with the dead, injured, and emotionally unstable. A decision to attempt rescue of others might have to be made at this point.

d. Teaches miners how to handle the stresses of confinement. The following factors should be considered:

    1. The importance of roles and role relationships, as they are expected to apply to the unique conditions of the mine. These roles will be partly controlled by the personality, interpersonal, group dynamics, and psychological forces which occur in the rescue chamber environment. They seem to be determined by two types of conditions: the impact period, which is characterized by task-oriented behavior; and the survival period, which is characterized by emotionally-oriented behavior.

    2. The expected types of behavior during confinement.

e. Teaches the miners specific tasks to perform. The essential tasks are:

    1. Manager selection (by experience)
    2. Supply inventory
    3. Emergency equipment review
    4. Reconnaissance
    5. Manager selection (by vote)
    6. Food, water rationing
    7. Medical services
    8. Atmosphere control
    9. Sanitation services
    10. Recreational services
    11. Sleeping arrangements (may change)
    12. Security of rescue chamber.

9. REFERENCES

1. National Academy of Engineering, Committee on Mine Rescue and Survival Techniques, *Mine Rescue and Survival*, USBM Open File Report 4-70, Washington, DC, March 1970.
2. Westinghouse Electric Corporation, *Coal Mine Rescue and Survival*, Vol. 1, Final Report, USBM Contract No. H0101262, Baltimore, MD, September 1971.
3. Maser, K.R., D.S. Kingery and D. Hoadley, *Design of Reusable Explosion-Proof Bulkheads for a Crosscut Refuge Chamber*, Final Report, USBM Contract No. H0133050, Pittsburgh, PA, November 1975.
4. Berry, D.R., T.E. Billou, A.B. Boghani, M. Burnett, D. Hoadley, K.R. Maser and R.H. Trent, *Development of Emergency Escape Systems Guidelines for Underground Metal and Nonmetal Mines*, USBM Contract No. J0255017, Washington, DC, May 1976.
5. Private Discussion with Mr. J.H. Kravitz, Chief Mine Emergency Operations Mine Safety Health Administration, Alequippa, PA, March 1979.
6. Ward, D.C., R.W. Dalzell, J. Nagy, E.J. Kloos, C.H. Myers, and E.J. Harris, *Rescue Shelter Analysis for Coal Mines*, Unpublished Internal Report, Pittsburgh Technical Support Center (MSHA), 1973.
7. Private Communications with W.K. Redsell, Senior Executive Engineer Mining Health and Safety Branch, Ontario Ministry of Labor, September 1978.
8. Internal Memo, E.J. Kloos, MESA, February 12, 1976.
9. Private Communications through Dipl-Ing A. Schewe Bergban-Forsdrung GmbH ESSEN, West Germany, 1978.
10. Levenetz, N.B., *Bergrethungswesen*, Band IV, Teil 11, *Unterirdische Zufluchtsräume*, Staatlicher wissenschaftlich-technischer Bergverlag, 1933.
11. Department of Defense, Office of Civil Defense, *Shelter Design and Analysis*, Vol. 3, Environmental Engineering for Shelters, TR-20-Vol. 3, May 1969.

12. Long, R.G., R.L. Chufo and R.A. Watson, *Technical Guidelines of Installing, Maintaining, and Inspecting Underground Telephone Systems*, USBM Handbook, U.S. Department of Interior, 1978.